Climatic Changes and Social Transformations in the Near East and North Africa During the 'Long' 4th millennium BC: A Comparative Study of Environmental and Archaeological Evidence

Joanne Clarke [a,*], Nick Brooks [b], Edward B. Banning [c], Miryam Bar-Matthews [d], Stuart Campbell [e], Lee Clare [f], Mauro Cremaschi [g], Savino di Lernia [h], Nick Drake [i], Marina Gallinaro [j], Sturt Manning [k], Kathleen Nicoll [l], Graham Philip [m], Steve Rosen [n], Ulf-Dietrich Schoop [o], Mary Anne Tafuri [p], Bernhard Weninger [q], Andrea Zerboni [r]

[a,*] Department of Art History and World Art Studies, University of East Anglia, Norwich, NR4 7TJ, UK, joanne.clarke@uea.ac.uk, tel: +441603592461, fax: +441603593642.

[b] Climatic Research Unit, University of East Anglia, Norwich, NR4 7TJ, UK, npjbrooks@googlemail.com

[c] Anthropology, University of Toronto, Toronto, Ontario, M5S 2S2, Canada, ted.banning@utoronto.ca

[d] Geological Survey of Israel, Jerusalem, 9550, Israel, matthews@gsi.gov.il

[e] School of Arts, Languages and Cultures The University of Manchester, Manchester M13 9PL, UK, stuart.campbell@manchester.ac.uk

[f] Deutsches Archäologisches Institut, Orient-Abteilung, Podbielskiallee 69-71, D-14195 Berlin, Germany, leeclare@web.de

[g, r] Dipartimento di Scienze della Terra "A. Desio", Universita degli Studi di Milano, Via L. Mangiagalli 34, I-20133 Milano, Italy, mauro.cremaschi@unimi.it, Andrea.Zerboni@unimi.it

[h, j] Dipartimento di Scienze dell'Antichita, Sapienza Universita di Roma, Via dei Volsci 122, I-00185 Roma, Italy and GAES, University of Witwatersrand, Johannesburg, South Africa, savino.dilernia@uniroma1.it, marinagallinaro@gmail.com

[i] Department of Geography, King's College London, Strand Campus, London WC2R 2LS, UK, nick.drake@kcl.ac.uk

[k] Department of Classics, Cornell University, Ithaca, New York 14853-320, USA, sm456@cornell.edu

[l] Geography Department, University of Utah, Salt Lake City, UT 84112, USA, kathleen.nicoll@gmail.com

[m] Dept of Archaeology, Durham University, South Road, Durham, DH1 3LE, UK, graham.philip@durham.ac.uk

[n] Archaeology, Ben-Gurion University of the Negev, POB 653, Beersheva 84105 Israel, rosen@bgu.ac.il

[o] School of History, Classics and Archaeology, Old Medical School, Teviot Place, University of Edinburgh, EH8 9AG, UK, ulf.schoop@ed.ac.uk

[p] Dipartimento di Biologia Ambientale Sapienza Università di Roma P.le Aldo Moro, 500185 Roma, Italy, maryanne.tafuri@uniroma1.it

[q] Universität zu Köln, Institut für Ur- und Frühgeschichte Weyertal 125, D-50923 Köln, Germany, b.weninger@uni-koeln.de

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Abstract

This paper explores the possible links between rapid climate change (RCC) and social change in the Near East and surrounding regions (Anatolia, central Syria, southern Israel, Mesopotamia, Cyprus and eastern and central Sahara) during the 'long' 4th millennium (~4500-3000) BC. Twenty terrestrial and 20 marine climate proxies are used to identify long-term trends in humidity involving transitions from humid to arid conditions and vice versa. The frequency distribution of episodes of relative aridity across these records is calculated for the period 6300-2000 BC, so that the results may be interpreted in the context of the established arid episodes associated with RCC around 6200 and 2200 BC (the 8.2 and 4.2 kyr events). We identify two distinct episodes of heightened aridity in the early-mid 4th, and late 4th millennium BC. These episodes cluster strongly at 3600-3700 and 3100-3300 BC. There is also evidence of localised aridity spikes in the 5th and 6th millennia BC. These results are used as context for the interpretation of regional and local archaeological records with a particular focus on case studies from western Syria, the middle Euphrates, southern Israel and Cyprus. Interpretation of the records involves the construction of plausible narratives of human-climate interaction informed by concepts of adaptation and resilience from the literature on contemporary (i.e. 21st century) climate change and adaptation. The results are presented alongside well-documented examples of climatically-influenced societal change in the central and eastern Sahara, where detailed geomorphological studies of ancient environments have been undertaken in tandem with archaeological research. While the narratives for

the Near East and Eastern Mediterranean remain somewhat speculative, the use of resilience and adaptation frameworks allows for a more nuanced treatment of human-climate interactions and recognises the diversity and context-specificity of human responses to climatic and environmental change. Our results demonstrate that there is a need for more local environmental data to be collected 'at source' during archaeological excavations.

1 Introduction

In this paper we argue that the period from ~4500 BC to ~3000 BC[1] in the Near East, Eastern Mediterranean and North Africa was one in which climatic changes, some of which were rapid and of high amplitude, had discernable impacts on human groups. These impacts are evident in the archaeological record as changes in modes of subsistence, social organisation and settlement patterns, which manifested differently in different locales. In some cases links between climatic, environmental and societal change are quite clear, for example in the Sahara where a period of hyper aridity between ~4300 BC and ~3200 BC brought about a major population shift (Kuper and Kröpelin 2006; Manning and Timpson 2014, 30). In other cases they are much more opaque. In Mesopotamia, the expansion and subsequent contraction of the Uruk Culture from the middle and upper Euphrates during the 4th millennium BC broadly coincided with periods of rapid climatic change (RCC)

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[1] In this paper both Calibrated BC and Calibrated BP dates are used. When discussing the archaeological evidence the convention is to use Calibrated BC and when discussing environmental data the convention is to use Calibrated BP. We have maintained these conventions throughout the paper.

at ~3700/3600 BC and at ~3200 BC, but both of these processes may have been due entirely to social and economic factors.

What is evident is that, during the late 5th and 4th millennia BC (the 'long' 4th millennium BC) across the Eastern Mediterranean, Near East and North Africa, there were widespread cultural disruptions that proceeded at different rates, at different scales and in different ways, but all approximately at the same times. Many of these upheavals appear to have coincided with periods of RCC. However, linking social changes to RCC is extremely problematic. Our ability to identify the effects of climatic change on societal change is impeded by the enormous number of other possible explanations for the evidence we observe in the archaeological record. There has been considerable criticism in recent years of the ways in which both archaeologists and environmental scientists have tackled the potential impacts of RCC on cultural systems (Rosen 2007; Maher et al. 2011) including the tendency to gloss over the archaeological evidence. The assumption implicit in previous literature has been that abrupt arid 'events' impacted cultural behaviour in the past and brought about migrations, transitions and disruptions, including societal 'collapse' (e.g. Staubwasser and Weiss 2006, 379). Although this may be applicable, the Early and Middle Holocene also included periods of high climatic variability, which may have posed challenges for human societies. In addition, the 'collapse' model is somewhat unidirectional, and ignores the fact that RCC may mediate social change in other, more nuanced ways (Brooks 2006, 2013).

The aim of this paper is to describe in detail the cultural transitions that took place in regions surrounding the Eastern Mediterranean where climate proxies indicate rapid and/or high amplitude changes. The paper compiles, analyses and interprets published environmental proxies alongside archaeological records, and situates the results within current thinking around the concepts of resilience and adaptation. We aim to highlight the complexity of the evidence and we acknowledge that caution is needed when constructing narratives around the relationships between climatic and cultural changes. We will demonstrate, through our detailed presentation of the archaeological evidence, where rapid climate change provides a plausible explanation for cultural change in the period between 4500 BC and 3000 BC, where there are other explanations for cultural change, and where there is simply not enough evidence to make a definitive statement either way.

The concept of resilience has been defined by the International Panel on Climate Change (IPCC 2014, 1772) as "*The capacity of a social-ecological system to cope with a hazardous event or disturbance, responding or reorganizing in ways that maintain its essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.*" For any given society, the magnitude of a disturbance is likely to be more important than the direction of change (e.g. wetter to drier).

When faced with a climatic disturbance, a society might respond in one of the following ways:

1. Accommodate the disturbance through existing coping strategies and mechanisms without the need for longer-term adaptation;
2. Accommodate the disturbance through 'incremental adaptation', involving "*adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale*"

(IPCC 2014, 1758);

3. Change (aspects of) its character through ‘transformational adaptation’, involving “*Adaptation that changes the fundamental attributes of a system in response to climate and its effects*” (IPCC 2014, 1758);
4. Collapse as a result of its inability to cope with the disturbance coupled with a lack of capacity for either incremental or transformational adaptation (it might be argued that collapse is a form of transformational adaptation, for example involving the de-intensification of production and settlement in response to increased resource scarcity).

Different societies might pursue different adaptation strategies when faced with the same changes in climate, depending on existing environmental and cultural factors. Resilience and adaptation frameworks therefore help us move away from deterministic models of human-environment interaction and beyond existing causal models of climate-induced collapse (Brooks 2013). The four different responses to climatic disturbances listed above will have different levels of visibility in the archaeological record.

In this paper we use these different possible responses as a framework for interpreting periods of transition and stability evident in the archaeological record, in conjunction with palaeoclimatic and palaeoenvironmental evidence.

Figure 1. Map of the Near East and Eastern Mediterranean showing archaeological sites and regions and climate proxies used in the paper

2 Regional setting

2.1 Global and regional palaeoclimatic contexts

Abundant evidence indicates that the Middle Holocene was a time of profound climatic and environmental change, and the 4th millennium BC / 6th millennium BP[2] has been identified as a period of "significant rapid climate change" (Mayewski et al. 2004, 243). During the 6th millennium BP there were transitions to more arid conditions throughout the northern hemisphere sub-tropics and adjacent regions, and to cooler conditions at higher latitudes and altitudes (Damnati 2000; Guo et al. 2000; Brooks 2006; Magny et al. 2006; Thompson et al. 2006). However, these transitions commenced prior to the start of the 6th millennium BP in many locations. For example, Thompson et al. (2006) place the beginning of the Neoglaciation - a period of substantial glacier advance evident across the globe - around 6.4 kyr BP, coincident with an abrupt fall in the level of Lake Lunkaransar in the Thar desert which has been interpreted as indicating a regional shift to more arid conditions (Enzel et al. 1999). A weak monsoon episode has been inferred from a speleothem in Dongge Cave in southern China around 6.3 kyr BP (Wang et al. 2005), coinciding with the collapse of the summer monsoon over the Gilf Kebir in southwestern Egypt (Linstädter and Kröpelin 2004) and the beginning of a multi-millennial, stepwise transition to aridity apparent in sedimentary records from the Arabian Sea (Jung et al. 2004).

There is evidence of further step-wise transitions to aridity in northern Africa and western Asia during the 6th millennium BP. A shift to aridity in the Sahara between ~5.7 and 5.2 kyr BP observed in eastern tropical Atlantic

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[2] For discussion of environmental data we cite dates in calibrated radiocarbon years before present (BP), as this is the convention used in the majority of the source materials.

sediment records (deMenocal et al. 2000) coincides with a ‘severe 600-yr drought’ in the Zagros Mountains evident in δ^{18}O records from Lake Mirabad, and also Lake Zeribar (Stevens et al. 2006). Sirocko et al. (1993) infer an increase in Arabian aridity after 5.5 kyr BP based on an increase in dust flux (higher dolomite/$CACO_3$ ratios) identified from Arabian Sea sediments. Multiple studies provide evidence for a shift to drier conditions in South Asia around the same time (Enzel et al. 1999; Srivasta et al. 2003; Schuldenrein et al. 2004).

The above evidence indicates that the period from ~6.4 to ~5.0 kyr BP was characterised by approximately synchronous transitions to more arid conditions across many of the present day arid and semi-arid areas of the northern hemisphere. That these transitions were manifestations of a more widespread global climatic reorganisation is suggested by a change in the behavior of El Niño around 5.8 kyr BP (Sandweiss et al. 2007), a drought in Ireland of similar timing and duration to that recorded in Lakes Mirabad and Zeribar (Casseldine et al. 2005), a similarly synchronous reduction in river discharge into the Cariaco Basin off Venezeula (Haug et al. 2001), changes in the North Atlantic Meridional Overturning Circulation commencing around 5.8 kyr BP and lasting about a millennium (McManus et al. 2004), and a trend to drier and cooler conditions over equatorial East Africa from about 6.5 to 5.2 kyr BP indicated by δ^{18}O records from Mount Kilimanjaro and Mount Kenya (Barker et al. 2001; Thompson et al. 2002). A number of records from widely separated parts of the world, including many of those mentioned above, indicate RCC around 5.2 kyr BP (see Brooks 2010 for a review).

How these climatic disruptions impacted human societies is a question that is germane to both archaeologists and those interested in climate change and its potential effects on human societies. In the following sections we review cultural changes during the period between 6.4 kyr BP and 5 kyr BP in the regions adjacent to the eastern Mediterranean Sea, based on the published literature, and interpret them in their climatic and environmental contexts.

2.2 Regional archaeological contexts

This paper addresses potential climate-society interactions in Cyprus, Anatolia, the southern Levant (modern-day Israel, Jordan, Lebanon, the Palestinian Territories and Syria), Mesopotamia and parts of North Africa. The cultural variation (documented mainly in settlement plans and pottery) that characterised these regions in the 6th millennium BC began to be replaced in the 5th and 4th millennia BC by increased cultural homogeneity, largely brought about through interregional interaction, economic change and, in some regions, changing political relations (Wengrow 2001). Even so, trajectories towards social complexity were not synchronous across the region. Mesopotamia, for example, emerged at the end of the 4th millennium BC as a fully urbanised complex social system, and so did Egypt, but urbanism in Anatolia and the southern Levant emerged at the end of the 3rd millennium BC; in North Africa, a peculiar urbanization developed in the central Sahara in the 1st millennium BC. For this reason, chrono-typological terminology is out of sync across the region. The period encompassing 4500-3000 BC in Anatolia is defined by the Middle and Late Chalcolithic periods. In the southern Levant this period corresponds to the ‘Classic’ Chalcolithic (see Sharon 2013) and the Early Bronze Age I-II. In Cyprus it covers the Late Neolithic and Early to Middle Chalcolithic periods. In Northern Mesopotamia it corresponds to almost all of the Late Chalcolithic period, while in Southern Mesopotamia the cultural periods are named after type sites, the Ubaid and Uruk phases. In the central Saharan sequence this period maps onto the Middle and Late Pastoral periods. Understanding that the different nomenclature is a descriptive representation of the different speeds at which the majority of societies in these regions moved towards complexity (and, in most of these regions, urbanism) is critical.

Knowledge of the development of human societies in Anatolia between 4500 BC and 3000 BC tends to be patchy and is based on regional clusters of excavated sites that have produced discontinuous fragments of local cultural sequences. This means that surveys, for example, have not been able to differentiate securely between Middle and Late Chalcolithic sites (let alone subdivisions within these periods) resulting in the whole Chalcolithic period being treated as a single entity. No individual site west of the Taurus Mountains has yet produced a continuous sequence covering the transition from the Middle to the Late Chalcolithic. The only region where a more complete picture is available is the Anatolian southwest. Here, the transition can be reconstructed through a combination of the sequences unearthed at Tigani on the island of Samos and at the inland sites of Aphrodisias-Pekmez and Beycesultan (Schoop 2011, 158-162).

The southern Levant is, by contrast, more securely dated and better understood. The period between 4500 BC and 3000 BC encompasses the

'Classic' Chalcolithic (~4500-3800/3700 BC) and the Early Bronze Age I (~3700/3600-3200/3100 BC) both of which can be sub-divided into smaller discrete sub phases (Rowan and Ilan 2012). It is a period in which many of the elements considered necessary for complex urban society began to appear. Different lines of evidence indicate intensification of agricultural production, increasing social stratification, complex networks for trade in exotic items, unequal accumulation of wealth, and technological sophistication (including metallurgy) (Rowan and Ilan 2012, 88). Although there are broad similarities across a wide region, there is also considerable variation in architecture, burial practices, material culture, subsistence practices and trajectories of social change (Rowan and Golden 2009; Lovell and Rowan 2011).

Mesopotamia, like Anatolia, exhibits a high degree of geographic and environmental heterogeneity. The Tigris and Euphrates rivers flow southeast to the Persian Gulf and are vital for water, food, irrigation and transport. Travel between the north and south was via the major rivers and to the east and west via their many tributaries. The major route to the Levant was north and west via the well-watered foothills of the Zagros and anti-Taurus mountains. For the purposes of this paper the entire region has been divided into a northern region characterised by rainfall in amounts large enough to enable rain-fed agriculture and a southern region, where cultivation relied on irrigation along the major watercourses.

Broadly speaking, in the southern region the period between ~4500-4000 BC is known as the Terminal Ubaid, while the period between ~4000-3050 BC is known as the Uruk, after the sites at which distinctive Ubaid and

Uruk cultural assemblages were noted. It is during the Uruk period that the trajectories toward increasing social complexity and resource intensification accelerated. This process can be observed in the south as the development of higher level administrative systems, a marked increase in economic specialisation, centralisation of key religious, civic and militaristic activities, and increasing social stratification (Rothman 2001, 11). Although this trend begins in the Ubaid, its rate of acceleration increases significantly by 3700/3600 BC. Trajectories towards urbanism begin earlier in northern Mesopotamia than in the south. At the site of Tell Brak, Ur et al. (2007, 1188) record urban growth from the LC2 period (~4200-3900 BC) with significant expansion of the town in the LC3 period (~3900-3400 BC). The local contemporaneous cultural entities are collectively described as the Local Late Chalcolithic.

In North Africa, the ‘long’ 4th millennium BC saw a renewed spread of pastoralism through the central Sahara, and changes in pastoral livelihood strategies against a background of increasing aridity. In the eastern Sahara this period is characterised by in-migration to key localities where resources (principally water and pasture) were still available, followed by out-migration (e.g. to the Nile Valley) with the onset of hyper-aridity (Nicoll 2004; Kröpelin 2005). In the central Sahara, pastoral populations intensified transhumance and use of highland areas as lowland areas became drier. In-migration to oasis areas was associated with a combination of increased sedentism in lowland oases and increased mobility based on sheep and goats in the uplands (di Lernia 2002).

3 Materials and methods

3.1 Environmental data

In order to identify periods of RCC in the Eastern Mediterranean region during the Middle Holocene, we examined 20 terrestrial and 20 marine, continuous[3], well-dated records from the published literature, for the period 8.3-4.0 kyr BP (Tables 1 and 2). This period was selected as it includes the 'long' 4th-millennium BC, from around 6.4-5.0 kyr BP, and is bracketed by the frequently discussed episodes of apparent RCC centred around 8.2 and 4.2 kyr BP (e.g. Cullen et al. 2000; Rohling and Pälike 2005; but see Weiss 2012 and papers therein for alternative views).

We restricted our examination of terrestrial records to speleothem ($\delta^{18}O$, $\delta^{13}C$, $^{234}U/^{238}U$ and diameter) and lake ($\delta^{18}O$, level) records, on the basis that these are likely to be the most reliable proxies for rainfall (although see the discussion of the Soreq Cave and Dead Sea records below). Pollen records were avoided in the wider regional analysis because of the possibility of anthropogenic influences resulting from landscape modification. Marine records examined include foraminiferal $\delta^{13}C$ records and mineralogical records. Records of different types from the same locations/cores were used; for example $\delta^{13}C$ and mineralogical records from northern Aegean site SL148 and southeast Levantine Sea site SL112 (Hamann et al. 2008; Kuhnt et al. 2008). We used only those records that can reasonably be viewed as proxies for local or regional rainfall, based on their identification as such by the authors of the studies from which the data were taken.

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[3] Some of these records were shorter than others, commencing after 8.3 kyr BP, and some marine records exhibit hiatuses during the Sapropel 1 period.

TABLE 1 HERE

TABLE 2 HERE

For each proxy record, the direction of change in the variable represented was identified for each century between 8.3 and 4.0 kyr BP, based on plots of the variables concerned extracted from the relevant studies. The results were recorded on a spreadsheet (Appendix A), with each proxy represented by a row and each century represented by a column. Each cell, representing a single century for a specific proxy, was populated by a symbol representing (i) an increasing value, (ii) a declining value, (iii) an increase followed by a decline or vice versa, (iv) no significant change, or (v) high variability embedded within a decline, an increase or no overall change in rainfall. Cells were colour coded to identify (i) 'global' maximum and minimum values (i.e. over the entire period examined), (ii) 'local' maximum and minimum values, and (iii) changes and trends in a particular direction. These minima, maxima and trends in the records were identified by visual inspection of the published records and thus represent a rapid analysis involving some degree of subjectivity. There is scope for a more detailed and rigorous analysis of these data using quantitative methods to identify maxima and minima, and variations in rates of change over time.

Based on the calculated relationships of the proxy records with rainfall (i.e. positively or negatively correlated) as described in the studies from which the data were derived, the spreadsheet symbols and colour codes were harmonised so that the results for each proxy were indicative of inferred changes in rainfall. For each century, the number of local and global inferred rainfall minima and maxima was summed across the proxy records. The results were examined to identify single centuries or multi-century clusters associated with a high frequency of inferred rainfall minima or maxima across records. The frequencies of inferred rainfall minima were compared with those for the well-established 8.2 and 4.2 kyr BP arid episodes.

3.2 Development of coupled social-ecological narratives

Results from the environmental analyses were compared with recent results from surveys and excavations for the period between 4500 BC and 3000 BC in regions surrounding the Eastern Mediterranean: Anatolia, the Levant, and Mesopotamia. For each of these regions, the number of inferred rainfall minima was calculated for running three-century periods across a subset of the marine and terrestrial records that were deemed most relevant.

Four detailed archaeological case studies were identified from the above regions for interpretation in the context of the environmental data: 1) The Beersheva Valley, Israel; 2) Cyprus; 3) Western Syria; and 4) The Middle Euphrates. While Anatolia is discussed in regional terms, there is as yet insufficient data to construct detailed archaeological/environmental narratives at the more local scale. In addition, two further case studies from North Africa are discussed, 5) Eastern Sahara and 6) Central Sahara, where links between climatic, environmental and social changes are already well established.

The results are presented as narratives of coupled social-ecological change within the resilience and adaptation frameworks presented above, insofar as such narratives are compatible with the archaeological and environmental evidence. Environmental interpretations are based principally on the analysis of the terrestrial and marine records described above and in Tables 1 and 2. However, additional studies are referenced where relevant.

We do not assume links between climatic and social changes during periods of RCC: the aim here is to identify *possible* connections between these changes in the form of *plausible* (and diverse) adaptation responses. The narratives in which these connections and responses are embedded should be interpreted as hypotheses for further testing.

4 Results

4.1 Terrestrial palaeoclimate data

Of the 20 terrestrial records examined (Table 1), 11 show clear signals of a drying commencing in the Middle Holocene, prior to 6 kyr BP, and continuing after 4 kyr BP (see figures for specific regions below). The Soreq Cave $\delta^{18}O$ and $\delta^{13}C$ records (Bar-Matthews and Ayalon 2011) exhibit a sinusoidal character throughout the Middle Holocene but indicate drying after 4 kyr BP, as does the Sofular Cave record (Göktürk et al. 2011). The Lake Mirabad and Gölhisar $\delta^{18}O$ records (Stevens et al. 2006; Eastwood et al. 2007; Roberts et al. 2011) show a drying up to ~5 kyr BP and ~4 kyr BP respectively, after which they indicate wetter conditions. The Ioannina $\delta^{18}O$ record (Frogley 2001; Lawson et al. 2004; Eastwood et al. 2007) exhibits no long-term trend. The only two records that indicate a change to wetter conditions are the Corchia speleothem $\delta^{13}C$ record (Zanchetta et al. 2014) and the Dead Sea lake-level reconstructions (Migowski et al. 2006). The former is contrary to the $\delta^{18}O$ record from the same speleothem, suggesting that this apparent discrepancy is most likely due to localised mechanisms that influence the $\delta^{18}O$ and $\delta^{13}C$ content in different ways (see the discuss of the Soreq Cave $\delta^{18}O$ and $\delta^{13}C$ records below). The Dead Sea record is more problematic, and is discussed in detail in Section 4.3.2.

The number of terrestrial records indicating a ‘local’ or ‘global’ rainfall minimum in each century considered is shown in Figure 2a. The century with the highest number of such minima is 5.2-5.3 kyr BP, with inferred rainfall minima in 8 records, followed by 5.6-5.7, 6.1-6.2 and 7.7-7.8 kyr BP, all of which are associated with minima in 6 records. Four of the records (1, 2, 16, and 17: see Table 1) do not start until ~7 kyr BP, so the frequency of inferred rainfall minima prior to this date should be seen as a potentially conservative estimate. The number of records with inferred rainfall minima corresponding to these centuries increases considerably when periods of three centuries are considered (Figure 2b), on the basis that (i) a single century is shorter than the resolution of some records, (ii) periods of RCC may have lasted for more than a century, and (iii) minima represent periods of inferred lowest rainfall that may follow periods of rapid rainfall decline, meaning that centuries containing minima may not encompass complete episodes of RCC.

Using running totals over 300-year periods (Figure 2b), rainfall minima cluster most strongly around 5.1-5.2 and 5.2-5.3 kyr BP (15 occurrences), followed by 4.1-4.2, 5.6-5.7 and 6.1-6.2 kyr BP (14 occurrences). Clusters of more than 10 minima (i.e. 50% of records) occur in centuries adjacent to those identified above, and also at 7.7-7.8 and 7.8-7.9 kyr BP (again note that counts prior to ~7kyr BP may be conservative).

While the incompleteness of some of the records means that we cannot reliably compare clusters of rainfall minima for the 8.2 kyr RCC with later periods, it is notable that the well-established 4.2 kyr RCC is not the most prominent such episode in these records. Indeed, the most prominent clusters of rainfall minima in Figure 2 occurs at the end of the long 4th millennium BC, around 5.2-5.3 kyr BP. On the basis of these data, we should probably consider the following periods as periods of RCC: the early-mid 8th millennium BP, the end of the 7th millennium BP, and the early-mid and late 6th millennium BP.

FIGURE 2 HERE

4.2 Marine data

The marine data (Table 2) paint a broadly similar picture to the terrestrial data, with 16 records exhibiting long-term trends consistent with increased regional aridity, three showing no clear trend, and one (silt input into site SL148 in the Northern Aegean) suggesting increased fluvial activity. However, the details of the marine records are somewhat different from those of the terrestrial records.

FIGURE 3 HERE

The maximum number of marine records exhibiting an inferred rainfall minimum in a single century is six (all global), for the period 4.0-4.1 kyr BP

(Figure 3a). Minima occur across five records for 5.2-5.3 kyr BP and 4.9-5.0 kyr BP. When 300-year running totals are examined (Figure 3b), the highest frequency of inferred rainfall minima are clustered around 5.0-5.1 and 5.1-5.2 kyr BP (12 in each case). These and adjacent centuries represent a peak in the distribution of minima, with a secondary peak clustered around 6.5-6.6 kyr BP. Five of the marine records do not start until 6.0 kyr BP, meaning that the frequencies of inferred rainfall minima prior to this date may be underestimates.

4.3 Archaeological evidence

4.3.1 Anatolia

4.3.1.1 General archaeological setting

Anatolia, part of modern Turkey, describes the landmass stretching between the Aegean Sea and the western flanks of the Taurus Mountains. It displays a considerable variability of geographical and climatic zones. Besides narrow coastal strips along the Black Sea and Mediterranean shores, much of its interior lies at altitudes around 1000 m asl, characterised by mountainous landscapes and considerable forest cover in antiquity.

Broadly speaking, its western and southern regions are characterised by a Mediterranean climate, while the northern and central part of the country are characterised by continental climate.

By 6000 BC the entire region was populated by early farming communities (Düring 2011) but our knowledge of subsequent development has remained fragmentary and marred by chronological insecurities. Until relatively recently, the Chalcolithic was conceptualised as a relatively short period, essentially representing a prelude to the Early Bronze Age (Düring 2008) but we now know that it lasted more than three millennia, from approximately 6200/6100 BC to 3000 BC (Summers 1993; Thissen 1993; Schoop 2005; Özdoğan 1996, 2007).

By the early fifth millennium BC, the beginning of the Middle Chalcolithic period, material culture assemblages show traits that have their roots in local ceramic traditions extending back into the 6th millennium BC. These earlier traits occur in combination with new shapes that represent a link to similar developments in the northern Aegean and the southern Balkans. This aspect of unity, noticeable in coastal ceramic assemblages from the Black Sea, the Aegean and the Mediterranean, as well as in inland sites on the Anatolian Plateau, appears to have come to an, apparently rather abrupt, end by the last quarter of the 5th millennium BC (Schoop 2011). This junction marks one of the most profound episodes of typological discontinuity in Anatolian prehistory. Subsequent traditions are more diversified and it is often difficult to recognise morphological links between contemporaneous local ceramic traditions.

This overall diversity also makes it difficult to identify changes in economic practices. By the 5th millennium BC, food production was fully established, augmented by marine resources at some coastal sites. In the 4th millennium BC, there are indications of a growing interest in specific resources, such as a new emphasis on hunting at inland sites (red deer, equids); elsewhere pig raising and/or dairying become important. A sudden general interest in wool-based textile production is evident both in the artefactual and faunal assemblages (Arbuckle et al. 2009; Arbuckle 2012). For the first time in Anatolian prehistory, a destructive human impact on the landscape and surrounding settlements becomes visible; at present, such evidence is limited to a few sites located in the Troad and on the northern part of the Plateau (Riehl and Marinova 2008; Marsh 2010; Marsh and Kealhofer 2014). Whether these developments are indicative of more complex economic arrangements or of the emergence of new social practices is under debate (cf. Schoop 2014).

Similar ambiguity exists for the question of social differentiation. Although Anatolia did not experience development toward urbanism at this time in the same way as the Upper Euphrates region or Northern Syria (Özdoğan 2002; Çevik 2007), opinion is divided on the question of whether the 4th millennium BC was characterised by the emergence of societies with stable social hierarchies (Eslick 1988; Steadman 2011). Seen as a whole, the evidence indicates an intricate pattern of general discontinuity, re-adjustment and limited persistence of earlier practices after ~4300 BC. By the early mid-fourth millennium BC, communities in all the different landscapes and ecological zones of Anatolia had left behind the traditions linking them to their Neolithic heritage and had embarked on new trajectories which eventually led to the emergence of the more steeply stratified societies of the Early Bronze Age. Evidence from southwestern Anatolia suggests that this transition happened rapidly between ~4200 and 4000 BC. While the social and economic background to these developments remains poorly understood, and while there is some evidence for differences in regional trajectories, the timing and overall direction of change is broadly similar throughout the region. This makes it likely that these changes were at least partly driven by shared or common factors. Environmental or climatic factors may well have played a role but the limitations of the archaeological record make it difficult, at present, to arrive at a more specific understanding of the situation.

4.3.1.2 Local environmental evidence

An analysis of Ca and Sr isotope ratios from annually laminated sediments from Nar lake in central Turkey indicates a shift from predominantly moist, stable conditions in the Early Holocene to a drier and less stable Late Holocene ~6.5-6 kyr BP (Allcock 2013, 189). Data from the nearby lake, Eski Acıgöl, show a shift to drier conditions between 7.5 and 6.25 kyr BP (Roberts et al. 2001; Jones et al. 2007) (Figure 4), although Roberts et al. (2011, 148) record the disappearance of varved deposits at Eski Acıgöl and the establishment of salt-tolerant diatom species, indicating a fall in the lake level, around 6.5 kyr BP.

Lake Tecer, to the northeast of Nar and Eski Acigöl, records multi-centennial wet and dry phases during the 6th to 3rd millennia BP, with intense droughts at the end of the 6th, 5th and 4th millennia BP, and a period of humidity between 5850 kyr BP and 5250 kyr BP (Kuzucuoğlu et al. 2011, 179). At Lake Gölhisar in southwestern Turkey, isotopic fluctuations from ~8.8-5.1 kyr BP suggest oscillations between aridity and humidity, with increased $\delta^{18}O$ and $\delta^{13}C$ values indicating generally drier conditions after ~5.1 kyr BP (Eastwood et al. 2007). In contrast, Wick et al. (2003) and Eastwood et al. (2007) (Figure 4), record annually laminated sediments from Lake Van, suggesting optimum climatic conditions and a maximum extension of the Kurdo-Zagrian oak forest after this date (Wick et al. 2003, 674) (Figure 4).

Lake Van, however, is situated over 600 km to the east of Eski Acıgöl, in a different climatic and ecological zone (Göktürk et al. 2011) and lower $\delta^{18}O$ values may reflect changes in seasonality (Stevens et al. 2006). Figure 4 shows a selection of regional climate proxies for Anatolia, alongside two key global climate proxies, the GISP2 non sea salt [K^+] and GRIP $\delta^{18}O_{ice}$ records from Greenland.

Figure 5 shows the distribution of inferred episodes of reduced rainfall across 15 climate proxies for Anatolia and immediately adjacent regions, including lakes for which continuous, well-dated records were available (Eski Acıgöl, Van, Gölhisar, and Ionnina) (see review by Eastwood et al. 2007; Roberts et al. 2011), the Sofula Cave speleothem (Göktürk et al. 2011) (Figure 4) and marine records from the northern and southern Aegean (Kuhnt et al. 2008; Hamann et al. 2008) (Figure 4). Such episodes are common prior to 5.8 kyr BP, even though this period is characterised by generally wetter conditions than in the later Holocene in many records, namely those from Gölhisar, Van and Eski Acıgöl (Roberts et al. 2011), Sofular Cave (Göktürk et al. 2011), and some of the sedimentary records from site GeoTü SL148 (Hamann et al. 2008). Reduced-rainfall episodes are clustered around 8.0-8.1, 7.7-7.8, 6.5-6.7, 6.0-6.1, 4.8-5.0 and 4.1-4.2 kyr BP. From a minimum around 5.7-5.8 kyr BP, coinciding with the onset of the period of humidity described by Kuzucuoğlu et al. (2011), the number of inferred arid episodes steadily increases to around 4.8-5.0 kyr BP.

FIGURE 4 HERE

FIGURE 5 HERE

4.3.1.3 Interpretation

In both the archaeological and climatic data there is evidence that the period between 4500 BC and 4000 BC (6.5 to 6 kyr BP) was a period of significant change in much of Anatolia. Although the scale, speed and duration of social change is not well documented due to a dearth of archaeological evidence and inadequate radiocarbon dating series, it is clear that the social changes observed across a wide region occurred after an environmental shift to drier conditions between 4500 to 4000 BC. In addition, arid episodes cluster around 3000 BC (~5.0 kyr BP) (Figure 5), and again this corresponds broadly with the transition from the Chalcolithic period to the Early Bronze Age in Anatolia.

The lack of widespread evidence of societal collapse or settlement abandonment suggests that Anatolian populations successfully navigated whatever climatic and environmental changes they faced. The ubiquity of the cultural transitions at the beginning and end of the long 4th millennium BC suggests ‘transformational’ adaptation that replaced less viable or less successful behaviours with ones that were more suited to new conditions. However, the interpretation of social changes in 4th millennium BC Anatolia as adaptations to RCC and its consequences remains highly speculative, and should be seen as a hypothesis to be tested through high-resolution environmental and archaeological studies at localised site level or micro-regional scale.

4.3.2 The southern Levant

4.3.2.1 Archaeological setting

The period between 4500 BC and 3000 BC is represented by the Chalcolithic and Early Bronze Ages I-II. The ‘Classic’ Chalcolithic begins at ~4500 BC and ends at ~3800/3700 BC (Bourke et al. 2004) but the process of settlement abandonment extended over the period between 4000 BC and 3700 BC. The Early Bronze I commences abruptly at ~3700 BC. In the northern Negev desert no Chalcolithic site survives beyond ~3700 BC and those that date beyond 3800 BC are contentious (Burton and Levy 2011, 179). In the Dead Sea region Chalcolithic settlement disappeared by ~3900-3800 BC, based on revised dates from Teleilat Ghassul (Bourke et al. 2004).

Regev et al. (2012, 555) record the beginning of the Early Bronze IA at ~3700 BC, the transition from the Early Bronze IA to the Early Bronze IB at somewhere between 3450 BC and 3100 BC, and the transition from the Early Bronze IB to the Early Bronze II between 3050 BC and 2950 BC (Regev et al. 2012, 558). The transition from the Early Bronze IB to the Early Bronze II is generally accepted to have been a change from complex open un-walled settlements with dispersed buildings to a hierarchy of compact fortified settlements; the first truly urban communities in the Near East (but see Philip 2001; Chesson and Philip 2003 for an alternative view). The transition was traditionally seen as the outcome of a long process of social change, resulting in the emergence of fully complex societies, but more recent studies indicate that there was also a crisis in Early Bronze I society (Chesson and Philip 2003). These changes have yet to be fully explained but are interesting in that they are coeval with the abandonment of the Uruk period colonies in Northern Mesopotamia.

4.3.2.2 Local environmental evidence

The most relevant climate proxies for the southern Levant and Cyprus are the Soreq Cave speleothem record (Bar-Matthews et al. 2003; Bar-Matthews and Ayalon 2004, 2011; Grant et al. 2012; Zanchetta et al. 2014), the Jeita Cave speleothem in Lebanon (Verheyden et al. 2008), the Dead Sea sediment cores, which record lake high stands (Migowski et al. 2006), and marine cores from site SL112 in the southeast Mediterranean sea (Kuhnt et al. 2008; Hamman et al. 2008) (Figures 6 and 7).

These climate proxies indicate a general shift towards aridity starting in the late 8th to late 7th millennium BP depending on the proxy. Sand content and the end member indicative of fluvial sources from site SL112 indicate increased aridity after around 7.5 kyr BP. Quartz/smectite ratios from the same core, most likely reflecting sediment input from the Nile (and therefore rainfall in eastern tropical Africa), increase until about 5.9 kyr BP and then stabilise. The Jeita Cave record indicates a shift towards aridity starting in the mid-7th millennium BP that is associated with a phase of extreme variability between about 6.2 and 5.9 kyr BP and a step-wise shift to more arid conditions between about 5.9 and 5.7 kyr BP, with a further intensification of aridity after about 5.5 kyr BP. Marine foraminifera records from site SL112 indicate increased aridity from about 6 kyr BP, but are not available between this date and the start of Sapropel S1 around 9.6 kyr BP (Kuhnt et al. 2008).

The Soreq cave and Dead Sea records paint a more complex picture. The Dead Sea reconstruction by Migowski et al. (2006, 423) indicates a decline in lake levels from around 10 kyr BP to a minimum at ~7.8 kyr BP, followed by a long-term trend of increasing levels until the mid-3rd millennium BP. This rise is interrupted by a period of high variability with no overall trend between about 7.2 and 5.6 kyr BP. Within this period and subsequently, there are numerous lake level minima whose durations are measured in decades, between 6.8-6.9, 6.4-6.5, 6.1-6.2, 5.6-5.7, 5.1-5.3 and 4.1-4.3 kyr BP. While the long-term trend is contrary to the other records described above, decadal-scale low stands tend to correspond with periods of RCC identified in other regional proxies.

There is considerable divergence between the Soreq Cave $\delta^{18}O$ and $\delta^{13}C$ records in the 8th millennium BP, when high $\delta^{13}C$ values are associated with low $\delta^{18}O$ values. This may been explained as a result of deluge events during periods of high rainfall causing the removal of soil cover, which resulted in water infiltrating to Soreq Cave with little interaction with soil CO_2 (Bar-Matthews et al. 2000, 2003; Zanchetta et al. 2014). There is some divergence between the $\delta^{18}O$ and $\delta^{13}C$ records during parts of the 7th millennium BP, but from about 6.4 kyr BP these records exhibit a consistent, roughly sinusoidal pattern on millennial timescales, on which is superimposed a high degree of shorter-term variability. Both records indicate drying until around 5.6-5.7 kyr BP, followed by an increase in humidity until around 4.8-4.9 kyr BP, after which conditions again become more arid.

There is a very high degree of variability in Soreq records, particularly in the $\delta^{18}O$ record between about 6.7 and 5.4 kyr BP, suggesting a high degree of climatic instability during this period. The records suggest heightened aridity from 5.7-5.4 kyr BP (5.6-5.5 kyr BP in the $\delta^{13}C$ record) and 5.3-5.2 kyr BP. The $\delta^{18}O$ record suggests very brief periods of high rainfall around 6.45, 6.23, 5.74, 5.43, 5.30, 5.10 and 4.75 kyr BP. The high-rainfall episodes at 5.74, 5.30 and 4.75 kyr BP are also apparent in the $\delta^{13}C$ record, with the other episodes being absent or offset in this record.

The Dead Sea record indicates a significant fall in lake levels from ~8.2-7.8 kyr BP, following a declining trend from the Early Holocene. From ~7.8-3.5 kyr BP the trend is one of increasing levels, although this is reversed from ~6.9-6.2 kyr BP, and there are numerous shorter-term reversals lasting decades to centuries superimposed on this trend. By and large, these reversals coincide with periods of aridity (increased $\delta^{18}O$) in the Soreq Cave record, with a similar correspondence between high Dead Sea levels and negative $\delta^{18}O$ excursions. However, there are periods during which the longer-term trends in the Dead Sea and Soreq records diverge, for example ~6.2-5.6 and 4.8-4.0 kyr BP. This may be due to shifts in the seasonal distribution of rainfall, as postulated by Stevens et al. (2006) for Lakes Mirabad and Zeribar, but may also be partly due to the different chronological scales of resolution of the records.

Figure 8 shows the distribution of episodes of aridity inferred from the 12 most relevant climate proxies for the southern Levant examined in this study, based on a sliding 3-century period, showing a clustering of these episodes around 7.6-7.8, 5.6-5.8, 5.2-5.3, and 4.3-4.4 kyr BP, with a weaker clustering around 6.7-6.9 kyr BP. The general trend is for the frequency of arid episodes to increase after 6.4 kyr BP, with some amelioration of this trend between 5.1 and 4.6 kyr BP. However, it should be noted that only 8 records are represented for the period before 7 kyr BP, meaning that the dry episode count for the earlier part of the series might be conservative. It should also be emphasised that the episodes represented in Figure 8 are ones of relative rather than absolute aridity, meaning that dry periods occurring within an otherwise wet period (e.g. prior to ~6.5 kyr BP) may be considerably wetter than those occurring during drier periods. It is also important to note that periods of apparently very high rainfall (discussed above) occurred within, between, and immediately before or after some of these arid episodes.

FIGURE 6 HERE

FIGURE 7 HERE

FIGURE 8 HERE

In the following sections we highlight two case studies that demonstrate the possible impacts of climatic change on social change. We have chosen these examples because we believe the evidence for climatic drivers of social change to be unequivocal.

4.3.2.3 Case study 1: the Negev Desert, 4500-3000 BC

The climate proxies represented in Figures 6 to 8 are used to interpret the archaeological record of a region extending from north of the Beersheva Basin to the southern edge of the Negev Highlands. These data are augmented by alluvial stratigraphies from wadis in the northern Negev (Rosen 2007, 78), pollen analysis (Rossignol-Strick 1999; Langgut et al. 2014 for later periods) and snail shell isotope studies (Goodfriend 1991). While the proxy climate data do not correlate perfectly, they indicate increased rainfall in the second half of the 5th millennium BC in the northern Negev (Rosen 2007, fig. 5.7), increased river flow perhaps to the point of perennial flow in the northern Negev systems (now ephemeral streams) (Levy and Goldberg 1987; Rosen 2007, 99-101), and a southward extension of the C3 vegetation system by up to 40-50 km (Goodfriend 1991). Early in the 4th millennium BC these conditions gave way to a drier climate, the consequent cessation of perennial stream flow in some wadis, and apparent C3 retreat. It is important to emphasise that these trends are complex and marked by constant fluctuations.

Climatic and environmental fluctuations are much less marked in the southern, drier areas of the study zone. Based on the formation of Reg soils, Enzel et al. (2008, 171) have demonstrated that the southern Negev has been permanently hyperarid at least since the Middle Pleistocene, and that the wetter Negev episodes were probably restricted to the northern Negev. They infer the co-existence of much wetter conditions in central and northern Israel and hyper-arid conditions in the southern Negev with a transition zone located north of the Negev Highlands (Enzel et al. 2008, 173). Specifically, the pollen diagram from the Atzmaut rock shelter in the central Negev does not record the 5th millennium BC rainfall spike, although the rise in Graminae (Poaceae) at the end of the 4th/beginning of the 3rd millennium BC suggests that the later amelioration is recorded there (Babenki et al. 2007), albeit of a lesser amplitude.

Archaeologically, the bioclimatic gradient is reflected in two separate cultural systems, the farming system of the northern Negev and the Mediterranean zone, and the desert pastoral system of the central Negev and areas farther south (Rosen 2011a). In the Beersheva Basin, settlement data and analyses of radiocarbon assays indicate the presence of farming populations in the second half of the 5th millennium BC (Gilead 1994). These new settlements were perhaps made possible by increased water flow along the Wadi Beersheva, allowing for simple flood plain irrigation (Rosen 1987) and increased precipitation probably permitting dry farming of the interfluves (Katz et al. 2007). The entire system was abandoned sometime in the early 4th millennium BC, and continuity with the succeeding cultures of the Early Bronze Age is evident only tens of kilometers farther north and on the Coastal Plain.

In contrast, the archaeological record indicates cultural continuity throughout the 4th millennium BC among the desert pastoral groups to the south. Living in an environment that was already arid, these communities would not have been directly affected by regional increases in aridity, although they may have been indirectly affected through their interactions with other zones that felt the direct effects of RCC. We propose a model of opportunistic incremental adaptation in the mid-late 5th millennium BC in which farming systems responded to increased rains by moving into previously uninhabited zones along the Wadi Beersheva, following expanding rainfall geography. RCC in the early-mid 4th millennium BC in a region that was effectively on the threshold of farming viability caused the collapse of the system (or transformation adaptation involving migration and resettlement elsewhere). In contrast, the pastoral systems to the south were resilient to regional climatic changes by virtue of their existing adaptation to aridity.

Settlement along the Wadi Beersheva was not renewed until the late 2nd millennium BC, although a few late 4th millennium BC villages are known in the eastern part of the region, one of which developed into the desert gateway town of Arad, *circa* 3000 BC. Although the evolution of Arad seems to correspond to the late 4th millennium climatic amelioration indicated in the pollen diagram from the Atzmaut rock shelter and from the Soreq Cave speleothem record, there is a general consensus among scholars that the site's *raison d'etre* was the copper trade and the development of trade links to the desert hinterland (Ilan and Sebbane 1989; Amiran et al. 1997). The absence of a developed village agricultural hinterland is telling in this case. There was no general village agricultural florescence stimulated by the climatic amelioration, but rather Arad served primarily as an economic node.

Farther south, the Timnian desert pastoral groups do not share similar cultural trajectories to the farming systems further north. Although the period around 3000 BC shows a major increase in site numbers, virtually all of these are attributable to either outposts associated with the site of Arad (Beit-Arieh 2003) or various types of pastoral encampments (Haiman 1992; Rosen 2011b). If at some ultimate level this florescence can perhaps be linked to climatic amelioration, at another more proximate level, all evidence suggests that the primary factors involved in this demographic spike relate to the rise of urban Arad. In this sense, resilience in the case of the Timnian culture is not only to environmental change, but also to social change. The Timnian pastoral society adapted to changing social circumstances, shifting its economic strategies from pure subsistence in the earliest part of its history, to connections through the metal trade with the sedentary Chalcolithic communities and through more intensive trade of a wider range of goods with Arad in the Early Bronze Age.

4.3.2.4 Case study 2: Cyprus, 4500-3000 BC

Although Cyprus does not qualify as a typical marginal environment (i.e., unable to sustain uninterrupted rain-fed agriculture due to rainfall of <300 mm per year) it acts like a marginal environment in times of drought because consecutive years of low rainfall will have a disproportionately adverse effect on crops and vegetation. This is because Cyprus has no standing bodies of water and the rain-fed rivers that flow both north and south from the Troodos and Kyrenia Mountains are deeply down cut and water is quickly and violently dispersed. Cyprus also has no accessible deep aquifers that can sustain agriculture in the event of a drought. Thus, more than a couple years of drought in the past (as today) would have resulted in a marked reduction in the availability of water, a decline in the variety and density of vegetation, and an unequal degree of drying on the central and coastal plains in contrast with the mountainous regions (Christodoulou 1959, 19).

There are no climate proxies from Cyprus; palaeoclimatic reconstructions rely on the extrapolation of regional proxies (Brayshaw et al. 2011). More localised environmental evidence comes from archaeological sites. Although the environmental data for Cyprus are slim, the archaeological record is relatively comprehensive, with good absolute (radiocarbon) and relative (stratigraphical) chronologies, and it is possible to reconstruct an independent trajectory of societal change that can be compared with the climate proxies for correspondences between the two.

From ~4500 BC until ~4000 BC, Cyprus was characterised by small sedentary, villages. Subsistence was based on mixed farming of staple food crops, herding sheep/goats and pigs, and a reliance on hunting deer (Croft 2010). Villages were abandoned at ~4000/3800 BC to be replaced by ephemeral (possibly seasonal) sites established in previously uninhabited areas. Plant and animal remains included the same species as previously, although an elevated percentage of deer are represented in the faunal assemblages, indicating an increased reliance on hunting (Croft 1991). In contrast, grinding tools used in processing cereals remained common in artefact assemblages suggesting there was no commensurate decline in cultivation.

Between ~3500 and ~3300 BC there is a return to a sedentary way of life and by ~3000 BC large, socially complex agricultural villages with evidence of unequal distribution of wealth, social heirarchy and storage of surplus become prevalent across the island (Peltenburg 1996). There is a rise in the consumption of pigs at the expense of both deer and ovicaprines (Croft 1991, 71) and intensification in the processing of cereals and legumes. At ~3000 BC, or a little after, there is evidence of a sharp decline in the size and number of settlements. Middle Chalcolithic occupations at Erimi-*Pamboula*, Kissonerga-*Mosphilia*, and Souskiou-*Laona* all have evidence of disruption and abandonments. Between ~3000 BC and ~2700 BC there is virtually no archaeological evidence for occupation on Cyprus. Radiocarbon dates from recent excavations at Politiko-Kokkinorotsos (Webb et al. 2009), however, partly fill this gap. The interesting feature of this site being that unlike the preceding late-4th millennium BC agricultural villages, Kokkinorotsos appears to be an early-3rd millennium BC hunting station (Webb et al. 2009).

Ancient terra rossa-like soils found in association with cultural deposits at Kalavasos-Kokkinoyia (Clarke, forthcoming) and Kalavasos-Ayious (Todd and Croft 2004, 216) give a glimpse of possible changes in the climate at the end of the 5th millennium BC and the beginning of the 4th millennium BC. At the first site terra rossa-like soil is found at the very base of a feature in contact with the underlying limestone bedrock, where it must have formed. It is sealed by an archaeological deposit of pottery and stone tools dating to ~4200 BC, which means the soil formed before this date. The presence of a terra rossa-like soil at the base of the chamber, and sealed by archaeological material indicates, that at sometime prior to 4200 BC the climate in Cyprus was both warm and humid. At the nearby site, Kalavasos-Ayious, local conditions indicate that the climate was considerably drier at the beginning of the 4th millennium BC (Todd and Croft 2004, 216). Current radiocarbon evidence places the time span of occupation at Ayious from ~3800 to ~3600 BC. (Knapp 2013, 201). Todd and Croft (2004, 216) noted that during excavation a truncated fossil soil containing a small admixture of sherds and other prehistoric materials was located at the bottom of the pit overlying the natural deposits. This soil was terra rossa-like in composition, with fine mud-like silicates. It was however, riddled with specks of calcrete, which indicate a drying out phase. This is consistent with the climatic trajectories inferred from the regional proxy records (Figures 6 to 8).

The cultural transitions in Cyprus ~4000 BC are consistent with adaptation to more arid conditions, indicated by the regional climate proxies around this time. The abandonment of permanent settlements and the ephemeral nature of new sites alongside an increased emphasis on hunting suggests a less predictable and productive environment in which greater effort was required to secure food resources. It is notable that this cultural transition occurs during a period characterised by extreme climate variability, followed by a transition to aridity as inferred from both the Soreq Cave and the Jeita Cave records. The archaeological record of early 4th-millennium BC Cyprus suggests transformational adaptation focused on relocation and enhanced mobility, although this was accompanied by continuity in at least some crop and tool types. By 3500 BC societies on Cyprus began to re-establish themselves in permanent settlements and these continued to thrive and grow in sophistication and complexity throughout the remainder of the 4th millennium BC. A second period of settlement discontinuity occurred at the beginning of the 3rd millennium BC with an apparent return to greater mobility based on hunting. Whether these changes were related to the environmental evidence of further regional aridification at ~3100 BC is unknown at this stage but they are not contemporary by at least 100 years.

4.3.2.5 Interpretation

Prior to 4000 BC virtually all regions of the Levant were populated by small to medium-sized sedentary agricultural villages at varying stages of social complexity and resource intensification. Sometime around 4000 BC or slightly later, widespread cultural upheaval occurred across the region, but the speed, scale and timing of these upheavals was different for different sub-regions and even for different sites. Broadly speaking, however, many sites had been abandoned by ~3900/3800 BC (Braun and Roux 2013). Where there is enough evidence to examine the nature of the relationship between the environmental data and the cultural evidence, it appears that extreme climatic variability around ~4000-3800 BC precipitated settlement abandonment and a shift to a more mobile way of life. Even when dealing with potentially long-lived sites in optimal lowland locations such as the Jordan Valley, it has proved difficult to demonstrate continuity of occupation through this period (Braun and Rouz 2013, although this may reflect the burial of small early 4th millennium BC occupations deep below later tell debris.

In some regions of the southern Levant there is evidence of discontinuity, settlement shift and a return to a more mobile way of life around the end of the 4th millennium BC, while in Cyprus the transition to greater mobility occurs slightly later at the beginning of the 3rd millennium BC. The need to fortify towns, like Arad ~3000 BC, hints at a possible increase in raiding parties, suggesting stress on resources, although Arad may have been particularly vulnerable to raiding because of its role in the copper trade. Whatever the case, disruption around the end of the 4th millennium BC in the southern Levant and Cyprus may have been exacerbated by RCC.

4.3.3 Mesopotamia

4.3.3.1 Archaeological setting

The period between 4500 and 4000 BC in Southern Mesopotamia is known as the Terminal Ubaid, which gives way to the Early Uruk culture ~4000 BC. In the north the period between 4500-3000 BC is known as the Late Chalcolithic (LC) and is subdivided into five phases (LC1 to LC5) on the basis of small changes in the archaeological record. It is during LC3 (~3800-3500 BC) that southern, Middle Uruk elements begin to appear in the north in some number (Wilkinson et al. 2012, 143), although sites across the region engaged with this process to different degrees and at slightly different points in time (McMahon 2013). At Tell Brak in northeast Syria, continuity in local traditions is overlaid with the appearance of southern Uruk elements in quantity from ~3500 BC. In contrast, at Tell Sheikh Hassan on the Euphrates, the interaction begins at ~3800/3700 BC and the material culture is dominated by southern elements (Sürenhagen 2013). From ~3400-3100 BC (LC5) an Uruk ‘colony’ is established at the site existing side-by-side with the local indigenous population; elsewhere this Uruk ‘intrusion’ spans the period from ~3700-3100 BC (Schwartz 2001). Contemporaneous with the terminal phase of the Uruk intrusion into the north is a rapid increase in settlement density around the principal city of Uruk-Warka (Nissen 1998; Matthews 2003). This coincides with or follows a large decline in settlement density in the Nippur-Adab region immediately to the north of the Uruk region in LC5 (Pollock 2001). The Middle Euphrates Uruk colonies of Habuba Kabira, Sheikh Hassan and Jebel Aruda disappear from the north at ~3100 BC, after which there is a decline in the scale of settlement in the reigon (Ur 2010) while the Uruk Culture in the south transitions into the Jemdat Nasr period (3050 BC to 2900 BC) and then into the Early Dynastic 1. The latter process appears to be relatively smooth and a function of the acceleration toward urbanism that began centuries before. Thus, although there is expansion and contraction of economic activity and in settlement in terms of the appearance and subsequent disappearance of the southern Mesopotamian ‘colonies’, there is general continuity of indigenous settlement in the well-watered regions of the north and of the Uruk cities in the south.

4.3.3.2 Local environmental evidence

The most relevant climate proxies for Mesopotamia are the records from Lake Mirabad and Lake Zeribar (Stevens et al. 2001; 2006; Wasylikowa et al. 2006). Located in the Zagros Mountains of southwestern Iran, both are relevant for examining environmental conditions in the vicinity of the Tigris and Euphrates rivers, which played a key role in the development of human societies in Mesopotamia. Sediment records from Lake Van may also reflect changes in climate in the vicinity of the headwaters of the Tigris and Euphrates. Other studies have used marine sediment records from the Arabian Sea and Gulf of Oman as proxies for regional aridity in the Arabian Peninsula and Mesopotamia (Sirocko 1993; Cullen et al. 2000). The records most relevant to Mesopotamia are reproduced in Figure 9.

Figure 10 shows the frequency of episodes of low rainfall across $\delta^{18}O$ records from Lakes Van, Mirabad and Zeribar (Stevens et al. 2006; Roberts et al. 2011) and from speleothems from Hoti and Qunf caves in northern and southern Oman respectively (Fleitmann et al. 2007), as well as sediment records from the northern Red Sea (Arz et al. 2003) and the Gulf of Oman (Cullen et al. 2000). Nine out of 10 records suggest an arid episode between

5300 and 5100 BP, with 8 records indicating a rainfall minimum sometime between 6200 and 6500 BP.

FIGURE 9 HERE

FIGURE 10 HERE

In addition to changes reflected in the records represented in Figures 9 and 10, the *Marine Transgression* impacted settlement in the alluvial regions of Southern Mesopotamia. Recent geomorphological and environmental research by Pournelle (2012), in combination with extensive landscape surveys (Adams and Nissen 1972; Adams 1981; Wright 1981) has enabled comprehensive mapping of changing settlement patterns during the 5th and 4th millennia BC. Pournelle says that, “In terms of human habitation and environmental exploitation, the ocean’s rise and fall is most significant in its see-saw effect on the [Euphrates and Tigris] rivers’ debouchment into the Gulf”. These changes in sea level, accompanied by a prograding and retrograding delta will have significantly impacted the way in which cities in the southern alluvium negotiated their economic and subsistence strategies. Pournelle records that “By 4550 (cal) BC, the sea had completely swamped the Euphrates Valley and the ancient marshes, and extended as far inland as Ur.” (Pournelle 2012, 19).

Pournelle’s work has demonstrated that during the first half of the 5th millennium BC sites in the southern alluvium were located on exposed ancient river levees and elevated ground between channels in locations bordering marshes and swamps. By the beginning of the Uruk period ~4100 BC, virtually every exposed ‘turtleback’ became the site of a village or town. Little archaeological evidence for fishing survives, but literary evidence suggests that fishing was a mainstay of the economy in the southern alluvium (Pournelle 2012, 23).

4.3.3.3 Case study 3: Western Syria, 4500-3000 BC

Wilkinson et al. (2014) and Lawrence and Wilkinson (2015) have argued that lowland agricultural basins such as the Orontes Valley were settlement ‘cores’, marked by long-term stability in site location. The implication for our study is that communities in such regions were able to accommodate RCC, either through their existing strategies, or by ‘incremental adaptation’. The problem from our perspective is that these sorts of strategies might be difficult to detect in the archaeological record, while simultaneously creating long-lived occupations, in which the crucial 4th millennium BC evidence is buried below many metres of later deposit.

In recent years the outline of a chronological and material culture framework for the period ~5000-3000 BC in north and west Syria has emerged. Excavations at Tell Zedian in the Euphrates Valley (Stein 2012, Fig. 1a Table 1), reinforced by evidence from Tell Brak in north-east Syria (Oates et al. 2007, 590) indicate that the distinctive painted ceramics of the Ubaid tradition had largely disappeared by 4500 BC. Accordingly, the transition to the succeeding LC1, characterised by mineral-tempered flint-scraped bowls (Stein 2012, 132), can be placed around the mid-5th millennium BC. The rather better documented LC2 and LC3, characterised by chaff-tempered ceramics, span the period between 4200-3850 and 3850-3700 BC respectively (Stein 2012b, 135).

This case study is focused upon the upper Orontes Valley, around the present-day cities of Homs and Hama. The key excavated sites are Tell Nebi Mend (TNM), a large 9 ha multi-period tell, and Tell Arjoune, which appears to represent the eroded remnants of a series of short-lived prehistoric occupations (Parr et al. 2003, 2). The two sites are located 1 km apart on the west and east banks of the Orontes River respectively. The earliest deposits at TNM (Phases 1-5) date to the 7th millennium BC (Parr et al. 2015, 66, Fig. 2.26). Radiocarbon dates from the subsequent Phase 6 fall in the early 4th millennium BC, indicating a gap in occupation at the site.

Material at Arjoune dates to the 6th and early 5th millennia BC (Gowlett 2003, 29) indicating occupation covering the gap between TNM Phases 5 and 6. Thus while the locality witnessed continuous occupation, settlement may have shifted between the two locations. Occupation at Arjoune is unlikely to have continued beyond 4400 BC, as the site has not produced any chaff-tempered pottery (Matthias 2003, 36).

Chaff-tempered ceramics were present in substantial quantities in TNM Phases 6-12, which (as yet unpublished) radiocarbon dates suggest fall between 4050 and 3700 BC, thus contemporary with LC2 and LC3 further north. The period between 3350 and 3050 BC at TNM witnessed the introduction of new vessel forms in well-fired, reddish fabrics that contained markedly less chaff, termed Fabrics B and E by Matthias (2000, Fig. 23.4, 33-68). These forms continue in slightly modified form in the early 3rd millennium BC deposits at the site, and so provide a ceramic indicator of occupation falling between 3400-3300 cal. BC and the appearance of the well-known EB IV ceramic types around 2500 BC.

Using this framework to interpret the settlement evidence from the Upper Orontes Valley, the 4th millennium BC represented a marked intensification compared to earlier periods. There is considerable continuity in settlement across the 4th and 3rd millennia BC with most of the locations that would become enduring components of the tell landscape of the later 3rd and 2nd millennia BC, occupied by the 4th millennium (Lawrence et al. 2015, 8, Fig. 6b; Philip and Bradbury in press). The most striking characteristic of settlement in the Upper Orontes Valley appears to be its stability, inasmuch as this can be reckoned from surface collections, with the essential settlement structure of the region established in the 4th millennium BC. While some settlements were present along its seasonal tributaries, the bulk of settlement (measured as aggregate settled area) was concentrated along the banks of the Orontes (Bartl and al-Maqdissi 2014; Philip and Bradbury in press). No settlements were identified that were located beyond the present-day 300 mm isohyet.

Both TNM and Arjoune offer evidence pertinent to an understanding of past subsistence practices. A comparison of the archaeobotanical data from Arjoune (Moffat 2003, 241-243) and TNM Phases 6-12 (Walker 2013) reveals no major change in the range of domestic or weed species present. The exception is the appearance of olive in the later occupation.

When the faunal evidence is considered, the main difference between the evidence from the Neolithic/Chalcolithic deposits and the 4th millennium BC occupation is the marked reduction in the proportion of pigs, and a concomitant increase in the number of caprines in the later period: this may reflect the emergence of wool-bearing sheep in the 4th millennium BC (Grigson 2003; Grigson 2015a, 2015b).

TABLE 3 HERE

The settlement history of the adjacent basaltic landscape, which occupies the area west of the Orontes River, is quite different. To summarise (Philip and Bradbury 2010), this area is dry and barren in summer but receives annual precipitation of 500-600 mm, and during late winter and spring offers good grazing and pools of standing water. Evidence for Neolithic activity consists mainly of concentrations of diagnostic chipped stone around the larger seasonal lakes. However, in the 4th and 3rd millennia BC settlement took the form of a small number of occupations located along the main drainage systems, supplemented by a larger number of irregular stone enclosures, often located away from the valley bottoms: these are probably associated with the seasonal management of animal herds (Philip and Bradbury 2010, 145). The similarity of the ceramics collected from the valley bottom sites and the enclosures suggests that they were part of a single settlement system. Our limited knowledge of the local basalt-tempered pottery, which interestingly is quite different from the ceramics found on contemporary sites east of the Orontes, means that we can date this activity only to the broad period ~4200-2500 BC. What is clear is that the ‘long’ 4th millennium BC witnessed a significant expansion of animal herding in this otherwise lightly occupied landscape.

While a few particularly favoured locations in the Syrian steppe to the east of the Orontes have produced material of probable Chalcolithic-EBA date (Geyer et al. 2014, 12, 14), activity between the Late PPNB and the EB IV (~6200-2500 BC) is infrequent and appears to have focused largely on hunting and mobile herding. The evidence from the arid region around the oasis of Palmyra indicates that following a relatively extensive presence of Pre-pottery Neolithic settlement, “the evidence for the Pottery Neolithic, Chalcolithic and Bronze Age is extremely scanty” (Morandi Bonacossi and Iamoni 2012: 34) and mostly concentrated within the limits of the oasis (Cremaschi and Zerboni 2012). This is consistent with a drier phase during these periods and a recorded drop in Palmyra and Abu Fawares lake levels and increased wind activity (Cremaschi and Zerboni 2012).

The changes described above might be explained as responses to regional economic developments. For example, the major expansion of settlement on the steppe to the east of the Orontes dates to the EB IV period in the 3rd millennium BC (Geyer 2001; Morandi Bonacossi 2007), when this area became the focus of large-scale animal raising associated with the emergence of early states in the region such as Palmyra, Mari and Ebla (Cooper 2006; Wilkinson et al. 2014). The inferred expansion of herding activity west of the Orontes after ~4200 BC might be explained in similar social and economic terms, for example in response to the economic opportunities created by the growth of settlements in the Orontes Valley.

Nonetheless, the role of climatic and environmental change should not be discounted. Indeed, many of the social changes addressed here are at least compatible with adaptation to changes in rainfall and water availability. It is significant that occupation of the upper Orontes Valley intensifies in the 4th millennium BC, during a time of increasing regional aridity that signals a long-term shift to a drier climate, and that settlement is concentrated along the banks of the Orontes. The stability of settlement from the 4th millennium BC onwards in the Orontes valley might be viewed as a ‘transformational adaptation’ in the form of a shift to permanent sedentism along the Orontes. Parallel developments in the basalt areas west of the Orontes involved a shift in activity from seasonal lakes to the main drainage systems, where runoff would have been concentrated in a drier climate. Both of these phenomena are consistent with the concentration of populations and/or economic activities in *refugia* in which resources remained available in an environment that was otherwise becoming less productive (Brooks 2006, 2010).

4.3.3.4 Case study 4: the Middle Euphrates, 4500-3000 BC

Wilkinson (2004) and Wilkinson et al. (2012) have undertaken research on the Middle Euphrates region, documenting settlement patterns and mobility during the 4th to 3rd millennia BC. The region can be divided into two different agricultural / ecological zones; a northern, well-watered region that shows long-term settlement stability throughout the entire period, and a second, southerly, marginal region, which forms part of a larger “Zone of Uncertainty”, with current rainfall <300 mm per year. The latter region includes the Uruk Intrusion sites, Habuba Kabira, Jebel Aruda and Tell Sheikh Hassan and was characterised by rapid expansion and contraction of settlement, what Wilkinson et al. (2012, 143) call “a boom and bust growth of towns perhaps encouraged by the opportunities afforded by the high risk, but high rewards of the ‘Zone of Uncertainty’”. During the LC3-4 (3700-3300 BC) there is widespread evidence of intense contact with the Uruk world but by 3100 BC this interaction ends and the Uruk Intrusion sites are abandoned. At the beginning of the Early Bronze Age (~3050 BC) local indigenous populations establish new sites close to the abandoned Uruk Intrusion sites, at crossings along the Euphrates River. Two pairs of sites, Tells Hadidi and Sweyhat and Selenkayihe and Halawa thrive through the 3rd millennium BC.

The analysis by Wilkinson and others indicates that the region north of the “Zone of Uncertainty” supported a moderately dense pattern of local LC settlement dating back beyond the 5th millennium BC. Thus, there is evidence of long-term continuity of settlement in the well-watered rain-fed agricultural regions.

Survey data from within the “Zone of Uncertainty” (Wilkinson et al. 2012) demonstrate that the region was devoid of settlement (although probably used by pastoralist communities) until the establishment of the Uruk sites in the 4th millennium BC. People living in the large towns during the LC3-4 within this zone show risk-averse strategies of village-based herding and cultivation of domestic wheat, barley and lentils. There is evidence of close ties with the metal producing regions of eastern Anatolia as well as long-distance links with southwestern Iran and southern Mesopotamia (Wilkinson et al. 2012, 168-172).

The nature of the Uruk Intrusion sites – paired settlements on opposite banks of the Euphrates – suggests that the Uruk Intrusion was motivated at least in part by a desire to control and tax trade conducted via navigable waterways. It may also have been intended to maintain trade links with northern Mesopotamia at a time when existing trade relations and mechanisms between north and south were breaking down. Schwartz (2001, 243) notes that “In the period following the Uruk expansion, the material culture of Syria becomes regionalized and almost completely devoid of connections to contemporaneous Mesopotamia.”

The period covered by the Uruk expansion (LC3-5) coincides with a “severe 600-yr drought” from ~3700-3100 BC indicated by the Lake Mirabad and Zeribar records (Stevens et al. 2006), while the beginning of the expansion coincides with a cluster of inferred rainfall minima around 3600-3700 ± 100 yrs BC (Figure 9). The Uruk expansion, and the subsequent establishment of intrusive migrant towns, therefore appears to have commenced at a time of regional RCC and proceeded during a period of climatic deterioration characterised by severe and protracted aridity.

The final Uruk contraction coincides with the strongest clustering of inferred rainfall minima around 3100-3200 BC (Figure 10). This contraction is associated with the widespread abandonment of settlements in the Nippur-Adab area with a concomitant increase in settlement density around Uruk-Warka (Pollock 2001, 191-192).

4.3.3.5 Interpretation

The climate records from Lakes Mirabad and Zeribar suggest sharp seasonality in rainfall, characteristic of a Mediterranean climate from 8000 to 4500 BC. The reliability of wet winters would have structured agricultural practices in both the northern and southern regions. This climate regime coincides with the beginnings of agriculture in the Fertile Crescent (north

Syria, south-eastern Turkey and northern Iraq) during the Early Neolithic and continued until the beginning of the Late Chalcolithic period. Thus, relative climate stability will have facilitated the cultural continuity that we observe in the rain-fed regions of the north. There is no evidence for settlement in the southern alluvium before the 6th millennium BC but this may be due in part to the marine transgression.

After 4500 BC, the climate data suggest a shift back to a continental climate, with sharp diurnal temperature ranges and cold dry winters. Between 4500 and 4000 BC it is difficult to associate social changes with periods of RCC, other than to note that the early centuries of the terminal Ubaid fall within a period of increased aridity, as does the disappearance of the Ubaid from the north at ~4100 BC, and the expansion of herding west of the Orontes Valley ~4200 BC. Otherwise, there do not appear to have been any major social changes related to this shift either within the rain-fed regions of the north, or the southern alluvium, and we interpret the apparent cultural continuity as indicative that the speed and amplitude of change was such that people were able to adapt their existing strategies.

The most significant changes in both culture and climate occur during the 4th millennium BC, when increased aridity in the north coincides with an intensification of settlement in the Orontes Valley and locational shifts in herding activities to the west, both of which are consistent with more intensive exploitation of areas in which resources are concentrated in an otherwise drying environment. In the south, marine regression is likely to have played a role in the growth of settlement in the alluvium. The Uruk intrusion occurs and persists during a multi-century period of aridity, and its collapse coincides with a period of RCC, suggesting a possible move to secure trade disrupted by environmental deterioration, followed by the crossing of an environmental threshold beyond with this strategy was no longer viable. While this interpretation is speculative, it is worthy of further consideration.

Thus, the evidence suggests that Mesopotamia's cultural development benefitted from a reliable climate regime in the Neolithic and Chalcolithic periods and that the 'urban revolution' coincided with a period characterised by regional climatic deterioration in the form of increased aridity punctuated by RCC in the 4th millennium BC.

4.3.4 North Africa

In contrast to Mesopotamia or the Levant, where environmental approaches are only exceptionally applied to the archaeological record, Saharan archaeology has been at the forefront of studies of human-environment coevolution (Figure 11). Kuper and Kröpelin (2006, 803) describe the Sahara as "a unique natural laboratory for the reconstruction of the links between changing climate and environments, and human occupation and adaptation, with prehistoric humans as sensitive indicators of past climate and living conditions." The following discussion demonstrates how comprehensive collection and analyses of localised environmental and archaeological data can provide much more detailed information on microenvironments and their impacts on individual sites and locales.

FIGURE 11 HERE

4.3.4.1 Eastern Sahara

The Egyptian Western Desert (Eastern Sahara) is characterised by different hydrological basins that have provided proxy data for the reconstruction of environmental dynamics during the Last Holocene Humid Phase. Although the evidence is patchy, recent research has centred on the role of climate in the development of early societies in the region. A re-evaluation of the relevant available climatic and palaeoenvironmental data has defined six main ecological phases between 13500 and 3500 BP, mainly in the evolution of water basins (Gallinaro 2008).

Between 6600 and 5200 BP the region appears to have been marked by considerable environmental and hydrological variability, with specific localised responses to a general drying trend. The onset of the phase is characterised by the drying of the southern minor endorheic basins (NW Sudan) and a severe regression and fragmentation of the major hydric systems – Oyo Lake (Ritchie et al. 1985) and the West Nubian Palaeolake, (Hoelzmann et al. 2001), which finally desiccate between 5200-4200 BP. Northern oases, playa basins and the Fayum system record a short wet period, followed by increasing aridity between 6200 and 5800 BP. The environmental collapses in these areas followed a differentiated trend likely depending on their latitude and hydrological catchment. The Gilf Kebir and the Wadi Howar remain wetter until the late 6th millennium BP when a severe climatic crisis is recorded in the Gilf Kebir around 5300 BP (Kröpelin 2005). In contrast, the Wadi Howar dried more gradually with an estimated final collapse more than two millennia later at ~3000 BP (Kröpelin 2007).

The above environmental data have been calibrated against the archaeological evidence using frequency distribution curves of radiocarbon dates indicative of human occupation between ~4600 and ~3200 BC. This evidence indicates that the hyper-arid regions were largely abandoned during this period, while the main playa basins and the oases show a low intensity of human occupation and the better-watered regions of the Gilf Kebir, Wadi Howar and the Nile Valley/Fayum show an increase in human occupation.

In the Gilf Kebir the rainfall regime shifted from monsoon to Mediterranean around 6200 BP, which produced favourable conditions for in-migration from drier regions. This, coupled with changes in landscape use, corresponded to a new cultural phase at Gilf Kebir (named Gilf C) ~4350-3500 BC. Land use shifted from a pattern based on large campsites, located near to wadis, with temporary exploitation of the plateau rim, to one of more dispersed, smaller sites. This pattern corresponds with a transition from hunting and gathering to a mobile herding economy (Linstädter and Kröpelin 2004).

In the Wadi Howar, major transformations began around 6000 BP with a new cultural phase, the Wadi Howar 2, dated to ~4000-2200 BC. Settlements at this time were highly variable in size and tended to cluster in the most favourable areas, close to the main wadi courses. Like the Gilf Kebir, the economy shifted from hunting, gathering and fishing to herding (Jesse and Keding 2007).

In the Dakhla Oasis, the Bashendi B cultural phase (~5600-3800 BC) is represented by mobile pastoral communities that roamed different ecological areas and shared cultural traits over a wide region of the Western Desert.

Exotic precious items suggest the existence of some social differentiation (McDonald 2002). Around 3800 BC the emergence of the local Sheikh Muftah culture (3800-2200 BC) represents an impoverishment of the previous Bashendi B phase. It is characterised by small groups of herders living within the oasis in temporary campsites located close to water sources. Social complexity seems to reduce and precious items disappear, while lithic artefacts and pottery show increasing contacts with the Nile Valley (McDonald 2002).

Extensive excavations around the Nabta playa have enabled archaeological, palaeobotanical, and palaeontological reconstructions of the critical adaptations and transitions from foraging to food production, domestication and the practice of animal husbandry (Close 1987). More than 100 published radiocarbon dates demonstrate that occupations coincided with wet phases, and that arid, harsh conditions caused abandonment (Nicoll 2001, 2004). Interpretation of the material culture suggests that the Neolithic people at Nabta developed more elaborate traditions and practices with increasing social complexity over time and as the climate became drier (Close 1987; Wendorf & Schild 1998, 2001). Drought conditions around Nabta became acute at ~6000 BP; water sources dried up, and the grassland disappeared. A poor state of preservation characterises the rare archaeological sites that existed at this time. These are referred to as the Final Neolithic Culture, called El Bunat el Ansam (4500-3300 BC, Wendorf and Schild 2001). Data come from three cemeteries in the area of Gebel Ramlah (some 25 km northwest of Gebel Nabta (Kobusiewicz et al. 2009). The pottery vessels reflect contacts with the Nile valley and the quality and quantity of the grave goods, including exotic materials, as well as complex burial rites, shared by the whole burial population, has fostered discussion about the possible presence of social complexity (Wendorf and Schild 2001).

The area was inhospitable after 5300 BP (3350 BC), and hyperarid by 4780 BP, hyperaridity prevailed, and the Sahara became established. This profound environmental change precipitated migration – an “Exodus event” in which people left desert locales for more reliable water sources. As the Nabtan and desert peoples relocated, they inevitably contributed their own culture and beliefs to the birth of ancient Egyptian religion and the Pharonic civilisation, which was organized around irrigation agriculture within the densely populated Nile River Valley (Nicoll 2004, 2012).

The ecological crisis starting in 6600 BP had different effects in different areas, and the phase can be characterised by regionalism and increasing contacts with the emerging Nile Valley. Wide areas of the Western Desert are abandoned or depopulated and the general trend is toward a pastoral mobile economy. Population displacement and aggregation in favourable areas, like the Nile Valley, took place at different rates and on different time scales.

4.3.4.2 Central Sahara

The south-western corner of Libya has been the subject of a long-term research program (1991-2011) carried out by the Italian-Libyan Mission in the Acacus Mountains and Messak Settafet plateau, and encompasses an area of more than 60,000 km^2. It includes highly diversified elements of the landscape, such as mountains, plateaux, dune-fields and fluvial valleys

(Cremaschi and di Lernia1999). The data are based on extensive and intensive geoarchaeological survey and some excavated archaeological contexts (e.g., Biagetti and di Lernia 2013; Cremaschi and di Lernia 1998, 1999, 2001; di Lernia 2006; Cremaschi and Zerboni 2011; Cremaschi et al. 2014). The Holocene sequence has been divided on the basis of major social changes usually (but not always) connected to vast environmental variations (mostly due to abrupt or rapid climatic change) (di Lernia 2002). The cultural phase of interest here is the Middle Pastoral Period, ~4800 BC to the Late Pastoral Period ~ 3700 BC).

Palaeoenvironmental proxies come from lacustrine sediments (Cremaschi 2001; Zerboni 2006) in the sand seas, stratigraphic sequences from rock shelters and caves, and calcareous tufa (Cremaschi 1998; Cremaschi 2002; Cremaschi et al. 2010, 2014), and from dendroclimatology of the *Cupressus dupreziana* (Cremaschi et al. 2006).

The beginning of the Middle Pastoral follows a dry period, which lasted at least 300 years, reflected in a variety of indicators (di Lernia 2002), in particular, the stratigraphic series from mountain contexts in the Acacus and Messak. Here an increase of desert-adapted plants (Mercuri 2008), the ingression of aeolian sand (Cremaschi and di Lernia 1998) and the collapse of cave vaults (Cremaschi 1998) document aridity during this period. In addition, the radiocarbon database of contexts firmly related to human occupations (more than 180 dates) shows a hiatus before 4800 BC (di Lernia 2002).

In contrast, lowland records from freshwater environments found in the sand seas show relicts of lacustrine sediments indicating lake high stands in the very same period (Cremaschi and Zerboni 2009). However, the sedimentary pattern (e.g. organic layers alternating with authigenic calcareous mud), geochemical data from carbonate minerals (high evaporation rate indicated by isotopic signals of C and O) and the occurrence of a mollusc assemblage including highly drought-resistant species, suggest stong seasonal fluctuations of lake levels during the middle Holocene (Cremaschi 1998; Zerboni 2006; Cremaschi and Zerboni 2011; Zerboni et al. in press).

The difference between the two sets of proxies requires a comment: information from caves and rock shelters provide direct evidence of human occupation, and appear to be more synchronous with the environmental changes than the lacustrine data. The ecological response to aridification of freshwater-dependant environments seems to be slightly delayed. As elsewhere in the Sahara (Lézine 2009) lacustrine environments connected to surface aquifers apparently show a higher resilience to rapid climate changes and therefore a certain delay in recording them (Cremaschi and Zerboni 2009). However, as evident from sedimentological data, this period corresponds to a phase of oscillation of lakes level and so is subject to variation.

Once established the Middle Pastoral communities of the central Sahara show a great stability: food security is based on cattle (Dunne et al. 2012), together with the herding of small livestock and seasonal hunting. The settlement pattern features a transhumance system between lowlands and highlands on a seasonal basis (large summer sites in the sand seas, small winter sites in the mountains; di Lernia et al. 2013). The socio-cultural traits show homogeneity over a very large region, a kind of Saharan *koiné*: this is evident in the subsistence basis (full pastoral organisation), ideology and rituals (rock art, ceremonial monuments) and material culture (shape and decoration of pottery).

Environmental data combined with evidence of human occupation highlight variations and discontinuities, especially at the end of the long 6th millennium BP. There is now a good concordance between the terrestrial and lacustrine record for the period between ~ 4800 and 4300 BC. The indications are of a high stand in the lake levels and stratigraphic continuity in the cave series. From ~5300 BC there are indications of a continuous lowering of lake levels and in the rock shelters and caves there is the first hard evidence of dung accumulation. This trend becomes more pronounced by ~3700 BC. A clear indication of increased aridity comes from the dendroclimatology of *Cupressus dupreziana* (Cremaschi et al. 2006). This record shows two intervals of decreased tree ring width, interpreted as a sub-centennial phase of severe droughts dated between ~3700 and 3600 BC. The preservation of organic matter, such as sheep/goat droppings, demonstrates limited bacterial activity due to increasing aridity, whereas the systematic use of the rock shelters as pens for sheep/goat indicate a strongly reorganised subsistence basis.

The instability at the beginning of the 4th millennium BC probably lasted around (or at least) three centuries and no significant changes are recorded in the settlement systems, nor significant variations in the mortality curves of living sites. The capacity of pastoral communities to cope with changing and possibly unstable environmental conditions reveals the resilience of these populations.

Even if difficult to date precisely, a major change is suddenly recorded at around 3900 BC. Culturally, the bulk of the data come from “megalithic” sites, in particular large, isolated stone tumuli (> 10m) hosting the inhumations of adult males. Funerary practices, osteological features and isotopic data reveal a quite distinct pattern when compared to the Middle Pastoral phase. People are no longer interred in the rock shelters (Tafuri et al. 2006; di Lernia and Tarfuri 2013) but in formal areas for the deceased, usually away from the settlement and within stone monuments located in dominant positions (di Lernia et al. 2001). The shift is also visible in the settlement organisation and in some traits of the material culture. Sites in the ergs are now ephemeral transient encampments, probably the remains of overnight stops. Small groups of herders still visit the Acacus and Messak in the winter season, using the caves as specialised stables. The pottery containers are different from Middle Pastoral open vessels: an increase of necked vases is apparent and the decoration does not cover the entire pot (as in the past) but only the rims. The lithic industry is less abundant and even more opportunistic: however, it is with the Late Pastoral that we notice the presence of finely made exotic tools – such as pre-dynastic knifes and, more raw materials from very far regions (such as alabaster, carnelian, turquoise etc). All these elements reflect a ‘new’ social organisation based on a large-scale mobility and specialised pastoralism (di Lernia 2002). These nomadic Late Pastoral herders seem to exploit large areas of the now-hyperarid central Sahara and possibly represent a mobile elite, as also suggested in other African areas (MacDonald 1998).

It is very likely that the transition from Middle to Late Pastoral was triggered by environmental changes: in particular, it is plausible that social changes were due to migratory drifts of small human groups that brought new customs and rituals, as well as internal socio-organisation. These groups had to negotiate with locals and the outcome was a complex reorganisation of these pastoral societies, yet to be fully defined.

5 Discussion and conclusions

A number of studies have proposed connections between episodes of RCC and cultural changes in the Eastern Mediterranean and elsewhere during the Middle Holocene (e.g. Cullen et al. 2000; Staubwasser and Weiss 2006). There is a tendency for these studies to be based on little more than temporal coincidences and models of RCC-induced societal collapse, and to make limited use of the mass of archaeological data. Other studies have attempted to construct more nuanced narratives of coupled social-ecological change mediated by rapid and severe climate change (e.g. Brooks 2006, 2013). All, however, are characterized by general narratives addressing large spatial scales, and drawing primarily on global rather than regional or local climate proxies.

Here we have presented detailed local and regional case studies, interpreted using systematic analysis of closely located climate proxies. We have demonstrated that episodes of RCC, involving periods of inferred rainfall minima, occurred across multiple records, clustering around certain dates. Across the 20 terrestrial records analysed, aridity occurs at 5700-5800 BC, 4100-4200 BC, 3600-3700 BC and 3100-3300 BC. In marine records, aridity is implied at 4500-4600 BC, 3200-3300 BC and 2900-3000 BC. In both terrestrial and marine records, the clustering is strongest at the end of the 4th millennium BC. The distribution of RCC maps well onto the ‘long’ 4th millennium BC and supports the interpretation that the period represented a transition from a moist, relatively stable climate to a climate characterize by instability and increasing aridity. Step-wise shifts to aridity were associated with multiple episodes of RCC.

Disaggregation of the climate proxies by region reveals geographic variations in the timing and rates of change to more arid conditions. In Anatolia, arid episodes cluster at 4500-4700 BC, 4000-4100 BC and 3000 BC. In the southern Levant, arid episodes are more numerous, clustering at 5600-5800 BC, 4700-4900 BC, 3600-3800 BC, 3100-3300 BC and 2200-2600 BC. In Mesopotamia, arid episodes cluster at 4300-4600, 3100-3600 BC and 2800-3300 BC, although it must be highlighted that these are identified based on data from sites located considerable distances from the Mesopotamian sites discussed in the text.

The archaeological evidence from our case studies suggests that periods of RCC were more than likely a factor in many of the social changes observed across the region between 4500 and 3000 BC, but there is considerable variability in the rate and type of changes that occur. In the case studies where environmental data from archaeological contexts are available it is clear that societal change was impacted by environmental change (the Beersheva Valley and the eastern and central Sahara). In Cyprus, Western Syria and the Middle Euphrates, the relationship is inferred but requires more local environmental data, while in western Syria and the Middle Euphrates the relationship is more speculative.

During the latter half of the 5th millennium BC, the data indicate that the shift toward an unstable, increasingly arid climate had begun. Archaeologically, these initial stages of climatic instability had little impact. Across the region social and economic systems appear relatively stable. There is evidence of population growth and economic expansion, for example in Syria and in the Beersheva Valley, but stability and continuity are the predominant features of the late 5th millennium BC.

The situation changes in the 4th millennium BC: a period of profound social change in many parts of the Eastern Mediterranean. At the beginning of the period there are considerable settlement upheavals, including abandonments, dislocations, shifts and changes in subsistence practices in both the southern Levant and Cyprus. In Syria we observe an intensification of settlement in the Orontes Valley, while to the west pastoralists focus their activity along major drainage channels. In the Middle Euphrates, Uruk settlements were established in marginal areas (the Zone of Uncertainty) during a time of severe climatic deterioration, perhaps to secure lines of supply during a period of aridity coinciding with the 600-year drought recorded in Lakes Mirabad and Zeribar, and a multi-century period of inferred RCC.

The case studies examined here furnish us with abundant evidence of changes that might be interpreted using resilience and adaptation frameworks. For example, the stability of occupation in the Orontes Valley indicates that, if settlement in this resource-rich locality represented an adaptation to climatic deterioration in the wider region, it was a successful one that was sustained throughout the 4th millennium BC and beyond. Elsewhere, we might contrast the apparent resilience of the populations of the hyper-arid northern Negev, which were already well adapted to aridity, with the ‘boom and bust’ vulnerability of groups moving into the Beersheva Valley in the second half of the 5th millennium BC during a period of increased rainfall, and the subsequent collapse of the same societies in the early 4th millennium BC during a shift toward aridity.

Other case studies suggest adaptations that were successful for long periods, but which encountered limits as the climate deteriorated further. For example, it is plausible that the Uruk intrusion represented an economic adaptation to the impacts of climate change that was not sustainable in the face of the RCC at the end of the 4th millennium BC, perhaps due to river flow falling below a threshold that made navigation and the transport of goods difficult or impossible. In-migration to ‘refugia’ such as the Gilf Kebir, and changes in resource exploitation strategies, allowed people to inhabit the eastern Sahara after the onset of increased aridity in the late 5th millennium BP, but these strategies came up against hard climatic limits when the region transitioned to hyper-aridity from the late 4th to early 3rd millennium BC. In the central Sahara, adaptations based on transhumance had a limited lifetime due to the eventual transition to hyper-aridity in the lowlands, although further adaptation in the form of sedentism in oasis areas and a move to sheep and goat husbandry in upland areas proved highly durable.

While most of the discourse around adaptation to 21st century climate change focuses on incremental adaptation intended to ‘protect’ existing economic and cultural systems and practices, the ‘long’ 4th millennium BC highlights the limits of resilience in the face of severe climatic and environmental changes. It thus illustrates the need for transformational adaptation in the face of profound changes in climatic and environmental conditions.

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Artwork

Figure 1. Map of the Near East and Eastern Mediterranean showing archaeological sites and regions and climate proxies used in the paper

Figure 2. (a) Frequency of inferred rainfall minima across the 20 terrestrial records listed in Table 1, by century, for the period 4.0 – 8.3 kyr BP. Black indicates a 'global' minimum in the proxy record, i.e. a minimum across the whole period represented. Grey indicates a 'local' minimum in the record, i.e. over a section of the period represented. (b) The same data, plotted as 300-year running totals (i.e. the number of minima for each century is sum of number in that century and previous and subsequent century). Note that four of the records (1, 2, 16, 17) extend back only as far as the end of the 8th millennium BP (6th millennium BC), meaning that the number of inferred dry episodes represented prior to this date may be conservative, and results for this earlier period should be treated with caution.

Figure 3. (a) Frequency of rainfall minima across the 20 marine records listed in Table 3, by century, for the period 4.0 – 8.3 kyr BP. (b) The same data, plotted as 300-year running totals, as in Figure 2b. Shading as in Figure 2. Note that four records (8, 10, 19, 20: see Table 2) extend back only as far as

6 kyr BP, and one (11) only extends back to 5.2 kyr BP.

Figure 4. Selected records most relevant to Anatolia, listed in order of decreasing latitude, with Greenland records for comparison: Greenland GRIP $\delta^{18}O_{ice}$ indicative of temperature; Sofular Cave $^{234}U/^{238}U$ (Gökturk et al. 2011); North Aegean marine site GEoTü SL148 silt fraction end-member 3 indicative of fluvial sources (Hamann et al. 2008); Lake Ioannina $\delta^{18}O$ (Eastwood et al. 2007); Lake Van $\delta^{18}O$ (Roberts et al. 2011); Lake Eski Acigöl $\delta^{18}O$ (Roberts et al. 2011); Lake Gölhisar $\delta^{18}O$ (Roberts et al. 2011). The bottom curves show the smoothed and unsmoothed Greenland GISP2 non sea salt [K^+] record.

Figure 5. Frequency of rainfall minima across 15 climate proxy records (terrestrial records 5-10 in Table 1 and marine records 1-9 in Table 2) most relevant to Anatolia indicating episodes of increased aridity, plotted against time (kyr BP), based on a 300 year running total with shading as in Figure 2. Note that one record (marine record 8) extends back only as far as 6 kyr BP.

Figure 6. Selected records most relevant to the Levant: southeast Levantine Sea site SL112 silt fraction end-member 3 indicating fluvial sources (Hamann et al. 2008); Soreq Cave $\delta^{13}C$ and $\delta^{18}O$ (Bar-Matthews and Ayalon 2011; Zanchetta and Bar-Matthews 2014); Jeita Cave speleothem $\delta^{18}O$ and $\delta^{13}C$ (Verheyden et al. 2008); reconstructed Dead Sea levels (Migowski et al. 2006). Note that the Soreq cave curves reproduced here are based on lower resolution data than the analysis of dry episodes represented in Figure 7, due to the lengths of the available records.

Figure 7. Soreq Cave $\delta^{18}O$ and $\delta^{13}C$ records for period 8.3-4.0 kyr BP, including high-resolution section from 7.0 kyr BP (based on Bar-Matthews et al. 2003; Bar-Matthews and Ayalon 2011; Grant et al. 2012).

Figure 8. Frequency of rainfall minima across 12 climate proxy records most relevant to the Levant (terrestrial records 13-18 in Table 1 and marine records 10-15 in Table 2) indicating episodes of increased aridity, plotted against time (kyr BP), based on a 300 year running total with shading as in Figure 2b. Two terrestrial records (16 and 17 in Table 1) extend back only as far as 7 kyr BP, and two marine records, (10 and 11 in Table 2) extend back to 6.1 and 5.3 kyr BP respectively. Results prior to 7 kyr BP should be treated with particular caution.

Figure 9. Selected records most relevant to Mesopotamia, in listed in order of decreasing latitude: $\delta^{18}O$ records from Lake Van (Roberts et al. 2011) and Lake Mirabad (Stevens et al. 2006) northern Red Sea Aridity Index and $\delta^{18}O$ record of G. ruber (Arz et al. 2003); Gulf of Oman $CaCO_3$ (Cullen et al. 2000); speleothem $\delta^{18}O$ from Hoti and Qunf caves in northern and southern Oman respectively (Fleitmann et al. 2007).

Figure 10. Frequency of rainfall minima across 10 climate proxy records most relevant to Mesopotamia (terrestrial records 9, 11, 12, 19 and 20 from Table 1 and marine records 16-20 from Table 2; see text for description) indicating episodes of increased aridity, plotted against time (kyr BP), based on a 300

year running total wit shading as in Figure 2. Three records (marine records 16-18 in Table 2) extend back only as far as 7.3 kyr BP and two (marine records 19 and 20) to 6.0 kyr BP.

Figure 11. Map of the central and eastern Sahara showing locations mentioned in the text.

Tables with Captions

Table 1. Terrestrial records used in this study.

	Author and year	**Location of record**	**Type of record**	**Correlation with rainfall**
1	Zanchetta et al. 2014	Corchia, Italy	δ^{18}O speleothem	-ve
2	Zanchetta et al. 2014	Corchia, Italy	δ^{13}C speleothem	-ve
3	Frisia et al. 2006	Grotta Savi, Italy	δ^{13}O speleothem	+ve
4	Frisia et al. 2006	Grotta Savi, Italy	δ^{18}C speleothem	+ve
5	Gökturk et al. 2011	Sofular Cave	δ^{13}C speleothem	-ve
6	Gökturk et al. 2011	Sofular Cave	^{234}U/^{238}U	-ve
7	Eastwood et al. 2007	Ionnina	δ^{18}O	-ve
8	Roberts et al. 2011	Eski Acigol	δ^{18}O	-ve
9	Roberts et al. 2011	Van	δ^{18}O	-ve
10	Roberts et al. 2011	Golhisar	δ^{18}O	-ve
11	Stevens et al. 2006	Zeribar	δ^{18}O	-ve
12	Stevens et al. 2006	Mirabad	δ^{18}O	-ve
13	Verheyden et al. 2008	Lebanon	δ^{18}O speleothem	-ve
14	Verheyden et al. 2008	Lebanon	δ^{13}C speleothem	-ve
15	Verheyden et al. 2008	Lebanon	Speleothem diameter	+ve
16	Bar-Matthews and Ayalon 2011	Soreq cave	δ^{18}O speleothem	-ve
17	Bar-Matthews and Ayalon 2011	Soreq cave	δ^{13}C speleothem	-ve
18	Migowski et al 2006 - detail	Dead Sea	Lake level	+ve
19	Fleitmann et al. 2007	Hoti Cave N Oman	δ^{18}O	-ve

20	Fleitmann et al. 2007	Qunf Cave S Oman	$\delta^{18}O$	-ve

Table 2. Marine records used in this study. Note that record 14 is assumed to be correlated with Nile flows, and therefore with rainfall in the Nile headwater regions.

	Author and year	**Location of record**	**Type of record**	**Correlation with rainfall**
1	Hamann et al. 2008	N Aegean SL148	Clay %	+ve
2	Hamann et al. 2008	N Aegean SL148	Silt %	+ve
3	Hamann et al. 2008	N Aegean SL148	Sand %	+ve
4	Hamann et al. 2008	N Aegean SL148	Quartz/Illite	-ve
5	Hamann et al. 2008	N Aegean SL148	EM1 N. Afr. Aeolian	-ve
6	Hamann et al. 2008	N Aegean SL148	EM3 fluvial gen.	+ve
7	Kuhnt et al. 2008	N. Aegean SL148	$\delta^{18}C$ U. Med.	-ve
8	Kuhnt et al. 2008	S. Aegean SL123	$\delta^{18}C$ U. Med.	-ve
9	Kuhnt et al. 2008	S. Aegean SL123	$\delta^{18}C$ P. Araminensis	-ve
10	Kuhnt et al. 2008	Levantine B. SL112	$\delta^{18}C$ U. Med.	-ve
11	Kuhnt et al. 2008	Levantine B. SL112	$\delta^{18}C$ P. Araminensis	-ve
12	Hamann et al. 2008	SE Levantine Sea SL112	Sand %	+ve
13	Hamann et al. 2008	SE Levantine Sea SL112	Quartz/Semectite	-ve (Nile)
14	Hamann et al. 2008	SE Levantine Sea SL112	EM1 N. Afr. Aeolian	-ve
15	Hamann et al. 2008	SE Levantine Sea SL112	EM3 fluvial gen.	+ve
16	Arz et al. 2003	N. Red Sea GeoB 5804-4	Aridity Index	-ve
17	Arz et al. 2003	N. Red Sea GeoB 5804-4	Clay wt %	+ve
18	Arz et al. 2003	N. Red Sea GeoB 5804-4	Sedimentation rate	+ve
19	Cullen et al. 2000	Gulf of Oman M5-422	% dolomite	-ve
20	Cullen et al. 2000	Gulf of Oman M5-422	% $CaCO_3$	-ve

Table 3. Relative proportion of major ungulate species (data from Grigson 2003, Tables 18-20; Grigson 2015, Fig. 13; Grigson in press).

	TNM 7th millennium BC	Arjoune 6th mill BC	Arjoune 5th mill BC	TNM Chalco-EB
Caprines	69.4	60.7	48.1	73.5
Cattle	15.1	18.0	25.7	17.3
Pig	15.5	21.3	26.2	9.2

Potential reviewers

1. Eddie Peltenburg, Emeritus Professor, Archaeology, University of Edinburgh, telephone: +44 131 667 9538 E-mail: epeltenb@ed.ac.uk
2. Dr Lisa Schipper, Stockholm Environment Institute, E-mail: lisa.schipper@sei-us.org
3. Dr Kevin White, Geography and Environmental Science, University of Reading, telephone: +44 118 378 7752, k.h.white@reading.ac.uk,