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OVERVIEW

20,000 years of societal vulnerability and adaptation to climate change in southwest Asia

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The Fertile Crescent, its hilly flanks and surrounding drylands has been a critical region for studying how climate has influenced societal change, and this review focuses on the region over the last 20,000 years. The complex social, economic, and environmental landscapes in the region today are not new phenomena and understanding their interactions requires a nuanced, multidisciplinary understanding of the past. This review builds on a history of collaboration between the social and natural palaeoscience disciplines. We provide a multidisciplinary, multiscalar perspective on the relevance of past climate, environmental, and archaeological research in assessing present day vulnerabilities and risks for the populations of southwest Asia. We discuss the complexity of palaeoclimatic data interpretation, particularly in relation to hydrology, and provide an overview of key time periods of palaeoclimatic interest. We discuss the critical role that vegetation plays in the human–climate–environment nexus and discuss the implications of the available palaeoclimate and archaeological data, and their interpretation, for palaeonarratives of the region, both climatically and socially. We also provide an overview of how modelling can improve our understanding of past climate impacts and associated change in risk to societies. We conclude by looking to future work, and identify themes of "scale" and "seasonality" as still requiring further focus. We suggest that by appreciating a given locale's place in the regional hydroscape, be it an archaeological site or palaeoenvironmental archive, more robust links to climate can be made where appropriate and interpretations drawn will demand the resolution of factors acting across multiple scales.

This article is categorized under:
Human Water > Water as Imagined and Represented
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KEYWORDS

archaeology, Holocene, hydrology, Iran, Levant, palaeoclimate, Turkey

1 | INTRODUCTION

Climate, including drought, has influenced societal change in southwest (SW) Asia, not just in the last decades (e.g., Kelley, Mohtadi, Cane, Seager, & Kushnir, 2015), but for millennia (e.g., Kaniewski, Van Campo, & Weiss, 2012). The Fertile Crescent, its hilly flanks and surrounding drylands have long been a critical region for studying human societal change, first, as being an initial stepping point out of Africa for the first anatomically modern humans (Bae, Douka, & Petraglia, 2017; Hershkovitz et al., 2018), and then as a center for some of the earliest agricultural villages (Barker, 2009; Willcox, Buxo, & Herveux, 2009) and cities (Lawrence, Philip, Hunt, Snape-Kennedy, & Wilkinson, 2016; Ur, 2017). Since these early developments, the region has been the scene of many further social, technological and economic changes and exchanges. While climate has often been discussed as one potential driver for these developments (e.g., Büntgen et al., 2016; H. Weiss, 2016), the modern complex social, economic, and environmental landscapes of the region emphasize the importance of a nuanced, multidisciplinary understanding of past climate change and its relationship to human behaviors (e.g., Jones, Maher, Richter, Macdonald, & Martin, 2016; Ur, 2015). Understanding the vulnerabilities of social and natural systems to change requires high-resolution reconstructions and modelling of the co-evolution of climate and human communities through time, and SW Asia provides a uniquely long record to explore these dynamics. With climate model projections for the region indicating rising temperatures and reduced rainfall in the coming decades (Pachauri et al., 2014), it is important to consider prehistoric and historical datasets regarding the relationships between climate, water availability and people to frame the impact of these changes on populations in the area today.

This study focuses on research published over the last decade since the last comprehensive reviews of the region's palaeoclimate of the late Pleistocene and Holocene by Robinson, Black, Sellwood, and Valdes (2006) and Enzel et al. (2008). Recent progress in modelling capabilities and improvements in data quality across a range of disciplines now allows us to better test hypotheses of human–climate–environment interactions in the past at a variety of scales, both in time and space. With current geopolitical unrest in the region, a renewed focus on topics of migration and conflict, linked directly or indirectly to drought (e.g., Flohr et al., 2017; Gleick, 2014; Kelley et al., 2015), a long-term perspective on these issues is especially timely. In this study we outline our current understanding of climatic changes in SW Asia over the last 20,000 years and integrate this information with the latest archaeological and historical evidence. This combined approach provides a multiscalar perspective on the relevance of past climate, environmental, and archaeological research in assessing present day vulnerabilities and risks for human populations in the region. We build on a long history of collaborations between the social and natural palaeoscience disciplines (c.f. Roberts et al., 2018).

The review focuses on the region from present day Turkey, south along the eastern Mediterranean coast, southeast to the Arabian Peninsula and east to the Iranian Plateau (Figure 1). This region marks a meeting point between continents and weather systems that adds to the complexity of reconstructing palaeoclimate and the related, or not, trajectory of past human histories. The last 20,000 years witnessed one of the most dramatic global climatic changes (glacial/interglacial transition), but also includes the full scope of Holocene climatic variability. This time period also includes the development of agriculture and

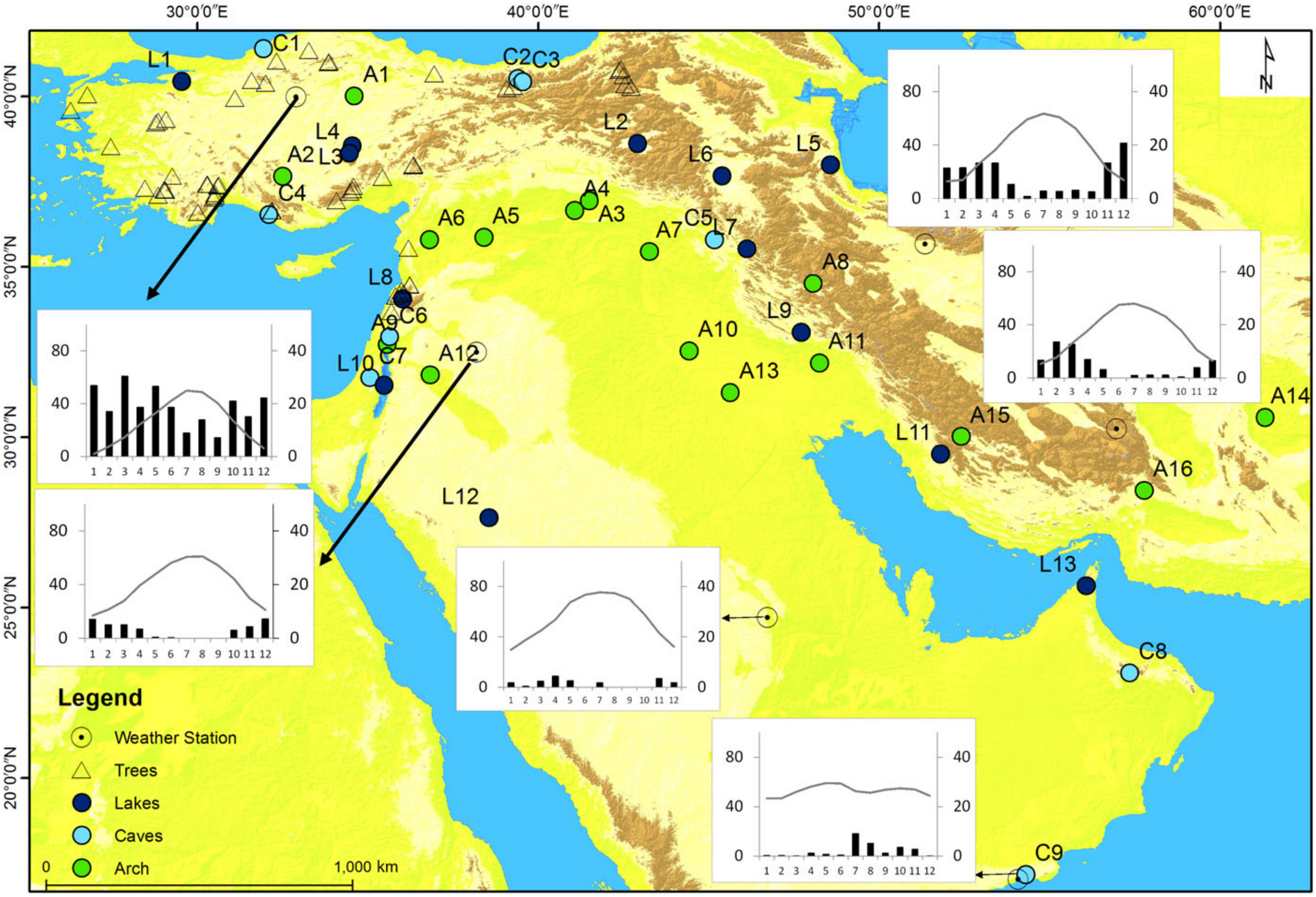


FIGURE 1 Map of the region showing key palaeoenvironmental archives (Table 1; tree rings from Touchan et al., 2014), archaeological sites, and climate seasonality across the region (data from KNMI Climate Explorer). Climate plots show mean monthly (January–December) precipitation (mm; left hand axis) and average air temperature (°C; right hand axis). Archaeological sites shown are A1: Hattusas, A2: Çatal Hoyuk, A3: Tell Leilan, A4: Tell Brak, A5: Abu Hureyra, A6: Ebla, A7: Assur, A8: Godin Tepe, A9: Ohalo II, A10: Babylon, A11: Susa, A12: Azraq, A13: Uruk, A14: Shahr-I Sokta, A15: Tall-e Malyan and A16: Konar Sandal

the first urban societies, the first example of which can be found in this region. There are important records of environmental change through our time period of focus from the seas surrounding our study region (e.g., Heyvaert & Baeteman, 2007; Leroy et al., 2011), including insight into sea-level change (Benjamin et al., 2017; Goldberg, Lau, Mitrovica, & Latychev, 2016) and how this may have impacted the movement of people, but we do not focus on these directly here. We focus on the environments where people were living, that is, the archaeological sites that they inhabited and terrestrial archives of palaeoenvironmental change, from trees, caves, and lakes and wetlands.

We discuss the complexity of palaeoclimatic data interpretation and its associated uncertainties, particularly in relation to hydrology, before providing an overview of key time periods of palaeoclimatic interest and relating them to archaeological narratives. Vegetation plays a critical role in the human–climate–environment nexus acting as both a control on, and being affected by, natural and anthropogenic environmental change, and we outline some of the outstanding questions regarding vegetation change over the last 20,000 years. We discuss the implications of available palaeoclimate and archaeological data, and their interpretation, on climatic and social palaeonarratives of the region. We also provide an overview of how modelling of climate, palaeoenvironmental archives and people can improve our understanding of past climate impacts and associated change in risk to societies. We end this review by discussing potential future directions for research in order for multiple disciplines to develop more sophisticated, evidence-based hypotheses of the impact of environmental change on societies in the past, integrating complementary, yet distinct, types of palaeoenvironmental and archaeological datasets.

1.1 | Regional climate

As a framework for this review, we very briefly outline here the modern climatology of the region. In general, SW Asia is characterized by wet winters and springs and dry, warm, summers, although the rainfall source areas and circulation patterns that drive these are varied (Enzel, Kushnir, & Quade, 2015) and complicate attempts to reconstruct palaeoclimate beyond local, site-specific, conditions (Stevens et al., 2001). Winter and spring storms from the Atlantic and Mediterranean extend over the Anatolian Plateau and into northern and west Iran, and across the Levant into northern Arabia. Additional rains, particularly in the south of the region come from the Red Sea, tropical Africa and the Gulf of Oman (Enzel et al., 2015).

Summers are characterized by dry and warm conditions, except in the most southerly parts of the Arabian Peninsula where Africa and Indian Monsoon systems bring precipitation to the mountains of Yemen and Oman. These weather systems also impact the dry conditions of the rest of the region indirectly, due to circulation patterns that bring either descending air, linked to Hadley Cell circulation, or warm and dry north, north-easterly winds across the region (e.g., Lionello et al., 2006).

The balance between winter and summer conditions is the key to water availability and a broad regional picture of local palaeoenvironmental conditions is needed to pull apart any of the subtleties evident in the modern climate regime in the past, or how this might have changed through time.

1.2 | Chronology

Archaeological and palaeoclimate discussions, and particularly comparisons between different records, require robust chronological control, and much has been written on this in general and for our study region (e.g., Blockley & Pinhasi, 2011; Maher, Banning, & Chazan, 2011). In Section 2, we discuss the common dating methods for each of our climate archives of focus. Issues relating to dating archaeological sites are discussed in the later sections (e.g., Section 6). Different disciplines, and dating methods, traditionally use particular chronological conventions (e.g., AD/BC, CE/BCE, BP) such that direct comparisons can be confusing. Here, we use a common chronological notation of ka, thousands of years ago, noting the type of age estimate used where appropriate, more recent events are described in years AD. All radiocarbon age estimates are calibrated unless otherwise stated.

2 | ARCHIVES AND PROXIES: CLIMATE AND HYDROLOGY

Some of the continued uncertainty around proxy interpretation comes from the need to understand the nature of climate experienced by different archives and how these signals are recorded by different proxies within the archives before being incorporated into the geological record. This is an important issue when interrogating any proxy record, but is especially so when considering that record in terms of change that may impact the populations using a given resource, in this case water.

The concept of drought propagation (Box 1) provides a useful starting point for understanding the translation of meteorological anomalies or climate changes through to hydrological changes (in fluxes or hydrochemistry) and then onto the proxy system. This concept has largely been derived from studies of humid catchments and it should be noted that the semiarid to arid climate experienced by much of SW Asia may show important differences; for instance, the sensitivity of the relative partitioning of precipitation into available soil moisture, runoff and groundwater recharge may vary markedly for different types of climate change or anomaly (Van Loon & Van Lanen, 2012). Lakes and speleothems, for example, may be more sensitive to meteorological changes that affect runoff and groundwater recharge generation such as rainfall intensity changes (Cuthbert, Baker, et al., 2014; Cuthbert, Rau, et al., 2014; Markowska et al., 2016). Vegetation, including trees, dependent on soil moisture may have a higher sensitivity to hydrological changes influencing the long-term balance between infiltration and evapotranspiration and are more obviously susceptible to direct human impact, such as through forest clearance or grazing.

Due to the large lag time and attenuation of hydrological change between many groundwater and some surface water bodies (Cuthbert et al., 2017; Cuthbert et al., 2019), certain climate proxy archives may be relatively insensitive to meteorological droughts recorded by others (Box 1). In addition, it is worth noting that modern drought, as defined here, is mostly relevant in the wetter parts of the region, as some areas are always dry with rare rainfall events the exception to mean conditions. Understanding the likely governing hydrological processes and the position of the archive and proxy in the landscape (Figure 2) are, therefore, key to interpreting these differences, and linking proxy records back to climate.

We briefly review here the key terrestrial regional palaeoenvironmental archives and consider their place in the regional hydroscape. Given the strong precipitation gradients across the region (Figure 1), the presence of a tree, speleothem or wetland in the landscape is itself a measure of hydrological state. The presence, or growth, of the archive can therefore be used as a first-order proxy for a threshold in water availability (Vaks et al., 2003).

2.1 | Trees

In low latitudes, including over SW Asia (St. George & Ault, 2014), tree growth is typically more sensitive to moisture availability than temperature. Trees are large-scale integrators of both changes in water supply and demand, they themselves are key parts of the hydrological cycle and are typically better indicators of soil moisture and/or hydrological drought (Box 1). Outside of the humid tropics, trees typically put on a single ring of growth every year, allowing precise annual dating of records using cross-dating, as first described by Douglass (1941). Due to the precisely dated nature of these records, they can

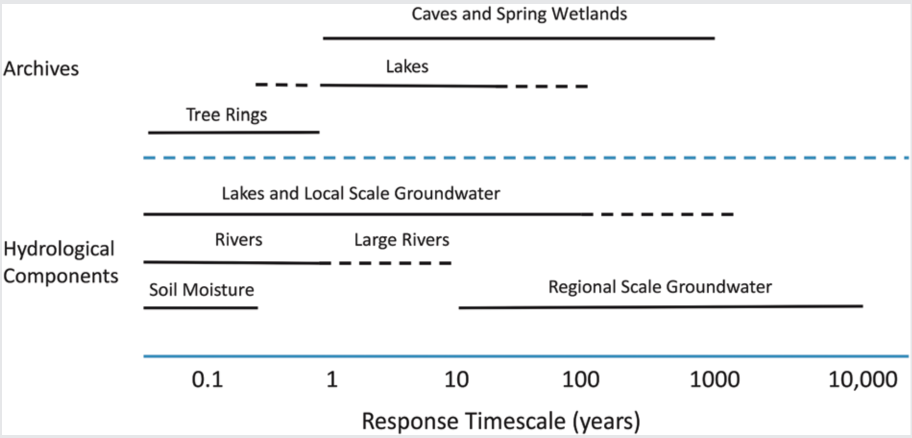
BOX 1

DROUGHT AND ITS PROPAGATION

Drought, defined as a deficit of water compared to normal conditions (Van Loon, 2015), is hypothesized to play a significant role in societal behaviour in SW Asia today (Kelley et al., 2015) as well as in the past (e.g., Weiss, 2016). Drought can be defined in multiple ways (Van Loon, 2015), and these different definitions can help us to conceptualize the impacts of hydrological change, broadly, on human populations at different points through time (Rohling, 2016).

Meteorological drought: A precipitation deficiency, possibly combined with increased evaporation.
Soil-moisture (agricultural) drought: Soil moisture deficit, often linked to crop failure.
Hydrological drought: Lower than average availability of surface and subsurface water.

Meteorological drought is filtered by catchments and their biophysical characteristics such as geology, soils and vegetation, so that agricultural and hydrological drought, those more likely to be captured by geological archives and impact human populations, can be damped relative to, or lag behind, the climatic forcing.



Typical response times to a climatic perturbation (e.g., meteorological drought) of critical components of the hydrological cycle for SW Asia, and the geological archives that are the focus of this study. A simple conceptual framework is complicated by the large scale of some SW Asian catchments, such as the Tigris and Euphrates Rivers, where response time may be further delayed due to the significant potential distance from the source of the perturbation, as well as smoothing of the signal in longer residence time systems.

In modern hydrology, droughts are generally at the annual scale or greater, but less than decadal, and therefore reflect movement away from the longer-term mean which is itself derived from approximately three decades of data (Van Loon, 2015). There are few archives, beyond tree rings and varved lake records, which could record such drought at this resolution in the past. Care must be taken, therefore, in discussing drought using relatively low-resolution proxy records which may more likely record changes in mean climate state, and thus lead to different societal impacts (Ur, 2015).

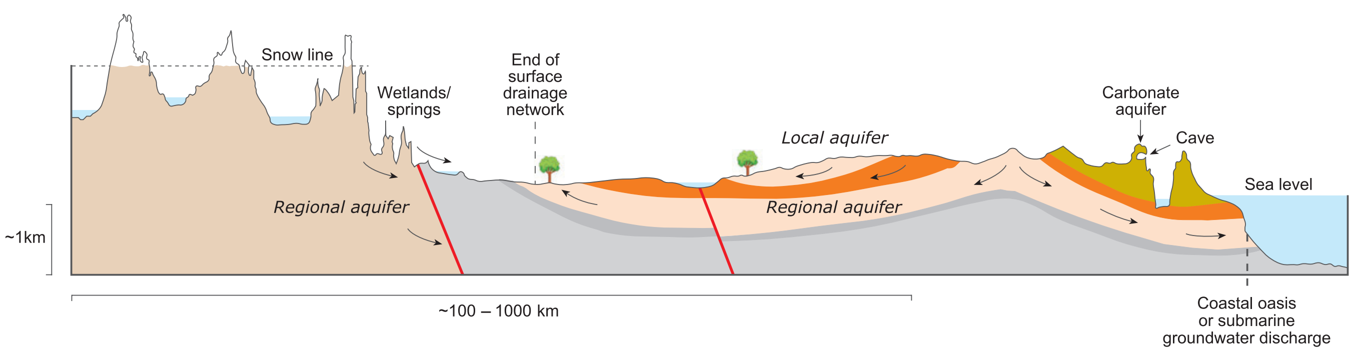


FIGURE 2 Typical Southwest Asia hydroscape, highlighting key parts of the hydrological cycle and location of key terrestrial archives within this system

be calibrated using instrumental climate observations to develop quantitative reconstructions of specific climate variables, including the Palmer Drought Severity Index (B. I. Cook, Anchukaitis, Touchan, Meko, & Cook, 2016; B. I. Cook, Ault, & Smerdon, 2015), precipitation (Grissino-Mayer, 1996), streamflow (Woodhouse, 2001), and temperature (Büntgen et al., 2016). This calibration in turn allows for quantitative comparisons between tree-ring-based palaeoclimate reconstructions and the instrumental climate record (Griffin & Anchukaitis, 2014) and climate model simulations of the past (e.g., B. I. Cook et al., 2015; E. R. Cook, Seager, et al., 2015). Furthermore, because trees are fairly ubiquitous across broad geographical regions, individual sampling sites can be combined into networks to generate gridded spatial reconstructions. Such reconstructions can be especially informative for understanding climate dynamics because many modes of natural climate variability have distinct spatial fingerprints that manifest in these reconstructions (Herweijer, Seager, Cook, & Emile-Geay, 2007).

One of the biggest disadvantages to tree rings as palaeoclimate proxies is the relatively short lifespan of individual trees, typically hundreds to, occasionally, several thousands of years. This limits the length of most well replicated tree-ring reconstructions to the last 2,000 years. An additional side effect of the relatively short lifespan is the difficulty of preserving centennial scale (or longer) variability in tree-ring-based reconstructions, a phenomenon often referred to as the "segment length curse" (E. R. Cook, Briffa, Meko, Graybill, & Funkhouser, 1995). However, considerable strides have been made to ameliorate this problem, beginning with use of "regional curve standardization" (Briffa et al., 1992) and followed up by the development and use of "signal-free" detrending methods (Melvin & Briffa, 2008). In doing so it is possible to preserve multicentennial variations in climate in large tree-ring datasets composed of overlapping tree-ring series from living trees and remnant wood samples.

Over SW Asia specifically, the availability of tree-ring chronologies is limited by the extreme aridity in much of the region (precluding growth of trees) and the long history of human settlement and occupation (which can make it difficult to find old, undisturbed trees). This is highlighted in Figure 1 (tree ring data from Touchan et al., 2014), which shows that tree-ring chronologies in SW Asia are largely found in Turkey, Syria, Jordan, and Lebanon, with recent work also identifying chronologies in Cyprus and Iran (Griggs, Pearson, Manning, & Lorentzen, 2014; Nadi, Bazrafshan, Pourtahmasi, & Bräuning, 2017). Among these, the longest chronologies (>200 years) are confined to Turkey, Jordan, and Lebanon.

2.2 | Caves

Caves are abundant throughout the region and a number of speleothem-based palaeoclimate reconstructions have been developed for Turkey, Lebanon, Israel, Iraq, and Oman (Table 1). The chronologies of all stalagmite records are primarily based on uranium-series dates, which are sometimes supported by annual layer counts (e.g., Fleitmann et al., 2004; Flohr et al., 2017). Typical chronological uncertainties of stalagmite records vary between 0.5 and 2% of the absolute age, depending on the uranium content and purity of the calcite.

Oxygen and carbon stable isotope ratios ($\delta^{18}O$ and $\delta^{13}C$, respectively, using the common delta notation) of stalagmite calcite are the most frequently used hydroclimate proxies. Stalagmite $\delta^{18}O$ values are primarily influenced by the $\delta^{18}O$ of cave drip water, usually a function of surface precipitation, where $\delta^{18}O$ of precipitation is influenced by multiple climate parameters such as temperature, and the origin and amount of rainfall (see below). The interpretation of $\delta^{18}O$ stalagmite calcite values is therefore not straightforward, and may be further complicated by other factors, as shown by recent work in other semiarid environments, that demonstrate that speleothems respond to complex recharge, as well as in-cave, processes (e.g., Baker et al., 2018; Cuthbert, Baker, et al., 2014; Cuthbert, Rau, et al., 2014; Markowska et al., 2016). The majority of stalagmite records from the region have been interpreted as reflecting changes in the amount of precipitation (e.g., Bar-Matthews, Ayalon, Gilmour, Matthews, & Hawkesworth, 2003; Cheng et al., 2015; Fleitmann et al., 2003; Flohr et al., 2017) and changes in the source of moisture (e.g., Fleitmann et al., 2007; Ünal-İmer et al., 2015).

Like $\delta^{18}O$, stalagmite $\delta^{13}C$ values are influenced by several environmental factors that include changes in surface vegetation (including vegetation density, proportion of C_3 to C_4 photosynthetic plants), soil microbial activity, recharge conditions (open vs. closed system recharge), and kinetic fractionation processes during calcite precipitation in the cave (drip rates and cave air pCO_2). Almost all factors influencing $\delta^{18}O$ and $\delta^{13}C$ values in stalagmites are therefore influenced, directly or indirectly, by temperature and precipitation.

Trace elements are an additional climate proxy increasingly measured at high resolution from speleothems, where magnesium, barium, phosphorous, and uranium concentrations appear to be additional proxies for the amount of precipitation (Flohr et al., 2017). However, their full potential as an additional hydrological proxy in stalagmites from across the region is not yet fully exploited.

2.3 | Lakes and wetlands

There is a relatively long history of palaeoenvironment research from lake archives from across the region (Table 1 and see summaries in Roberts et al., 2018; Roberts & Reed, 2009). A number of proxies have been regularly used including pollen

TABLE 1 Key Lake and Cave sites from SW Asia (Figure 1)

Site		Elevation (masl)	Duration (ka)	Selected references
Lakes and wetlands				
Iznik	L1	85	36.2–present day	Roeser et al. (2012); Ülgen et al. (2012)
Van	L2	1,648	600–present day	Çağatay et al. (2014); Cukur et al. (2014); Kuzucuoğlu et al. (2010); Kwiecien et al. (2014); Litt and Anselmetti (2014); Stockhecke et al. (2014); Wick, Lemcke, and Sturm (2003)
Eski Acıgöl	L3	1,270	17–present day	M. D. Jones, Roberts, and Leng (2007); N. Roberts et al. (2001); Turner, Roberts, and Jones (2008); Woldring and Bottema (2001)
Nar	L4	1,363	13.8–present day	Dean et al. (2013, 2015); England, Eastwood, Roberts, Turner, and Haldon (2008); M. D. Jones, Roberts, Leng, and Turkes (2006); N. Roberts et al. (2016); Woodbridge and Roberts (2011)
Neor	L5	2,500	13–present day	Ponel et al. (2013); Sharifi et al. (2015)
Urmia	L6	1,267	200–present day	Djamali et al. (2008); Stevens, Djamali, Andrieu-Ponel, and de Beaulieu (2012)
Zeribar	L7	1,300	42.6–present day	Stevens, Wright, and Ito (2001); Wasylikowa and Witkowski (2008); Wasylikowa et al. (2006)
Yammouneh	L8	1,360	400–present day	Develle et al. (2011) Develle, Herreros, Vidal, Sursock, and Gasse (2010); Gasse et al. (2015)
Mirabad	L9	800	9.3–present day	Griffiths, Schwalb, and Stevens (2001); Stevens, Ito, Schwalb, and Wright (2006)
Dead Sea	L10	418	220–present day	Litt, Ohlwein, Neumann, Hense, and Stein (2012); Migowski, Stein, Prasad, Negendank, and Agnon (2006); Neugebauer et al. (2014); Torfstein, Goldstein, Stein, and Enzel (2013)
Parishan	L11	823	3.9–present day	Djamali et al. (2016); M. D. Jones et al. (2015)
Tayma	L12	801	10–present day	Engel et al. (2012)
Awafi	L13	8	8.1–3	Parker et al. (2004, 2006, 2016)
Speleothems				
Sofular	C1	440	50–present day	Badertscher et al. (2014); Fleitmann et al. (2009); Göktürk et al. (2011)
Karaca	C2	1,536	77–6	Rowe et al. (2012)
Akcakale	C3	1,530	0.5–present day	Jex et al. (2011)
Dim	C4	232	90–10	Ünal-İmer et al. (2015); Ünal-İmer, Shulmeister, Zhao, Uysal, and Feng (2016)
Gejkar	C5	650	2.5–present day	Flohr et al. (2017)
Jeita	C6	100	20.3–0.4	Cheng et al. (2015); Verheyden, Nader, Cheng, Edwards, and Swennen (2008)
Soreq	C7	400	185–1	Bar-Matthews and Ayalon (2011); Bar-Matthews, Ayalon, Kaufman, and Wasserburg (1999); A. Matthews, Ayalon, and Bar-Matthews (2000); Orland et al. (2009)
Hoti	C8	800	330–present day	Burns, Matter, Frank, and Mangini (1998); Fleitmann et al. (2003, 2004); Neff et al. (2001)
Qunf	C9	650	10.3–0.4	Fleitmann et al. (2007)

(see Section 4), oxygen isotopes (Roberts et al., 2008), and diatoms (Vossel, Roeser, Litt, & Reed, 2018), with sediment chemistry, at increasingly high resolution given improvements in nondestructive scanner technologies, also becoming more common place (Sharifi et al., 2015). All these proxies have been used as records of changing water availability, with some debate surrounding these interpretations (Jones & Roberts, 2008). Radiocarbon dating or U-series methods (where old carbon impacts the radiocarbon chronology) are commonly used to establish the age of lake archives (e.g., Dean, Jones, et al., 2015) with individual age-estimate errors typically in the order of tens to hundreds of years. Recent advances in age-depth modelling using Bayesian techniques (Blaauw & Christen, 2011) have great potential in reducing these errors and calibration uncertainties. Tephrochronology, where applicable, is another way to provide further dating control (Eastwood, Tibby, Roberts, Birks, & Lamb, 2002). At some sites lake sediments are annually laminated (varved) opening up the possibility of annual, or seasonal, records of past change (Zolitschka, Francus, Ojala, & Schimmelmann, 2015).

There has been much recent interest in identifying former lakes and wetlands in landscapes where they are either currently absent or greatly diminished, and in the interpretation of their sedimentary archives (Pigati, Rech, Quade, & Bright, 2014) particularly in the Arabian Peninsula (Engel et al., 2017; Enzel et al., 2015; Enzel, Quade, & Kushnir, 2017) and Jordan (Catlett et al., 2017; Jones et al., 2016). These studies follow a long history of research into lake levels in the more humid parts of the region, such as Konya (Roberts, 1983), Lake Van (Kuzucuoğlu et al., 2010), and the Dead Sea/Lake Lisan (Torfstein et al., 2013).

Irrespective of the uncertainty surrounding the nature of some water bodies, there is clear evidence for a greater presence of open water in the past. This is usually explained by some combination of enhanced precipitation, enhanced groundwater recharge, decreased open water evaporation, and enhanced local and/or regional groundwater discharge. In addition to the effects of changing precipitation and evaporation, the increase in human population over the Holocene will also have resulted in increased consumption of water, potentially impacting lakes and wetlands (Jones et al., 2015).

Evidence that is currently available points to localized wetland development in the past, particularly in more arid parts of the region (Jones, Maher, Richter, et al., 2016). If recharge was regionally enhanced, then this would also have created a regionally raised water table, capable of forming water bodies or wetlands wherever the land was below that level. If a rise in regional unconfined water-tables is not supported by empirical evidence elsewhere in the region, then the more localized development of wetlands (in the absence of surface drainage networks) is likely to be related to fault-mediated discharges from confined aquifers or break in slope supply (i.e., springs). This poses an interesting problem for linking the timing of wetter land surfaces with wetter climates, since depending on the length of the groundwater systems involved (Box 1), the lags between the two could be thousands to tens of thousands of years (Cuthbert et al., 2017; Cuthbert et al., 2019). The Deep Sandstone Aquifer complex in Jordan, for example, consists of palaeowater that, while difficult to date, is largely a remnant of Late Pleistocene to Early Holocene climate (Abu-Jaber & El-Naser, 2016). Spring calcretes, such as those described in the Late Pleistocene of Wadi Sabra (Bertrams et al., 2012) and the Neolithic of Beidha (Rambeau et al., 2011), therefore, may mark paleosprings reflecting either local recharge at the times of deposition or an older, nonlocal, recharge event that took considerable time to propagate to the surface.

3 | SOME KEY TIME PERIODS OF CLIMATIC INTEREST

Here, we briefly summarize some of the key periods of interest in terms of regional environmental and climatic change, and particularly those that have been linked to substantial key societal changes in the region. We focus on key debates surrounding changing environments at different frequencies.

3.1 | Millennial scale changes

There is continued interest in the transition from the last glacial into the Holocene and the potential role this shift played in the transition to agriculture by Neolithic people (Box 2). Continuous records that span the full transition from 20,000 years BP into the early Holocene remain relatively scarce, but those available point to a gradient of conditions across the region. Lake levels of Lake İznik in northwest (NW) Turkey (Roeser et al., 2012) and Lake Van in eastern Turkey (Tomonaga et al., 2017)

BOX 2

THE YOUNGER DRYAS

The Younger Dryas, or more correctly the regional temporal and climatic manifestation of the late glacial stadial, has long been discussed as a potential trigger for the transition from hunting and gathering to agriculture through the last glacial–interglacial transition in SW Asia (e.g., Bar-Yosef, 2009; Bar-Yosef & Belfer-Cohen, 2002; Hillman, Hedges, Moore, Colledge, & Pettitt, 2001; Moore & Hillman, 1992), in part due to apparent correlations between societal and climatic changes (Balter, 2010). In general, the period is considered to have been drier across the region, from speleothem (e.g., Bar-Matthews et al., 1999; Verheyden et al., 2008) and pollen evidence (e.g., Baruch & Bottema, 1999; Kadosh, Sivan, Kutiel, & Weinstein-Evron, 2004; Van Zeist & Wright, 1963), but actual records for this time period remain relatively scarce, and chronological uncertainties in the palaeoclimate records remain (Meadows, 2005). Some recent work suggests that the Younger Dryas was cool, but not as dry as previously thought (Hartman, Bar-Yosef, Brittingham, Grosman, & Munro, 2016). Broadly speaking, the Younger Dryas drying has been described as a significant stress factor that influenced both the subsistence economy as well as the settlement pattern of late Pleistocene groups in the Levant (references above).

In recent years, archaeologists have begun to revise the scenarios for the impact of the Younger Dryas (Rosen & Rivera-Collazo, 2012). In the southern Levant, the chronological correlation between the Younger Dryas and the emergence of the late Natufian cultural assemblage of the Epipalaeolithic (Figure 6) is now largely in doubt (e.g., Caracuta et al., 2016; Grosman, 2013; Maher et al., 2011) and further north evidence for plant cultivation at Abu Hureyra during the late Natufian is now disputed (Colledge & Conolly, 2010). Evidence has also begun to emerge for substantial early and late Natufian settlement outside the original core zone (e.g., Richter, 2017; Richter, Arranz-Otaegui, Yeomans, & Boaretto, 2017; Rodríguez et al., 2013) and for more continuity in sedentary settlement in the Mediterranean zone (Grosman et al., 2016). Importantly, improvements in dating archaeological sites, also suggest that the Pre-Pottery Neolithic A now began within the Younger Dryas (e.g., Blockley & Pinhasi, 2011; Wicks et al., 2016). Thus, recent work has reduced the apparent importance of the Younger Dryas as a trigger event for the onset of the first crop-based agricultural societies.

were relatively low at the last glacial maximum (LGM), for example, although pore-water salinity from the latter only provides a multimillennial resolution record, and there are high terraces around Lake Van radiocarbon dated to ~25 and ~21 ka (Kuzucuoğlu et al., 2010). The advance of glaciers (Sarikaya & Çiner, 2015) and continuous speleothem growth in Dim Cave in SW Turkey (Ünal-İmer et al., 2015; Figure 3), as well as high levels of Lake Lisan in the Dead Sea Basin (Torfstein et al., 2013; Figure 3), and continuous deposition of speleothems in the vicinity of the Dead Sea (Frumkin, Bar-Yosef, & Schwarcz, 2011), suggest relatively wetter conditions. This spatial pattern is complicated by the timing of shifts in condition, which suggest relatively wetter conditions up to the LGM (26–21 ka), but very dry conditions after it (18–15 ka), the youngest dates for highstands at Lake Konya, for example, are radiocarbon dated at ca. 21 ka (Roberts, 1983).

Lake $\delta^{18}O$ records from across the eastern Mediterranean show a transition from the late glacial to the early Holocene from positive to negative, generally interpreted to indicate wetter conditions (Roberts et al., 2008). The transition occurs relatively abruptly in some records; for example, in less than 200 years (with over half the shift in oxygen isotopes occurring in just 9 years) at Lake Nar in central Turkey (Dean, Jones, et al., 2015; Figure 3). There are also differences in the cave $\delta^{18}O$ records through the transition, with a positive shift recorded in Sofular Cave in NW Turkey and a negative shift recorded further south in Dim and Soreq caves (Figure 1). These differences probably reflect differing controls on the isotopic composition of rainfall at these sites, the balance between changing conditions in the source waters in the Black and Mediterranean Seas, respectively, and the changing amount of local rainfall (Bar-Matthews et al., 2003; Fleitmann et al., 2009). The Hoti and Qunf Cave $\delta^{18}O$ records (Figure 3) from Oman both reflect the strength of the Indian Ocean monsoon (Fleitmann et al., 2007). These latter examples underline that varying factors can influence environmental signals recorded by the same proxy ($\delta^{18}O$) in the same type of archive (caves) across the region in different ways, most notably here due to the different sources of rainfall.

A wetter early Holocene continued until ~7 ka, when a transition to drier conditions began in the eastern Mediterranean (Clarke et al., 2016; Roberts, Brayshaw, Kuzucuoğlu, Perez, & Sadori, 2011), with a similar trend of decreasing monsoonal

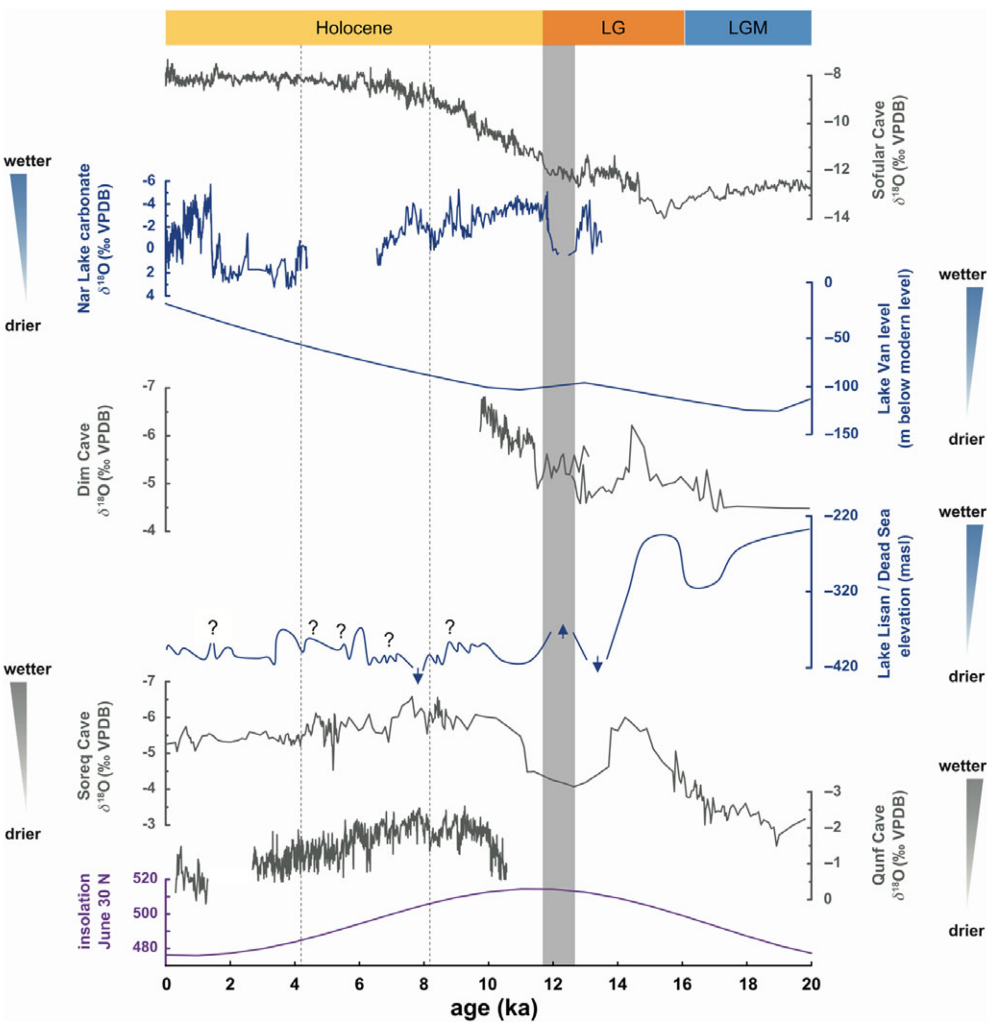


FIGURE 3 Summary of regional palaeoenvironmental change for the last 20 ka. Key time periods (LG, late glacial; LGM, last glacial maximum) and climatic events discussed in the text are highlighted (late glacial stadial, grey shading; 8.2 and 4.2 ka, dashed lines). Note that each record is plotted based on its own chronology. Insolation data are from A. Berger and Loutre (1991), see Table 1 for site references

rains documented in southern Arabian speleothems (Fleitmann et al., 2003, 2007). The end of the early Holocene "humid" period ~5.9 ka in SE Arabia (Parker et al., 2006; Fleitmann et al., 2007) corresponds with the end of the Neolithic in this region (Preston et al., 2015) and with evidence for violence and conflict, possibly over water resources, coeval with increasing aridity (Kutterer & Uerpmann, 2012; Uerpmann, Uerpmann, & Jasim, 2008).

In general, these millennial scale trends in the region follow summer insolation trends (Figure 3). A reduction in insolation through the Holocene led to a southward shift in the boreal summer Inter Tropical Convergence Zone, and weaker summer monsoonal rains in southern Arabia, while in the eastern Mediterranean region this drying was caused by a northerly shift in westerly storm tracks that reduced winter precipitation (Dean, Jones, et al., 2015).

3.2 | Abrupt events

In the Holocene, where more continuous, higher resolution records are available, the longer term millennial trends in climate are punctuated by centennial- and multi-decadal-scale periods that are drier than the millennial average. The recognition of these brief events in any archive is partly sample-resolution dependent, but even some relatively high-resolution records such as the Sofular Cave record in NW Turkey (Göktürk et al., 2011) do not document all of the events recorded elsewhere during the Holocene.

A drying around 9.3 ka, linked to an event in the Greenland ice cores (Rasmussen, Vinther, Clausen, & Andersen, 2007), has so far only been observed in the Lake Nar and Qunf Cave records (Dean, Jones, et al., 2015; Fleitmann et al., 2008) as well as potentially being a factor in the slowdown of speleothem growth at Dim Cave (Ünal-İmer et al., 2015). In the Nar, Qunf and Hoti Cave records, the 8.2 ka event, again recognized in the Greenland ice cores and across much of northern Europe (e.g., Alley & Agustsdottir, 2005; Daley et al., 2011), lasts longer than the 9.3 ka event, perhaps explaining why it is documented as a drier period in many more records from across SW Asia. It is expressed as an isotopic shift to more positive values in Soreq Cave, Israel (Bar-Matthews et al., 2003) and Hoti and Qunf caves, Oman (Fleitmann et al., 2007), an interruption of sapropel S1 in the eastern Mediterranean (Kotthoff et al., 2008), and increased sediment flux rates from SE Arabia (Parker et al., 2016). It has also been detected in the Riwasa playa lake on the plains of NW India (Dixit, Hodell, Sinha, & Petrie, 2014).

Assessing and interpreting any cultural and societal impact of the 8.2 ka event is controversial. It has been proposed that it prompted migration and settlement abandonment in Turkey and contributed to the Neolithization of the Aegean and SW Europe (Weninger et al., 2006, 2014). However, there is much evidence for continuity in settlement over the centuries around 8.2 ka on the Anatolia plateau (Baird, 2012b) and Neolithic communities are present in western Turkey several centuries before the 8.2 ka event. Recent evaluation of archaeological evidence suggests that the 8.2 ka event had no systematic regional scale impact on societies (Flohr, Fleitmann, Matthews, Matthews, & Black, 2016; Maher et al., 2011), although local impacts can be detected (Roffet-Salque et al., 2018).

A dry period ~5.2 ka is recorded by speleothems from Israel (Bar-Matthews & Ayalon, 2011) and lakes/wetlands in SE Arabia (Parker et al., 2006) and Turkey (Kuzucuoğlu et al., 2011) and has been linked by some to the end of the late Uruk period societies in Mesopotamia (H. Weiss, 2003). Another period of drought at ~4.2 ka (Kaniewski, Marriner, Cheddadi, Guiot, & Van Campo, 2018) is recorded in lakes in Turkey (Dean, Jones, et al., 2015; Eastwood, Leng, Roberts, & Davis, 2007), SE Arabia (Parker et al., 2006), the Dead Sea (Litt et al., 2012), and in the Gulf of Oman (Cullen et al., 2000). This drying period, which has been identified in South Asia as a weakening of the monsoon (Berkelhammer et al., 2012; Dixit, Hodell, & Petrie, 2014; Prasad et al., 2014), has been linked as contributing to the "collapse" of the Akkadian civilization in Mesopotamia, the possible disintegration of urban communities in the southern Levant (Staubwasser & Weiss, 2006; Weiss, 2016), the decline in known settlement in SE Arabia at the end of the early Bronze Age (Preston et al., 2015) and significant changes to settlement systems and irrigation technologies in SE Iran (Fouache, Francfort, Cosandey, & Adle, 2015). This event has come under recent focus with the subdivision of the Holocene (Cohen, Finney, Gibbard, & Fan, 2013; Walker et al., 2018) and we discuss more of the detail relating to the impact on societies of the 4.2 ka event in Section 5.

The final significant dry period was centered at ~3.2–3.1 ka and has been described from Turkey (Roberts et al., 2001; Wright, Fairbairn, Faith, & Matsumura, 2015), Lake Zeribar in Iran (Stevens et al., 2001) and Jeita Cave in Lebanon (Verheyden et al., 2008). Similar to the ~5.2 and 4.2 ka events, high resolution analysis suggests that this drier period comprised several drought episodes interspersed within decades of wetter climate (Kuzucuoğlu, 2009). Hittite texts referred to drought (Kuzucuoğlu, 2015) and their civilization declined at the end of the Bronze Age, with their capital Hattuşa destroyed ~3.18 ka (Weiss, 1982). There is also evidence of crop failures in Syria (Kaniewski et al., 2010) and evidence of large-scale migration/displacement of "Sea Peoples" throughout the eastern Mediterranean including Anatolia and the Levantine littoral (Van De Mieroop, 2008) at this time. However, as with previous climatic events, which as noted above are not seen in all regional proxy records, not all societies were impacted in the same way. Physical anthropological studies at Tell Dothan, in the West Bank, suggest continuation of a sedentary lifestyle of agronomists through this period (Gregoricka & Sheridan, 2017).

The ~9.3, 8.2, 4.2, and 3.2 ka events are approximately coeval with Bond events, periods of increased ice rafting in the North Atlantic (Bond et al., 1997). The 5.2 ka event seen in SW Asia, however, does not appear to have an equivalent in the North Atlantic. Much of the precipitation that falls in the eastern Mediterranean originates from the North Atlantic, so it is unsurprising that the majority of these dry "events" coincide with cool sea surface temperature events in the North Atlantic which led to a reduction in cyclogenesis (Bartov, Goldstein, Stein, & Enzel, 2003). Nonetheless, the fact that some of these dry "events" last longer, in the Nar and Qunf records, for example, than the more discrete "events" of the North Atlantic, suggests there may have been other underlying causes, perhaps related to changes in solar activity via the winter Siberian High (Rohling & Palike, 2005). It is also important to consider the impact of the Indian summer monsoon (ISM), and its periods of fluctuation during the Holocene (Jones et al., 2006). As noted above, the 4.2 ka event has been linked to weakening monsoon in NW India, and also in the Himalayas and Central India. Biophysical nonlinear feedback mechanisms have been suggested as a possible factor prolonging phases of increased aridity in SW Asia (Parker et al., 2016).

3.3 | The last 2,000 years

There are a number of high-resolution (annual or near-annual) records from, or attributed to, the region covering the last 2,000 years (Figure 4). In the eastern Mediterranean, the medieval climate anomaly (MCA) was generally wetter and the little ice age (LIA) drier (Luterbacher et al., 2012; Roberts et al., 2012). A recent multiproxy speleothem record from northern Iraq suggests increasingly dry conditions over the last 1,000 years in that part of SW Asia (Flohr et al., 2017).

One of the most recent and comprehensive reconstructions of hydroclimate over SW Asia and adjacent regions through the last 2 ka is the Old World Drought Atlas (OWDA; E. R. Cook, Seager, et al., 2015). The OWDA is an annually resolved, tree-ring-based reconstruction of the summer season (June–July–August) Palmer Drought Severity Index (PDSI) at half degree spatial resolution across Europe and the Mediterranean. PDSI is a normalized indicator of soil moisture availability (negative values indicating drought), integrating changes in moisture supply (precipitation) and demand (evapotranspiration) on timescales of typically 12–18 months. Spatial coverage of the OWDA extends into SW Asia, though the proxy coverage there is poor relative to other areas, limiting robust analyses over this region to 0.9 ka and later (Cook et al., 2016).

One notable feature of SW Asia in the OWDA is the tendency towards anti-phased hydroclimate variability between the southern Levant (including Israel, Jordan, southern Syria, Lebanon) and a region encompassing Greece, Anatolia, and the Black Sea (Figure 5; Cook et al., 2016). This feature is persistent across centuries, with strong and significant antiphase coherency from interannual to multidecadal timescales. The spatial fingerprint of this dipole bears a strong resemblance to the pattern that would be expected from variability in the North Atlantic Oscillation (Cook et al., 2016). Such a dipole has been described previously (Xoplaki, Gonzalez-Rouco, Luterbacher, & Wanner, 2004), and its persistent existence in the OWDA suggests that it is a robust feature of natural hydroclimate variability in the region.

The OWDA has also shed some light on the early 21st century AD drought in the Levant region that may have contributed, in part, to the recent social unrest in Syria (Gleick, 2014; Kelley et al., 2015). Over the Levant, this protracted period of drought (1998–2012 in the OWDA) is the most intense 15-year drought of the last 900 years, and also includes the single most severe individual drought year in the record; 2000 AD (Cook et al., 2016). The OWDA, therefore, provides some independent support for analyses that suggest this recent drought was exceptional relative to natural variability, a sign that the expected drying from anthropogenic climate change in the region may already be beginning to occur (Kelley et al., 2015).

4 | BIOGEOGRAPHY AND VEGETATION CHANGE

SW Asia encompasses four major biogeographical regions: (a) the Saharo-Sindian region in the south, comprising desert vegetation and pseudo-savannas in the Arabian Peninsula and southern Mesopotamia and tropical arid vegetation in the southern Arabian Peninsula and southern Iran; (b) the Irano-Turanian region in the center and east, comprising *Artemisia* steppes in internal Iranian plateaus and Mesopotamia with open woodlands and steppe forests of deciduous trees and junipers in the Irano-Anatolian mountains; (c) the Mediterranean region in the west comprising typical Mediterranean vegetation in western and southern Anatolia and the Levant; and (iv) the Euro-Siberian region in the north and northwest including mesic deciduous and mixed conifer-deciduous forest in the South Caspian and Black Sea regions (White & Léonard, 1990). Halophytic and hygro-halophytic vegetation also occurs locally in endorheic depressions (Zohary, 1973). Continentality, winter temperatures and precipitation seasonality are the most important parameters determining the boundaries between these regions (Djamali, Brewer, Breckle, & Jackson, 2012).

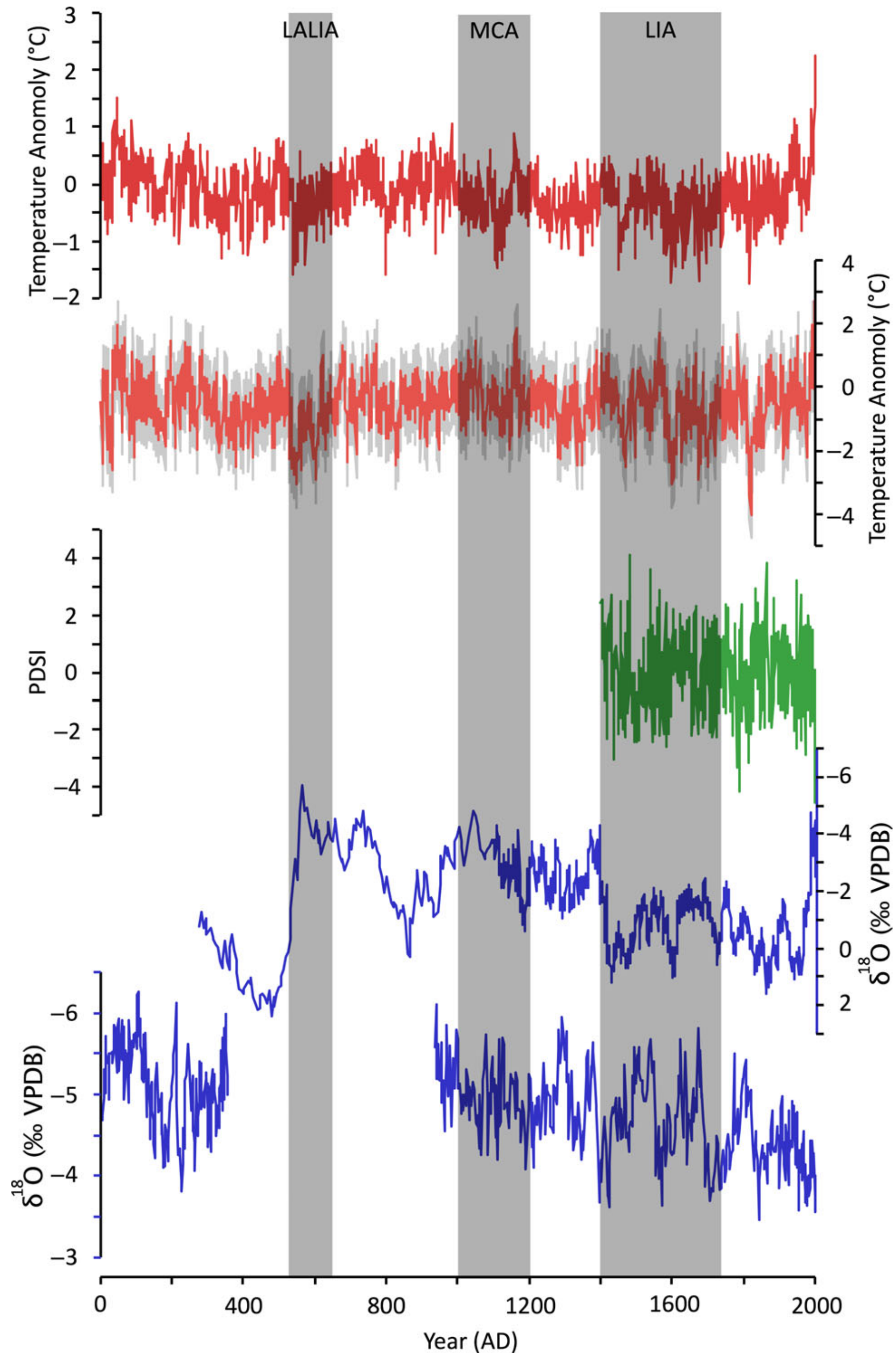


FIGURE 4 High resolution records of the last 2000 years. From the top: European temperature anomalies from the PAGES2k consortium (Ahmed et al., 2013), European summer temperature anomalies (Büntgen et al., 2011), Palmer Drought Severity Index (PDSI) reconstruction for southwest Asia (Cook et al., 2016) and oxygen isotope records from Lake Nar (Jones et al., 2006), and Gejker Cave (Flohr et al., 2017). Grey shading picks out the Late Antiquity Little Ice Age (LALIA), Medieval Climate Anomaly (MCA), and Little Ice Age (LIA) as presented in Büntgen et al. (2016)

4.1 | Last glacial maximum

The relatively sparse pollen data that extend back to the LGM indicate the dominance of an extremely dry steppe in most of the continental interior of SW Asia (Djamali et al., 2008; Litt, Pickarski, Heumann, Stockhecke, & Tzedakis, 2014; van Zeist & Bottema, 1977). Modern analogues for this cold, dry steppic vegetation can be found in the subalpine zone of the Irano-Turanian mountains (Djamali et al., 2011). Forest elements of the Euxino-Hyrcanian region along the southern Caspian Sea and Black Sea were less severely affected by Quaternary glaciations making them refugia for numerous species which were mostly eliminated from northern European regions (Leroy & Arpe, 2007). In contrast to most regions of SW Asia, the

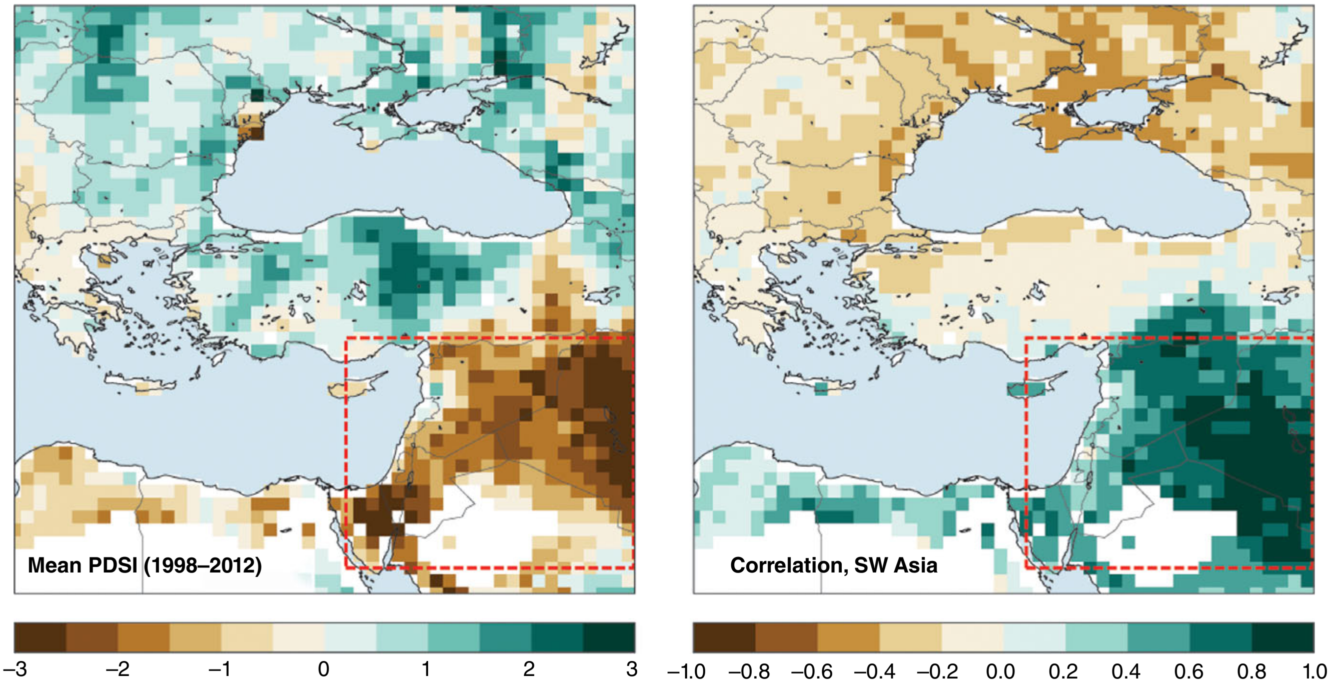


FIGURE 5 Spatial patterns in the Old World Drought Atlas (Cook et al., 2016) of mean Palmer Drought Severity Index (PDSI) values and correlation with the southwest Asia zone (red box) through the last 600 years (Figure 4)

ecotones between the Euxino-Hyrcanian and Irano-Turanian region appear to have been only moderately affected by LGM climates (Miebach, Niestrath, Roeser, & Litt, 2016). Importantly, lowland parts of the Levant also appear to have been only moderately affected by the cold–dry LGM climate; these regions provided crucial refugia for animal and plant resources and human populations during this time period (Asouti et al., 2015; Asouti & Austin, 2005; Roberts et al., 2018).

4.2 | Late glacial vegetation

Increasing number of late glacial vegetation records show moderate afforestation during the late glacial interstadial followed by a re-expansion of steppe during the late glacial stadial (Box 1; Aubert et al., 2017). However, in contrast to the LGM which is almost everywhere characterized by Artemisia-Chenopodiaceae steppe reflecting a cold–dry climate, late glacial vegetation dynamics display contrasting patterns in different regions of SW Asia. In the mountain region of NW Iran and eastern Anatolia it is characterized by the dominance of a dry steppe with a slight expansion of boreal trees (e.g., *Betula*) and desert shrubs (*Ephedra*) while in the Levant and the biome transitional zone of northern Turkey, more trees were present in the landscape (Miebach et al., 2016).

4.3 | Early Holocene delayed vegetation advance and the precipitation paradox

Postglacial afforestation by deciduous trees in temperate Europe began at the onset of the Holocene (Berglund, Barnekow, Hammarlund, Sandgren, & Snowball, 1996), however, a different pattern is evident in the much of the Mediterranean region. In the northern and western Mediterranean basin afforestation also occurred at the onset of the Holocene (e.g., Pons & Reille, 1988; Watts, 1985), indicating that the peninsulas of southern Europe and northern borderlands of Greece were important primary refugia. However, pollen data from the south-central Mediterranean (Sicily and Malta) show afforestation delayed until about 7.3 ka (Gambin et al., 2016; Tinner et al., 2009). This Early Holocene delay is also especially marked in the upland interiors of the Irano-Anatolian plateaus (Djamali et al., 2010) where pollen data show a 3,000–5,000-year lag between the onset of climatic amelioration at the beginning of the Holocene and the expansion of deciduous oak woodland.

The delayed response of woodland in inner Anatolia and the Zagros-Anti-Taurus mountains to climatic amelioration at the start of the Holocene has been much discussed in the literature and several hypotheses have been advanced to explain it. Ecological dynamics including autecology (growth rates of individual woodland trees), rates of dispersal, competition, starting positions and locations of primary and secondary refugia, suitable edaphic conditions and physical geographical barriers may all have affected the rate of migration and expansion of forests into regions of sparse tree cover (Roberts et al., 2011; van Zeist & Bottema, 1991).

Early interpretations of pollen data suggested that climatic aridity was responsible (Roberts & Wright, 1993), but more recent stable isotope data show that there was probably increased moisture availability during the early Holocene (Roberts et al., 2008). Other hypotheses invoked suggest that the "oak steppe-parklands" in the Zagros-Anti-Taurus arc and mountains of central Anatolia and NW Iran may have been anthropogenically maintained through the use of both natural and human-induced fire (Roberts, 2002). Micro-charcoal records show the start of the Holocene was a period of frequent/intense wildfires, which would have tended to maintain open (e.g., grassland) vegetation at the expense of closed woodland (Turner, Roberts, Eastwood, Jenkins, & Rosen, 2010). In addition, it is clear the nuts/fruits of terebinth/almond woodland were an important resource for early sedentary communities in central Anatolia. These trees are less visible in the pollen record, but are found in anthracological records from archaeological sites (Asouti & Kabukcu, 2014), and may be evidence of woodland response to increased precipitation and temperature in central Anatolia from the beginning of the Holocene. Landscapes may also have been maintained by people to aid their growth (Baird et al., 2018), as well as for more general vegetation management for grazing, fuel, fodder, and timber (Asouti & Kabukcu, 2014). Although recent data (Roberts et al., 2018) have shown a long-term trend of increasing population for the Neolithic of the early Holocene, it can be postulated that the density of archaeological sites and overall population levels for this time period in the Zagros-Anti-Taurus arc and mountains/plateau of central Anatolia and NW Iran were insufficient to effect vegetation on the regional scale and with the synchronicity that the pollen data appear to infer.

An alternative hypothesis considers that climate seasonality during the early Holocene was greater due to enhanced solar radiation which fueled more intensive ISM circulation, resulting in more rainfall that spilled over into the Arabian Peninsula and North Africa, but led to an extended dry season in the continental interior of the Zagros-Anti-Taurus arc and plateau of central Anatolia and NW Iran, bioclimatically favoring grasslands over deciduous woodlands (Djamali et al., 2010). The important role of seasonality of precipitation has been shown to control biome distribution and biogeographical regionalization in SW Eurasia (Djamali et al., 2012). Furthermore, radiocarbon ages of the expansion of deciduous oak and juniper at pollen sites in the Zagros-Anti-Taurus arc and mountains and plateau of central Anatolia and NW Iran are coeval with the timings for the southward retreat of the Intertropical Convergence Zone (ITCZ) and concomitant southeastward retreat of the ISM. Thus postglacial re-expansion of deciduous oak woodlands was consequently delayed until weakening of the ISM at ~6.3 ka (Djamali et al., 2010).

5 | THE ARCHAEOLOGICAL DATASETS

Given the previous discussion it is worth reflecting on human response to the inferred rises in precipitation and temperature in the early Holocene. Evidence from the Anatolian plateau suggests a rapid human response with sedentary behaviors appearing immediately following the beginning of the Holocene in a major contrast to the very low visibility of settlement evidence on the Anatolian plateau in the Younger Dryas compared to the Bølling-Allerød/late glacial interstadial (Baird et al., 2013, 2018). Interestingly, this response seems significant based on the spread of terebinth/almond woodland juxtaposed with rich grasslands and wetlands supporting large game-like aurochs, boar, and equid in some density, as opposed to sedentism related to increased cereal and legume density as in the late glacial interstadial in the southern Levant (Baird, 2012b). In this section we review some of the wider issues regarding the archaeological datasets available from the region which are important for discussion of human–climate–environment relationships.

5.1 | Data availability

The archaeological and historical datasets from SW Asia and the surrounding regions that can be used to investigate human–environment interaction and the impact of climate and environmental change are, like the palaeoenvironmental records, not resolved at consistent chronological or spatial scales (e.g., Lawrence et al., 2016; Maher et al., 2011; McCormick et al., 2012). Archaeological surveys have varying extent, intensity and methods, sometimes leaving considerable gaps in our knowledge of individual periods and areas with differential distribution of excavated sites and surveyed regions (e.g., de Miroschedji, 2003; Hole, 1987; Petrie, Weeks, Potts, & Roustaei, 2006; Singh et al., 2009; Wilkinson et al., 1994).

Turkey, despite its substantial land area, has witnessed much less intensive archaeological investigation than most areas to its south, notably the Fertile Crescent areas of the Levant and Mesopotamia. This is a conjunction of the size of the land mass, alongside regulations and predilections that have focused work on long-term excavation of major sites, especially of Bronze Age and Classical periods, some excavated for over 100 years (e.g., Hattusas and Ephesus), along with major rescue projects related to various dams on the Tigris and Euphrates rivers. Thus a few areas are well-researched, for example, the Konya Plain, stretches of the Tigris and Euphrates, and limited areas around major sites like Troy and Miletos, while the northern half of the country remains relatively poorly understood. As a result, some questions, for example, the apparent rarity of

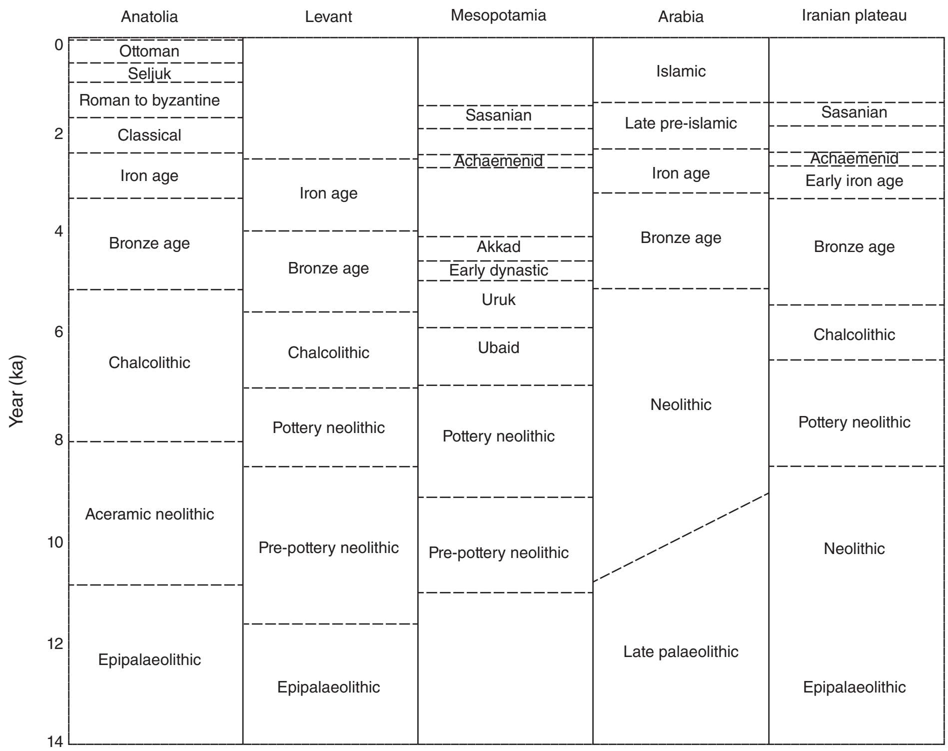


FIGURE 6 Summary of reginal archaeological chronologies. Derived from, for Anatolia (Allcock & Roberts, 2014), for the Levant (Finkelstein & Piasetzky, 2007; Maher et al., 2011; Regev, Finkelstein, Adams, & Boaretto, 2014), for Mesopotamia (Matthews, 2013; Nishiaki & Le Miere, 2005), for the Arabian Peninsula (Magee, 2014), and for the Iranian Plateau (Potts, 2013). The dating of some of these periods is complicated and debated, and varies within some of the regions defined here. Some periods were too short-lived to appear on this summary figure. More details can be found in the references provided

Epipalaeolithic and Neolithic sites, are very hard to resolve as genuine phenomena or a function of previous archaeological research focus (Düring, 2010; Düring, Glatz, & Şerifoğlu, 2012). However, the data that are available do still allow some insights into human–environment interactions (Allcock, 2017).

In the case of the prehistory of the Levant, there is considerable disparity between Israel, which has been intensively surveyed and has a high number of recorded archaeological sites, and neighboring regions, where far fewer sites are known. For example, although Lebanon has an analogous geographical and environmental context to Israel, very few Epipalaeolithic, Pre-Pottery Neolithic A and B (see Figure 6 for explanation of archaeological time periods) sites have been documented there, and even fewer have been excavated. Recent fieldwork in both northeast and southeast Jordan has demonstrated that this region was actually much more densely populated during the late Epipalaeolithic and the end of the Neolithic than previously thought (Akkermans, Huigens, & Bruning, 2014; Bertrams et al., 2012; Rambeau et al., 2011; Richter, 2017; Rollefson, Rowan, & Wasse, 2014; Rowan et al., 2015). Recent fieldwork in Saudi Arabia is extending the archaeological record of Neolithic occupation associated with palaeolake deposits and watercourses that were created/activated in the early Holocene (Breeze et al., 2017; Jennings et al., 2015; Matter et al., 2016). Consideration of sea-level changes since the LGM and related marine transgression in the Persian Gulf indicate that previous potential areas of refugia for people during periods of climate-induced stress are now submerged (Cuttler, 2013; Rose, Černý, & Bayoumi, 2013).

In southern Mesopotamia, there has been a long tradition of archaeological excavations and survey that provide insight into changing settlement systems, including the rise of urbanism, and the concomitant fluctuations in population size and distribution (e.g., Adams, 1969; Adams & Nissen, 1972). Similar data have also long been available for parts of Iran (e.g., Alden, 2013; Hole, 1987; Smith et al., 1972), and there are growing datasets for northern Mesopotamia and the adjacent uplands (e.g., Lawrence et al., 2016; Wilkinson et al., 1994), and parts of SE Arabia (al-Jahwari & Kennet, 2008, 2010; Magee, 2014) and also south Asia (e.g., Kumar, 2009; Possehl, 1999).

5.2 | Water use

Since the development of agriculture (Box 2) there has been a more pressing need for people to deal with soil-moisture or hydrological droughts, in ways other than moving across the landscape, and these choices and adaptions have been the key to the resulting degree of societal success. Access to water in some areas is reasonably straightforward, such as the parts of northern Mesopotamia and Iran that receive sufficient direct winter rainfall to support dry farming, and the various piedmont areas that receive broadly predictable water supplies via run-off onto alluvial fans (Petrie & Thomas, 2015; Prickett, 1986; Sherratt, 1980).

Some societies adapted to and developed specific niche environments. Cities in southern Mesopotamia, for example, grew and developed within or on the edges of an anastomosed and deltaic riverine system characterized by abundant salt- and freshwater marshes (Pournelle, Algaze, Crawford, McMahon, & Postgate, 2012; Wilkinson, Ur, & Hritz, 2013). These environments allowed early southern Mesopotamian societies not only access to varied and abundant resources and productive strategies, but also provided a buffer against significant climate fluctuations, such as at 4.2. ka (see discussion above), which are argued to have dramatically affected rain-fed agricultural systems in northern Mesopotamia (Weiss, 2015). In Bronze Age, SE Iran and SE Arabia, integrated oasis agro-pastoral systems developed from the domestication of the date palm, which created an anthropogenic ecosystem of sub-canopy microclimates suitable for the cultivation of a variety of crops in hot and arid environments (Tengberg, 2012).

In other areas, more careful management of water is required and this is evident from at least the middle Pre-Pottery Neolithic B (PPNB, ca. 9 ka) onwards (Richter, 2016). Early Neolithic wells have been documented at Mylouthkia and Shillourokambos on Cyprus (Peltenburg, 2012), while the middle PPNB site of Wadi Abu Tulayha in south eastern Jordan's Jafr Basin produced evidence for a cistern and a dam (Fujii, 2007, 2008). Expansion in the use of water harvesting systems at specific locations, including terraces, qanats, dams and cisterns, may reflect a variety of factors influencing the people living there. Climatic and environmental factors (such as deforestation) may have played a key role in triggering expanded water harvesting. The Pottery Neolithic water harvesting and soil conservation instillations at Dhra' (south of the Dead Sea) seem to be an early example of such efforts (Kuijt, Finlayson, & MacKay, 2015), and may be related to the 8.2 ka dry event. Social and economic factors such as increased wealth or larger populations may also be factors in this. The motive for the early Bronze Age expansion of water harvesting and terrace agriculture in Jawa, northeast Jordan, for example, is difficult to ascertain. However, it is noteworthy that the age of the water harvesting systems at the site (Meister et al., 2017) corresponds with the aforementioned 5.2 ka drying event. On the other hand, water harvesting by the Nabateans of Petra from around 2–1.2 ka (Beckers, Schutt, Tsukamoto, & Frechen, 2013) seems to correspond to a wetter episode in the southeastern Mediterranean at the time (Dermody et al., 2012). Moreover, hydrological studies of the terrace systems suggests that they may have been introduced there as flood control measures rather than for water harvesting or as an agricultural installation (Al Qudah, Abdelal, Hamarneh, & Abu-Jaber, 2016).

5.3 | Water demand

The impact a hydroclimatic anomaly will have on a given society depends on the reliance that group has on the resource, their adaption capacity, and how supply can, or cannot continue to meet demand. Recent challenges to SW Asian societies in terms of drought mitigation have been exacerbated by substantial regional population growth and migration (Kelley et al., 2015). It is important to therefore consider resource demand in the past, to the extent that it is possible from the archaeological dataset, as well as the severity of past reduction in rainfall, in assessing the potential risk of drought to past societies.

Estimating population sizes from archaeological datasets is notoriously difficult due to the uncertainties in the representation of sample datasets as being real reflections of larger number of people within sites and across landscapes that we may not be able to detect. While localized estimations of populations may be possible on a site level at well-preserved and extensively excavated sites, in order to extend these to the larger landscape beyond a site, we need improved and coherent methods to assess demographic trends (see Section 6). Even at well-excavated sites, chronological resolution often makes it very difficult to determine whether buildings within the same archaeological phase were occupied simultaneously or slightly apart in time (Birch-Chapman, Jenkins, Coward, & Maltby, 2017). There are also challenges posed by populations that are mobile across the landscapes that they inhabit, who left an archaeological record that is challenging to interpret in terms of demography. Archaeologists have often extrapolated population size from one small excavated area to an entire site by calculating available living space within the excavated area and multiplying it by the total size of the site (Hassan, 1978). This approach, however, is largely untested in real terms, since the scale and character of architecture in the unexcavated parts of the site is unknown, and because there is even less control over chronology beyond the excavated area (Birch-Chapman et al., 2017). Additionally, although site size is often combined with number of archaeological sites in a given area (Sumner, 1994), it is unclear whether such signatures necessarily reflect population growth or whether they are indicative of population aggregation. In arid areas such as Arabia, assessing population sizes in the early-mid Holocene is complicated by the common practice of residential mobility at various geographical scales (Cavulli & Scaruffi, 2013; Crassard & Drechsler, 2013; Lézine et al., 2010; McCorriston, Harrower, Martin, & Oches, 2012; Zazzo et al., 2016). Moreover, for the subsequent Bronze Age agro-pastoral communities of eastern Arabia, the burial archaeology record is at times much more prominent than that of contemporaneous settlement (Cleuziou & Tosi, 2007; Højlund, 2007), providing an alternative perspective on population size, distribution and, where skeletal remains are preserved, local demographic parameters (e.g., Baustian & Martin, 2010; Martin, 2007; McSweeney, Méry, & al Tikriti, 2010).

5.4 | Resilience or collapse?

There has been considerable interest in linking climate events identified in climate proxy records, and periods and phases of cultural transformation identified in archaeological sequences (Büntgen et al., 2016). In this regard it is interesting to compare the human responses to well-documented climate change events in inner Anatolia (see also Section 3). Both the 8.2 and 4.2 ka events are seen in Anatolian plateau proxies (as discussed above). The 4.2 ka event seems particularly significant for people in terms of either a major decline in frequency and scale of sites in areas like the Çarşamba fan (Baird, 2001) and other parts of Anatolia (Bachhuber, 2015), or major settlement restructuring with population concentration and growth of a few large sites. In the same areas the 8.2 ka event is not represented by any major settlement discontinuities (Baird, 2012a), although there may be subtle responses such as those also seen in north Syria. Rather than collapse, the 8.2 ka event on the Anatolian plateau has been linked with population displacement (Clare & Weninger, 2014) and the spread of the Neolithic into western Anatolia, although the latter has been recently questioned (Berger et al., 2016; Kılınç et al., 2017).

The contrasts in the same areas between these two climatic events may be due to their relative severity, but this was likely combined with the resilience of Neolithic communities at lower population levels and with significant flexibility in subsistence practices. These may have included ability to vary mobility, degrees of reliance on agriculture relative to foraging and pastoralism, and landscape exploitation practices that may have had significant incidental or deliberate conservation features. By 4.2 ka human populations had achieved much greater scale and density than that of previous millennia (Bachhuber, 2015; Baird, 2001), highly dependent on large-scale agriculture in prime but sensitive semiarid locations like the Konya basin alluvial fans, and were more dependent on elaborate land management schemes. People here had probably started to impact the landscape at a level much greater than in earlier millennia and operated in highly competitive political contexts (Bachhuber, 2015).

The western parts of South Asia are affected by both winter Mediterranean and summer monsoonal rainfall systems that produces a climatically and ecologically diverse landscape that is subject to interannual and more long-term variability. In this context, the available palaeoclimate records have variable proximity to archaeological sites and regions of interest, which means that it is illogical to draw simple correlations between evidence for climate change and cultural changes observed in the archaeological record (e.g., Petrie, 2017; Petrie et al., 2017; R. P. Wright, 2010). Furthermore, beyond spatial coverage, one of the biggest challenges with palaeoclimate records from South Asia has been the limited chronological control of the data. Most of the early climate records have poor chronological control (Madella & Fuller, 2006), and while this has been improved by more recent studies (Berkelhammer et al., 2012; Dixit et al., 2018; Dixit, Hodell, & Petrie, 2014; Dixit, Hodell, Sinha, & Petrie, 2014), their spatial distribution remains limited and contested (Finné, Holmgren, Sundqvist, Weiberg, & Lindblom, 2011). It will only be with spatially proximate proxy records from different zones within the region that it will be possible to characterize climatic variability accurately across the region as a whole, and link to local archaeological evidence.

6 | MODELLING CLIMATE, PROXIES, AND HUMAN RESPONSES

Modelling can help fill some of the gaps in the spatial and temporal coverage of climatic, hydrological and archaeological data identified above, and allow uncertainties in interpretations of these data to be better understood.

6.1 | Modelling climate

Concerted modelling efforts of past climates such as the Climate and Paleoclimate Modelling Intercomparison Projects (CMIPs, PMIPs), has usually focused only on key intervals such as the LGM (~21 ka) and the mid-Holocene (~6 ka). In SW Asia these time intervals are often transition periods in proxy records, leading to some difficulties in data model comparison (Reuter, Buenning, & Yoshimura, 2017). The most comprehensive modelling study of the Mediterranean region for the Holocene yet attempted has been performed by Brayshaw, Rambeau, and Smith (2011) who analyzed regional Mediterranean climate simulations, carried out at 2,000-year intervals from 0 ka to 12 ka. At 6 ka the model suggested that the annual average surface air temperature in the region was relatively similar to modern levels, however, cooler winters and warmer summers caused by insolation change meant that the seasonal cycle was amplified by 2–3°C. A multimodel ensemble from PMIP2 (Braconnot et al., 2007), suggested that Turkey and SW Asia were 2–5°C cooler than today at the LGM, and 1–2°C warmer at 6 ka. Brayshaw et al. (2011) did not find substantial summer precipitation in the eastern Mediterranean at any time 0–12 ka, however, during the wet season (October–May) simulations representing 8–12 ka showed an increase in precipitation over the eastern Mediterranean (Turkey, Syria, Lebanon, Jordan). They suggested that these patterns were due to changes in lower tropospheric circulation which meant a stronger south-westerly flow in winter. Perez-Sanz, Li, Gonzalez-Samperiz, and Harrison (2014) noted that CMIP5 models generally show an increase in 6 ka precipitation in the Mediterranean region, but also noted the difficulties in modelling precipitation for the region.

The challenge of model disagreement is further highlighted by modelling of LGM precipitation across the region. Robinson et al. (2006) suggested that the eastern Mediterranean and the Levant had reduced winter precipitation relative to modern levels; but Arpe, Leroy, and Mikolajewicz (2011) showed that with a high resolution version of the ECHAM5 climate model, a shift in circulation at the LGM could lead to enhanced precipitation over the Levant. This shift in circulation did not occur in lower spatial resolution versions of ECHAM5. Models generally agree that the seasonal patterns of precipitation are similar between the LGM and the preindustrial period (ca. 1750 AD) with most of the precipitation in the winter season and summers being very dry. Robinson et al. (2006) noted that LGM evaporation was in excess of LGM precipitation in this region, despite the drop in temperature. They also note that in the LGM a significant amount of the modelled winter precipitation falls as snow.

The addition of isotope hydrology to General Circulation Models of climate potentially improves the comparison of climate model output to proxy records of change. Risi, Bony, Vimeux, and Jouzel (2010) modelled global changes in the oxygen isotope values of precipitation ($\delta^{18}O_p$) between the LGM and the preindustrial period. In SW Asia they found no strong change in $\delta^{18}O_p$ between the two periods, despite the LGM being 3–9°C cooler. Reuter et al. (2017) found that modelled $\delta^{18}O_p$ at 6 ka was more negative than present day, due to a combination of effects including changes in local surface temperature and precipitation amount.

6.2 | Proxy system models

Palaeoclimatic archives and proxies filter the climate signal, as discussed above, such that comparison of climate model output with geological records requires an understanding of the systematics of the archive, such as that provided by Proxy System Models (PSMs; Dee et al., 2015; Evans, Tolwinski-Ward, Thompson, & Anchukaitis, 2013). These models have different levels of complexity from regression-based models, such as of PDSI from tree rings (Cook et al., 2016), through to transfer function approaches from pollen (Eastwood et al., 2007) or diatoms (Woodbridge & Roberts, 2011), and more mechanistic models of lakes and wetlands (Jones & Imbers, 2010; Rohling, 2016). The more mechanistic PSMs allow for the investigation of the impact of changing climate seasonality, including the impact of changing amounts of snow relative to rainfall, on these archive systems (Dean et al., 2018).

Given our discussions above, a key challenge in PSMs for SW Asia is correctly modelling the hydrology of a given archive, a crucial part of the *Environment Model* in the PSM framework of Evans et al. (2013). Dryland environments present particular challenges for hydrological models (Wheater, Sorooshian, & Sharma, 2007), but there has been some success in using hydraulic models, which can better represent the water routing at the event scale (e.g., Jarihani, Larsen, Callow, McVicar, & Johansen, 2015; Massuel et al., 2011). The very large spatial heterogeneity in rainfall, soil properties, and vegetation that combine to produce runoff in dryland environments is difficult to capture (Jothityangkoon, Sivapalan, & Farmer, 2001), meaning the processes driving modern dryland hydrology remain poorly understood. There is a lack of understanding of hydrological systems in the present day, from systems with heavy anthropogenic modification, to aid benchmarking such models. On top of this, groundwater spring resources may have notably lagged responses to climate (see discussion above) and, therefore, these proxies of water availability may be spatially and temporally incoherent, and have little fit to climate model outputs. This is a substantial knowledge gap, and leads to challenges in constraining the water supply for past populations.

6.3 | Modelling human water demand

A number of recent studies have begun to use computational techniques to address questions of settlement scale and resource demand in the archaeological record. At the most basic level, the presence of humans in a region requires a supply of accessible, potable water. This has a bearing on the most arid regions of SW Asia, which appear to have only been periodically inhabitable over the last 20,000 years (Groucutt & Petraglia, 2012). The known Upper Palaeolithic and Epipalaeolithic record in Arabia is sparse (Maher, 2010), and the region was not recolonized until the late Pleistocene/Early Holocene (Crassard, Petraglia, Drake, et al., 2013; Crassard, Petraglia, Parker, et al., 2013; Hilbert et al., 2014). Consequently, Breeze et al. (2015) have demonstrated that modelled palaeohydrological features are a good predictor of the location of archaeological sites in the hyperarid interior of the Arabian Peninsula. Bretzke, Drechsler, and Conard (2012) also found that modelled water availability is correlated with the distribution of sites in the Palaeolithic of the Syrian Desert, both in terms of where settlements were located, and the intensity of occupation through time.

On a larger scale, the aggregate demand for water in the region can be assumed to track its net population. The difficulty of deriving absolute estimates of population size in archaeological contexts was discussed previously, but in recent years archaeologists have increasingly used the summed radiocarbon or "dates as data" method (Chaput & Gajewski, 2016; Rick, 1987) to model long-term demographic trends. Although not without its critics (Bamforth & Grund, 2012; Contreras & Meadows, 2014; Torfing, 2015), the application of this technique has produced significant insights into the relationship between population and climate (Bevan et al., 2017; Shennan et al., 2013) and the results correlate well with other demographic proxies (Downey, Bocaege, Kerig, Edinborough, & Shennan, 2014; Lechterbeck et al., 2014; Woodbridge et al., 2012).

Several authors have recently applied the summed radiocarbon technique to corpuses of dates from SW Asia, focused primarily on the Pleistocene–Holocene transition (Borrell, Junno, & Barcelo, 2015; Flohr et al., 2016; Roberts et al., 2018). The overall trend evident in each study is one of the exponential population growth, with a marked "boom" beginning around 14.5 ka. This agrees with earlier population growth estimates based on palaeoanthropological (Guerrero, Naji, & Bocquet-Appel, 2008) and site frequency data (Goring-Morris & Belfer-Cohen, 2010). The evidence for demographic responses to specific climate events is more equivocal. Borrell et al. (2015) found a pronounced break in settlement in the northern Levant—the "near abandonment of the region"—corresponding to early Holocene warming, but this was not replicated in the larger dataset of Roberts et al. (2018). The latter authors did see a synchronicity between climate events and population events, but stressed the overall continuity of settlement in the region. Similarly, Flohr et al. (2016) tested the human response to the 9.2 and 8.2 ka climate events and found that the population was resilient to both. All three studies found evidence for significant regional variation in population dynamics and demographic response to climate, highlighting the importance of factoring local environmental conditions into this class of model.

For the later prehistoric and historic periods, demographic trends can be modelled more concretely using quantitative historical data, an approach sometimes dubbed "cliodynamics" (Turchin, 2008). Reba, Reitsma, and Seto (2016) recently produced a database of estimated urban population growth between 5.7 ka and the present. This database is of particular interest because not only was SW Asia the location of the world's earliest urban societies, the advent and growth of these societies is frequently linked to growing demand and centralized management of water resources (Wilkinson & Rayne, 2010). Integrating this data into linked models with the climate record, and with the prehistoric summed radiocarbon sequence, is therefore a promising avenue for future research.

Modelling has also been used to reconstruct water demand on subregional or site-local scales. This reveals considerable variation in people's reliance on hydrological resources depending on the environmental and cultural context. In the Late Pleistocene of steppic eastern Jordan, for example, Byrd, Garrard, and Brandy (2016) modelled mobile foragers as needing to be only within one or two days' walk of freshwater, and posit that they only temporarily gathered at perennial water sources during the dry season. By contrast, Whitehead, Smith, and Wade (2011) and Whitehead et al. (2008) constructed a model of the hydrological resources of the nearby early Bronze Age site of Jawa, concluding that its system of diversions and storage ponds was constructed to support a permanent, sedentary population of 6,000 or more people and their livestock. Even in the same environmental zone, therefore, the human response to hydroclimatic events can be expected to differ radically between social contexts.

7 | SUMMARY

Our review of this topic has highlighted the continued challenges involved in answering the key research questions regarding human vulnerability to climate change over the last 20,000 years. The paper illustrates a considerable, and growing, body of literature from across the palaeoscience disciplines dealing with these issues in SW Asia. Development of new analytical technologies will continue to provide new ways of examining archaeological and palaeoenvironmental archives and further add to our knowledge base. For example, new excavations and palaeoclimate reconstructions in Anatolia, Iraqi Kurdistan, southern Mesopotamia, Iran, Arabia, and South Asia are providing opportunities, not only to improve the spatial resolution of data available, but to implement the use of the full-spectrum of state of the art bio-archaeological approaches. Archaeobotany and archaeozoology have been widely used for some time, but isotopic analysis of human and animal remains is being increasingly utilized to investigate questions of mobility, diet and the impact of climate change on water availability and use (e.g., Chase, Ajithprasad, Rajesh, Patel, & Sharma, 2014; Chase, Meiggs, Ajithprasad, & Slater, 2014, 2018; P. J. Jones, 2018; Kenoyer, Price, & Burton, 2013; Kutterer & Uerpmann, 2012; Riehl, Pustovoytov, Weippert, Klett, & Hole, 2014; Valentine et al., 2015). Residue analysis of ceramics from new excavations, and also museum collections, is also now being attempted (Craig et al., 2013; Gregg, 2010; Gregg, Banning, Gibbs, & Slater, 2009).

Coming to a conclusion regarding ongoing work is difficult, so here we summarize two key themes that pervade this paper and are likely foci of future work. While collaboration across the palaeoscience disciplines working in SW Asia has often been the norm, our review here highlights the need for these communities to look further, to hydrologists, soils scientists and modelers, for example, to take such work forward. We need to fully integrate data and approaches, new and existing, in interdisciplinary ways towards answering focused research questions (Jones, 2013).

7.1 | Scale

Although modelling, quantitatively or conceptually, is likely to aid future interpretation of new and existing datasets, a major challenge is integrating widely divergent scales of archaeological and palaeohydrological data. For example, how do we best compare regional summed radiocarbon population proxies to site-specific water management strategies, with palaeoenvironmental data conditioned by regional climatic and local hydrological and ecological states?

To aid resolving such complexity more care needs to be taken in understanding the likely spatial relevance of a given proxy record, and the public availability of instrumental meteorological and climate-model data give one way make this possible (e.g., Jex, Phipps, Baker, & Bradley, 2013; Yiğitbaşıoğlu et al., 2015), alongside improved monitoring of archive systems (e.g., Dean, Eastwood, et al., 2015; Djamali et al., 2009). Some of the nonconformity between scales can also be addressed by palaeoenvironmental work in direct association with individual archaeological sites, that is, from the local hydroscape, and only then linking to, often more continuous, palaeoclimate records from further away (Jones, Maher, Richter, et al., 2016). Modelling, particularly of local, hydrology is often a "missing link" in the palaeonarratives reviewed here. Appreciation of a given locale's place in the regional hydroscape, be it a palaeoenvironmental archive or archaeological site, allows more robust links to climate to be made where possible, and demands the resolution of factors acting across multiple scales.

7.2 | Seasonality

Palaeoenvironmental records rarely have the resolution to pick apart conditions in multiple seasons of a given year, but many reflect conditions of a particular season (Dean et al., 2018). Given the very different seasonal conditions across SW Asia, even with a first-order conceptual hydrological understanding, the balance between the now predominant winter wet season and summer dry season is likely to be important for water availability, and the climatic systems that ultimately control these conditions range from the Atlantic Ocean to east Asia, and from Iceland to south of the equator. Over the last 20,000 years, the timing (Stevens et al., 2001) and type (Robinson et al., 2006) of precipitation across the region may have changed, as would have the degree of summer evaporation (Djamali et al., 2010). The balance of seasonal precipitation and evaporation patterns is a primary control on recharge, and will therefore impact water availability and how a given palaeoenvironmental archive records shifting patterns. Changing amounts of snowfall, and snowmelt, would also alter this filtering of climate by hydrological systems, and are an important focus for future work, especially in understanding glacial–interglacial changes in proxy records from the region.

7.3 | Close

The water resources available to a given group of people at any time is a function of climate moderated by landscape and technology, such as vegetation type and quantity, soil cover and stability, geology, and topography, which influence surface- and groundwater systems, and the people themselves. People have been making the most of these resources, and adapting as they change, across SW Asia for over 20,000 years. Whatever the complications in detailing the finer points of past societies' relationships with changing water availability it is clear that dealing with changing elements of that relationship is far from a new issue for people, in SW Asia arguably for longer than anywhere else. Our review here highlights the need for a multidisciplinary, multiscalar approach to furthering work in this area. A 20,000-year perspective shows that societies are often vulnerable to changing climate and have sometimes struggled to adapt. The implications for resilience in our own, present day and projected future contexts are salutary.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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