Oasis or Mirage? Assessing the Role of Abrupt Climate Change in the Prehistory of the Southern Levant

Lisa A. Maher, E.B. Banning & Michael Chazan

*Few prehistoric developments have received as much attention as the origins of agriculture and its associated societal implications in the Near East. A great deal of this research has focused on correlating the timing of various cultural transformations leading up to farming and village life with dramatic climatic events. Using rigorously selected radiocarbon dates from archaeological sites and palaeoenvironmental datasets, we test the predominate models for culture change from the early Epipalaeolithic to the Pottery Neolithic (*c. *23,000–8000 cal.* BP*) to explore how well they actually fit with well-documented and dated palaeoclimatic events, such as the Bølling-Allerød, Younger Dryas, Preboreal and 8.2 ka event. Our results demonstrate that these correlations are not always as clear or as consistent as some authors suggest. Rather, any relationships between climate change and culture change are more complicated than existing models allow. The lack of fit between these sources of data highlight our need for further and more precise chronological data from archaeological sites, additional localized palaeoclimatic data sets, and more nuanced models for integrating palaeoenvironmental data and prehistoric people's behaviours.*

Ever since V. Gordon Childe (1928) first proposed a climatic explanation for the origins of agriculture, some version of climatic determinism has been a pervasive force in explanations of culture change in the Near East during the late Pleistocene and early Holocene. Despite early and later attempts to discredit either Childe's 'oasis theory' specifically (Braidwood 1951; 1960) or climatic explanations more generally (Bar-Yosef 1996), climate change has persisted as a 'prime mover' in explanations of culture change, including the beginnings of food production (Bar-Yosef 1987; 1990; 1995; Bar-Yosef & Belfer-Cohen 1989; 1991; Bar-Yosef & Kislev 1989; Bar-Yosef & Kra 1994; Bar-Yosef & Meadow 1995; Belfer-Cohen & Bar-Yosef 2000; Binford 1968; Byrd 2005; Grosman & Belfer-Cohen 2002; Henry 1985; 1991; Moore & Hillman 1992; Munro 2003; Rossignol-Strick 1999; Weiss & Bradley 2001; Wright 1993; Wright & Thorpe 2003). Recent concerns about global warming have, if anything, increased academic interest in human adaptations to climate change toward the end of the Pleistocene (e.g. Burroughs 2005; Mackay *et al.* 2005; Schwartz & Randall 2003).

Meanwhile, our picture of climate changes during the late Pleistocene and early Holocene has improved immensely, especially over the last two decades (Alley *et al.* 2003; Bar-Matthews *et al.* 1997; 1999; Bar-Matthews & Ayalon 2003; Bartov *et al.* 2002; Severinghaus *et al.* 1998; Severinghaus & Brook 1999; Thomas *et al.* 2007; Weaver *et al.* 2003). Oxygen-isotope variations measured from polar ice-cores allow detailed reconstructions of oceanic circulation, sea levels, and temperature, and models of glacial and interglacial phases (e.g. Weaver *et al.* 2003). Extensive loess deposits found throughout Europe and Asia (Kemp & Derbyshire 1998; Kukla 1970) and, to a lesser degree, the Negev (Bowman *et al.* 1986; Goldberg 2001; Goring-Morris & Goldberg 1990) preserve a somewhat comparable continental record of recent climate change. In the Levant, detailed records of continental climate change have been documented from cave speleothems (Bar-Matthews *et al*. 1997; 1999; Bar-Matthews & Ayalon 2003), Lisan (Bartov *et al.* 2002) and later Dead Sea lake levels (Enzel *et al.* 2003; 2008; Frumkin 1998; Frumkin *et al.* 1994; 1999), palaeosols

Cambridge Archaeological Journal 21:1, 1–29
doi:10.1017/S0959774311000011 Received 30 Mar 2010; Accepted 10 Jun 2010; Revised 9 Aug 2010

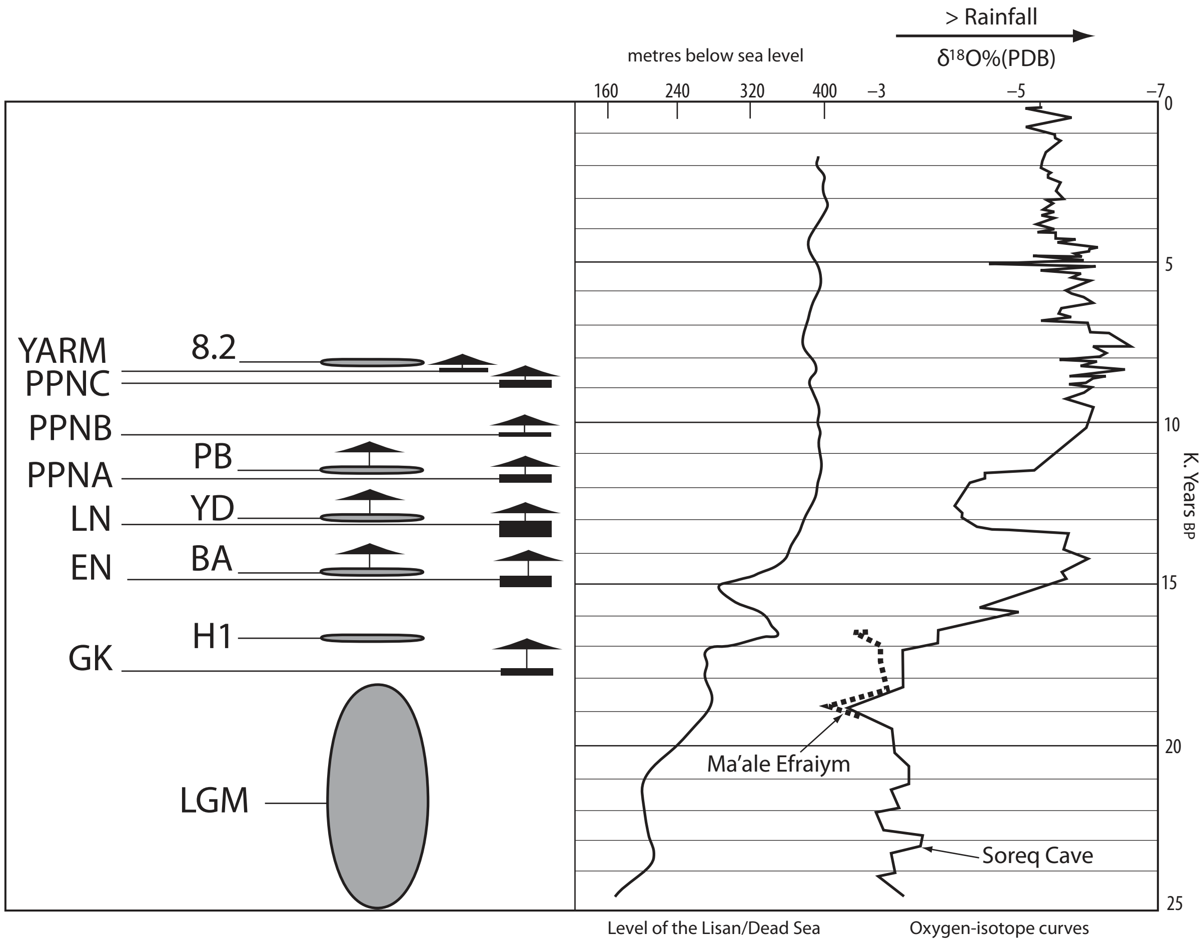

Figure 1. *Correlation of oxygen-isotope and speleothem data as derived from several Near Eastern sources with global climatic events and Near Eastern prehistoric periods. (Data from Bartov* et al. *2007; Bar-Matthews* et al. *1997; Vaks* et al. *2003.)*

(Gvirtzman & Wieder 2001; Magaritz 1986; Khresat *et al.* 1998; Khresat 2001) and geomorphological studies of archaeological sediments (Cordova 2000; Cordova *et al.* 2005; Goldberg & Bar-Yosef 1990; 1992; 1994; 2001; Goldberg & Bar-Yosef 1982; Goldberg & Brimer 1983; Hunt *et al.* 2004; Maher 2005).

The unprecedented precision with which we can now date major climatic events at the global, regional and local scales begs the question of just how closely we can associate these events with the cultural changes they are purported to have triggered (Fig. 1). The answer to this question has substantial implications in the Levant for our understanding of the processes that led to food production, village life and socio-economic hierarchies. Yet, despite past attempts to correlate climatic events with cultural ones (e.g. Bar-Yosef & Kra 1994; Byrd 2005, 244–52), the answer is still unsatisfactory, in part because of a failure to make full use of recent advances in both the quality of the radiocarbon calibration curve (Balter 2006; Reimer *et al.* 2004; Reimer *et al.* 2006) and the analysis of radiocarbon dates (e.g. Bronk Ramsey 2000; Bronk Ramsey *et al.* 2006; Buck *et al.* 2006).

We now have a large number of well-dated archaeological sites, a comprehensive picture of late Pleistocene climate change, and an increasingly refined archaeological record with which to work. Yet, to date, these complementary lines of evidence are rarely integrated into a cohesive absolute chronology directly applicable to specific prehistoric events (although see Issar & Zohar 2007; Rosen 2007). Studies of the effect of climate change on prehistoric societies have tended to ignore the uncertainty introduced by the need to calibrate radiocarbon dates from archaeological sites before correlating archaeological phenomena with the global and local oxygen-isotope curves. Because of this uncertainty, the correlations between archaeological phenomena and palaeoclimatic events should be treated as probability statements. In an effort to move beyond simple criticism, this article will adopt a probability approach and will use Bayesian modelling (Baylis & Ramsey 2004; Buck *et al.* 1991; 1992; 1994a,b; 1996; Buck & Sahu 2000; Steier & Rom 2000; Steier *et al.* 2001; Zeidler *et al.* 1998) and currently available radiocarbon data bases for the Levant to test the probability of particular models that correlate climate changes with cultural events. Several models currently dominate the literature:

1. Sedentary, socially-complex groups appeared quickly at the beginning of the Early Natufian and are correlated with the onset of the Bølling-Allerød (e.g. Bar-Yosef & Belfer-Cohen 1989; Bar-Yosef & Meadow 1995; Grosman 2003; Grosman & Belfer-Cohen 2002; Henry 1989; Kaufman 1992).
2. The beginning of the Younger Dryas caused resource stress and triggered a decline in settlement density and increase in mobility at the beginning of the Late Natufian (e.g. Belfer-Cohen & Bar-Yosef 2000; Byrd 2005; Grosman & Belfer-Cohen 2002; Grosman 2003), brought the Mushabian to an end or triggered the Harifian (Goring-Morris 1991; Goring-Morris *et al.* 2009).
3. The end of the Younger Dryas is correlated with the onset of large settled villages in the Pre-Pottery Neolithic A (or, for some authors, at the Khiamian/Sultanian boundary) (e.g. Bar-Yosef & Belfer-Cohen 1989; Byrd 2005; Goring-Morris & Belfer-Cohen 1998).
4. The 'collapse' of the Pre-Pottery Neolithic B is correlated with the 8.2 ka climatic event (e.g. Bar-Yosef 2001; Simmons 2007).

While we do not advocate any of these hypotheses, nor the 'layer-cake' model of cultural periods they imply (see below), we have chosen to test them because they are widely cited explanations for shifts in subsistence, technological innovation, settlement patterns, mobility and the emergence of social complexity. Indeed, here we intend to demonstrate that current evidence (radiocarbon, palaeoclimatic and archaeological) does not support simple cause-and-effect relationships between rapid climate-change events and cultural changes.

For the hypothesis that a climatic event triggered a particular set of cultural responses to be credible, two conditions should be satisfied. First, it should be highly probable that the climatic event preceded the postulated cultural response. We might expect even the recognition of and response to a rapid and deleterious event to take at least a decade or two, while the response to opportunities afforded by a climatic 'amelioration' might take many decades. Second, there should be a plausible theory to explain the cultural changes as a response to the climatic ones. If, for example, one hypothesized response is to make smaller lunates or to retouch them differently, this should be explicable by changes in the design of the composite tools of which they were a part, and those in turn by plausible alterations to hunting strategies which are a response to changes in prey distribution and structure, and so on, that depend, at least in part, on climate. In this article, we only propose to address the former condition.

In this light, we address several specific questions related to the above-mentioned hypotheses, including:

1. Did the Heinrich I cold event occur at or slightly before the onset of the Geometric Kebaran?
2. What is the relationship between the Bølling-Allerød and the Early Natufian?
3. What is the probability that the onset of the Younger Dryas coincides with the end of the Mushabian?
4. What is the probability that the onset of the Younger Dryas coincides with or precedes the beginning of the Late Natufian?
5. What is the probability that the onset of the Younger Dryas coincides with the beginning of the Harifian?
6. What is the probability that the sudden Preboreal onset coincides with the beginning of PPNA? Or with the beginning of the Sultanian?
7. Does the 8.2 ka event coincide with the end of the Late PPNB? Alternatively, does it coincide with the end of the PPNC and beginning of the Yarmoukian?

Who's who of the terminal Pleistocene and early Holocene

Several cultural-chronological schemes have been proposed for the Epipalaeolithic and Neolithic periods of the southern Levant (e.g. Bar-Yosef 1970; Belfer-Cohen & Goring-Morris 2002; Byrd 1994; 1998; 2005; Gilead 1988; Goring-Morris 1987; Goring-Morris & Belfer-Cohen 1998; Henry 1983; 1995; Kuijt & Goring-Morris 2002; Simmons 2007; Verhoeven 2004). Although there is no consensus, we present here a simplified version that is widely accepted (Table 1). This conventional model is a 'layer-cake' or 'abutting' one, each new culture or period appearing, with few exceptions, when an older one comes to an end. We do not suggest that this is the best cultural-chronological model, or that it is entirely consistent with the evidence. Instead we are formalizing the most commonly accepted model that is either explicit or implicit in recent explanations that

Table 1. *Main cultural-chronological periods of the Epipalaeolithic and Neolithic of the southern Levant, showing existing 'layer-cake' model for the Mediterranean and arid zones (e.g. Goring-Morris* et al. *2009), in which each period abuts earlier and later periods. The 68 per cent confidence intervals are from our Bayesian analyses of the boundaries between periods, again assuming no overlap. Note that the table omits cultural entities not discussed in the text.*

Archaeological entities of the Epipalaeolithic and Neolithic				
Approximate dates in conventional model (ka cal. BP)	**Mediterranean zone**	**68% confidence interval (ka cal. BP)**	**Arid zone**	**68% confidence interval (ka cal. BP)**
7.5–7.0	Wadi Rabah	7.8–7.7	Pottery Neolithic	
8.5–7.8	Yarmoukian	8.45–8.36		
9.0–8.5	PPNC	9.0–8.7?	PPNB	
10.4–9.0	PPNB	10.45–10.3		
11.6–10.4	PPNA	11.87–11.66	PPNA	11.78–11.61
12.9–11.6	Late Natufian	13.22–12.97	Harifian	13.09–12.9
14.6–12.9	Early Natufian	14.99–14.72	Mushabian/Geometric Kebaran	
17.5–14.6	Geometric Kebaran	17.74–17.43		
23.0–17.5	Kebaran		Kebaran Nebekian Masraqan/Qalkan	

have associated climate change with cultural changes and earliest agriculture (e.g. Kuijt 2000, 9). Other possibilities are to assume some overlap between successive periods (a very 'forgiving' type of model), or to assume a hiatus between periods. There is some data to support these alternative possibilities. For example, 'geometric' industries are documented in areas such as eastern Jordan prior to the Geometric Kebaran; Early and Middle Epipalaeolithic industries in southern Jordan, the Negev and Sinai, eastern Jordan, and the Mediterranean Zone are defined differently amongst researchers and poorly articulated chronologically and typologically; and subdivisions within the Late Epipalaeolithic are inconsistently typological or radiometric (Goring-Morris *et al*. 2009; Maher 2005; Olszewski 2006). Similar controversies exist within the Neolithic. As a result, using the material culture record to define start and end dates for cultural periods is far from clear-cut and likely not synchronous throughout the region. We explore the implications of some of these alternatives below.

History of climatic explanations in Near Eastern prehistory

Although Pumpelly (1905) already cited desiccation as the cause of the collapse of central Asian cities, V. Gordon Childe was the first to use climate change at the end of the Pleistocene in an explanation for the origins of food production. He saw humans and the animals they hunted converging on oases and streams as shifts in rain-bearing winds at the end of the Pleistocene caused desertification in North Africa (Childe 1928; 1942). Subsequently, Braidwood (1951; 1960; Braidwood & Howe 1960) largely dispelled confidence in Childe's theory, first, by noting that the end of the Pleistocene was not the only major episode of global warming and that earlier episodes had not led people to domesticate plants or animals. Second, he undertook fieldwork in Iraqi Kurdistan that suggested that environmental conditions at the Pleistocene/Holocene boundary there changed but little (1960; 1973; Braidwood & Howe 1960).

Binford (1968) employed a new model for the beginnings of food production in which population movements play a major role by increasing pressure on food resources in regions that were the recipients of immigrants. However, climate plays a supporting role in that Binford saw rising sea levels, themselves the result of glacial melting at the end of the Pleistocene, as encouraging dependence on aquatic resources. The latter led to increased sedentism and population growth, ultimately causing these growing populations to impinge on neighbouring populations outside the optimal zones near the coast. Population pressure on resources in these less-optimal zones would then result in the kind of stress that encouraged innovative or more labour-intensive subsistence technologies.

Bar-Yosef proposed that agriculture arose as a response by Late Natufian groups to deteriorating climate and increased resource stress during the Younger Dryas (1982; 1987; 1995; 1996; Bar-Yosef & Meadow 1995; Bar-Yosef & Vogel 1987). Risk-reduction strategies involved pooling resources, expanding territories and increasing group interaction, coordinated by an accompanying increase in the complexity of social organization. Bar-Yosef & Belfer-Cohen (1989) were among the first to argue a direct link between oscillating wet/warm and cool/dry phases and specific Epipalaeolithic entities at the end of the Pleistocene. For example, they linked the onset of a climatic amelioration after the Late Glacial Maximum (LGM) with the development and expansion of Geometric Kebaran groups and the subsequent aridity of the Younger Dryas with resource stress within aggregated Natufian populations. Moore & Hillman (1992) and Rossignol-Strick (1999, 528) agree that the emergence of the Neolithic and the processes allowing plant domestication were direct consequences of the extreme aridity of the Younger Dryas.

Grosman and Belfer-Cohen (Grosman 2003; Grosman & Belfer-Cohen 2002) adhere to the importance of the Younger Dryas in shaping Late Natufian and PPNA adaptations. They regard Natufian groups as the predecessors of Neolithic food-producing societies and seek causes for the rapid shift in economy, sedentism and social complexity in the dramatic environmental changes of the Younger Dryas. Again, they see climate change as a direct cause of Late Natufian resource stress that resulted in both increased mobility and intensification of food-production. Grosman (2005) later refined this scenario by modelling radiocarbon dates from Natufian and Neolithic sites to propose a link between the onset of the PPNA (rather than the Late Natufian) and the Younger Dryas.

Binford (2001, 453–7) has more recently returned to the question of climatic and demographic change leading up to the early Neolithic. He now sees climate stress of the Younger Dryas as encouraging higher mobility in the Late Natufian (2001, 454) as hunter-gatherers attempted to 'explore previously avoided areas to see if conditions were better than those where they were localized. Their world had changed and the conditions of stability upon which their strategic planning depended were no longer reliable'. Interestingly, Binford (2001, 452) suggests that 'during the Younger Dryas itself, there are no dated archaeological remains', thus demonstrating our need for better control over the chronological association of the cultural and climatic events. This is an odd comment in light of abundant Late Natufian and PPNA dates (see below), many of which fall within the Younger Dryas episode. Binford's modelling also predicts that 'a return to maximum mobility and extensive egocentric networks' (2001, 454) should have followed the Younger Dryas. He notes that the archaeological data instead indicate settlement instability and the likely failure of institutionalized social networks during the PPNA. He argues (2001, 456) that PPNA settlers began to cultivate plants at springs and other water sources in the Jordan Valley by translating 'knowledge from prior experience to new, very different habitat conditions'.

K. Wright (1994) argues that only the stress associated with the Younger Dryas drought conditions would have warranted the higher processing costs associated with increasing dependence on cereals. By contrast, Munro (2003) sees the Younger Dryas as causing Natufian populations, at the beginning of the Late Natufian, to cope with the changing climate by shifting to fast, small game (like hares and birds), yet we lack specific evidence that the Younger Dryas caused food stress or resource intensification that led to the adoption of agriculture.

McCorriston & Hole (1991) similarly pointed out that simple environmental causes are not sufficient to have pushed or pulled Natufian groups into an agricultural lifestyle and attempt to explain why agriculture arose *at that particular point in time*. They argue that it was the confluence of several environmental and social factors, each of which formed a piece of the puzzle. They list a series of environmental, social, ideological and technological preconditions that must have been set in place before Natufian groups could cross the threshold and become farmers. In other words, agriculture arose because the right people were in the right place, at the right time. Although local palaeoenvironmental conditions played a crucial role in contributing to the origins of agriculture, in and of themselves, they were not a primary cause.

Byrd (2005, 245) uses radiocarbon evidence to argue that the beginning of the Natufian coincides with the beginning of the warmer and wetter conditions of the Bølling inter-stadial. Like Bar-Yosef, he then sees a correspondence between the Late Natufian and the Younger Dryas in the southern Levant (Byrd 2005, 251). He places Khiamian PPNA sites within the Younger Dryas but argues that the onset of PPNA village life in the Sultanian, Aswadian and Mureybetian phases coincides with the increase in temperature and precipitation of the Preboreal phase

Table 2. *Palaeoclimatic events of the last 25,000 years discussed in the text, with date of onset and associated errors and estimated durations (dates from Alley* et al. *1997; 2003; Bar-Matthews* et al. *1999; Barber* et al. *1999; Bond* et al. *1992; Enzel* et al. *2008; Lowe* et al. *2008; van der Plicht* et al. *2004; Severinghaus & Brooks 1999; Severinghaus* et al. *1998; Weaver* et al. *2003).*

Date of onset (cal. BP)	Error (±)	Name	Peak	Duration (years)
8245	20	8.2 Event	8175	160
11,570	10	Pre-Boreal	11,400	1500
12,900	120	Younger Dryas	N/A	1200
14,670	35	Bølling-Allerød	N/A	1800
16,800	150	Heinrich 1 Event	16,600	100–500
25,000	500	Last Glacial Maximum	22,000	8000

at 11.6 ka. 'While correlation is not causation, it is clear, however, that Early Natufian sedentism and then PPNA early village life flourished immediately after rapid improvements in climate initiated by the Bølling and Preboreal events' (Byrd 2005, 252). He goes on to argue that environmental stress cannot therefore be used to explain these changes, but rather focuses on social and ideological dynamics that took place when climate was benign.

All of the explanations described thus far rely heavily on large-scale climate change as a primary cause of social, technological and economic transformation; namely in terms of adaptive responses to periods of stress or abundance. An interesting aspect of all these theories is their presumptions about the quality of the climate inherent in the words we use to describe climate change. Warm and moist are often synonymous in the literature with climatic amelioration, climatic improvement and generally favourable conditions, with the presumption that warm and wet were ideal conditions for cultures to flourish, innovate and, according to some authors, become more complex. Conversely, there is a widespread assumption that cool, dry periods impose severe stresses that forced human populations to innovate and intensify or, alternatively, return to 'simpler' life ways. The value-lading of these terms and the simplistic models of culture–climate interaction that they imply are topics to which we will return later.

Major climatic events of the late Pleistocene/ early Holocene

In order to discuss the validity of linking climate and culture change during the Epipalaeolithic and Neolithic of southwest Asia, we briefly review current reconstructions of the palaeoclimatic record (Table 2). Our dating of the climatic events depends heavily on the GRIP core data. These cores offer extremely high precision because they are dated through actual counting of annual layers defined by regular variation in electrical conductivity, dust, nitrate, calcium and ammonium ions, which are particularly clear back to the Younger Dryas (Johnsen *et al.* 2001). Well-dated volcanic eruptions and other tie points were used to anchor this sequence. In general, we follow the most commonly cited dates and standard deviations cited in the GRIP literature. Other proxies are more problematic in their dating. (For a more detailed summary of data from various palaeoclimatic data and reconstructions of changing climatic conditions for the Levant, refer to Enzel *et al.* (2008), Robinson *et al.* (2006) or Rosen (2007, 44–80, fig. 4.7).)

Last Glacial Maximum (LGM)

Although oscillations in temperature and humidity characterized much of the Pleistocene, our focus here is the impact of these fluctuations at the end of the Pleistocene. Cold and dry conditions of the LGM occurred between 25 and 18 ka cal. BP, reaching a height at *c.* 22 ka cal. BP. Global records for late Pleistocene climatic conditions derive mainly from ice cores (e.g. Lowe *et al.* 2008) that document persistent cold and dry conditions until *c.* 19–17 ka cal. BP. In the Levant, isotopic records from cave speleothems in Soreq Cave show that δ^{18}O values reach a peak at 19 cal. BP and mark very cold conditions (Bar-Matthews *et al.* 1997; 1999). Several authors have attempted to summarize pollen records from a variety of sites throughout the Mediterranean (Meadows 2005; Rossignol-Strick 1995; 1997; Wright & Thorpe 2003). Where present, pollen from archaeological sites seems to agree generally with other pollen evidence (Leroi-Gourhan & Darmon 1991) regarding a shift from chenopods and other dry, cool species to more forested conditions at the end of the LGM, with a brief return of these arid-adapted plants at the Younger Dryas (Deckers *et al.* 2009; Rosen 2004; 2007). Geomorphological evidence suggests that a drop in regional water levels accompanying the cool and dry conditions of the LGM resulted in stream incision and downcutting of existing Pleistocene stream terraces (Goldberg 1994; Goodfriend 1987; Goodfriend & Magaritz 1988; Rosen 1986; 2007). Sediments surrounding and within the Dead Sea basin indicate the presence of a large lake, Lake Lisan, during the LGM (Bartov *et al.* 2002; 2003; Begin *et al.* 1974; Neev & Emery 1967). Low evaporation rates kept lake levels high throughout the LGM, but subsequent changes in temperature and evaporation caused fluctuations and a gradual shrinking of the lake to *c.* 300 m bsl by 15 ka cal. BP (with a brief rise in levels *c.* 17 ka cal. BP). Glacial conditions terminated in the southern Levant with the relatively sudden onset of warm and wet conditions at 14.67 ka cal. BP, a period known as the Bølling Interstadial.

Heinrich 1 Event

Although the resolution of the terrestrial palaeoclimatic record in the Near East is currently not as refined as the marine record for identifying this very brief climatic episode prior to the Bølling-Allerød (although see Bar-Matthews *et al.* 1997; 1999), the Heinrich 1 (H1) event is discussed here because of its potential relationship to the Middle Epipalaeolithic.

Heinrich events are rapid-cooling events caused by an abrupt influx of large volumes of freshwater into the Atlantic Ocean as northern hemisphere glaciers dump icebergs into the ocean (Bond *et al.* 1992; Bond & Lotti 1995; Heinrich 1988; Hemming 2004; Roche *et al.* 2004). They are identifiable in the sedimentary record of cores from the Atlantic Ocean as a decrease in oceanic salinity due to the input of freshwater, a decrease in surface sea temperatures and changes in foraminifera. Terrestrially, they are marked by pollen changes and notable increases in $\delta^{18}O$ levels as documented in speleothems. It appears that, throughout the last glacial period, these events occur on average every 7000 years and last for a duration of 100–500 years (Heinrich 1988). The causes of Heinrich events, including H1, are largely unknown, with debates centred on either internal forces (Alley *et al.* 2005) or external atmospheric forces (Bond *et al.* 1992). Particularly notable for our discussion, it appears that these events are immediately followed by abrupt shifts to warmer climates, such as the Bølling-Allerød. The Heinrich 1 event occurred about 16.8–16.5 ka cal. BP.

The Bølling-Allerød

The Bølling-Allerød began with a rapid-warming event about 14.67–14.6 ka cal. BP (Alley *et al.* 2003; Landmann *et al.* 1996; Martrat *et al.* 2004; Severinghaus & Brook 1999; Weaver *et al.* 2003). Following the cold and dry LGM, the Bølling-Allerød interstadial was triggered by the melting of Antarctic ice sheets in an event called Meltwater Pulse IA (Weaver *et al.* 2003). This warm and wet phase is well-documented in marine records, where global temperatures rose *c.* 4–5°C, along with atmospheric CO_2 concentrations (from 200 ppm to 280 ppm). The onset of the Bølling-Allerød also coincided with a *c.* 20 m rise in sea levels over 500 years.

In some regional climatic records, the Bølling warm phase is separated from the Allerød warm phase by the Older Dryas (Dryas II); marked by a brief return to glacial conditions (cool and dry). It dates to *c.* 14.5–13.7 ka cal. BP, but is less securely dated than most of the other climatic events mentioned in this paper (Severinghaus & Brook 1999). With a relatively short duration, it also does not appear to have had a major impact in the eastern Mediterranean region (see Bar-Matthews *et al.* 1997; 1999) and is not discussed further here. Rather, the Bølling-Allerød are taken together as one prolonged phase of climatic amelioration in the southern Levant (Bar-Matthews *et al.* 1997; Bar-Matthews & Ayalon 2003; Bartov *et al.* 2002; Frumkin 1998; Frumkin *et al.* 1994; 1999; Gvirtzman & Wieder 2001; Wieder & Gvirtzman 1999).

The Bølling-Allerød is documented by several different palaeoclimatic records in the Near East. A steep decline in $\delta^{18}O$ values from Soreq Cave, indicating warming of temperatures and a gradual increase in moisture (rainfall), reached a low at 14 ka cal. BP (Bar-Matthews *et al.* 1999). Renewed alluviation and terrace aggradation throughout the southern Levant accompanied this warm and wet period, and these terraces are associated with several Epipalaeolithic sites dated *c.* 17.5–15 ka cal. BP (Goldberg 1994). A subsequent return to extensive stream incision marks lowered water tables and the onset of the Younger Dryas. Warm and wet conditions are also documented in Lisan Lake levels (Bartov *et al.* 2002; 2003), palaeosol development (Goldberg 1994; 1981; Goodfriend & Magaritz 1988), decreased salinity in Lake Zeribar, Turkey (Wasylikowa *et al.* 2006), and increases in arboreal pollen, particularly *Pistacia* and *Quercus* species (Rossignol-Strick 1995; 1999).

The Younger Dryas (Dryas III)

The Younger Dryas (YD) is the climatic event that has attracted the most attention from archaeologists attempting to explain fundamental changes in settlement pattern, economy and social organization in the Natufian and PPNA periods of the southern Levant. Recent palaeoclimatic evidence now demonstrates that this arid period established itself very rapidly about 13 or 12.8 ka cal. BP (Alley *et al.* 2003; Martrat *et al.* 2004; Severinghaus *et al.* 1998; Severinghaus & Brook 1999; Weaver *et al.* 2003). Recognized as a global phenomenon (Andres *et al.* 2003), the Younger

Dryas witnessed a temperature drop of *c.* 6°C, re-advancement of northern glaciers and vast portions of Europe covered with steppic grasslands. After some 1300±70 years, it ended extremely abruptly, with a global increase in precipitation and a rise in temperature of about 7°C, about 11.64 ka cal. BP (Alley 2000; Fawcett *et al.* 1997; Severinghaus *et al.* 1998; Taylor *et al.* 1997), marking the beginning of the Holocene. The Younger Dryas is a significant arid phase in the Levant, exhibiting overall decreased precipitation and lowered lake levels. A rapid increase in δ^{18}O values from speleothems in Soreq Cave document intensively dry and cool conditions (Bar-Matthews *et al.* 1999; Geyh 1994) and Lake Lisan continued to drop substantially throughout the Younger Dryas, only rebounding somewhat in the Holocene to become the Dead Sea (e.g. Bartov *et al.* 2002; 2003; 2007; Bookman *et al*. 2006).

The Preboreal period: onset of the Holocene

The end of the Younger Dryas is defined by a dramatic rise in global temperature over about 50 years. This period of rapid warming is known as the Preboreal (pollen zone IV or the earliest sub-phase of the Boreal climatic phase) and dates from Greenland ice cores place its onset at 11.4 ka cal. BP (van der Plicht *et al.* 2004). Debates about the duration (approximately 1000 years) and nature of the Boreal period (or pollen zone) hinge on differences in dating techniques (radiocarbon dating and differential responses of pollen to the climate change) from region to region. Generally associated with the Palaeolithic–Mesolithic transition in Europe, the local effects of the Preboreal in the southern Levant for early Neolithic populations remain poorly defined. A two-step warming of sea-surface temperatures dated to 11.45–11.35 ka and 11.15–11.0 ka cal. BP, respectively, was triggered by meltwater and cooled the Nordic Sea (Hald & Hagen 1998). Some researchers define a Preboreal Oscillation (PBO) characterized by 200 years, between *c.* 11.3 and 11.15 ka BP, of cool and humid conditions immediately preceding the rapid warming of the Boreal (van der Plicht *et al.* 2004).

The onset of warmer and moister conditions in the early Holocene of the Near East is marked by several lines of evidence. Speleothem isotopes from Soreq Cave in central Israel document a drop in δ^{18}O values at 10.95–9.45 ka cal. BP (Bar-Matthews *et al.* 1999), representing a significantly warmer and wetter climate than the preceding Younger Dryas. Pollen records from various marine and terrestrial locales throughout the Mediterranean indicate a marked increase in *Pistacia* and *Quercus* (at terrestrial locales) and sapropels (at marine locales), a shift that Rossignol-Strick (1999) has termed the *Pistacia* phase. A recovery of the Dead Sea, with increased lake levels, around 9.95 ka cal. BP supports a return to warm and moist climatic condition (Rosen 2007, 77). Higher water tables, terrace aggradations, and accumulation of colluvial, alluvial and spring deposits at several sites throughout the southern Levant suggest increased precipitation and overall moister climatic conditions succeeding the Younger Dryas (Cordova 2000; Gvirtzman & Wieder 2001; Goldberg 1994; Rosen 2007; Schuldenrein & Goldberg 1981).

The 8.2 ka event

Recently, archaeological attention has shifted to another, more recent climatic event. About 8.2 thousand years ago, abrupt cooling in the North Atlantic associated with changes in thermohaline circulation was apparently precipitated by a collapse of the last dome of the Laurentide Icesheet and greatly reduced precipitation in north Africa and southwest Asia (Alley *et al.* 1997; Barber *et al.* 1999; Gasse 2000; von Grafenstein *et al.* 1998; Klitgaard-Kristensen *et al.* 1998). Recent information based on several Greenland cores indicates that this drier period lasted just 160 years, from 8.2 ka cal. BP, with a central event, defined by an anomaly of one standard deviation below the previous millennium's mean oxygen-isotopic values, of only 70 years (Thomas *et al.* 2007). This dramatic cooling event was felt most strongly in the North Atlantic, where average annual temperatures dropped *c.* 5°C and a large influx of freshwater (from Lakes Agassiz and Ojibway) caused both dramatic rises in sea level and oceanic circulation changes (Barber *et al.* 1999; Roche *et al.* 2004). In the Near East, changes are less well-documented, and there is debate as to whether changes outside the North Atlantic and Europe are really related to the 8.2 ka event. However, geochemical and geomorphological cave records from the Near East indicate that temperatures dropped *c.* 1°C and conditions were generally drier in the last half of the ninth millennium cal. BP (Bar-Matthews *et al.* 1999; Frumkin *et al.* 2001). Similar dry and cool conditions were documented in Levantine pollen records by decreases in oak, pistachio and other deciduous vegetation (Rossignol-Strick 1999). The 8.2 ka event appears to coincide with the deposition of gypsum and sands indicating low water levels of 416 m below sea level for the Dead Sea (Migowski *et al.* 2006). However, it is possible that the 8.2 ka event is superimposed on a longer-term Holocene climatic fluctuation that appears to date to 8.4–8.0 ka cal. BP (Thomas *et al.*

2007, 80), and it may be this less-dramatic event that the Near Eastern climate proxies are reflecting.

Associating climatic events with culture change in the Near East

The importance of high-resolution chronological data cannot be understated, particularly regarding some of prehistory's firsts, such as sedentism, the rise of village life and social hierarchies, and the domestication of plants and animals. In the southern Levant, many of these firsts occurred sometime between 20 and 9 ka BP. However, it should be noted that some phenomena, like sedentism, will likely never be narrowed to specific points in time or place as a result of their ambiguous and debatable natures (e.g. Bar-Yosef & Belfer-Cohen 1989; Boyd 2006). As we have seen, some authors see climatic amelioration as a 'pull' that encouraged sedentism, population growth and associated cultural changes (e.g. Byrd 2005), while others see climatic deterioration, and particularly the Younger Dryas and 8.2 ka event, as 'pushes' that forced people to make tough choices, including broadening their subsistence base, investing more time or effort in their technologies, or abandoning large or sedentary settlements in favour of smaller or less-permanent ones (e.g. Bar-Yosef 2001). In either scenario, however, a change in regional climate provides the impetus for a subsequent change in local archaeological entities.

It is thus crucial that we can determine whether the posited causes are likely to have preceded the alleged consequences. Here, Bayesian analyses of groups of radiocarbon determinations from sites with secure associations with some of the major cultural changes, especially in the southern Levant, offer a means to evaluate these cause-and-effect events. As in the previous section, we focus on several major climatic events in their turn. A complete list of the dates used (or discarded) appears in Table 3.

Testing the association between climatic and cultural change

Let us return to the question of whether the global climatic events, and particularly the very rapid beginnings of the Younger Dryas and 8.2 ka event, could have contributed to the major cultural changes that archaeologists have used to identify the start of new cultural periods.

Our attempt to accomplish this makes use of Bayesian calibration and analysis tools in the BCal on-line software, available at University of Sheffield (Buck *et al.* 1999). Previous attempts to make sense of radiocarbon evidence for this period have involved ordering uncalibrated dates by their means (e.g. Garrard *et al.* 1994, 179–80), grouping the medians of the upper and lower 68 per cent confidence limits of the calibrated distributions (Bar-Yosef 2001, 8), graphing the one-sigma bars of uncalibrated determinations (Henry 1989, 116) or the 68 per cent confidence bars of the calibrated distributions (Byrd 2005, 251–2), presenting histograms of the means of uncalibrated determinations (Kozłowski 1994, 257), stacking the probability density plots of calibrated dates (Willcox 2007, 23), or cumulating the uncalibrated or calibrated date distributions, somewhat as in kernel density analysis, after rejecting outliers (Stutz 2004, 19–25). By contrast, we use groups of calibrated dates ordered by commonly used chronological models to test the hypothesis that a climatic event occurred before, during, or after the beginning or end of a cultural period.

Importantly, Bayesian methods rely on modelling (Bronk Ramsey 2008; Buck *et al.* 1992; Buck & Sahu 2000; Nicholls & Jones 2004; Sahu 2004). In this case, this requires us to make some assumptions about the chronological order of the cultural entities and the boundaries between them, which can overlap, abut, or exhibit a hiatus. Overlap is cautious and conservative in that it leads to longer periods and allows more ambiguity about the relationship between the climatic events and the cultural ones. For the data we have here, a hiatus can rarely be sustained, given the very real overlap in dates that we often find in our data, because it leads to too many logical inconsistencies in the models. In the results that follow, it has been our aim to test abutting models, because these have been the predominant models for the main chrono-cultural units in the literature. In other cases, overlaps or avoiding statements about boundaries allows us to deal with cultural entities that were probably partly contemporary, such as the Harifian and Late Natufian.

In order to make the analysis manageable, we broke the models down into smaller ones. For example, to determine the boundary between Early and Late Natufian, it was not necessary to include other groups of dates. To determine the duration of the Late Natufian, however, it was necessary to include both Early Natufian and PPNA dates. Consequently, we tended to create 'layer-cake' models with two or three chrono-cultural groups at a time.

We also 'cleaned up' the available data, using a protocol modified from Spriggs's (1989) 'chronometric hygiene' (see also Fitzpatrick 2006). First, to make the models run successfully, it was necessary to remove the most serious outliers. These showed extremely wide (>1500 years) divergence from

Table 3. *Radiocarbon determinations (uncalibrated* BP*) included and excluded from models discussed in the text, along with reasons for pooling or exclusion (dates from Aurenche* et al. *2001; Bar-Yosef & Kra 1994; Bar-Yosef 2000; Byrd 2005; Housley 1994; Stutz 2004).* bnd = burned, *ch. = charred, L Neol. = Late Neolithic, MEP = Middle Epipalaeolithic, n.d. = no data, p = posterior outlier probability.*

Site	Lab no.	BP	±	Material	*p*	Reason for rejection
Pottery Neolithic						
'Ain Rahub	TU-47	7480	90			only one date
Byblos	GrN-1544	7360	80	charcoal		uncertain relation to Yarmoukian
	W-627	6650	200	charcoal		major outlier
Jebel Abu Thawwab	GrN-15192	5540	110			only one date
Munhata 2b	Ly-4927	7330	70	charcoal	0.04	
	M-1792	7370	400	charcoal		large error
Nahal Qana Cave	RT-1544	7054	78	charcoal	0.05	
	RT-861D	6980	180	charcoal	0.04	
Sha'ar Hagolan	OxA-7884	6980	100	charcoal	0.06	
	OxA-7885	7270	80	charcoal	0.04	
	OxA-7917	7410	50	charcoal	0.04	
	OxA-7918	7465	50	charcoal	0.03	
	OxA-7919	7495	50	charcoal	0.04	
	OxA-7920	7245	50	charcoal	0.04	
	OxA-9417	7285	45		0.04	
Tabaqat al-Bûma	TO-1407	7800	70	bone	0.97	
	TO-7665	7350	160	bone	0.03	
	TO-7666	7830	670	bone		large error
Pre-Pottery Neolithic C (PPNC)						
'Ain Ghazal	AA-1165	7820	240	charcoal	0.03	
	AA-1166	8950	350	charcoal	1.00	
	AA-5196	7670	100	charcoal	0.05	
	AA-5198	7960	75	charcoal	0.03	
	AA-5201	8235	70	wood	0.04	
	AA-5202	8310	70	wood	0.05	
	AA-5203	8200	75	wood		residual, from flot
	AA-5205	7895	95	charcoal		uncertain PPNC/Yarm
	GrN-17494	7825	65	charcoal	0.05	
	GrN-17495	7915	95	charcoal	0.03	
Ashkelon	OxA-7881	7630	65	soil/ash		material
	OxA-7882	8000	110	soil/ash		material
	OxA-7883	7990	90	soil/ash		material
	OxA-7915	7995	50	soil/ash		material
	OxA-7916	7935	50	soil/ash		material
Atlit-Yam	Pta-3950	8000	90	charcoal		PPNC?
	RT-707	8140	120	charcoal		PPNC?
	RT-944A	7670	85	barley		pool with next
	RT-944C	7610	90			pool with last
Tel 'Ali	OxA-7886	7975	70	charcoal	0.03	
	OxA-7921	7940	50	charcoal	0.03	
	OxA-7922	135	35	charcoal		major outlier
	OxA-7923	6030	45	charcoal		major outlier
Wadi Shu'eib	Bta-35083	8760	280	charcoal	0.85	
	Bta-35085	8120	280	charcoal	0.02	
Yiftahel	RT-702b	7460	210	charcoal		only one date
Late Pre-Pottery Neolithic B (PPNB)						
'Ain Ghazal	AA-5197	8090	75	charcoal	0	
	AA-5199	8270	75	charcoal	0.03	
	AA-5206	7990	80	peas	0.03	
	AA-25425	8080	65	charcoal	0.06	
	AA-25426	8205	65	charcoal	0.04	
	AA-25427	7910	60	charcoal	0.03	
	AA-25428	7910	60	charcoal	0.03	
	AA-25429	7980	55	seeds	0.03	
	GrN-12971	8460	90	charcoal	0	

Site	Lab no.	BP	±	Material	*p*	Reason for rejection
'Ain Ghazal	GrN-12972	8165	50	charcoal	0.04	
	GrN-14259	8310	230	charcoal	0	
	KN-4877	8208	77	charcoal	0	
	KN-4878	8253	786	charcoal	0	
	KN-4879	7952	77	charcoal	0.03	
	KN-4880	7726	73	seeds	0.16	
	KN-4881	7880	82	seeds	0.03	
	KN-4882	7809	74	seeds	0.06	
	KN-4883	8230	76	charcoal	0.03	
	KN-4884	7857	74	seeds		uncertain LPPNB/PPNC
	KN-4885	7939	87	charcoal	0.03	
	KN-5054	8236	81	charcoal	0.03	
	KN-5055	8162	62	charcoal	0.05	
	KN-5056	8236	81	charcoal	0.09	
Azraq 31	OxA-870	8350	120	charcoal		
	OxA-871	1280	90	bone		major outlier
	OxA-2412	8275	80	charcoal		
Ba'ja	BIN-5035	7887	43	charcoal	0.04	
	BIN-5036	7910	44	charcoal	0.03	
	BIN-5123	8100	33	?	0.09	
Basta	GrN-14538	8155	50	charcoal		only one date
Dhuweila	BM-2349	8190	60	charcoal	0.04	
	OxA-1637	8350	100	charcoal	0.04	
Khirbet Hammam	GrN-26146	8120	60	charcoal	0.06	
	GrN-26147	8370	40	charcoal	0.05	
Wadi Shu'eib	Bta-35080	10,220	250	charcoal		residual/ old wood
	Bta-35084	7660	210	charcoal	0.06	
	Bta-35086	8500	160	charcoal	0.06	
	Bta-35087	9100	140	charcoal	0	
	Bta-35088	7810	340	charcoal	0.03	
Middle Pre-Pottery Neolithic B						
'Ain Ghazal	AA-1164	9100	140	charcoal		
	AA-1167	8570	180	charcoal	0	
	AA-5200	8780	70	charcoal	0	
	AA-25037	8775	75	charcoal	0	
	Bta-19906	8970	150	charcoal	0	
	Bta-19907	8520	110	charcoal	0	
	GrN-12959	9000	90	charcoal	0	
	GrN-12960	9030	80	charcoal	0	
	GrN-12961	8930	60	charcoal	0	
	GrN-12962	8680	190	charcoal	0	
	GrN-12963	8970	80	charcoal	0	
	GrN-12964	8970	80	charcoal	0	
	GrN-12965	9050	80	charcoal	0	
	GrN-12966	9200	110	charcoal	0	
	GrN-12967	8930	80	charcoal	0	
	GrN-12968	8970	110	charcoal	0	
	GrN-12969	8810	80	charcoal	0	
	GrN-12970	8650	200	charcoal	0	
	GrN-14257	8720	80	charcoal	0	
	GrN-14258	8810	160	peas	0	
	GrN-14538	8155	50	charcoal	0	
	KN-5188	8515	50	charcoal		MPPNB/ LPPNB
	OxA-1472	8660	80	charcoal	0	
	OxA-1473	8700	80	charcoal	0	
	UCR-1718	7590	810	charcoal		large error
	UCR-1721	8620	320	charcoal	0	
	UCR-1722	8070	230	charcoal	0	

Table 3. *(cont.)*

Site	Lab no.	BP	±	Material	*p*	Reason for rejection
Ghwair I	DRI-3251	8806	52	charcoal	0	
	DRI-3252	8880	117	charcoal	0	
	DRI-3253	9027	116	charcoal	0	
	DRI-3254	8659	178	charcoal	0	
	DRI-3255	8755	311	charcoal	0	
	DRI-3256	8754	52	charcoal	0	
	Hd-17219	8812	61	charcoal	0	
	Hd-17220	8627	46	charcoal	0	
	Hd-17221	8528	89	charcoal	0	
Shkarat Msaied	WK-15159	8977	60	?	0	
	WK-15160	9144	55	?	0	
Wadi Shu'eib	Bta-35081	8600	100	charcoal	0	
	Bta-35082	8670	210	charcoal	0	
	Bta-35089	9160	190	charcoal	0	
Pre-Pottery Neolithic A (PPNA)						
Abu Madi	Pta-2699	10,110	100	charcoal	0.03	
	Pta-4551	9790	100	charcoal	0.07	
	Pta-4552	9920	80	charcoal	0.04	
	Pta-4568	9970	120	charcoal	0.03	
	Pta-4572	9790	100	charcoal	0.07	
	Pta-4577	9870	100	charcoal	0.05	
	Pta-4580	9800	80	charcoal	0.09	
Dhra'	AA-38141	10,031	69	charcoal	0.03	
	AA-38142	10,059	73	charcoal	0.03	
	AA-38143	9984	67	charcoal	0.03	
	AA-38144	10,000	68	charcoal	0.03	
	ISGS-2898	9960	110	charcoal	0.03	
	ISGS-3266	8519	170	charcoal	0.99	
	ISGS-3277	9610	170	charcoal	0.03	
	ISGS-3278	9940	180	charcoal	0.03	
	ISGS-A0246	9913	59	charcoal	0.05	
	ISGS-A0248	9835	65	charcoal	0.09	
Gesher	Pta-4553	10,020	100	charcoal	0.03	
	Pta-4595	9870	80	charcoal	0.06	
	RT-814A	10,590	140	charcoal	0.81	
	RT-814B	10,390	220	charcoal	0.08	
	RT-868A	9820	140	charcoal	0.05	
	RT-868B	9790	140	charcoal	0.05	
Gilgal	Pta-4583	9830	80	charcoal	0.08	
	Pta-4585	9710	70	charcoal	0.05	
	Pta-4588	9920	70	charcoal	0.05	
	RT-777A	9950	150	charcoal	0.03	
	RT-777B	9900	220	charcoal	0.03	
Hatoula	GifA-91138	8890	120	bone	0.96	
	GifA-91360	10,030	140	bone	0.03	
Iraq ad-Dubb	AA-38140	9592	64	wood	0.03	
	AA-38145	9941	72	charcoal	0.04	
	OxA-17077	9959	100	charcoal	0.03	
	OxA-2567	9950	100	charcoal	0.04	
Jericho	BM-105	10,250	200	charcoal		old assay
	BM-106	10,300	200	charcoal		old assay
	BM-110	10,180	200	charcoal		old assay
	BM-250	10,300	500	charcoal		old assay
	BM-251	9390	150	charcoal		old assay
	BM-252	9320	150	charcoal		old assay
	BM-1321	9226	76	charcoal		old assay
	BM-1322	9376	85	charcoal		old assay
	BM-1323	9382	83	charcoal		old assay
	BM-1324	9427	83	charcoal		old assay
	BM-1326	9225	217	charcoal		old assay
	BM-1327	9551	63	charcoal		old assay
	BM-1407	11,086	90	charcoal		old assay
	BM-1787	9280	100	charcoal		old assay

Site	Lab no.	BP	±	Material	*p*	Reason for rejection
Jericho	BM-1789	9200	70	charcoal		old assay
	GL-39	8800	160	charcoal		old assay
	GL-40	8690	150	charcoal		old assay
	GL-43	8895	150	charcoal		old assay
	GL-46	7300	200	charcoal		old assay
	P-377	9582	89	charcoal		old assay
	P-378	9775	110	charcoal		old assay
	P-379	9695	84	charcoal		old assay
Netiv Hagdud	OxA-744	9700	150	barley	0.04	
	Pta-4555	9750	90	charcoal	0.06	
	Pta-4556	9660	70	charcoal	0.04	
	Pta-4557	9780	90	charcoal	0	
	Pta-4590	9700	80	charcoal	0.05	
	RT-502A	9790	380	charcoal	0.02	
	RT-502C	10,180	300	charcoal	0.03	
	RT-762A	9680	140	charcoal	0.04	
	RT-762B	9600	170	charcoal	0.03	
	RT-762C	9970	150	charcoal	0.03	
	RT-762D	9400	180	charcoal	0.04	
	RT-762F	9780	150	charcoal	0	
Sefunim	KN-I 336	9120	85	charcoal		only one date
Zahrat adh-Dhra'	OZE-605	9490	50	charcoal	0.05	
	OZE-606	9440	50	charcoal	0.05	
	OZE-607	9470	50	charcoal	0.05	
	Wk-9444	9323	59	charcoal	0.12	
	Wk-9445	9552	59	charcoal	0.03	
	Wk-9447	9603	59	charcoal	0.03	
	Wk-9568	9623	91	charcoal	0.03	
	Wk-9570	9528	61	charcoal	0.03	
	Wk-9633	9635	59	charcoal	0.03	
PPNA—Khiamian						
Hatoula	GifA-91139	10,170	120	bone	0.04	
Salibiya 9	Pta-3008	12,300	470	charcoal		large error
	Pta-3385	18,500	140	charcoal		only one date, major outlier
Wadi Faynan 16	Bta-120204	13,010	50	snail shell		on shell
	Bta-120205	9690	50	charcoal	0.05	
	Bta-120206	9420	50	charcoal	0.06	
	Bta-120207	9400	60	charcoal	0.06	
	Bta-120208	12,830	50	snail shell		on shell
	Bta-120209	11,830	50	snail shell		on shell
	Bta-120210	10,220	60	charcoal	0.34	
	Bta-120211	9890	50	charcoal	0.06	
Late/Final Natufian						
Hilazon Tachtit	RT-3760	10,750	50	charcoal	0.06	
	RT-4592	10,530	60	charcoal	0.04	
	RT-4593	10,770	65	charcoal	0.07	
Iraq ad-Dubb	GX-17077	11,145	120	charcoal	0.04	
	GX-17398	11,175	400	charcoal		large error
	GX-17399	10,785	285	charcoal	0.04	
Jericho	BM-1407	11,086	90	charcoal		old assay
	GL-69	9850	240	charcoal		old assay
	GL-70	10,800	180	charcoal		old assay
	GL-72	9800	240	charcoal		old assay
	P-376	11,166	107	charcoal		old assay
Mallaha	GifA-99091	460	60	charcoal		major outlier
	GifA-99332	10,530	100	charcoal	0.03	
	GifA-1004300	10,540	90	charcoal	0.04	
Nahal Oren	BM-764	10,046	318	collagen		pos. mixed/ disturbed
	OxA-389	2940	120	wheat		pos. mixed/ disturbed

Table 3. *(cont.)*

Site	Lab no.	BP	±	Material	*p*	Reason for rejection
Late/Final Natufian *(cont.)*						
Nahal Oren *(cont.)*	OxA-390	33,000	0	wheat		pos. mixed/ disturbed
	OxA-395	3100	130	wheat		pos. mixed/ disturbed
	OxA-396	6650	190	wheat		pos. mixed/ disturbed
Rakefet Cave	I-7030	10,580	140	bone	0.04	
	I-7032	10,980	260	bone	0.05	
Rosh Horesha	I-5496	13,090	200	charcoal	1.00	
	SMU-10	10,880	280	charcoal	0.05	
	SMU-90	10,490	430	charcoal		large error
Saflulim	OxA-2136	10,930	130	charcoal	0.06	
	OxA-2869	11,150	100	charcoal	0.04	
al-Wad Terrace	UCLA-	9795	600	bone		large error
Wadi Mataha	CAMS-55897	11,200	50	collagen		only one date
Harifian						
Abu Salem	I-5498	9970	150	charcoal	0.07	
	I-5499	10,230	150	charcoal	0.03	
	I-5500	10,230	150	charcoal	0.03	
	Pta-3080	11,660	90	charcoal	0.85	
	Pta-3286	10,420	100	charcoal	0.04	
	Pta-3289	10,300	100	charcoal	0.04	
	Pta-3290	10,340	90	charcoal	0.04	
	Pta-3291	10,140	80	charcoal	0.04	
	Pta-3292	10,550	90	charcoal	0.04	
	Pta-3293	10,420	100	charcoal	0.03	
Maaleh Ramon E	Pta-3371	10,530	100	charcoal	0.04	
	Pta-3483	10,430	80	charcoal	0.04	
Maaleh Ramon W	Pta-3687	10,400	100	charcoal	0.03	
	RT-1068N	10,000	200	charcoal	0.05	
Nahal Sekher 6	OxA-2137	12,200	150	charcoal		major outlier
	RT-1032N	9460	130	?		only one date
Ramat Harif	Pta-3001	10,300	100	charcoal	0.04	
	Pta-3009	10,500	100	charcoal	0.04	
	Pta-3284	10,380	100	charcoal	0.03	
	Pta-3285	10,390	100	charcoal	0.03	
	Pta-3286	10,100	100	charcoal	0.04	
	Pta-3288	10,250	100	charcoal	0.04	
Early Natufian						
Beidha	AA-1463	12,910	250	charcoal	0.10	
	AA-1464	12,130	190	charcoal	0.05	
	AA-1465	12,450	170	charcoal	0.03	
Hatoula	GifA-91141	11,020	180	bone		
Hayonim Cave B	OxA-742	12,360	160	grain	0.03	
	OxA-743	12,010	180	grain	0.05	
Hayonim Terrace	OxA-1899	10,000	100	barley		poss. L Neol.
	OxA-2569	11,220	110	ch. bone		poss. L Neol.
	OxA-2570	11,820	120	ch. bone		poss. L Neol.
	OxA-2572	11,460	110	ch. bone		poss. L Neol.
	OxA-2573	10,100	160	ch. bone		poss. L Neol.
	OxA-2975	11,790	120	ch. bone		poss. L Neol.
	OxA-2977	11,720	120	ch. bone		poss. L Neol.
	SMU-231	11,920	90	charcoal		poss. L Neol.
Kebara	OxA-2798	12,470	180	bone		only one date
	UCLA-	9200	400	bone		large error
Mallaha	Ly-1660	11,590	540	bone		large error
	Ly-1661	11,740	570	bone		large error
	Ly-1662	11,310	880	bone		large error
Salibiya I	RT-505A	11,530	1550	charcoal		large error
Sefunim	Hv-4074	12,250	65	charcoal	0.06	
	Pta-2827	10,960	390	collagen	0.35	

Site	Lab no.	BP	±	Material	*p*	Reason for rejection
al-Wad Cave	Pta-1367	10,680	190	charcoal	0.67	
	Pta-1368	12,950	200	charcoal	0.19	
	Pta-5435	12,620	110	charcoal	0.04	
	UCLA-	11,920	660	bone		large error
al-Wad Terrace	UCLA-	11,475	600	bone		large error
	UCLA-	11,920	660	bone		large error
Wadi Hammeh 27	OxA-393	11,920	150	ch. seeds	0.05	
	OxA-394	12,200	160	ch. seeds	0.04	
	OxA-507	11,950	160	ch. seeds	0.05	
Wadi Judayid	SM-803	12,784	659	charcoal		large error
	SM-805	12,090	800	charcoal		large error
	SM-806	12,750	1000	charcoal		large error
Mushabian						
Mushabi XIV	MC-992	13,260	200	charcoal	0.04	
	Pta-2157	12,700	90	charcoal	0.06	
	QC-202	12,900	235	charcoal	0.05	
	RT-473A	13,800	150	charcoal	0.05	
	SMU-171	12,990	110	charcoal	0.05	
	SMU-225	13,800	130	charcoal	0.05	
Shunera 4	Pta-3003	11,000	140	charcoal	0.23	
	Pta-3690	11,700	140	charcoal	0.04	
Tor Hamar C	ETH-806	12,320	95	?	0.04	
	SMU-1399	12,680	320	charcoal	0.04	
Geometric Kebaran/Middle Epipalaeolithic						
Arabi I	SMU-2373	14,500	190	charcoal		only one date
Azraq 17 (lower)	OxA-869	13,260	200	charcoal		only one date
G. Mishraq J504 (Hisma)	SMU-905	11,985	110	charcoal		only one date, Early Hamran?
Jilat 10	OxA-520	14,790	200	charcoal	0.09	
	OxA-918	12,700	300	charcoal	0.04	
	OxA-1000	13,120	180	charcoal	0.03	
Jilat 22 (lower)	OxA-2409	13,490	110	charcoal	0.06	
	OxA-2410	13,490	110	charcoal	0.06	
Jilat 22 (middle)	OxA-1771	13,040	180	charcoal	0.03	
	OxA-1772	12,840	140	charcoal	0.05	
Jilat 22 (upper)	OxA-1770	11,920	180	charcoal	0	
Julat 8	OxA-521	13,310	120	charcoal		only one date
	OxA-636	10,540	160	charcoal		major outlier
Kebara	OxA-2799	14,500	250	bone	0	
Kharaneh IV D	GrN-15193	14,570	350	charcoal	0.04	
	KN-4192	15,200	450	charcoal		large error
	KN-4193	15,700	160	charcoal	0.99	
	Q-3072	9840	120	bone		major outlier
	Q-3073	10,620	125	bone		major outlier
Laguma North	Pta-2730	12,900	500	charcoal		large error, only one date
Mushabi XIV	MC-992	13,690	150	charcoal	0.08	
	QC-201	13,750	285	charcoal	0.06	
	RT-447d	13,830	490	charcoal		large error
	RT-473b	14,100	100	charcoal	0.04	
	SMU-226	14,330	120	charcoal	0.03	
Mushabi XVI	RT-447c	13,060	220	charcoal	0.03	
Mushabi XVII	SMU-217	13,930	110	charcoal	0.05	
	SMU-661	14,170	480	charcoal		large error
Nahal Neqarot	OxA-4795	14,760	110	charcoal		only one date
Nahal Oren	UCLA-1776a	15800	300	bnd bone		only one date
Nahal Rut 8	RT-1071	6570	180	charcoal		only one date, major outlier

Table 3. *(cont.)*

Site	Lab no.	BP	±	Material	*p*	Reason for rejection
Nahal Zin D5	I-5497	13,170	230	charcoal		only one date
	SMU-7	18,840	680	charcoal		large error
	Tx-1121	15,820	1730	charcoal		large error
Neve David	OxA-859	13,400	180	ch. bone	0.04	
	OxA-892	12,610	130	ch. bone	0.09	
Qadesh Barnea 8	Pta-2158	14,130	160	charcoal	0.04	
	Pta-2159	13,390	120	charcoal	0.05	
Shunera III	Pta-3696	5210	70	ostrich eggshell		material, only one date
Umm et-Tlel	Bta-69598	14,650	70	?		out of region
	Bta-79221	14,490	200	?		out of region
	Gif-93129	14,700	1130	?		large error, out of region
Uyyun al-Hammam	OxA-20973	13,650	50	bone	0.05	
	OxA-20974	13,720	55	bone	0.05	
	OxA-20977	13,785	60	bone	0.05	
	OxA-20978	13,685	55	bone	0.05	
	TO-11704	12,400	180	human bone	0.14	
Wadi Fazael 10, 11	OxA-2870	15,450	130	charcoal		only one date
Wadi Hammeh 50	ANU-8472	14,500	100	mela-nopsis		material, assignment based on date
	ANU-8473	15,390	180	mela-nopsis		material, assignment based on date
	ANU-8474	15,180	140	mela-nopsis		material, assignment based on date
	ANU-8475	14,490	120	mela-nopsis		material, assignment based on date
	ANU-8476	15,340	170	mela-nopsis		material, assignment based on date
Wadi Hammeh 51	ANU-8471	16,820	340	mela-nopsis		material, assignment based on date
Wadi Mataha	CAMS-55899	14,100	130	collagen		only one date
Kebaran/Early Epipalaeolithic						
Jilat 6 (upper)	AA-5491	16,575	120	charcoal	0	
	AA-5492	15,470	130	charcoal	0	
	AA-5493	16,695	120	charcoal	0	
	AA-5494	16,700	140	charcoal	0	
	OxA-524	15,520	200	charcoal	0	
	OxA-525	16,010	200	charcoal	0	
Nahal Oren	UCLA-1776a	15,800	300	bnd bone		
	UCLA-1776b	16,880	340	bnd bone	0	
	UCLA-1776c	18,250	320	bnd bone	0	
Ohalo II	OxA-2564	19,680	180	barley	0	
	OxA-2565	19,310	190	barley	0	
	OxA-2566	19,110	390	barley	0	
	Pta-5374	19,400	220		0	
	RT-1244	18,360	230	charcoal	0	
	RT-1246	15,550	130	charcoal	0	
	RT-1248	19,800	360	charcoal	0	
	RT-1251	19,000	190	charcoal	0	
	RT-1297	17,500	200	charcoal	0	
	RT-1342	19,500	170	charcoal	0	
	RT-1343	18,600	220	charcoal	0	
	RT-1358	18,760	180	charcoal	0	
	RT-1616	19,590	150	pistachio	0	
	RT-1617	18,700	180	poplar	0	
	RT-1618	19,220	180	*Tamarix*	0	
	RT-1619	19,860	190	*Tamarix*	0	
	RT-1620	20,830	180	charcoal	0.07	
	RT-1621	20,070	270	*Rhamnus*	0	
	RT-1622	20,190	170	pistachio	0	
	RT-1623	18,210	240	*Tamarix*	0	
	RT-1624	20,840	290	charcoal	0	
	RT-3537	19,550	250		0	
	RT-3539	19,940	210		0	
Rakefet	I-6865	18,910	300	bone	0	
	I-7031	15,460	200	?	0	
Tabaqat al-Bûma	TO-989	13,110	130	bone		major outlier
	TO-991	14,850	160	bone		major outlier
Tor-at-Tariq	Bta-57900	16,670	270	charcoal	0	
	UA-4390	16,570	380	charcoal	0	
	UA-4392	15,580	250	charcoal	0	
	UA-4293	16,790	340	charcoal	0	
Urkan ar-Rub IIa	OxA-1503	14,440	150	charcoal	0	
	OxA-2835	15,190	130	charcoal	0	
	OxA-2836	14,860	130	charcoal	0.03	
	OxA-2837	14,650	120	charcoal	0	
	OxA-2838	15,050	160	charcoal	0	
	OxA-2839	14,800	130	charcoal	0	
	OxA-2840	14,880	120	charcoal	0	
	OxA-2841	15,730	130	charcoal	0	
	OxA-2842	14,980	200		0	
Uwaynid 14 (upper)	OxA-864	19,800	350		0	
	OxA-865	18,900	250		0	
	OxA-868	19,500	250		0	
Uwaynid 14 (middle)	OxA-866	18,400	250		0	

expected values, likelihood of contamination from lower or higher strata (i.e. single-period sites have low prior probability of such contamination, while an unusual date that falls well within the range of dates from a higher or lower stratum has a high probability of being intrusive or residual), or both (see Table 3). We also omitted a few dates because they were on shell or soil, but we did not go so far as to reject charcoal, since this would have eliminated 90 per cent of our data base. As a result, there is a possibility that some of the dates reflect the 'old-wood' problem, potentially indicating the age of tree-rings that are decades, or even centuries, older than the cutting date or cultural use. On present evidence, however, we have no unbiased basis for eliminating charcoal samples that might exhibit a dating disjunction (Dean 1978), and subjectively eliminating those that do not fit our prior expectations would be tautological. In other cases, we rejected radiocarbon determinations because their association with the relevant period was uncertain, the statistical error on the determination was 400 radiocarbon years or greater, or the

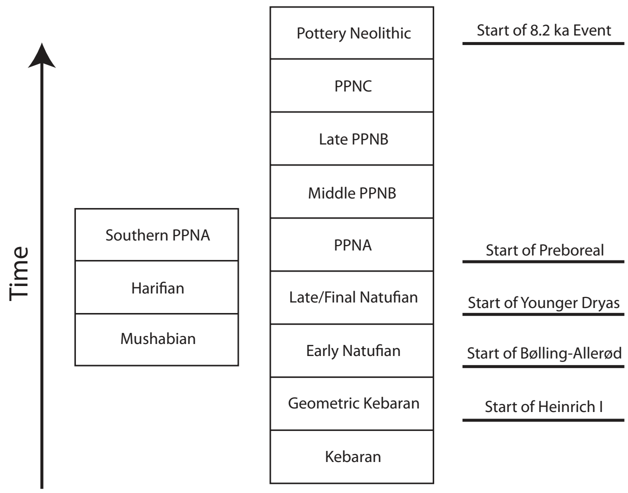

Figure 2. *Example model of 'groups' of dates used in the analysis, with Kebaran, Geometric Kebaran, Early Natufian, Late Natufian, PPNA, Middle PPNB, Late PPNB, PPNC and Pottery Neolithic (Yarmoukian) abutting, and Mushabian, Harifian and southern PPNA abutting but with no predefined relationships to the other entities in the model. To the right are several 'floating parameters' whose relationships to the other entities we tested. Note that dates used for 'southern PPNA' are also included within the 'PPNA' group.*

Table 4. *Estimated dates of major transition 'events' in the late Pleistocene and early Holocene of the southern Levant. The Early PPNB is not included in this model because of its uncertain status in the southern Levant. The PPNC onset is subjectively estimated because all attempts to run abutting models for the LPPNB/PPNC boundary suffered from high dependence. It cannot be considered a reliable estimate. *The Early/Late Natufian boundary shown is for a model including PPNA, and would be later otherwise.*

Culture/Period	Date of onset (68% confidence, ka cal. BP)	Date of onset (95% confidence, ka cal. BP)
Wadi Rabah	7.8–7.7	7.9–7.6
Yarmoukian	8.45–8.36	8.52–8.3
PPNC	9.0–8.7?	9.0–8.7?
Late PPNB	9.53–9.45	9.56–9.4
Middle PPNB	10.45–10.3	10.54–10.26
PPNA	11.9–11.7	12.1–11.6
Late Natufian	13.58–13.04*	13.74–12.95*
Early Natufian	15.08–14.74	15.37–14.57
Geometric Kebaran	17.89–17.66	18.0–17.5

radiocarbon assay itself was suspect. For example, some samples from Wadi al-Hammeh, where diagnostic lithics were lacking, were assigned to periods solely on the basis of their radiocarbon dates (Edwards *et al.* 1996; Edwards 2001); consequently, including these dates would be tautological. And, while large statistical errors do not in themselves cause radiocarbon determinations to be inaccurate (*contra* Byrd 2005, 245) — they have poor precision but not bias — such imprecise dates do not help us arrive at precise estimates of the dates for events of interest. Finally, dates obtained from very old radiocarbon assays, when the radiocarbon method was not as reliable, were omitted (e.g. Jericho). Table 3 shows which dates were rejected and for what reason, as well as the posterior outlier probabilities for the determinations we retained.

We then evaluated all remaining radiocarbon determinations by assigning each a prior probability of 0.05 of being an outlier (or higher for a very few cases that diverged many centuries from expectation). In contrast to rejecting statistical outliers, the BCal software which we use simply weights the determinations by their outlier probabilities so that a calibrated date with a posterior probability of 0.2 of being an outlier only contributes 80 per cent weight to the analysis. However, one with a posterior probability of 1.0 of being an outlier is effectively excluded.

It is also important to recognize that the results of Bayesian analyses are always provisional. Different runs of the same model can yield somewhat different results, and we also expect results to change as new information accumulates, including changes to the calibration curve itself, as mentioned below. In order to ensure that our results are reasonably reproducible, we have run each of the final models at least three separate times, only changing the seed for the random number generator. Although we usually report the results from only one of these runs, we only use results when all of the runs show closely similar results. Despite these precautions, none of the dates on cultural entities provided below should be considered final or definitive; they are only plausible dates in the light of the evidence we used and given the assumptions we made.

Analysis of available dates (Table 3) with the models shown in Figure 2 allows us to estimate the dates of the boundaries between periods (assuming abutting periods). The results, with a variety of assumptions, appear in Table 4 and Figure 3. To simplify, we round off the calibrated dates to the nearest decade and report the lowest and highest dates for the 68 per cent confidence intervals (ignoring gaps that occur in multi-modal density plots).

Did the Heinrich 1 cold event occur at or slightly before the onset of the Geometric Kebaran?

Occurring about 16.8–16.5 ka, the H1 event is purported to coincide with the cultural changes associated with the Geometric Kebaran, in particular the expan-

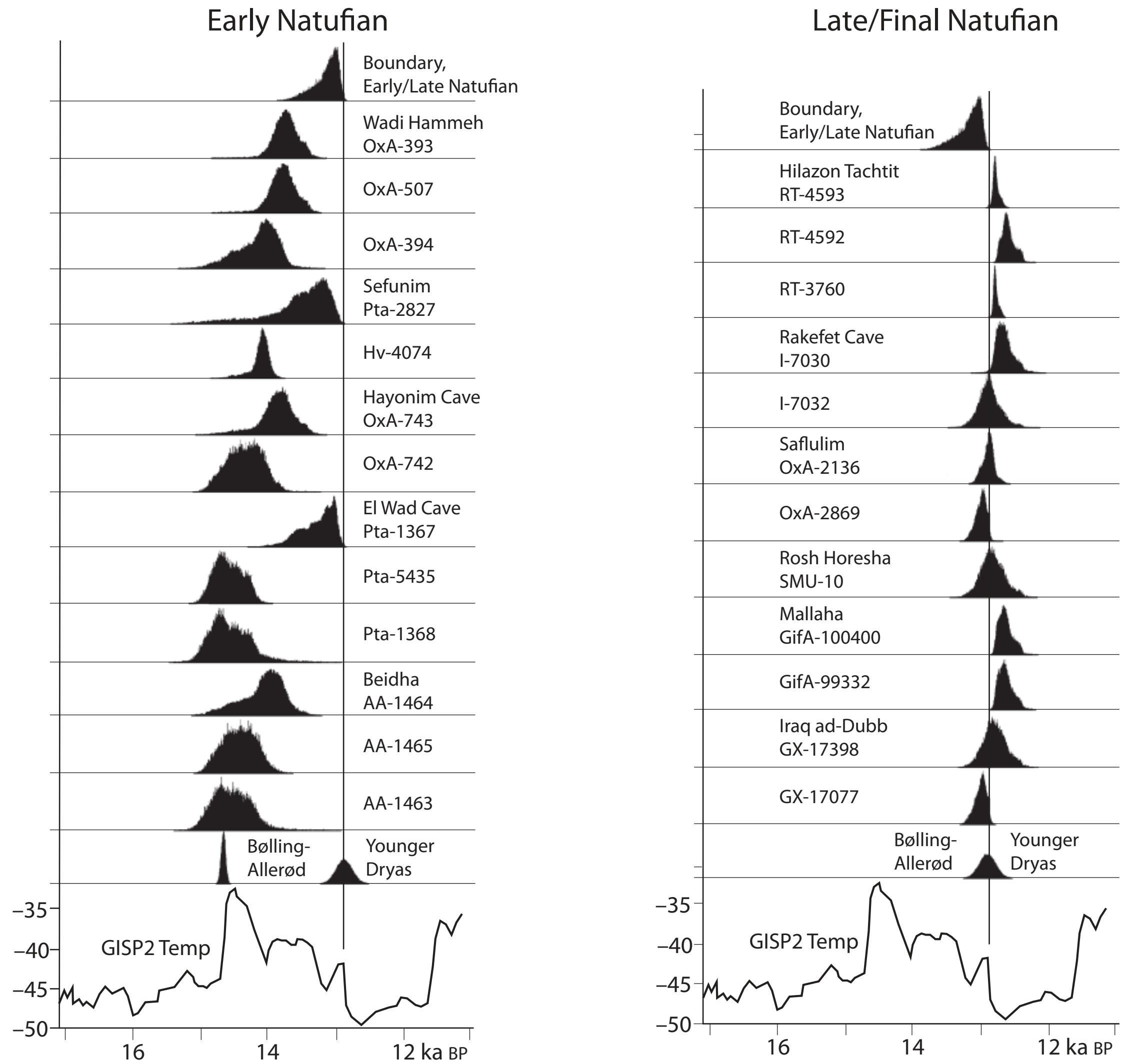

Figure 3. *High-probability density (HPD) regions for the calibrations of determinations for Early Natufian and Late/Final Natufian samples, shown with the HPD regions for the boundary between the Early and Late Natufian (top), and the beginning of the Bølling-Allerød and the Younger Dryas, and the temperature curve for the GISP2 core (last after Johnsen* et al. *2001). Ticks on the y-axis of the HPD regions indicate probability densities of 0 and 0.001 per decade, or (bottom) degrees Celsius. Note that all the HPD graphs are for models that are constrained by the order of the 'groups,' and are thus narrower than for ordinary calibrations, and the Early/Late Natufian boundary is from a model that includes PPNA.*

sion of these groups into previously arid zones to the east and south, resulting in a much larger geographical distribution than preceding Kebaran groups (Goring-Morris *et al.* 2009). Our analyses, based on an abutting model of the Kebaran and Geometric Kebaran, show that the latter began about 17.89–17.66 ka cal. BP, preceding the Heinrich 1 event by 795–1145 years (at 68 per cent confidence). The probability that the Heinrich 1 event preceded the beginning of Geometric Kebaran, given this simple 'layer-cake' model, is thus less than 0.0005.

What is the relationship between the Bølling-Allerød and the onset of the Natufian?

Several archaeologists have noted the likely association of this warm and wet phase with larger, more sedentary campsites in either the Geometric Kebaran or Early Natufian (Byrd 2005; Maher 2005; Rosen 2007). Assuming that the rapid Bølling warming began *c.* 14.67±0.035 ka cal. BP, we can easily reject the hypothesis that it was responsible for the cultural changes that herald the Geometric Kebaran (see above), but still need to evaluate the hypothesis that it triggered the Early Natufian. As some authors have already noted (e.g. Bar-Yosef 2000; Byrd 2005, 245; Stutz 2004; Grosman & Belfer-Cohen 2002), this event appears close to the beginning of Early Natufian. Meanwhile, geomorphological analyses at Geometric Kebaran sites suggest that at least many of them were occupied during a period of surface stability and pedogenesis (Cordova *et al.* 2005; Goldberg 1981; Goldberg & Bar-Yosef 1982; Goodfriend & Magaritz 1988; Maher 2005), which is suggestive of the possibility that the Bølling began before the end of the Geometric Kebaran. Our analyses here confirm previous suggestions that the Early Natufian began close to the beginning of the Bølling-Allerød, at about 15.08–14.74 ka cal. BP (68 per cent confidence), but slightly preceded it. Even the latest estimates for the Geometric Kebaran in an abutting model indicate that the Bølling-Allerød began far too late to be implicated in the emergence of the Geometric Kebaran, or even to have encouraged larger, more sedentary Geometric Kebaran camps, toward the end of the period. The probability that the Bølling-Allerød began before the emergence of the Early Natufian, according to the abutting model, is only about 0.09. Our analysis indicates that the Bølling-Allerød began 60–410 years (at 68 per cent confidence) after the beginning of Early Natufian. Thus it would seem unlikely that the former was a necessary precondition for the latter.

Is the Younger Dryas associated with the Mushabian, the Late Natufian or the Harifian?

As we noted above, many archaeologists have argued that this sharp deterioration in climatic conditions may have precipitated major restructuring of Natufian social and economic systems (Bar-Yosef 2001, 16–17; Belfer-Cohen & Bar-Yosef 2000; Byrd 2005, 260; McCorriston & Hole 1991; Valla 1995; Wright 1994). Specifically, many of these authors make an implicit or explicit association between resource stress caused by the Younger Dryas and an increase in mobility associated with the beginning of the Late Natufian (e.g. Belfer-Cohen & Bar-Yosef 2000).

The Bayesian analyses contribute to an evaluation of the hypothesized association between the Younger Dryas, which we estimated as beginning 12.9±0.12 ka cal. BP (Severinghaus *et al.* 1998), and the Late Natufian. Our original results, which placed the most likely boundary between Early and Late Natufian at 13.22–12.97 ka cal. BP on the basis of the 2004 calibration curve, indicated a high probability of 0.93 that the Younger Dryas event began after the Late Natufian had begun, and with a lag time of some 53–388 years (see also Stutz 2004). However, the 2009 calibration curve became available shortly before we completed this article, and re-running our models with the new curves led, in this instance, at 68 per cent confidence to an Early/Late Natufian boundary about 13.58–13.04 ka cal. BP, some 230–680 years before the Younger Dryas began, and leaving a probability of only 0.04 that the Younger Dryas began before the Late Natufian. However, we must note some difficulty with convergence in this case, as these results come from a model constrained by both Early Natufian and PPNA dates; a model omitting the PPNA dates yields a result very close to the beginning of Younger Dryas, but with a slightly greater probability of being earlier than the latter. Overall, however, we would argue that the more complete, former model is more realistic.

Our models indicate that it is easier to implicate the Younger Dryas in the demise of the Mushabian. This culture, which exploited the dry southern portions of the Levant, has dates that indicate that it came to an end around 12.85–12.68 ka cal. BP, using a model in which Mushabian, Harifian and the most southerly PPNA sites represent abutting periods. For the purposes of this model, we included PPNA dates from Abu Madi, Tor Hamar, Dhra‘, Zahrat adh- Dhra‘, and Wadi Faynan 16. This is extremely close to the Younger Dryas rapid cooling (*contra* the results of Stutz 2004; 2009, 489), indicating that the onset of Younger Dryas took place anywhere from 250 years before to 33 years after the end of the Mushabian, at 68 per cent confidence. Our models indicate a higher probability (0.71) that the Mushabian ended after the Younger Dryas cooling than before it, making it plausible that Younger Dryas desiccation was at least partly responsible.

This of course has implications for the Harifian, since we here used abutting models. Several publications, including Stutz (2004, 15), suggest that the Harifian represents an arid-land adaptation during this period. As just noted, there is quite a good correspondence between the Mushabian/Harifian boundary and the Younger Dryas, with the Harifian apparently beginning 12.85–12.68 and ending 11.8–11.63 ka cal. BP, for a total duration of 950–1220 years in a model constrained by abutting with the Mushabian (earlier) and southerly PPNA (later). As for the end of the Mushabian, the early Harifian appears most likely to have begun shortly after the Younger Dryas started.

We hasten to add that the Younger Dryas began much too early to be a plausible trigger for the PPNA. An abutting model indicates that the boundary between Final Natufian and PPNA probably occurs about 11.9–11.7 ka cal. BP, making it some 950–1250 years later than the beginning of Younger Dryas, and much closer instead to the beginning of the Preboreal period.

Although this would place the alleged cause before the effect, it seems too long a lag to make a plausible explanation for the changes associated with PPNA.

The Preboreal period and the onset of the PPNA? The Preboreal period and the beginning of the Sultanian?
The end of the Younger Dryas comes close to the Natufian/PPNA boundary. However, it is likely found within the early PPNA. As already noted, at 68 per cent confidence the PPNA begins 11.9–11.7 ka cal. BP, and the elapsed time from the beginning of PPNA to the end of Younger Dryas and beginning of Preboreal is 90–300 years. The probability that the Preboreal began before the PPNA is only 0.03. Thus, although there is a slight possibility that the Younger Dryas/Preboreal boundary is associated with the beginning of the PPNA, it much more likely comes somewhat after. This is consistent with at least some prehistorians' views. Byrd (2005, 252) suggests that, while the Khiamian PPNA occurred within the last years of the Younger Dryas, settled village life of the Sultanian PPNA did not begin until the onset of the Preboreal.

But does the Younger Dryas/Preboreal boundary really correspond with the beginning of the Sultanian? This requires a model that distinguishes Khiamian sites from Sultanian ones, a distinction that not all scholars of the PPNA would uphold (Nadel 1990; Garfinkel 1996; Kuijt & Mahasneh 1998). If, however, we accept the assignment of some dated assemblages to either Khiamian or Sultanian (omitting determinations from sites where the distinction is most suspect), there is an additional problem in that the only 'Khiamian' dates that survive chronometric hygiene are one from Hatoula and four from Wadi Faynan 16. Adjusting our models to assume that the Khiamian abuts and comes between Late Natufian and Sultanian, we find that the model fails, probably because the Khiamian dates overlap too much with the Sultanian ones. Taking the alternative approach of running two separate models, one of the Late Natufian/Khiamian boundary, and another omitting the Khiamian dates to find a Late Natufian/Sultanian boundary, allows us to see if the Khiamian dates have any impact, specifically in the direction of an earlier boundary. Our results show a Natufian/Khiamian transition about 12.5–12.15 ka cal. BP, mainly reflecting the earlier date on Hatoula, while a Natufian/Sultanian transition would occur about 11.9–11.6 ka cal. BP. The latter model, omitting the dates from Hatoula and Wadi Faynan 16, shows better correspondence to the onset of the Preboreal (but still preceding it by 50–290 years). The Khiamian boundary indeed precedes the Sultanian one substantially (590–900 years), even though there is considerable overlap between the models, as the Wadi Faynan dates would fit easily within the Sultanian group. Although the Khiamian indeed seems older in this analysis, given the small sample size and other issues, we do not consider this very convincing evidence either that the Khiamian constitutes a chronologically well-defined unit between the Natufian and the Sultanian or that the beginning of the latter corresponds with the onset of the Preboreal. However, this question appears to warrant further analysis with new evidence and, of course, does not preclude the possibility that conditions of the Preboreal were conducive to development of larger and more complex settlements during the course of the PPNA, not to mention the PPNB.

The 8.2 ka event and the end of the PPNB or PPNC?
A number of archaeologists have been tempted to associate the abandonment of large, sedentary Middle or Late PPNB villages in the southern Levant with drought conditions of the 8.2 ka event (e.g. Bar-Yosef 2001, 27–8). Weninger *et al.* (2006, 417) argue that dry, cool conditions associated with the 8.2 ka event were dramatic enough to cause major disruptions to cultural trajectories throughout the Mediterranean, including the complete abandonment of some sites (MPPNB villages in Jordan) and the impetus for the spread of agriculture west into Europe. Other authors argue that the 8.2 ka event caused a 'collapse' of final PPNB/PPNC villages in the Levant (Staubwasser & Weiss 2006, 378). Some have suggested that this event may be marked at several sites throughout the Levant by episodes of colluviation, possibly attributed to increased or more intense rainfall and localized deforestation (Rosen 2007, 80). However, any association between the PPNB and the 8.2 ka event has resulted from confusion that results from the co-existence of calibrated and uncalibrated dates and the 8.2 ka event is almost a full millennium too late to explain any PPNB abandonments (cf. Simmons 2007, 185). Consequently, some have attempted to associate the 8.2 ka cooling event with the end of the PPNC and onset of the Late Neolithic.

All models that include sets of dates from the Middle and Late PPNB, PPNC and Yarmoukian allow us easily to reject any association of Middle or Late PPNB abandonment with the 8.2 ka event. The end of the Middle PPNB, about 9.53–9.45 ka cal. BP at 68 per cent confidence, is 1200–1280 years before the 8.2 ka event. There is so much overlap among published dates from Late PPNB and PPNC contexts that, at present, we have been unable to get satisfactory results for the LPPNB/PPNC transition, and can only subjectively estimate it in the range of 9.0–8.7 ka cal. BP.

However, the PPNC/Yarmoukian boundary falls about 8.46–8.35 ka cal. BP (68 per cent confidence), indicating that the 8.2 ka event clearly falls within the Yarmoukian period of the Pottery Neolithic, as defined by a robust group of dates from Sha'ar Hagolan, Munhata 2B, Nahal Qana, and Tabaqat al-Bûma, and continues to do so even if we exclude the last. The 160-year 8.2 ka event likely began 105–220 years after the beginning of the Yarmoukian, while its central, most marked, 70-year phase came some 140–260 years after. The probability that the former preceded the beginning of the Yarmoukian is less than 0.01.

Nor does the 8.2 ka event correspond with the end of the Yarmoukian. This is more difficult to estimate because of uncertainties about even relative chronology at this time (Banning 2007) but, if we make the assumption that it continued until the beginning of the Wadi Rabah period (e.g. dated occupations at Hagoshrim, Megadim, Tel Dover and Tel Hanan in Israel), then the Yarmoukian ended about 7.8–7.7 ka cal. BP. In this model, the onset of the 8.2 ka event preceded the Yarmoukian/Rabah boundary by 430–560 years.

As noted above, however, it is possible that the 8.2 ka event punctuates a somewhat longer and less dramatic cooling episode that lasted from 8.4–8.0 ka (Thomas *et al.* 2007). This event would have a much more plausible connection with the PPNC/Yarmoukian boundary, which nearly centres on 8.4 ka. In this scenario, there is quite a high probability that they are coincident or nearly so. However, it would remain to make a convincing argument as to why a slight cooling of temperature would lead people to adopt pottery in a major way (the main characteristic for distinguishing Yarmoukian from PPNC material culture). In addition, some large PPNC sites, notably 'Ain Ghazal, continued to be occupied into the Yarmoukian, and there were some new large villages, notably Sha'ar Hagolan, suggesting less settlement reorganization than the old *hiatus palestinien* (Perrot 1968) implied.

Overall, the 8.2 ka event has little chance of being responsible for the beginning of the Yarmoukian and, most certainly, had nothing to do with the demise of PPNB. There is a somewhat more convincing argument to be made for connecting the Yarmoukian with a less dramatic cooling trend that began about 8.4 ka.

Discussion

Our analyses suggest that the conception of climate as a trigger for shifts in adaptation and culture is not supported by available data. This does not disqualify climatic instability as the context for the lengthy transition from mobile hunter-gatherer to sedentary agricultural societies in the Levant, but suggests that the dynamic interaction between shifting environmental conditions and innovations in technology, subsistence and social organization was rather more complex.

Superficially, comparison of the cultural periods and climatic events appears to show correlations, particularly given the imprecision of the cultural chronology. Particularly, the Early Natufian began close to the start of the Bølling-Allerød, the Late Natufian close to the onset of the Younger Dryas, and the PPNA close to the start of the Preboreal. However, in almost every case, the onset of the cultural period appears most likely to have preceded the climatic event, in some cases by several centuries. Consequently, we must question the identification of climate change as a trigger.

The structure of the model, as well as basic elements of probability must also be taken into account when assessing these results. The models we use here assume that archaeological periods do not overlap in time; if one allows for overlap this will shift the timing for the archaeological periods, generally making them begin earlier and end later. Since overlap models are so 'forgiving', they do not tend to lead to very precise estimates, yet it is quite possible that overlaps occurred at least sometimes, and could at least occasionally account for apparent inconsistencies between the global and local records.

In addition, before we take too much comfort in whatever correlations between climatic events and cultural ones might survive further analysis, we should heed the statistician's reminder that even completely random events have a substantial probability of coincidence with climatic events, especially if we allow ourselves the freedom to pick and choose the events and their nearness to one another (Good & Hardin 2009, 7–9, 227–8). Taking our estimated dates for the Geometric Kebaran, Early Natufian, Late Natufian, PPNA, Middle PPNB, Late PPNB, PPNC and Yarmoukian, we find that the average length of one of the cultural 'periods' is about 1250 years. If we generate random sequences of simulated periods of approximately the same average length, by sampling an exponential distribution with a mean of 1250 years, it is interesting to observe how often the modelled period boundaries correspond with climatic events, even if, as archaeologists rarely have done, we specify in advance that we will only count as a correspondence cases where the climate event and cultural one occur in the same small and specific interval. We repeated this sampling procedure 30 times, with the 'start date' or end of the sequence randomly selected between 9000 and 7000 cal. BP, and recorded the distribution of 'successful' correspondences. If we only count coincidences with the onset of rapid cooling events Heinrich 1, Younger Dryas, and the 8.2 ka event, and define successes as falling within 16.8–16.5, 13.0–12.8 or 8.4–8.1 ka BP, then we find that the random sequences show at least one correspondence 57 per cent of the time and at least two 11 per cent of the time. If we also count coincidences with the rapidly warming onsets of the Bølling-Allerød and Preboreal, defined as falling within 14.7–14.6 or 11.6–11.5 ka, we find at least one coincidence 70 per cent of the time and at least two 17 per cent of the time. The frequency of such coincidences would increase further if we allowed matches with other, less dramatic, climatic events. This demonstrates that there is a non-trivial probability of finding correspondence between at least some climatic and other kinds of events even when there is absolutely no causal connection. The number would also increase substantially if we increased the number of simulated 'periods' to represent more minor cultural changes or included regionally restricted cultures, such as the Harifian, whose onset and disappearance were not simultaneous with those of the major ones.

Our analysis evaluates whether the Levantine evidence is consistent with climate shifts that were synchronous on a global level. We are not aware of any compelling evidence that would support a time difference between events in the ice cores and climate shifts in the southern Levant that would have led the latter to take place before the former, especially since theories to explain the rapid climate changes mostly depend on processes in the North Atlantic. The Soreq speleothem does appear to show such an offset, with the initial impact of the Younger Dryas predating the ice core dates (Bar-Matthews *et al.* 1999). It seems most likely that this effect is a product of the chronological resolution of the Soreq core but this subject requires further attention.

Those who want to defend the relationship between rapid climate events and cultural changes may well point to the prevalence of charcoal dates in our data base. It is true that, if a large number of determinations on charcoal in our data base came from the central rings of large logs or from deadfall that had lain on the ground for decades before being collected as firewood, this could cause our analyses to overestimate the ages of the period boundaries somewhat. At present there is no way for us to check on this potential source of bias rigorously because archaeologists rarely report detailed descriptions of the charcoal pieces they dated and, for most periods, we have little or no evidence from 'short-lived' material. Aside from Ohalo, our only reasonable number of samples on seeds comes from the Late PPNB at 'Ain Ghazal. To test whether the charcoal samples are yielding systematically older determinations than the seeds, we re-ran models for the boundary between Middle and Late PPNB, with one version that only included charcoal from the Late PPNB deposits and another that only included the seeds. The Middle PPNB group in both versions included one date on seeds and the rest were on charcoal. Our hypothesis is that, if 'old wood' is biasing our results, the boundary should appear earlier in the charcoal version than in the seed version. The results show a Middle/Late PPNB boundary for the charcoal model at 9530–9450 cal. BP at 68 per cent confidence, and for the seed model at 9550–9460. Although this example only involves one of our periods, these results are remarkably consistent and suggest that we have no basis to reject charcoal samples among our data. In addition, and particularly in the most arid parts of the southern Levant, we might expect most of the charcoal to have come from branches and relatively small trees and shrubs rather than from the trunks of old oaks. This last source of samples, furthermore, was probably only common when there was demand for large building timbers, notably during PPNB.

Finally, lest it appear that we are dodging the climate-change hypothesis that has attracted the greatest interest, we turn to the proposed connection between the Younger Dryas and the domestication of plants. The identification of domestication as distinct from exploitation or management of wild plants and animals remains the subject of debate, while it is also difficult to characterize domestication as an event, so identifying any chronological correlation is problematic. The identification of morphologically domesticated rye at Abu Hureyra would seem the best candidate for food production during Younger Dryas (Hillman 2000; Hillman *et al.* 2001), although not all would concur with this identification (Willcox 2007, 31). Ordinarily, we do not include dates from Abu Hureyra in our analysis but, in this case, dates on the rye endocarps themselves would seem the most obvious targets of analysis. Hillman (2000, 376–9) identifies domestic rye in phases 2 and 3 of Abu Hureyra 1 (the Natufian stratum), and, with some apparently intrusive examples excluded, direct dating of three of the rye grains by AMS yielded determinations of 11,140±100 (OxA-8718), 10,930±120 (OxA-6685) and 10,610±100 (OxA-8719). The first and apparently oldest of these actually comes from phase 3, and should be coeval with the youngest date (Moore 2000, 111, 129). The OxA-6685 determination is from near the bottom of phase 2, and thus the oldest context. Consequently, OxA-8718 is either residual from an earlier layer or is a statistical outlier. Taking the three dates as a group, but ordered by their stratigraphic context, we find that the stratigraphically earliest rye grain probably dates 13.09–12.9 ka cal. BP at 68 per cent confidence. This is almost coeval with the beginning of Younger Dryas, or even a little earlier (from 240 years before to 30 years after). The other two dates are just a little later (13.0–12.8 and 12.8–12.6 ka cal. BP). Even without taking into account Hillman & Davies's (1992) suggestion that no more than about 200 years of harvest by sickle or uprooting would be required to result in domestication, the beginning of cultivation at this site could well date even before Younger Dryas began (probability of 0.75). However, this date is unconstrained by the dates on phase 1. If we also take into account the dates on seeds and bone from phase 1 (omitting one major outlier), our estimated age for the oldest domesticated rye at the site would be slightly later, at 12.9–12.7 ka cal. BP, and likely within the early Younger Dryas.

Aside from the controversial case of Abu Hureyra, current evidence for morphological domestication of grasses is much later. Recent analyses (Colledge *et al.* 2004; Nesbitt 2002; Willcox 1999; 2002; 2004; Willcox & Fornite 1999) have suggested that domesticated einkorn occurred by PPNA or Early PPNB in the Levantine corridor, while the PPNA levels at the cave site of Iraq ad-Dubb appear currently to exhibit the earliest dated examples that have been identified as domesticated barley and emmer/einkorn (Colledge 2001, 143–4; Colledge *et al.* 2004, S39–S40). If we test the dates from Iraq ad-Dubb against the YD/Preboreal boundary, we find a likely transition from the Late Natufian to PPNA at Iraq ad-Dubb of 12.1–11.4 ka cal. BP. This implies that the PPNA levels at the site could have begun from 530 years before to 150 years after the end of Younger Dryas and, if we assume a 'gestation' time of about 200 years for cultivation to have led to domestication of these species — toward the long end of Hillman's suggested range — is consistent with the view that initial cultivation of the wheat and barley could have occurred during the Younger Dryas. While this is not an entirely satisfactory approach to the question of cultivation during Younger Dryas, it suggests that further research on this question could be productive.

Somewhat surprisingly, the plant species that may show the earliest incontestable evidence for domestication is the fig. Since they are parthenogenic, depending on humans for their propagation, the examples of carbonized fig fruits and drupes found in PPNA deposits at Gilgal and Netiv Hagdud could only have been domesticates (Kislev *et al.* 2006, but see Lev-Yadun *et al.* 2006). However, these date about 11.6–10.9 ka cal. BP at Gilgal and 11.8–10.6 at Netiv Hagdud, most likely within the Preboreal.

Overall, however, it is clear that morphologically domesticated plants, and a clear economic reliance on them, did not become widespread until PPNB, well into the Boreal period.

Conclusion

As so many archaeologists have already noted, the dramatic environmental variations that we find along a transect from the Mediterranean coast, up the Lebanon Mountains or the hill country of Israel and Palestine, down into the rift valley, and up the Anti-Lebanon or Transjordanian chain onto the eastern plateaus must have had an equally dramatic effect on culture and history in this region (e.g. Bar-Yosef 1990; 1994). Given this topography, global changes in mean temperature and humidity, and associated changes in winds and precipitation, would likely have quite complicated consequences (Enzel *et al.* 2008). For example, rather than simply reducing precipitation across the board, a global drying episode could locally involve decreased seasonality (Stevens *et al.* 2001), more pronounced rain-shadow effects, decrease in the frequency of storms, decreased inter-annual climatic variability (Zielinski & Mershon 1997) or increased rainfall intensity (Field 1994). More recent pollen diagrams and sapropels from lake cores in Turkey confirm this — they show dramatically different trends than those documented from the southern Levant (Meadows 2005). As others have noted (Enzel *et al.* 2008; Robinson *et al.* 2006), not all parts of the Levant changed in the same manner or at the same time.

It may seem hard to believe, however, that such major climatic events as the Younger Dryas and the 8.2 ka event had no cultural impact at all. One possible reason for our failure to identify a really good fit between the cultural and palaeoclimatic events is that archaeologists have been conceiving of climatic change in the region too coarsely. Despite clues, including what seemed to be contradictions between pollen cores, geomorphology, and speleothem data, that the Levant did not experience climate change uniformly or in lock-step with global patterns, there has been a tendency to assume that interstadials were universally welcome and that cooler periods, especially the Younger Dryas, were universally cold, dry, resource-poor and unpleasant.

In addition, there are some indications that cooling episodes, including the relatively dramatic Younger Dryas, did not have such a negative effect on the Levant as some authors suppose. Substantial continuity in plant species identified before, during and after the Younger Dryas, for example, 'would appear to indicate that the climatic deterioration was not a catastrophic event and may merely represent a period of cooler, less stable conditions, which did not result in radical changes in the vegetation cover' (Willcox 2007, 25). Indeed, it is even possible that the cooling could have resulted in a shift of some useful species to more southerly or lower-altitude zones.

The distributions of Late Natufian and Khiamian sites, for example, might be more easily explicable if we take this more nuanced approach to climate change. It should have seemed odd that Late Natufian settlement should actually expand out of the Early Natufian heartland (and especially into what are now desert areas) if the Late Natufian was really a simple response to desiccation at the beginning of Younger Dryas. However, when we consider that our analyses of calibrated dates suggest that the Late Natufian may have lasted on the order of 1300–1800 years and began before the onset of the Younger Dryas, then expansion into the south and east is not so unexpected. A further adaptation of Harifian groups to the arid conditions of the Negev during the Younger Dryas also seems entirely plausible. However, we are still unable to explain the shift from the Early to Late Natufian in the Mediterranean core, if, as seems likely, it began prior to the Younger Dryas.

A more nuanced approach to the possibility that resource stress influenced cultural behaviour might include close examination of site locations. Which locations show continuity of settlement right through a climatic event (e.g. 'Ain Ghazal during 8.2 ka event)? Do these contrast with locations that became abandoned or were the sites of new settlement? The fact that there were many new settlements in the Jordan Valley during the PPNA could have resulted from the higher humidity of the Preboreal; however, their preferred locations also seem to indicate that they were taking advantage of surface water and springs, and their associated resources, on alluvial fans.

Severinghaus *et al.* (1998) state that the onset of both the Bølling-Allerød and the Younger Dryas were rapid events, occurring within a decade or so and terminating within a similar timescale. As our resolution of these terminal Pleistocene climatic phases becomes more refined, it becomes increasingly apparent that they are characterized by very short periods of dramatic and rapid change (Younger Dryas and Preboreal) that, arguably, do not seem to be ideal or stable conditions in which to undertake radical economic and social changes. This is in contrast to many of the models of culture change (see above) that posit a push towards change during periods of stress, most notably in explanations for food production.

The shift to settled village farming in the Levant now appears, however, to have been a lengthy and regionally variable process (Willcox 2007, 32). This process overlapped with a period of climatic instability, which provides the context in which settled villages developed in the Natufian or PPNA, but farming and village life seem to have thrived only during the relatively more stable conditions of the Preboreal, in PPNB. Abbo *et al.* (2010) have recently argued that agriculture is best understood in the context of such stability. Despite the identification of possible domesticates at Abu Hureyra, Iraq ed-Dubb and Gilgal, it is only in the PPNB that we find clear evidence of a farming economy that included the storage of grain and pulses on more than a very small scale (e.g. Garfinkel *et al.* 1988; van Zeist & Bakker-Heeres 1982; but see Kuijt & Finlayson 2009). It is only in the later part of the PPNB that domesticated animals were either introduced or locally domesticated in the southern Levant. This would be surprising if climate stress that reduced the availability of gazelle had triggered a shift to domesticable species (Munro 2003).

In sum, it seems that many of the simple equations that archaeologists have posited between climatic and cultural events in the Levant during the late Pleistocene and early Holocene are suspect. This does not rule out the possibility that climatic change had an important role in cultural events of this era. Most likely climatic changes had some substantive impacts on culture in late prehistory, just as in later periods. For example, populations may have increased and settlements became quite large during the Early Natufian, perhaps taking advantage of the Bølling-Allerød's higher precipitation and associated increases in available food resources, even if, as our analyses suggest, the Early Natufian actually started somewhat earlier than the Bølling-Allerød. Meanwhile, Mushabian hunter-gatherers, who were able to exploit what are now quite desert areas of the Negev and Sinai during that same era, apparently were not able to continue to do so for long during the Younger Dryas, at least not without adapting their technology or economic strategy.

But our results do cast doubt on some specific hypotheses about the relationship of rapid cooling events or periods of warmer, wetter climate to such interesting cultural developments as increased sedentism, agricultural origins, or village abandonment. While the Early Natufian flourished during the climatic amelioration of the Bølling-Allerød, the latter is unlikely to have ushered the cultural changes that allow us to distinguish the Natufian from the Geometric Kebaran. Furthermore, the Late Natufian probably also enjoyed these conditions for a few centuries before the onset of the Younger Dryas. Consequently, climate change appears an unlikely candidate for the initiator of cultural changes that archaeologists use to distinguish the two phases of the Natufian, including changes in lithic technology, mobility and settlement pattern, and reliance on ground stone.

Rapid warming at the Younger Dryas/Preboreal boundary appears to have occurred some way into the PPNA, when better climatic conditions may have encouraged sedentism and larger settlements, but could not have been responsible for other cultural changes that heralded the beginning of the PPNA, such as changes in projectiles and, by extension, hunting strategies. At present the data do not contradict Byrd's (2005) suggestion that there was association between the Sultanian and the Preboreal, but the data for the Khiamian, in particular, are really insufficient for us to test this adequately, whether or not the Khiamian has any real meaning as a cultural 'period'.

Most notably, the 8.2 ka event cannot have been responsible for some of the cultural changes that have been attributed to it. It was much too late to have had anything to do with the abandonment of Middle or Late PPNB villages, or the cultural changes associated with the PPNC. Indeed, far from exhibiting any cold, dry episodes, the early Holocene, including the entire Pre-Pottery Neolithic, appears to have been the warmest and wettest of all of the post-glacial periods in the Levant (Rossignol-Strick 1999). Furthermore, the 8.2 ka event, *sensu stricto*, is unlikely to be associated with the inception or the demise of the Yarmoukian Pottery Neolithic, although the smaller pool of radiocarbon determinations for most of the Late Neolithic prevents more definitive evaluation, and it is conceivable that the Yarmoukian is associated with a less dramatic climatic change that began two centuries before the 8.2 ka event.

Finally, we should contemplate yet another factor that could be leading to dissonance between the fine-grained climatic record and the cultural models we have tested here: the assumptions of those cultural models themselves. Traditionally, we have treated entities such as the Early Natufian and Late Natufian as rather monolithic units, something like 'cultures', but ones that also behave like chronological periods, by assuming that changes in such things as lithic morphology would occur in lock-step progression with other changes, in settlement pattern, economy, burial practices, and so on. A more nuanced approach would not presume that adoption of new lithic tool types should necessarily occur at the same time as changes in settlement pattern or demography, and a possible direction for future work would be to refine our chronologies for some of these changes independently, rather than as packages, and in terms of shifting frequency or scale, rather than just presence or absence of a trait. In that context, it is possible, for example, that Natufian settlement patterns could turn out to have undergone significant changes after the onset of Younger Dryas, while changes in some aspects of tool technology that we tend to use as *fossils directeurs* took place significantly earlier.

Acknowledgements

We would like to thank Caitlin Buck for advice on the handling of radiocarbon outliers and chronometric hygiene, as well as Lianne Maitland for assistance in the preparation of Figure 3. We thank several people for helpful discussions about cultural-chronological relationships in the Near East, including Nigel Goring-Morris, Anna Belfer-Cohen, Kevin Gibbs, Jay Stock, Naama Goren-Inbar, Danielle Macdonald, Aaron Stutz and Tobias Richter. Portions of this work were funded by a Social Sciences and Humanities Research Council of Canada Grant to Banning and Maher.

Lisa A. Maher
Leverhulme Centre for Human Evolutionary Studies
University of Cambridge
Fitzwilliam St
Cambridge
CB2 1QH
UK
Email: l.maher@human-evol.cam.ac.uk

E.B. Banning
Department of Anthropology
University of Toronto
19 Russell St
Toronto, ON
M5S 2S2
Canada
Email: ted.banning@utoronto.ca

Michael Chazan
Department of Anthropology
University of Toronto
19 Russell St
Toronto, ON
M5S 2S2
Canada
Email: mchazan@chass.utoronto.ca

References

Abbo, S., S. Lev-Yadun & A. Gopher, 2010. Yield stability: an agronomic perspective on the origin of Near Eastern agriculture. *Vegetation History and Archaeobotany* 19(2), 143–50.

Alley, R.B., 2000. The Younger Dryas cold interval as viewed from central Greenland. *Quaternary Science Reviews* 19(1–5), 213–26.

Alley, R.B., P.A. Mayewski, T. Sowers, M. Stuiver, K.C. Taylor & P.U Clark, 1997. Holocene climatic instability: a prominent, widespread event 8200 yr ago. *Geology* 25(6), 483–6.

Alley, R.B., J. Marotzke, W.D. Nordhaus *et al*., 2003. Abrupt climate change. *Science* 299, 2005–10.

Alley, R.B., J.T. Andrews, D.C. Barber & P.U. Clark, 2005. Comment on 'Catastrophic ice shelf breakup as the source of Heinrich event icebergs' by C.L. Hulbe *et al*. *Paleoceanography* 20, PA1009, doi:10.1029/2004PA001086.

Andres, M.S., S.M. Bernasconi, J.A. McKenzie & U. Röhl, 2003. Southern Ocean deglacial record supports global Younger Dryas. *Earth and Planetary Science Letters* 216(4), 515–24.

Aurenche, O., P. Galet, E. Régagnon-Caroline & J. Évin, 2001. Proto-Neolithic and Neolithic cultures in the Middle East — The birth of agriculture, livestock raising and ceramics: a calibrated ^{14}C chronology 12, 500–5500 cal BC. *Radiocarbon* 43(3), 1191–202.

Balter, M., 2006. Seeking agriculture's ancient roots. *Science* 316, 1830–35.

Banning, E.B., 2007. Wadi Rabah and related assemblages in the southern Levant: interpreting the radiocarbon evidence. *Paléorient* 33(1), 77–101.

Bar-Matthews, M. & A. Ayalon, 2003. Climatic conditions in the eastern Mediterranean during the Last Glacial (60–10 ky bp) and their relations to the Upper Palaeolithic in the Levant: oxygen and carbon isotope systematics of cave deposits, in *More Than Meets the Eye: Studies on Upper Palaeolithic Diversity in the Near East*, eds. A.N. Goring-Morris &. A. Belfer-Cohen. Oxford: Oxbow Books, 13–18.

Bar-Matthews, M., A. Ayalon & A. Kaufman, 1997. Late Quaternary paleoclimate in the eastern Mediterranean region from stable isotope analysis of speleothems at Soreq Cave, Israel. *Quaternary Research* 47(2), 155–68.

Bar-Mathews, M., A. Ayalon, A. Kaufman & G.J. Wasserburg, 1999. The eastern Mediterranean paleoclimate as a reflection of regional events: Soreq Cave, Israel. *Earth and Planetary Science Letters* 166(1–2), 85–95.

Bar-Yosef, O., 1970. The Epipalaeolithic Cultures of Palestine. Unpublished PhD thesis, Hebrew University, Jerusalem.

Bar-Yosef, O., 1982. The Natufian of the southern Levant, in *The Hilly Flanks and Beyond: Essays on the Prehistory of Southwestern Asia Presented to Robert J. Braidwood*, eds. T.C. Young, P.J. Smith & P. Mortensen. Chicago (IL): Oriental Institute of the University of Chicago, 11–42.

Bar-Yosef, O., 1987. Late Pleistocene adaptations in the Levant, in *The Pleistocene Old World: Regional Perspectives*, ed. O. Soffer. New York (NY): Plenum Press, 219–36.

Bar-Yosef, O., 1990. The Last Glacial Maximum in the Mediterranean Levant, in *The World at 18000 BP*, eds. C. Gamble & O. Soffer. London: Unwin Hyman, 58–77.

Bar-Yosef, O., 1994. The Lower Paleolithic of the Near-East. *Journal of World Prehistory* 8(3), 211–65.

Bar-Yosef, O., 1995. The role of climate in the interpretation of human movements and cultural transformations in western Asia, in *Palaeoclimate and Evolution with Emphasis on Human Origins*, eds. E.S. Vrba, G.H. Denton, T.C. Partridge & L.H. Burckle. New Haven (CT): Yale University Press, 507–23.

Bar-Yosef, O., 1996. The impact of the Late Pleistocene– Early Holocene climatic changes on humans in southwest Asia, in *Humans at the End of the Ice Age: the Archaeology of the Pleistocene–Holocene Transition*, eds. L.G. Straus, B.V. Eriksen, J.M. Erlandson & D.R. Yesner. (Interdisciplinary Contributions to Archaeology.) New York (NY): Plenum Press, 61–78.

Bar-Yosef, O., 2000. The impact of radiocarbon dating on Old World archaeology: past achievements and future expectations. *Radiocarbon* 42(1), 23–39.

Bar-Yosef, O., 2001. From sedentary foragers to village hierarchies: the emergence of social institutions. *Proceedings of the British Academy* 110, 1–38.

Bar-Yosef, O. & A. Belfer-Cohen, 1989. The origins of sedentism and farming communities in the Levant. *Journal of World Prehistory* 3(4), 447–98.

Bar-Yosef, O. & A. Belfer-Cohen, 1991. From sedentary hunter-gatherers to territorial farmers in the Levant, in *Between Bands and States*, ed. S.A. Gregg. Carbondale (IL): Southern Illinois University at Carbondale; Center for Archaeological Investigations, 181–202.

Bar-Yosef, O. & M. Kislev, 1989. Early farming communities in the Jordan Valley, in *Foraging and Farming: the Evolution of Plant Exploitation*, eds. D. Harris & G. Hillman. London: Unwin Hyman, 632–42.

Bar-Yosef, O. & R.S. Kra (eds.), 1994. *Late Quaternary Chronology and Paleoclimates of the Eastern Mediterranean,* Tuscon (AZ): Radiocarbon.

Bar-Yosef, O. & R.H. Meadow, 1995. The origins of agriculture in the Near East, in *Last Hunters-First Farmers: New Perspectives on the Prehistoric Transition to Agriculture*, eds. T.D. Price & A.B. Gebauer. Santa Fe (NM): School of American Research Press, 39–94.

Bar-Yosef, O. & J. Vogel, 1987. Relative and absolute chronology of the Epipalaeolithic in the southern Levant, in *Chronologies in the Near East*, eds. O. Aurenche, J. Evin & F. Hours. (British Archaeological Reports International Series 379.) Oxford: BAR, 219–46.

Barber, D.C., A. Dyke, C. Hillaire-Marcel *et al.*, 1999. Forcing of the cold event of 8,200 years ago by catastrophic drainage of Laurentide lakes. *Nature* 400, 344–8.

Bartov, Y., M. Stein, Y. Enzel, A. Agnon & Z. Reches, 2002. Lake levels and sequence stratigraphy of Lake Lisan, the Late Pleistocene precursor of the Dead Sea. *Quaternary Research* 57, 9–21.

Bartov, Y., S.L. Goldstein, M. Stein & Y. Enzel, 2003. Cata-

strophic arid episodes in the eastern Mediterranean linked with the North Atlantic Heinrich events. *Geology* 31(5), 439–42.
Bartov, Y., Y. Enzel, N. Porat & M. Stein, 2007. Evolution of the Late Pleistocene–Holocene Dead Sea basin from sequence stratigraphy of fan deltas and lake-level reconstruction. *Journal of Sedimentary Research* 77(9), 680–92.
Baylis, A. & C.B. Ramsey, 2004. Pragmatic Bayesians: a decade of integrating radiocarbon dates into chronological models, in *Tools for Constructing Chronologies: Crossing Disciplinary Boundaries*, eds. C.E. Buck & A.R. Millard. (Lecture Notes in Statistics 177.) London: Springer, 25–41.
Begin, Z.B., A. Ehrlich & Y. Nathan, 1974. Lake Lisan, the Pleistocene precursor to the Dead Sea. *Bulletin of the Geological Society of Israel* 63, 1–30.
Belfer-Cohen, A. & O. Bar-Yosef, 2000. Early sedentism in the Near East: a bumpy ride to village life, in *Life in Neolithic Farming Communities: Social Organization, Identity and Differentiation*, ed. I. Kuijt. New York (NY): Kluwer Academic/Plenum Publishers, 19–37.
Belfer-Cohen, A. & N. Goring-Morris, 2002. Why microliths? Microlithization in the Levant. *Archeological Papers of the American Anthropological Association* 12, 57–68.
Binford, L.R., 1968. Post-Pleistocene adaptations, in *New Perspectives in Archaeology*, eds. L.R. Binford & S.R. Binford. Chicago (IL): Aldine, 313–42.
Binford, L.R., 2001. *Constructing Frames of Reference: an Analytical Method for Archaeological Theory Building Using Ethnographic and Environmental Data Sets.* Berkeley (CA): University of California Press.
Bond, G., H. Heinrich, W. Broecker *et al.*, 1992. Evidence for massive discharges of icebergs into the North-Atlantic Ocean during the last glacial period. *Nature* 360, 245–9.
Bond, G.C. & R. Lotti, 1995. Iceberg discharges into the North-Atlantic on millennial time scales during the last glaciation. *Science* 267, 1005–10.
Bookman, R., Y. Bartov, Y. Enzel & M. Stein, 2006. Quaternary lake levels in the Dead Sea basin: two centuries of research, in *New Frontiers in Dead Sea Palaeoenvironmental Research*, eds. Y. Enzel, A. Agnon & M. Stein. (Special Papers 401.) Boulder (CO): Geological Society of America, 155–70.
Bowman, D., A. Karniell, A. Issar & H.J. Bruins, 1986. Residual colluvio-aeolian aprons in the Negev Highlands (Israel) as palaeo-climatic indicator. *Palaeogeography, Palaeoclimatology, Palaeoecology* 56(1–2), 89–101.
Boyd, B., 2006. On 'sedentism' in the Later Epipalaeolithic (Natufian) Levant. *World Prehistory* 38(2), 164–78.
Braidwood, R.J., 1951. From cave to village in prehistoric Iraq. *Bulletin of the American Schools of Oriental Research* 124, 12–18.
Braidwood, R.J., 1960. The agricultural revolution. *Scientific American* 203(3), 130–52.
Braidwood, R.J., 1973. The early village in southwestern Asia. *Journal of Near Eastern Studies* 32(1/2), 34–9.
Braidwood, R.J. & B. Howe, 1960. *Prehistoric Investigations in Iraqi Kurdistan*. (Studies in Ancient Oriental Civilization 31.) Chicago (IL): University of Chicago Press.
Bronk Ramsey, C., 2000. Comment on 'The use of Bayesian statistics for C-14 dates of chronologically ordered samples: a critical analysis'. *Radiocarbon* 42(2), 199–202.
Bronk Ramsey, C., 2008. Deposition models for chronological records. *Quaternary Science Reviews* 27(1–2), 42–60.
Bronk-Ramsey, C., C. Buck, S. Manning, P. Reimer & H. van der Plicht, 2006. Developments in radiocarbon calibration for archaeology. *Antiquity* 80, 783–96.
Buck, C.E. & S.K. Sahu, 2000. Bayesian models for relative archaeological chronology building. *Journal of the Royal Statistical Society Series C-Applied Statistics* 49, 423–40.
Buck, C.E., J.B. Kenworthy, C.D. Litton & A.F.M. Smith, 1991. Combining archaeological and radiocarbon information: a Bayesian approach to calibration. *Antiquity* 65, 808–21.
Buck, C.E., C.D. Litton & A.F.M. Smith, 1992. Calibration of radiocarbon results pertaining to related archaeological events. *Journal of Archaeological Science* 19(5), 497–512.
Buck, C.E., J.A. Christen, J.B. Kenworthy & C.D. Litton, 1994a. Estimating the duration of archaeological activity using ^{14}C determinations. *Oxford Journal of Archaeology* 133(2), 229–40.
Buck, C.E., C.D. Litton & E.M. Scott, 1994b. Making the most of radiocarbon dating: some statistical considerations. *Antiquity* 68, 252–63.
Buck, C.E., W.G. Cavanagh & C.D. Litton, 1996. *Bayesian Approach to Interpreting Archaeological Data.* Chichester: Wiley.
Buck, C.E., J.A. Christen & G.N. James, 1999. BCal: an online Bayesian radiocarbon calibration tool. *Internet Archaeology* 7.
Buck, C.E., C.J.F. ter Braak, A.R. Millard *et al.*, 2006. Bayesian palaeoclimate reconstruction — discussion on the paper by Haslett *et al. Journal of the Royal Statistical Society Series A-Statistics in Society* 169, 430–38.
Burroughs, W.J., 2005. *Climate Change and Prehistory: the End of the Reign of Chaos.* Cambridge: Cambridge University Press.
Byrd, B., 1994. Late Quaternary hunter-gatherer complexes in the Levant between 20,000 and 10,000 BP, in *Late Quaternary Chronology and Paleoclimates of the Eastern Mediterranean*, eds. O. Bar-Yosef & R.S. Kra. Tuscon (AZ): Radiocarbon, 205–26.
Byrd, B., 1998. Spanning the gap from the Upper Paleolithic to the Natufian: the Early and Middle Epipaleolithic, in *The Prehistoric Archaeology of Jordan*, ed. D.O. Henry. (British Archaeological Reports International Series 396.) Oxford: Archaeopress, 64–82.
Byrd, B., 2005. Reassessing the emergence of village life in the Near East. *Journal of Archaeological Research* 13(3), 231–90.
Childe, G., 1942. *What Happened in History.* Harmondsworth: Pelican Books.
Childe, V.G., 1928. *The Most Ancient East.* London: Routledge and Kegan Paul.
Colledge, S., 2001. *Plant Exploitation on Epipalaeolithic and*

*Early Neolithic Sites in the Levant. (*British Archaeological Reports International Series 986.) Oxford: BAR.
Colledge, S., J. Conolly & S. Shennan, 2004. Archaeobotanical evidence for the spread of farming in the eastern Mediterranean. *Current Anthropology* 45(4), 35–58.
Cordova, C., 2000. Geomorphological evidence of intense prehistoric soil erosion in the Highlands of Central Jordan. *Physical Geography,* 21(6), 538–67.
Cordova, C.E., C. Foley, A. Nowell & M. Bisson, 2005. Landforms, sediments, soil development, and prehistoric site settings on the Madaba-Dhiban Plateau, Jordan. *Geoarchaeology* 20(1), 29–56.
Dean, J.S., 1978. Independent dating in archaeological analysis, in *Advances in Archaeological Method and Theory*, vol. 1, ed. M.B. Schiffer. New York (NY): Academic Press, 223–55.
Deckers, K., S. Riehl, E. Jenkins *et al.*, 2009. Vegetation development and human occupation in the Damascus region of southwestern Syria from the Late Pleistocene to Holocene. *Vegetation History and Archaeobotany* 18(4), 329–40.
Edwards, P.C., 2001. Nine millennia by Lake Lisan: the Epipalaeolithic in the east Jordan Valley between 20,000 and 11,000 years ago, in *Studies in the History and Archaeology of Jordan*, vol. VII, ed. G. Bisheh. Amman: Department of Antiquity of Jordan, 85–93.
Edwards, P.C., P.G. Macumber & M.J. Head, 1996. The early Epipalaeolithic of Wadi al-Hammeh. *Levant* 28, 115–30.
Enzel, Y., R. Bookman, D. Sharon *et al.*, 2003. Late Holocene climates of the Near East deduced from Dead Sea level variations and modern regional winter rainfall. *Quaternary Research* 60(3), 263–73.
Enzel, Y., R. Amit, U. Dayan *et al.*, 2008. The climatic and physiographic controls of the eastern Mediterranean over the late Pleistocene climates in the southern Levant and its neighboring deserts. *Global and Planetary Change* 60, 165–92.
Fawcett, P.J., A.M. Ágústsdóttir, R.B. Alley & C.A. Shuman, 1997. The Younger Dryas termination and North Atlantic deep water formation: insights from climate model simulations and Greenland ice cores. *Paleoceanography* 12(1), 23–38.
Field, J., 1994. Rainfall patterns and landscape changes in Wadi Ziqlab, Jordan, in *Archaeology and the Environment: a Fragile Coexistence. Proceedings of the 24th Annual Chacmool Conference*, eds. R. Jamieson, S. Abonyi & N. Mirau. Calgary: Department of Archaeology, University of Calgary, 257–9.
Fitzpatrick, S.M., 2006. A critical approach to ^{14}C dating in the Caribbean: using chronometric hygiene to evaluate chronological control and prehistoric settlement. *Latin American Antiquity* 17(4), 389–418.
Frumkin, A., 1998. Salt cave cross-sections and their paleoenvironmental implications. *Geomorphology* 23(2–4), 183–91.
Frumkin, A., I. Carmi, I. Zak & M. Magaritz, 1994. Middle Holocene environmental change determined from the salt caves of Mount Sedom, Israel, in *Late Quaternary Chronology and Paleoclimates of the Eastern Mediterranean*, eds. O. Bar-Yosef & R.S. Kra. Tuscon (AZ): Radiocarbon, 315–32.
Frumkin, A., D.C. Ford & H.P. Schwartz, 1999. Continental oxygen isotopic record of the last 170,000 years in Jerusalem. *Quaternary Research* 51(3), 317–27.
Frumkin, A., G. Kadan, Y. Enzel & Y. Eyal, 2001. Radiocarbon chronology of the Holocene Dead Sea: attempting a regional correlation. *Radiocarbon* 43(3), 1179–89.
Garfinkel, Y., 1996. Critical observations on the so-called Khiamian flint industry, in *Neolithic Chipped Stone Industries of the Fertile Crescent, and Their Contemporaries in Adjacent Regions*, eds. S.K. Kozłowski & H.G.K. Gebel. Berlin: Ex Oriente, 15–21.
Garfinkel, Y., I. Cakrme & J.C. Vogel, 1988. Dating of horsebean and lentil seeds from the Pre-Pottery Neolithic B village of Yiftah'el. *Israel Exploration Quarterly* 37, 40–42.
Garrard, A., D. Baird & B. Byrd, 1994. The chronological basis and significance of the Late Palaeolithic and Neolithic sequence in the Azraq Basin, Jordan, in *Late Quaternary Chronology and Palaeoclimates of the Eastern Mediterranean*, eds. O. Bar-Yosef & R.S. Kra. Tuscon (AZ): Radiocarbon, 177–99.
Gasse, F., 2000. Hydrological changes in the African tropics since the Last Glacial Maximum. *Quaternary Science Reviews* 19(1–5), 189–211.
Geyh, M.A., 1994. The paleohydrology of the eastern Mediterranean, in *Late Quaternary Chronology and Paleoclimates of the Eastern Mediterranean*, eds. O. Bar-Yosef & R.S. Kra. Tuscon (AZ): Radiocarbon, 131–45.
Gilead, I., 1988. The Upper Palaeolithic to Epi-Palaeolithic transition in the Levant. *Paleorient* 14(2), 177–82.
Goldberg, P., 1981. Late Quaternary stratigraphy of Israel: an eclectic view, in *Préhistoire du Levant*, ed. J.C.P. Sanlaville. (Colloque no. 598.) Paris: CNRS, 55–66.
Goldberg, P., 1992. Micromorphology, soils, and archaeological sites, in *Soils in Archaeology: Landscape Evolution and Human Occupation*, ed. V.T. Holliday. Washington (DC): Smithsonian Institution Press, 145–67.
Goldberg, P., 1994. Interpreting Late Quaternary continental sequences in Israel, in *Late Quaternary Chronology and Paleoclimates of the Eastern Mediterranean*, eds. O. Bar-Yosef & R.S. Kra. Tucson (AZ): Department of Geosciences, Univeristy of Arizona, 89–102.
Goldberg, P., 2001. Some micromorphological aspects of prehistoric cave deposits. *Cahiers d'Archéologie du CELAT 10,* 161–75.
Goldberg, P. & O. Bar-Yosef, 1982. Environmental and archaeological evidence for climatic change in the southern Levant and adjacent areas, in *Paleoclimates, Paleoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory*, eds. J.L. Bintliff & W. van Zeist. (British Archaeological Reports 133.) Oxford: BAR, 399–414.
Goldberg, P. & O. Bar-Yosef, 1990. The effect of man on geomorphological processes based upon evidence from the Levant and adjacent areas, in *Man's Role in the Shaping of the Eastern Mediterranean Landscape*,

eds. S. Bottema, N. Entjes-Nieborg & W. van Zeist. Rotterdam: Balkema, 71–86.
Goldberg, P. & B. Brimer, 1983. Late Pleistocene geomorphic surfaces and environmental history of the Avdat/Havarim area, Nahal Zin, in *Prehistory and Palaeoenvironments of the Central Negev, Israel*, vol. 3: *The Avdat/Aqev Area*, part 3, ed. A.E. Marks. Dallas (TX): Southern Methodist University Press, 1–13.
Good, P.I. & J.W. Hardin, 2009. *Common Errors in Statistics (and How to Avoid Them).* 3rd edition. Hoboken (NJ): John Wiley & Sons.
Goodfriend, G.A., 1987. Chronostratigraphic studies of sediments in the Negev Desert, using amino acid epimerization analysis of land snail shells. *Quaternary Research* 28(3), 374–92.
Goodfriend, G.A. & M. Magaritz, 1988. Palaeosols and late Pleistocene rainfall fluctuations in the Negev Desert. *Nature* 332, 144–6.
Goring-Morris, A.N., 1987. *At the Edge: Terminal Pleistocene Hunter-gatherers in the Negev and Sinai. (*British Archaeological Reports International Series 361.) Oxford: BAR.
Goring-Morris, A.N., 1991. The Harifian of the southern Levant, in *The Natufian Culture in the Levant*, eds. O. Bar-Yosef & F.R. Valla. Ann Arbor (MI): International Monographs in Prehistory, 173–216.
Goring-Morris, A.N. & P. Goldberg, 1990. Late Quaternary dune incursions in the southern Levant: archaeology, chronology and palaeoenvironments. *Quaternary International* 5, 115–37.
Goring-Morris, A.N., E. Hovers & A. Belfer-Cohen, 2009. The dynamics of Pleistocene and Early Holocene settlement patterns and human adaptations in the Levant: an overview, in *Transitions in Prehistory: Papers in Honor of Ofer Bar-Yosef*, eds. J.J. Shea & D.E. Lieberman. Oxford: Oxbow Books, 185–252.
Goring-Morris, N. & A. Belfer-Cohen, 1998. The articulation of cultural processes and the late Quaternary environmental changes in Cisjordan. *Paléorient* 23(2), 71–93.
von Grafenstein, U., H. Erlenkeuser, J. Müller, J. Jouzel & S. Johnsen, 1998. The cold event 8200 years ago documented in oxygen isotope records of precipitation in Europe and Greenland. *Climatic Dynamics* 14(2), 73–81.
Grosman, L., 2003. Preserving cultural traditions in a period of instability: the Late Natufian of the hilly Mediterranean zone. *Current Anthropology* 44(4), 571–80.
Grosman, L., 2005. Computer Simulation of Variables in Models of the Origins of Agriculture in the Levant. Unpublished PhD theses, Hebrew University, Jerusalem.
Grosman, L. & A. Belfer-Cohen, 2002. Zooming onto the 'Younger Dryas', in *The Dawn of Farming in the Near East*, eds. R.T.J. Cappers & S. Bottema. (Studies in Early Near Eastern Production, Subsistence and Environment 6.) Berlin: Ex Oriente, 49–54.
Gvirtzman, G. & M. Wieder, 2001. Climate of the last 53,000 years in the eastern Mediterranean, based on soil-sequence stratigraphy in the coastal plain of Israel. *Quaternary Science Reviews* 20(18), 1827–49.
Hald, M. & S. Hagen, 1998. Early Preboreal cooling in the Nordic seas region triggered by meltwater. *Geology* 26(7), 615–18.
Heinrich, H., 1988. Origin and consequences of cyclic ice rafting in the northeast Atlantic Ocean during the past 130,000 years. *Quaternary Research* 29(2), 142–52.
Hemming, S.R., 2004. Heinrich events: massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint. *Reviews of Geophysics* 42(1), 1–43.
Henry, D.O., 1983. Adaptive evolution within the Epipalaeolithic of the Near East. *Advances in World Archaeology* 2, 99–160.
Henry, D.O., 1985. Preagricultural sedentism: the Natufian example, in *Prehistoric Hunter-gatherers: the Emergence of Cultural Complexity*, eds. T.D Price & J.A. Brown. New York (NY): Academic Press, 365–84.
Henry, D.O., 1989. *From Foraging to Agriculture: the Levant at the End of the Ice Age.* Philadelphia (PA): University of Pennsylvania Press.
Henry, D.O., 1991. Foraging, sedentism, and adaptive vigor in the Natufian: rethinking the linkages, in *Perspectives on the Past*, ed. G.A. Clark. Philadelphia (PA): University of Pennsylvania Press, 353–71.
Henry, D.O., 1995. *Prehistoric Cultural Ecology and Evolution: Insights from Southern Jordan.* (Interdisciplinary Contributions to Archaeology.) New York (NY): Plenum Press.
Hillman, G.C., 2000. The plant food economy of Abu Hureyra 1 and 2, in *Village on the Euphrates: From Foraging to Farming at Abu Hureyra*, eds. A.M.T. Moore, G.C. Hillman & A.J. Legge. Oxford: Oxford University Press, 327–422.
Hillman, G.C. & M.S. Davies, 1992. Domestication rate in wild wheats and barley under primitive cultivation: preliminary results and archaeological implications of field measurements of selection coefficient, in *Préhistoire de l'agriculture: nouvelles approches expérimentales et ethnographiques*, ed. P.C. Anderson. Paris: Éditions du CNRS, 113–58.
Hillman, G., R. Hedges, A. Moore, S. Colledge & P. Petitt, 2001. New evidence of Lateglacial cereal cultivation at Abu Hureyra on the Euphrates. *The Holocene* 11, 383–93.
Housley, R.A., 1994. Eastern Mediterranean chronologies: the Oxford AMS contribution, in *Late Quaternary Chronology and Palaeoclimates of the Eastern Mediterranean*, eds. O. Bar-Yosef & R.S. Kra. Tuscon (AZ): Radiocarbon, 55–73.
Hunt, C.O., H.A. El-Rishi, D.D. Gilbertson, J. Grattan, S. McLaren, F.B. Pyatt, G. Rushworth & G.W. Barker, 2004. Early Holocene environments in the Wadi Faynan, Jordan. *Holocene* 14(6), 921–30.
Issar, A.S. & M. Zohar, 2007. *Climate Change: Environment and History of the Near East.* Berlin: Springer-Verlag.
Johnsen, S.J., D. Dahl-Jensen, N. Gundestrup *et al.*, 2001. Oxygen isotope and palaeotemperature records from six Greenland ice-core stations: Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP. *Journal of*

Quaternary Science 16(4), 299–307.

Kaufman, D., 1992. Hunter-gatherers of the Levantine Epipalaeolithic: the sociological origins of sedentism. *Journal of Mediterranean Archaeology* 5(2), 165–201.

Kemp, R.A. & E. Derbyshire, 1998. The loess soils of China as records of climate change. *European Journal of Soil Science* 49, 525–39.

Khresat, S.A., 2001. Calcic horizon distribution and soil classification in selected soils of north-western Jordan. *Journal of Arid Environments* 47(2), 145–52.

Khresat, S.A., Z. Rawajfih & M. Mohammad, 1998. Morphological, physical and chemical properties of selected soils in the arid and semi-arid region in north-western Jordan. *Journal of Arid Environments* 40(1), 15–25.

Kislev, M.E., A. Hartmann & O. Bar-Yosef, 2006. Early domesticated fig in the Jordan Valley. *Science* 312, 1372–4.

Klitgaard-Kristensen, D., H.P. Sejrup, H. Haflidason, S. Johnsen & M. Spurk, 1998. A regional 8200 cal. yr BP cooling event in northwest Europe, induced by final stages of the Laurentide ice-sheet deglaciation? *Journal of Quaternary Science* 13(2), 165–9.

Kozłowski, S.K., 1994. Radiocarbon dates from Aceramic Iraq, in *Late Quaternary Chronology and Paleoclimates of the Eastern Mediterranean*, eds. O. Bar-Yosef & R.S. Kra. Tuscon (AZ): Radiocarbon, 255–64.

Kuijt, I., 2000. Life in Neolithic farming communities, an introduction, in *Life in Neolithic Farming Communities: Social Organization, Identity, and Differentiation*, ed. I. Kuijt. (Fundamental Issues in Archaeology.) New York (NY): Kluwer Academic/Plenum Publishers, 3–13.

Kuijt, I. & B. Finlayson, 2009. Evidence for food storage and predomestication granaries 11,000 years ago in the Jordan Valley. *Proceedings of the National Academy of Sciences of the USA* 106(27),10,966–70.

Kuijt, I. & N. Goring-Morris, 2002. Foraging, farming, and social complexity in the Pre-Pottery Neolithic of the southern Levant: a review and synthesis. *Journal of World Prehistory* 16(4), 361–440.

Kuijt, I. & H. Mahasneh, 1998. Dhra': an early Neolithic village in the southern Jordan Valley. *Journal of Field Archaeology* 25, 153–61.

Kukla, G.J., 1970. Correlation between loesses and deep-sea sediments. *Geologiska Föreningeas i Stockholm Förhandlingar* 92, 148–80.

Landmann, G., A. Reimer, G. Lemcke & S. Kempe, 1996. Dating Late Glacial abrupt climate changes in the 14,570 yr long continuous varve record of Lake Van, Turkey. *Palaeogeography, Palaeoclimatology, Palaeoecology* 122, 107–18.

Leroi-Gourhan, A. & F. Darmon, 1991. Analyses polliniques de stations Natoufiennes au Proche-Orient, in *The Natufian Culture in the Levant*, eds. O. Bar-Yosef & F.R. Valla. Ann Arbor (MI): International Monographs in Prehistory, 21–6.

Lev-Yadun, S., G. Ne'eman, S. Abbo & M.A. Flaishman, 2006. Comment on 'Early domesticated fig in the Jordan Valley'. *Science* 314, 1683.

Lowe, J.J., S.O. Rasmussen, S. Björck *et al.*, 2008. Synchronisation of palaeoenvironmental events in the North Atlantic region during the Last Termination: a revised protocol recommended by the INTIMATE group. *Quaternary Science Reviews* 27(1–2), 6–17.

Mackay, A.W., D.B. Ryves, R.W. Battarbee *et al.*, 2005. 1000 years of climate variability in central Asia: assessing the evidence using Lake Baikal (Russia) diatom assemblages and the application of a diatom-inferred model of snow cover on the lake. *Global and Planetary Change* 46(1–4), 281–97.

Magaritz, M., 1986. Environmental changes recorded in the Upper Pleistocene along the desert boundary, southern Israel. *Palaeogeography, Palaeoclimatology, Palaeoecology* 53, 213–29.

Maher, L.A., 2005. The Epipalaeolithic in Context: Palaeolandscapes and Prehistoric Occupation of Wadi Ziqlab, Northern Jordan. Unpublished PhD theses, University of Toronto.

Martrat, B., J.O. Grimalt, C. Lopez-Martinez *et al.*, 2004. Abrupt temperature changes in the western Mediterranean over the past 250,000 years. *Science* 306, 1762–5.

McCorriston, J. & F. Hole, 1991. The ecology of seasonal stress and the origins of agriculture in the Near East. *American Anthropologist* 93(1), 46–69.

Meadows, J., 2005. The Younger Dryas episode and the radiocarbon chronologies of the Lake Huleh and Ghab Valley pollen diagrams, Israel and Syria. *Holocene* 15(4), 631–6.

Migowski, C., M. Stein, S. Prasad, J.F.W. Negendank & A. Agnon, 2006. Holocene climate variability and cultural evolution in the Near East from the Dead Sea sedimentary record. *Quaternary Research* 66(3), 421–31.

Moore, A.M.T., 2000. The excavation of Abu Hureyra 1, in *Village on the Euphrates: From Foraging to Farming at Abu Hureyra*, eds. A.M.T. Moore, G.C. Hillman & A.J. Legge. Oxford: Oxford University Press, 105–31.

Moore, A.M.T. & G.C. Hillman, 1992. The Pleistocene to Holocene transition and human economy in southwest Asia: the impact of the Younger Dryas. *American Antiquity* 57(3), 482–94.

Munro, N.D., 2003. Small game, the Younger Dryas, and the transition to agriculture in the southern Levant. *Mitteilungen der Gesellschaft für Urgeschichte* 12, 47–71.

Nadel, D., 1990. The Khiamian as a case of Sultanian intersite variability. *Journal of the Israel Prehistoric Society* 23, 86–99.

Neev, D. & K.O. Emery, 1967. The Dead Sea: depositional processes and environments of evaporites. *Geological Survey of Israel Bulletin* 41, 1–147.

Nesbitt, M., 2002. When and where did domesticated cereals first occur in southwest Asia?, in *The Dawn of Farming in the Near East*, eds. R.T.J. Cappers & S. Bottema. Berlin: Ex Oriente, 113–32.

Nicholls, G. & M. Jones, 2004. Radiocarbon dating with temporal order constraints. *Applied Statistics* 50, 503–21.

Olszewski, D.I., 2006. Issues in the Levantine Epipaleolithic: the Madamaghan, Nebekian and Qalkhan (Levant Epipaleolithic. *Paléorient* 32, 19–26.

Perrot, J., 1968. La préhistoire Palestinenne, in *Supplément*

au Dictionnaire de la Bible, vol. VIII. Paris: Letouzey et Ané, columns 286–446.
van der Plicht, J., B. van Geel, S.J.P. Bohncke *et al*., 2004. The Preboreal climate reversal and a subsequent solar-forced climate shift. *Journal of Quaternary Science* 19(3), 263–9.
Pumpelly, P., 1905. *Explorations in Turkestan: Expedition of 1903*. Washington (DC): Carnegie Institute.
Reimer, P.J., M.G.L. Baillie, E. Bard *et al.*, 2004. IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* 46(3), 1029–58.
Reimer, P.J., M.G.L. Baillie, E. Bard *et al.*, 2006. Comment on 'Radiocarbon calibration curve spanning 0 to 50,000 years BP based on paired $^{230}Th/^{234}U/^{238}U$ and ^{14}C dates on pristine corals' by R.G. Fairbanks *et al.* (*Quaternary Science Reviews* 24 (2005) 1781–1796) and 'Extending the radiocarbon calibration beyond 26,000 years before present using fossil corals' by T.-C. Chin *et al.* (*Quaternary Science Reviews* 24 (2005) 1797–1808. *Quaternary Science Reviews* 25(7–8), 855–62.
Robinson, S.A., S. Black, B.W. Sellwood & P.J. Valdes, 2006. A review of palaeoclimates and palaeoenvironments in the Levant and eastern Mediterranean from 25,000 to 5000 years BP: setting the environmental background for the evolution of human civilization. *Quaternary Science Reviews* 25, 1517–41.
Roche, D., D. Paillard & E. Cortijo, 2004. Constraints on the duration and freshwater release of Heinrich event 4 through isotope modelling. *Nature* 432, 379–82.
Rosen, A.M., 1986. *Cities of Clay: the Geoarchaeology of Tells.* (Prehistoric Archaeology & Ecology.) Chicago (IL): University of Chicago Press.
Rosen, A.M., 2004. 'Phytolith evidence for plant use at Mallaha/Eynan', in Les fouilles à Mallaha en 2000 et 2001: 3ème rapport préliminaire, by F. Valla *et al*. *Journal of the Israel Prehistoric Society* 34, 189–201.
Rosen, A.M., 2007. *Civilizing Climate: Social Responses to Climate Change in the Ancient Near East.* Lanham (MD): AltaMira Press.
Rossignol-Strick, M., 1995. Sea–land correlation of pollen records in the eastern Mediterranean for the glacial-interglacial transition: biostratigraphy versus radiometric time-scale. *Quaternary Science Reviews* 14(9), 893–915.
Rossignol-Strick, M., 1997. Paléoclimat de la Méditerranée Orientale et de l'Asie du sud-ouest de 15,000 à 6000 BP. *Paléorient* 23(2), 175–86.
Rossignol-Strick, M., 1999. The Holocene climatic optimum and pollen records of sapropel 1 in the eastern Mediterranean, 9000–6000 BP. *Quaternary Science Reviews* 18(4–5), 515–30.
Sahu, S.K., 2004. Applications of formal model choice to archaeological chronology building, in *Tools for Constructing Chronologies: Crossing Disciplinary Boundaries*, eds. C.E. Buck & A.R. Millard. (Lecture Notes in Statistics.) London: Springer, 111–27.
Schuldenrein, J. & P. Goldberg, 1981. Late Quarternary palaeoenvironments and prehistoric site distributions in the lower Jordan Valley: a preliminary report. *Paléorient* 7(1), 57–71.
Schwartz, P. & D. Randall, 2003. An abrupt climate change scenario and its implications for United States National Security. http://www.edf.org/documents/3566_AbruptClimateChange.pdf
Severinghaus, J.P. & E.J. Brook, 1999. Abrupt climate change at the end of the Last Glacial period inferred from trapped air in polar ice. *Science* 286, 930–34.
Severinghaus, J.P., T. Sowers, E.J. Brook, R.B. Alley & M.L. Bender, 1998. Timing of abrupt climate change at the end of the Younger Dryas interval from thermally fractionated gases in polar ice. *Nature* 391, 141–6.
Simmons, A.H., 2007. *The Neolithic Revolution in the Near East: Transforming the Human Landscape.* Tucson (AZ): University of Arizona Press.
Spriggs, M., 1989. The dating of the Island Southeast Asian Neolithic: an attempt at chronometric hygiene and linguistic correlation. *Antiquity* 63, 587–613.
Staubwasser, M. & H. Weiss, 2006. Holocene climate and cultural evolution in late prehistoric-early historic West Asia. *Quaternary Research* 66(3), 372–87.
Steier, P. & W. Rom, 2000. The use of Bayesian statistics for ^{14}C dates of chronologically ordered samples: a critical analysis. *Radiocarbon* 42(2), 183–98.
Steier, P., W. Rom & S. Puchegger, 2001. New methods and critical aspects in Bayesian mathematics for 14C calibration. *Radiocarbon* 43, 373–80.
Stevens, L.R., H.E. Wright Jr & E. Ito, 2001. Proposed changes in seasonality of climate during the Lateglacial and Holocene at Lake Zeribar, Iran. *The Holocene* 11(6), 747–55.
Stutz, A., 2004. The Natufian in real time? Radiocarbon date calibration as a tool for understanding Natufian societies and their long-term prehistoric context, in *The Last Hunter-gatherers in the Near East*, ed. C. Delage. (British Archaeological Reports 1320.) Oxford: BAR, 13–37.
Stutz, A., 2009. The 'nature of transitions' in the Stone Age: a comparative approach, in *Transitions in Prehistory: Essays in Honor of Ofer Bar-Yosef*, eds. J. Shea & D.E. Lieberman. Oxford: Oxbow Books, 477–98.
Taylor, K.C., P.A. Mayewski, R.B. Alley *et al.*, 1997. The Holocene–Younger Dryas transition recorded at Summit, Greenland. *Science* 278, 825–7.
Thomas, E.R., E.W. Wolff, R. Mulvaney *et al.*, 2007. The 8.2 ka event from Greenland ice cores. *Quaternary Science Reviews* 26(1–2), 70–81.
Vaks, A., M. Bar-Matthews, A. Ayalon *et al.*, 2003. Paleoclimate reconstruction based on the timing of speleothem growth and oxygen and carbon isotope composition in a cave located in the rain shadow in Israel. *Quaternary Research* 59(2), 182–93.
Valla, F., 1995. The first settled societies — Natufian (12,500–10,200 BP), in *The Archaeology of Society in the Holy Land*, ed. T. Levy. London: Leicester University Press, 169–89.
Verhoeven, M., 2004. Beyond boundaries: nature, culture and a holistic approach to domestication in the Levant. *Journal of World Prehistory* 18(3), 179–282.
Wasylikowa, K., A. Witkowski, A. Walanus, A. Hutorowicz,

S.W. Alexandrowicz & J.J. Langer, 2006. Palaeolimnology of Lake Zeribar, Iran, and its climatic implications. *Quaternary Research* 66(3), 477–93.

Weaver, A.J., O.A. Saenko, P.U. Clark & J.X. Mitrovica, 2003. Meltwater pulse 1A from Antarctica as a trigger of the Bølling-Allerød warm interval. *Science* 299, 1709–13.

Weiss, H. & R.S. Bradley, 2001. What drives societal collapse? *Science* 291, 609–10.

Weninger, B., E. Alram-Stern, E. Bauer *et al*., 2006. Climate forcing due to the 8200 cal yr BP event observed at Early Neolithic sites in the eastern Mediterranean. *Quaternary Research* 66(3), 401–20.

Wieder, M. & G. Gvirtzman, 1999. Micromorphological indications on the nature of the Late Quaternary Paleosols in the southern coastal plain of Israel. *Catena* 35(2–4), 219–37.

Willcox, G., 1999. Agrarian change and the beginnings of cultivation in the Near East: evidence from wild progenitors, experimental cultivation and archaeobotanical data, in *The Prehistory of Food: Appetites for Change*, eds. C. Gosden & J. Hather. London: Routledge, 479–500.

Willcox, G., 2002. Geographical variation in major cereal components and evidence for independent domestication events in western Asia, in *The Dawn of Farming in the Near East*, eds. R.T.J. Cappers & S. Bottema. Berlin: Ex Oriente, 133–40.

Willcox, G., 2004. Measuring grain size and identifying Near Eastern cereal domestication: evidence from the Euphrates valley. *Journal of Archaeological Science* 31(2), 145–50

Willcox, G., 2007. The adoption of farming and the beginnings of the Neolithic in the Euphrates valley: cereal exploitation between the 12th and 8th millennia cal BC, in *The Origins and Spread of Domestic Plants in Southwest Asia and Europe*, eds. S. Colledge & J. Conolly. Walnut Creek (CA): Left Coast Press, 21–36.

Willcox, G. & S. Fornite, 1999. Impressions of wild cereal chaff in pisé from 10th millennium uncal BP at Jerf el Ahmar and Mureybit, northern Syria. *Vegetation History and Archaeobotany* 8(1–2), 21–4.

Wright, H.E., Jr, 1993. Environmental determinism in Near Eastern prehistory. *Current Anthropology* 34(4), 458–69.

Wright, H.E., Jr & J.L. Thorpe, 2003. Climate change and the origin of agriculture in the Near East, in *Global Change in the Holocene*, eds. A. Mackey, R. Battarbee, J. Birks & F. Oldfield. London: Arnold, 49–62.

Wright, K.I., 1994. Ground-stone tools and hunter-gatherer subsistence in southwest Asia: implications for the transition to farming. *American Antiquity* 59(2), 238–63.

Zeidler, J.A., C.E. Buck & C.D. Litton, 1998. Integration of archaeological phase information and radiocarbon results from the Jama River Valley, Ecuador: a Bayesian approach. *Latin American Antiquity* 9(2), 160–79.

van Zeist, W. & J.A.H. Bakker-Heeres, 1982. Archaeobotanical studies in the Levant, part 1: Neolithic sites in the Damascus Basin: Aswad, Ghoraifé and Ramad. *Palaeohistoria* 24, 165–256.

Zielinski, G.A. & G.R. Mershon, 1997. Paleoenvironmental implications of the insoluble microparticle record in the GISP2 (Greenland) ice core during the rapidly changing climate of the Pleistocene–Holocene transition. *Geological Society of America Bulletin* 109(5), 547–59.

Author biographies

Lisa Maher is interested in late Pleistocene and early Holocene hunter-gatherer behaviour in the Near East, North Africa and Arabia. She directs field work at two Epipalaeolithic sites in Jordan, Uyun al-Hammam and Kharaneh IV. A primary theme of her research is the integration of geoarchaeology, lithic analysis and mortuary archaeology to examine the interrelationships between people and their environment.

Ted Banning has conducted archaeological fieldwork in the Near East for 30 years, mainly on the Neolithic in the southern Levant, where he has worked at 'Ain Ghazal and directed a project in Wadi Ziqlab, Jordan. Among his interests are radiocarbon dating, Neolithic architecture, and archaeological survey.

Michael Chazan is an Associate Professor in the Department of Anthropology and Director of the Archaeology Centre at the University of Toronto. He co-directed excavations at the Epipalaeolithic site of Wadi Mataha, Jordan and currently co-directs a research project on the Earlier Stone Age of the Northern Cape Province, South Africa.