Dust clouds, climate change and coins: consiliences of palaeoclimate and economy in the Late Antique southern Levant Dust…

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Dust clouds, climate change and coins: consiliences of palaeoclimate and economy in the Late Antique southern Levant

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Dust clouds, climate change and coins: consiliences of palaeoclimate and economy in the Late Antique southern Levant

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The climate factor has become a focus of much historical and archaeological investigation, encouraged recently by improvements in palaeoclimatic techniques and interest in global climate change. This article examines correlations between climate and history in the Byzantine southern Levant (*c.* 4th–7th centuries AD). A proposed 5th century economic downturn attested to by numismatic trends is shown to coincide with palaeoclimatic evidence for drought. We suggest a climatic ultimate cause for the apparent economic decline. In addition, the relationship between the Dust Veil Index (DVI) and annual precipitation in Jerusalem suggests the likelihood of increased precipitation following the 536 AD volcanic dust veil. This prediction is borne out by high-resolution precipitation reconstructions from Soreq Cave speleothems and by sedimentation records of extreme flash flooding. These finds complement palaeoclimatic reconstructions from Europe showing a drop in precipitation after 536 AD. Drought in Europe and flooding in the Middle East are both expected outcomes of global cooling during volcanic winters, such as those described in historical accounts of the 530s AD.

Keywords palaeoclimate change, 536 AD dust veil, missing century, climate history, Byzantine Levant

Introduction

The aim of this article is to examine instances of consilience between economic and climatic developments in the Byzantine southern Levant (*c.* 4th–7th centuries AD). The question of climate change as an influencing factor in societal reorganization has been at the forefront of a variety of recent historical, archaeological and palaeoclimatic studies (e.g. Brooks 2013; Büntgen *et al.* 2011; 2016; Butzer and Endfield 2012; Caseldine and Turney 2010; Finné *et al.* 2011; Holmgren *et al.* 2016; Izdebski *et al.* 2016; Ljungqvist 2009; Manning 2013; McCormick *et al.* 2012; deMenocal 2001; McIntosh *et al.* 2000; Rosen 2007; Toohey *et al.* 2016; Weiss *et al.* 1993). A number of attempts have been made to examine the effects of climate change and fluctuation on ancient societies in the southern Levant (e.g. Bar-Matthews and Ayalon 2011; Bar-Matthews *et al.* 1998; Bruins 1994; Clarke *et al.* 2016; Ellenblum 2012; Faust and Ashkenazy 2007; Finkelstein and Langgut 2014; Frumkin 2009; Issar and Zohar 2004; Langgut *et al.* 2013; Migowski *et al.* 2006; Rambeau 2010; Riehl 2008; 2009; Riehl *et al.* 2014; Rosen 1995; 1997; 2007). In the case of the Byzantine southern Levant, the influence of climate on history has been debated for over a century (Evenari *et al.* 1982; Frumkin *et al.* 1998; Haiman 1995a: 48; Huntington 1911; Issar 2003: 25–27; Issar and Tsoar 1987; Issar *et al.* 1991; Kedar 1957: 185–86; Reifenberg 1955; Rosen 2007; Rubin 1989).

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Collaboration between palaeoclimatologists, historians and archaeologists in identifying convergences of their data and theories is essential to reconstructing the effects of ancient climate on history (Izdebski *et al.* 2016; McCormick 2013). This strategy exemplifies 'consilience', defined by E. O. Wilson as 'a "jumping together" of facts and fact-based theory across disciplines to create a common groundwork of explanation' (Wilson 1999: 8–9). Application of this approach to the Roman Empire as a whole has shown that in the key period of imperial expansion, *c.* 1–200 AD, a wetter and warmer climate prevailed in Eurasia (Büntgen *et al.* 2011; Luterbacher *et al.* 2012; Manning 2013; McCormick *et al.* 2012; Scheidel 2010: 10–11). This was followed by crisis and climatic instability *c.* 200–300 AD, and partial climatic and political recovery *c.* 300 AD. It has also been proposed that wetter conditions in the Levant beginning in the 4th or 5th century may explain the success of the eastern Roman Empire at this time (Harper 2017a; McCormick *et al.* 2012). In the 7th–8th centuries, by contrast, wetter and warmer climate is contemporaneous with the stabilization of successor states in the former western Roman Empire. Meanwhile in the East, 'the climatic picture remains sketchy for the era and area that saw the rise of the Islamic Empire and its near global economy in the late seventh and eighth century' (McCormick *et al.* 2012: 202).

These studies have highlighted the need for more local and detailed palaeoclimatic histories of the Roman Empire. In line with that goal, the present article examines relationships between the results of the detailed Soreq Cave palaeoclimate record (Bar-Matthews *et al.* 2003; Orland *et al.* 2009) and historical processes within the Byzantine southern Levant. Consiliences include a 5th century drop in both rainfall and numismatic finds, and the mid-6th century global dust veil during the last stage of Byzantine economic/demographic growth in Palestine. Although climatic desiccation in the 7th century is concurrent with the Sasanid and Islamic invasions, these events have a much more complex history. At present, causal linkages between climate change and 7th century conquest in the southern Levant are difficult to establish without recourse to determinism.

Trends of the Byzantine southern Levant and beyond

In the pre-modern historical and archaeological record of the southern Levant,[1] the Byzantine period (*c.* 4th–7th centuries AD) appears to be *the* peak phase of demographic growth and settlement (e.g. Rosen 2016; Safrai 1986: 26–27; 1998; Tsafrir 1996). However, framing this epoch's end is controversial (Avi-Yonah 1958; Avni 2011; 2014; Faust and Safrai 2015: 268–84; Haiman 1995a; 1995b; Hirschfeld 2006; Kennedy 1985; Liebeschuetz 1992: 34; Magness 2003; Milwright 2010: 30). Key methodological issues in that debate include the limitations of using archaeological survey data as a tool for assessing demographic changes, the lack of fine-tuned ceramic chronologies for the later Byzantine–Early Islamic centuries, and the difficulty in accounting for ancient economic growth and decline (Avni 2014: 21–23; Faust and Safrai 2005; 2015; Haiman 2012; Magness 2003; Scheidel 2008). In a recent series of surveys conducted in northern Israel using accurate Kfar Hananya pottery typology (Adan-Bayewitz 1993), the data pointed to a demographic decline already at the beginning of the Byzantine period (*c.* 350–400 AD).[2] Thus, while in broad resolution this period does seem to represent a global maximum of settlement (Hirschfeld 2004; 2007; Rosen 2009; 2016), local and temporal complexity abounds. The following two historical phenomena further suggest the need to refine the paradigm of monolithic growth throughout the Byzantine period in the southern Levant.

The 'missing' 5th century

In his book, *The Missing Century*, Safrai (1998) argued for a 5th century AD (408–491 AD) decline in demographic and economic vitality in the southern Levant, and the eastern Roman Empire generally. This conclusion was based primarily on quantitative numismatic data, particularly the marked decrease in identified bronze coins from the 5th century (Fig. 2). This trend is corroborated by an independent database compiled by Gitler, in which the number of coin finds annually is 4.5 for the years 383–408 AD, 0.4 for 408–489 AD, 0.7 in the 6th century and 0.4 in the 7th century (Gitler and Weisburd 2005; see also Bijovsky 2000–2002; 2012; Guest 2012). Although these trends are uncontested, critics of the 'missing century' hypothesis offer alternative explanations for the numismatic evidence (Bijovsky 2000–2002; 2012; Gitler and Weisburd 2005) or alternative evidence

[1] For the various geographical elements mentioned in the text, see Fig. 1.

[2] This includes the following surveys: 1) the Lower Golan survey (Ben David 2006); 2) the eastern Lower Galilee survey (Leibner 2004: 346–51); 3) the Rosh Pina survey (Stepansky 2012); 4) the Regavim Map (Gadot and Tepper 2012); 5) the eastern Upper Galilee survey (Frankel *et al.* 2001). The decline is evident in the last survey only if one differentiates between sites in the western Upper Galilee and those of the eastern Upper Galilee. Dating of the settlement patterns in these surveys (excluding no. 4) are based on the Kfar Hananya pottery typology developed by Adan-Bayewitz (1993). The decline process is evident in about one third of the settlements.

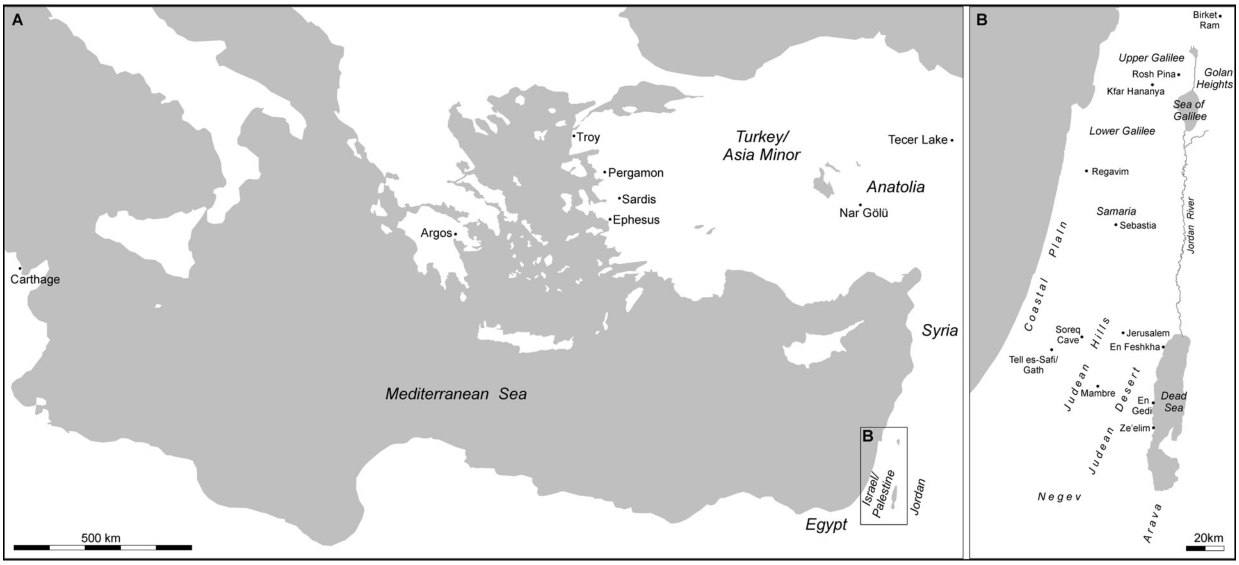

Figure 1. Geographical elements and locations mentioned in the text. (a) The Eastern Mediterranean; (b) Roman-Byzantine Palestine.

suggesting economic viability during the 5th century (Kingsley 2001; 2004). In spite of these criticisms, we adopt Safrai's view, for reasons discussed below.

Bijovsky (2000–2002; 2012) interprets the drop in dated coins as reflective of altered minting and currency practices in response to political and social developments. These include reduced official minting, increased local minting, reuse of 4th century coins in the 5th century, and the proliferation of *minimi* — small, common and mostly undated coins which were often traded in closed purses. In general, we do not deny that such responses may have occurred, but maintain that these are proximate, rather than ultimate, causes of the numismatic trends.

Regarding reuse of old coins in particular, the issue of coin 'shelf life' raises questions as to the dating of archaeological sites based on numismatic finds (Bijovsky 2000–2002; 2012; Safrai 1998: 13–18). In the context of the Byzantine southern Levant, this numismatic critique fits well with the reappraisal of ceramic chronologies spearheaded by Magness, potentially undermining traditional chronologies (Magness 2000; 2003). However, Safrai (2011–2014) has shown from coin hoard data that most coins deposited in a given hoard were issued in the century of deposition (see also Waner and Safrai 2001). This further supports his original assumption (Safrai 1998: 15–18) that the predominance of dated coins was deposited in the century of issue, even if some were not (Bijovsky 2000–2002; 2012; Foss 2015).

Gitler and Weisburd (2005: 552) argued that the 5th century was not a unique minimum for coinage but rather the 4th century was a unique maximum. This would appear to support Bijovsky's argument that the changes reflect specific minting practices instead of real economic growth and decline. It is true that the 4th century is anomalous among multi-centennial coin frequencies. However, we maintain that both the extreme rise in 4th century coinage and the 5th century fall were related to economic, and not merely fiscal, developments (see below).

Guest's (2012) study of nine eastern Mediterranean and six lower Danube sites reveals the 5th century slump in coin finds as widespread and significant on the multi-centennial scale (see also Noeske 2000: 207–09, 213–18, 347–53, 440–44, 468–73, 474–79, 598–607, 610–11, 625–28, 645–65, 672, 677–81, 701ff; Fig. 2b). Guest, like Bijovsky, attributes the decline to decreased imperial minting and extended circulation of 4th century coins, while also hinting at possible underlying economic causes. He cautiously speculates that 'this policy of reduced bronze output was a reaction to the devaluation of the small change already in circulation after the period of intensive production at the end of the fourth century' (Guest 2012: 118).

Both Bijovsky (2000–2002) and Guest (2012: 113) argue that people adapted to the tight monetary policy while maintaining commerce and trade. Foss (2015) seems more inclined to relate the 5th century decline in coin quantity (and quality) to real economic decline, in his review of Bijovsky's (2012) book on coinage in Byzantine Palestine. 'Bijovsky sees the reduction in size and quantity not as decline but as "creative monetary activity", a response to a fiscal crisis. The explanation remains murky, but Bijovsky's

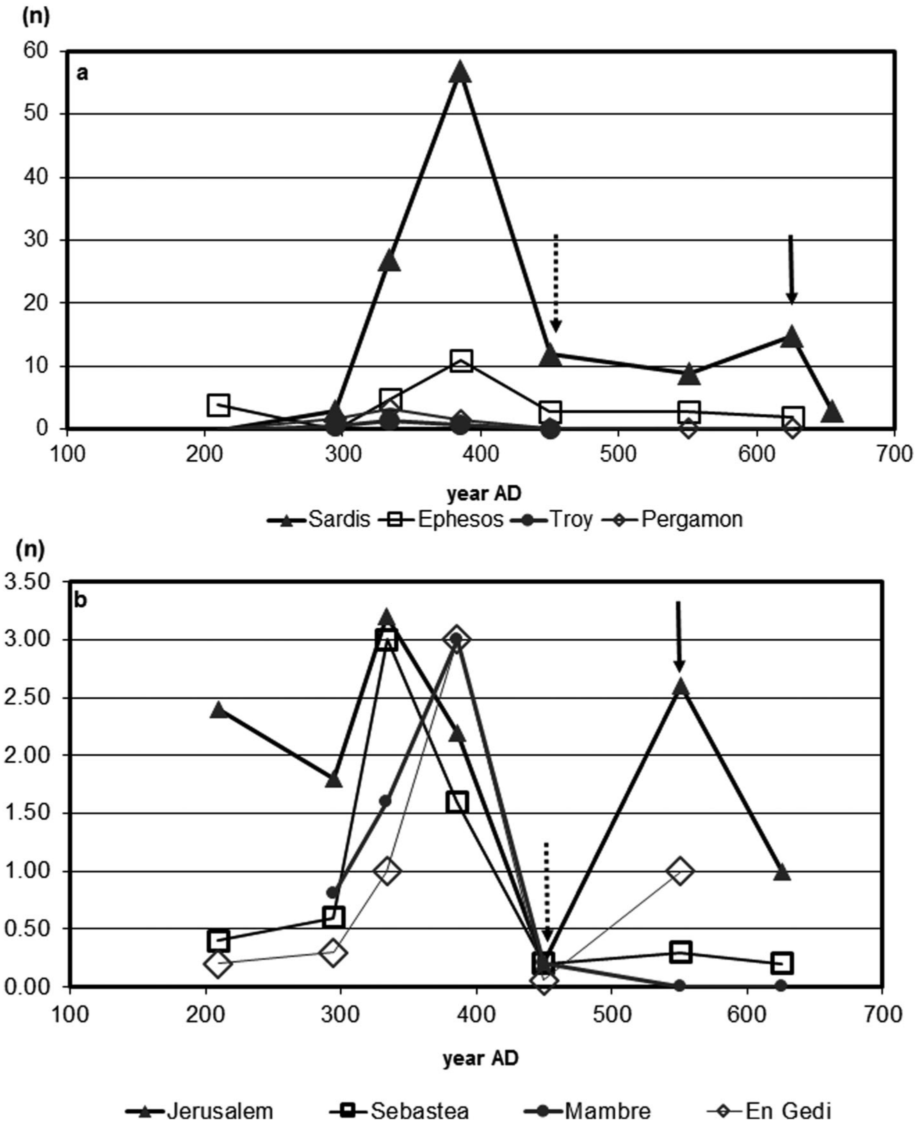

Figure 2. **(a) Average number of coins per year during the Roman-Byzantine periods in selected cities of eastern Asia Minor and Syria; (b) Average number of coins per year during the Roman-Byzantine periods in selected sites in Judea. Dashed arrows highlight the sharp decline in coin quantities during the 5th century AD. Black arrows highlight the partial increase in coin quantities after the 5th century AD.**

analysis of the coinage is exemplary (Foss 2015: 954)'. To be sure, the fact that people adapted to a lack of coinage while maintaining a modicum of commerce and trade does not mean that the economy flourished.

The main criticism of the 'missing century' hypothesis based on other types of evidence, derives from ceramic finds. Kingsley (2001: 54) considers the large 5th century deposits of Palestinian containers in the ceramic record from Carthage, Argos and other Mediterranean sites to be evidence against the disruption of trade networks postulated by Safrai (1998). He even goes so far as to claim that large-scale export from Palestine 'took off' in the first half of the 5th century and that quantitative ceramic evidence suggests 'regular and continuous wine export through the seventh century' (Kingsley 2004: 98). However, he admits that: 'Insufficient numbers of deposits of overlapping date have been excavated in the Mediterranean to assess subtle fluctuations in the scale of long-distance trade during the Byzantine period … ' (*Idem*).

Indeed, in order to rigorously evaluate the trade-related predictions of the 'missing century' hypothesis, a meaningful comparison of trade volume by century is needed for a number of sites. This could be accomplished through standardized quantitative ceramic analyses, as well as shipwreck archaeology. Parker's pioneering research on Mediterranean shipwrecks was recently made into an updated open-source database, a cursory examination of which appears to support a 5th century decline (Parker 1992: fig. 3; Strauss 2013; see also McCormick *et al.* 2013; Morley 2007: 572). However, the dearth of shipwreck excavations (rather than surveys), as well as the scarcity of standardized quantitative ceramic analyses, significantly limits the evidence for export trends (Kingsley 2004: 69). A similar situation abounds for the papyrological evidence. The 5th century is uniquely lacking among the otherwise rich set of economic papyri from Egypt (Harper 2016: 813), precluding meaningful economic conclusions for this short period.

At least until additional data becomes available, it may be concluded from the above that: (1) there is no adequate evidence for economic growth in the eastern Mediterranean of the 5th century, and (2) strictly fiscal explanations of the coin trends do not preclude economic ones. The following economic interpretation of the 5th century numismatic data builds on Safrai's (1998) 'missing century' hypothesis.

The quantity of incidental coin finds for a given century is a factor of the number of transactions and the number of coins used per transaction (Safrai 1998). Thus, both real economic growth and inflation (often caused by over-minting) should be positively correlated with a greater quantity of numismatic finds for a given period. This is exactly what is seen in the Roman Empire of the 4th century, a period of economic growth that has been attributed to monetary expansion (Banaji 2007: 3).

It is not possible in the scope of this article, to separate the influence of inflationary minting on incidental coin finds, from the influence of real economic growth on the same. However, it may be noted that the effects of increased minting on incidental coin finds will be limited if the number of transactions does not increase, i.e. in a stagnant economy. Similarly, economic growth under a tight monetary policy should yield relatively modest increases in coin finds for that period (with the effect of increased transactions potentially cancelled out by deflationary tendencies). This could have been the case for the early 6th century, which was a period of general economic growth (Morrisson and Sodini 2002). For the 6th century, the number of coins per year in Gitler and Weisburd's data is 75% higher than the 5th century, though on a different order of magnitude from that of the 4th century (Gitler and Weisburd 2005; see also Fig. 2; Guest 2012: 111; Safrai 1998). Thus, the very high frequency of 4th century coins seems to represent a combination of inflation and real economic growth, whereas the drastic coin decline in the 5th century reflects economic decline as well as — or inseparable from — monetary contraction.

The 4th century economic boom may be seen as a partial recovery from the 2nd and 3rd century crises associated with the Antonine pandemic (165 AD) and the Plague of Cyprian (250–270 AD), respectively (Banaji 2007; Bowman and Wilson 2009; Harper 2016). One of its effects was increased conglomeration of land and the means of production in large estates throughout the Roman East, as evidenced in particular by Egyptian sources (Bagnall 1992; Banaji 1992; 1999; 2007; Hardy 1968; Hickey 2009). Historical records also point to a similar process in Byzantine Palestine (Gil 2006; Jones 1958; 1964: 797; Safrai 1998: 37–50; Waner and Safrai 2001). Significantly, the 4th century boom was not followed by continued investment and growth, due to speculation and hoarding on the part of wealthy landowners (Ferrer-Maestro 2014).

In the late 5th and early 6th centuries, the numismatic evidence indicates that settlement in the southern Levant recovered, at least partially (Safrai 1998; Fig. 2). However, there were regions, such as the Galilee, where the recovery was not as clear, since the crisis there had been of a greater magnitude (Leibner 2009: 376–89). Perhaps this region's location on the margins of Palestine made it particularly vulnerable to the economic downturn.

The 6th century dust veil

The mysterious dust veil of 536 AD was one of the most widespread and influential climatic events of recorded history, attested to by extensive dendrochronologies, ice-core acid layers and historical sources (Arjava 2005; Baillie 1991; 1994; 2008; Baillie and McAneney 2015; Salzer and Hughes 2007; Stothers 1984; Stothers and Rampino 1983). Thought by some to be the result of a comet or asteroid strike (Baillie 1999; 2007; Rigby *et al.* 2004), recent ice-core and dendroecological evidence supports a volcanic cause (Baillie 2008; 2010; Larsen *et al.* 2008; Sigl *et al.* 2015; Toohey *et al.* 2016; thereby confirming Stothers 1984; 1999; Stothers and Rampino 1983). Recent multi-proxy data has attested to global climate forcing from two volcanic eruptions, one in 535 AD or early 536 AD, and the other in 539 AD or 540 AD (Sigl *et al.* 2015). These eruptions may have been similar to those in Pinatubo, 1991, Krakatau, 1883, or Tambora, 1815 (Larsen *et al.* 2008; Luterbacher 2015; Sigl *et al.* 2015; Toohey *et al.* 2016).

The immediate climatic effect of the dust veil would have been global cooling in the form of a volcanic winter. This would have caused a precipitation plunge in Europe and a rainfall rise in the Middle East (see below, 'The Dust Veil Index and rainfall in the southern Levant'). Indeed, multi-proxy studies have confirmed a marked drop in Eurasian temperatures during the mid-6th century, combined with a drop in western European summer precipitation (Büntgen *et al.* 2011; 2016; Mann *et al.* 2008; McCormick *et al.* 2012). This probably harmed agricultural production in northern Europe, but not necessarily in southern Europe (Toohey *et al.* 2016: 410). The global cooling was apparently sustained by ocean and sea positive feedback mechanisms, perhaps enhanced and continued by an independent decline in solar irradiance *c.* 500–700 AD (Büntgen *et al.* 2016; Manning 2013; Steinhilber *et al.* 2009; Vieira *et al.* 2011). The decade of 536–545 AD was the coldest, of the last 2,000 years, in Eurasia (d'Arrigo *et al.* 2001; Büntgen *et al.* 2011; 2016), and the entire period from 536–660 AD has been labelled the Late Antique Little Ice Age (Büntgen *et al.* 2016).

The dust cloud of 536 AD has been evoked to explain a variety of historical events, including: the rise of Anglo-Saxon dominance in Britain; gold hoarding, social change and ergotism in Scandinavia; the second-phase of the Migration Period Barbarian invasions in central Europe; political turmoil in Italy and Gaul; state instability in China; and the Maya Hiatus in south-eastern Mexico and northern Central America (Axboe 1999; Bondeson and Bondesson 2014; Büntgen *et al.* 2016; Gräslund and Price 2012; Gunn 2000).

In the eastern Mediterranean, Byzantine sources describe a sun-dimming fog which lasted over a year and caused a particularly harsh winter, drought, crop failure, pestilence and wars (Arjava 2005; Stothers and Rampino 1983). The dust veil of 536 AD was listed by Hirschfeld (2006) as one of several factors behind a 6th century settlement decline in the southern Levant, together with a series of earthquakes and the outbreak of Justinianic plague in 541–2 AD (e.g. Meier 2016); the latter may itself have been triggered by the dust veil (Baillie 1991: 234; Büntgen *et al.* 2011; Gage *et al.* 2008; Kausrud *et al.* 2010; Keys 1999; Stenseth *et al.* 2006). In Hirschfeld's view, these 6th century natural disasters marked the beginning of a demographic decline that continued with the Sasanid and Islamic conquests, and was completed by the 8th century (see also Foss 1975; 1997; cf. Avni 2014: 300–31; Findlay and Lundahl 2006). However, the paradigm of a 6th–8th century decline has been questioned (Avni 2014; Magness 2003; Peterson 2005; Schick 1995; 1998; Whitcomb 1988; 1994; 1995; cf. Haiman 2012). Harper (2017b) offers a more nuanced approach, acceding that Justinianic plague, devastating earthquakes, and war with Persia during the 6th century, significantly weakened the eastern Roman Empire, the Levant included. 'But in all, the southern Levant proved the most resilient corner of the entire ancient Mediterranean' (Harper 2017b: 270).

A palaeoclimatic assessment: climatic trends of the Byzantine southern Levant and beyond

The current environment of the southern Levant

The southern Levant (modern day Israel, Jordan and the Palestinian Authority) is situated on the eastern edge of the Mediterranean basin, at the junction between three main climate zones: sub-humid Mediterranean, semi-arid, and arid (Goldreich 2003). The climate is characterized by a sharp north–south and west–east rainfall gradient, yielding an average annual rainfall range from 1300 mm to less than 50 mm. The coastal plain and central hills in the north and west receive relatively high annual rainfall, ranging from 900 mm to 300 mm. The Jordan River valley and the Judean Desert in the east, and the Negev Desert and Arava Valley in the south, are characterized by semi-arid to extreme arid conditions, with annual rainfall of 300 mm to under 50 mm (Fig. 3).

The rainy season ranges from the end of October to the end of April; most of the annual precipitation falls during the months of December, January and February. The rains are frontal rains, characterized by short, intense events separated by long intervals. The climate is also characterized by seasonal fluctuations and cycles of drought (Goldreich 2003).

Long-term research on the response of ecological systems to inter-annual rainfall fluctuations in Israel has demonstrated that semi-arid regions are the most sensitive to the effects of climatic fluctuations (Lavee *et al.* 1998). This is true of annual vegetation in particular (Kutiel *et al.* 1995). Therefore, it can be inferred that climatic fluctuations would have particularly affected annual rangeland vegetation, since most grazing lands are found in semi-arid regions. In drought years, grazing activity moved from semi-arid zones to sub-humid zones causing high grazing pressure on the landscape and potential conflict between nomadic and sedentary people (Shmueli 1980).

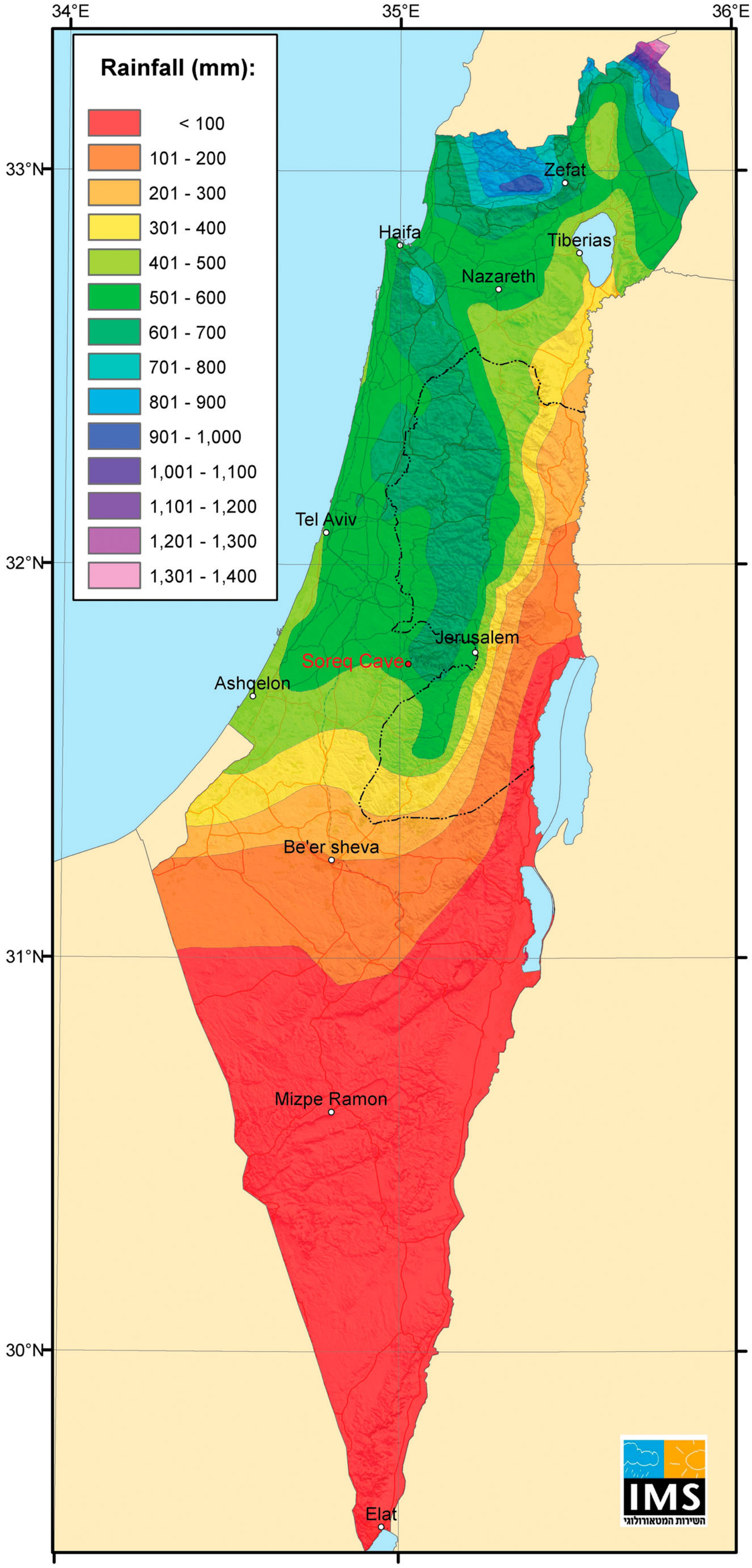

Figure 3. **Mean annual rainfall (mm) in various regions in Israel and the Palestinian Authority from 1981 to 2010 (Courtesy of the Israeli Meteorological Service).**

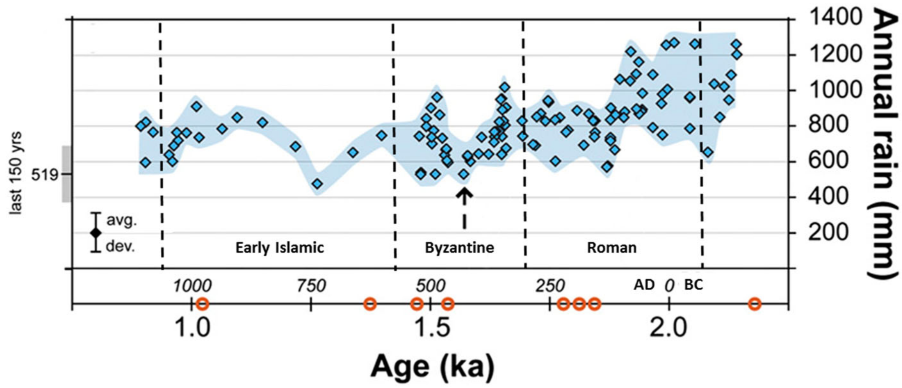

Figure 4. Calculated annual rainfall for the southern Levant during the last 2000 years, according to the Soreq Cave speleothem data. From Orland *et al.* 2009, fig. 6 with permission of Cambridge University Press. The plot estimates annual rainfall (mm) quantities calculated from the δ^{18}O values of wet-season calcite (light fluorescence) assuming a drip water temperature of 19°C and the effect of rainfall quantity on $\delta^{18}O_{rain}$: $\delta^{18}O_{rain}$ (‰VSMOW) = −0.0036 (annual ppt, mm) -3.9; the dashed arrow highlights sharp decreases of annual rainfall in the 5th century CE/1.5 ka. The shaded region represents the range of rainfall estimates calculated for drip water temperature between 18 and 20°C. The average deviation of modern rainfall data from the above equation is shown in the lower left of panel C. The mean and 1 s.d. range of annual rainfall in Jerusalem for the last 150 years, as collected by the Israel Meteorological Survey, is plotted on the left axis.

The Late Holocene climate record of the southern Levant

One of the major proxies used for palaeoclimate reconstruction in the Mediterranean region is the isotopic composition of speleothems (Bar-Matthews and Ayalon 2004; Bar-Matthews *et al.* 1998; Luterbacher *et al.* 2012). The conventional δ^{18}O profile used to reconstruct precipitation (e.g., Bar-Matthews *et al.* 2003; Schilman *et al.* 2002) was performed using a micro driller (0.5 mm in diameter), by drilling every 0.5 to 1.0 mm along the length of the speleothem and measuring the isotopic composition of the collected powder. More recently, a higher resolution study conducted by Orland *et al.* (2009) was based on ion microprobe analysis. In this study, oxygen analyses were made from ~10 μm-diameter spots along a 5.5 cm traverse of a sample that grew in the Soreq Cave between 2200 and 900 years BP, providing a seasonal resolution of rainfall data (Fig. 4).

Orland *et al.*'s (2009) study clearly demonstrates that relatively humid conditions prevailed during the first part of the Roman period (*c.* 100 BC–100 AD), with annual rainfall declining thereafter. The estimated annual rainfall at Soreq Cave during the second part of the Roman period varied from 600–800 mm. Whereas the Roman period was relatively wet, the Byzantine period was characterized by overall greater aridity and sharp rainfall fluctuation, as is also evident from the Dead Sea level record (Bookman *et al.* 2004; Enzel *et al.* 2003; Frumkin 1997). A distinct rainfall decline during the 5th century, recovering in the 6th, and declining steadily in the 7th century AD is evidenced by the significantly high and relatively long δ^{18}O and δ^{13}C peaks of Soreq Cave isotopic profiles (Figs 4, 5).

Vegetation during the Late Holocene

Palynological studies conducted at Birkat Ram in the Golan Heights (Neumann *et al.* 2007a), the Sea of Galilee (Baruch 1986), and the Dead Sea (Neumann *et al.* 2007b; 2010), show that throughout the late Holocene the southern Levant was characterized by Mediterranean-type vegetation. Olive pollen is a useful indicator of agricultural activity because cared-for olive trees produce large quantities of pollen, while abandoned trees do not (Langgut *et al.* 2014). Periods in which there is evidence of more olive pollen than natural woody plant pollen, are interpreted as times of high agricultural activity. Conversely, periods in which there is evidence of increased woody plant pollen and decreased olive pollen, are associated with low agricultural activity. An example recorded in all of the aforementioned studies is the transition from the Byzantine period to the early Islamic period, in which olive cultivation was apparently reduced to a minimum. In the studies by Neumann *et al.* (2007b; 2010), a reduction in the amount of olive pollen between the 3rd and 5th centuries AD was identified in a few Dead Sea sites.[3] This likely reflects a reduction of olive crops and could be correlated with a severe drought that occurred during this period.

[3]In particular, Ze'elim erosion gully ZA2; also core DS7-1SC north-east of Ein Gedi and outcrop EFE in the oasis of Ein Feshkha.

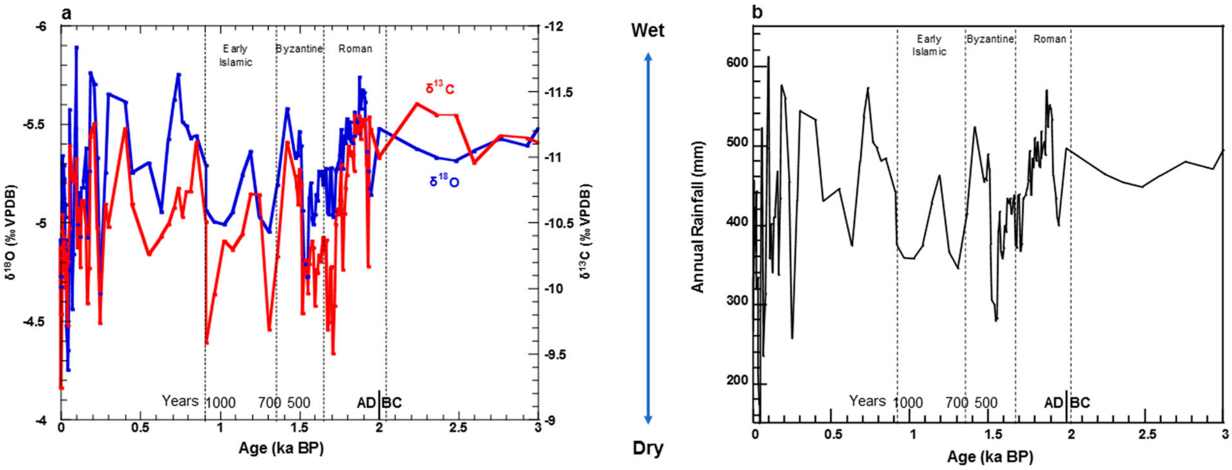

Figure 5. **The $\delta^{13}C$ record of the Soreq Cave speleothems during the last 3000 years. (a) $\delta^{18}O$ and $\delta^{13}C$ isotopic profiles of Soreq Cave speleothems during the last 3000 years. (b) Annual rainfall in the Soreq Cave region calculated for the last 3000 years, based on calibration curve plotted for $\delta^{18}O$ water against annual rainfall quantity (Bar-Matthews *et al.* 2003; their fig. 4).**

The $\delta^{13}C$ isotopic composition of speleothems from the Soreq Cave provides another proxy for the vegetation history record (Bar-Matthews *et al.* 2003; Bar-Matthews and Ayalon 2011). This reconstruction of the climate is based on the fact that lower $\delta^{13}C$ values signal wetter conditions, while higher values represent drier conditions. These trends may reflect relatively higher concentration of C3 vegetation (mainly trees) during the wet periods. It is possible that higher $\delta^{13}C$ values are indicative of an increasing distribution of C4 vegetation (shrubs and grasses) during the dry periods, or that the C3 vegetation was under stress (dry conditions, high temperatures and CO_2 deficiency), resulting in increased $\delta^{13}C$ values of the vegetation by up to 2–3‰. The Soreq Cave data ranges from -9.5‰ to -11.5‰ (Fig. 5a). It shows that over the past millennia, the region has been characterized by Mediterranean-type C3 vegetation. In addition, plotting the speleothem $\delta^{13}C$ record superimposed on the $\delta^{18}O$ record (Fig. 5a) reveals clearly that both exhibit identical trends. Thus, a trend toward lower $\delta^{13}C$ values (-11.3‰) is observed during the 1st century AD (~2000 BP), with significantly higher $\delta^{13}C$ values (-9.5–9.8‰) during the 4th to 6th centuries AD (~1700–1500 BP).

The pollen sediments, even those that have been radiocarbon dated, lack a continuous high-resolution chronology. Furthermore, although abandoned olive trees rapidly increase pollen production after pruning (Langgut *et al.* 2014), the converse does not follow and there may be a sub-centennial time lag between actual abandonment and the record thereof. Therefore, singular reliance on this proxy for historical interpretation on a centennial (or less) scale is problematic. However, when taken together with the speleothem proxy ($\delta^{13}C$), there appears to be good evidence for drought between the 4th and 5th centuries. Interestingly enough, further evidence for a significant drought during this same period comes from additional sites in Eurasia.

Additional evidence for 5th century drought in Eurasia

Several palaeoclimatic reconstructions from different parts of Eurasia corroborate a 5th century dry spell, perhaps beginning in the 4th century (Luterbacher *et al.* 2011: 75, fig. 1b; Luterbacher *et al.* 2012: 105, fig. 2.7; Manning 2013: 133, 149, n. 43). Tree-ring evidence from China suggests that the mid-5th century saw a multi-decadal drought in east and central Asia (Shao *et al.* 2010; Sheppard *et al.* 2004). In the Pyrenees, lake reconstructions suggest that some of the warmest winters of the past 2000 years occurred around 450 AD (Pla and Catalan 2005).

In central Anatolia, a multi-proxy diatom, $\delta^{18}O$ isotopes, and pollen from Nar Gölü lake, attest to a century-and-a-half drought *c.* 400–540 AD, which is corroborated by tree-ring precipitation reconstruction (Woodbridge and Roberts 2011), as well as stalagmite reconstructions (Göktürk 2011; Göktürk *et al.* 2011). This dovetails with Tecer Lake levels, also from central Anatolia: ‘It is therefore particularly significant that both sites register the period centred on the 5th-century AD as the most extreme drought phase of the last two millennia’ (Woodbridge and Roberts 2011: 3386–87).

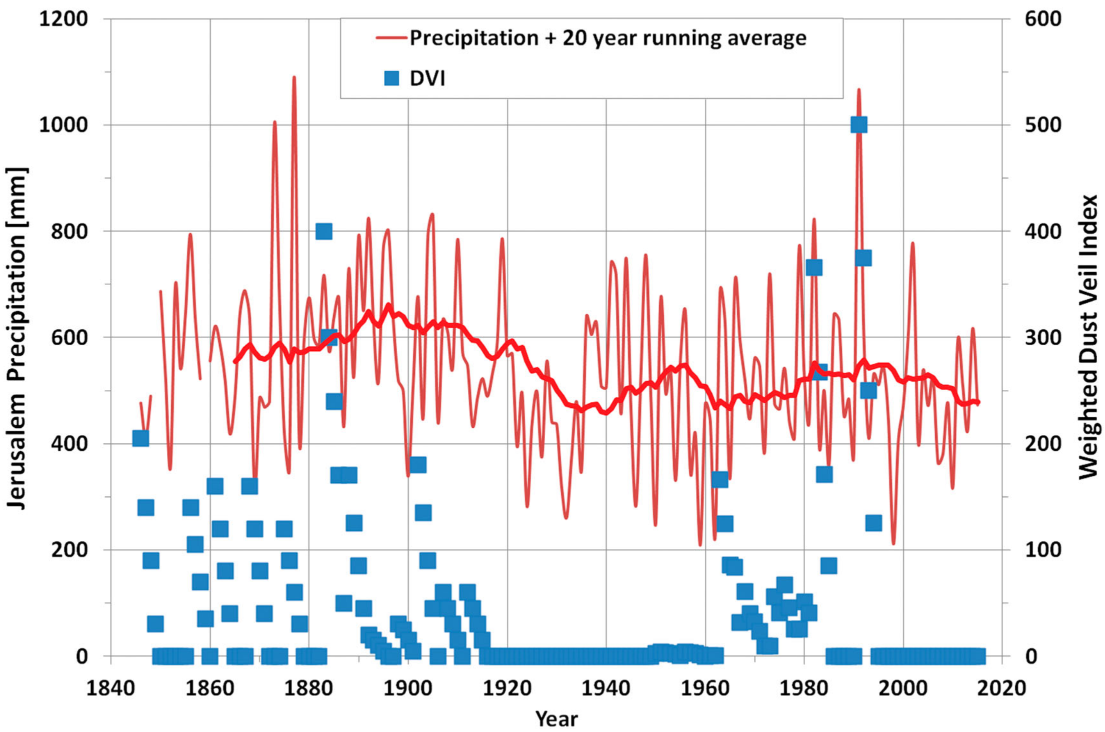

Figure 6. **Annual rainfall in Jerusalem during the last 170 years (light red) together with a 20-year running average (dark red), superimposed on the northern hemisphere weighted Dust Veil Index (DVI) used by Mann *et al*. (2000).**

Several additional studies support a serious drought in Asia Minor centred on the early 5th century, including evidence from written sources (synthesized in Haldon *et al*. 2014: 124–26, 154–60; Manning 2013: 161). The palaeoclimatic evidence from Asia Minor does not necessarily strengthen the palaeoclimatic reconstructions of the southern Levant because the two regions often follow different climatic regimes (Xoplaki *et al*. 2003). However, this century-long drought would have had important economic implications for the entire Roman East.

The Dust Veil Index and rainfall in the southern Levant

Violent volcanic eruptions spew massive quantities of particles (aerosols) into the stable stratosphere layer at altitudes of 10 to 18 km. The main effect of persistent volcanic aerosols in the atmosphere is the blocking of incoming sunlight, which results in global average cooling. However, absorption of solar and terrestrial radiation may cause heating of the high stratosphere, leading to stronger winter polar vortexes (Perlwitz and Graf 1995). This causes more pronounced cooling in the Middle East (Robock and Mao 1992) and enhanced rainfall in the southern Levant (Bookman *et al*. 2014).

Figure 6 presents annual rainfall records from Jerusalem during the last 170 years, superimposed on the northern hemisphere weighted Dust Veil Index (DVI) used by Mann *et al*. (2000). The DVI is a crude numerical estimate of the total quantity of solid matter thrown to the upper atmosphere by volcanic eruptions (Lamb 1970). The rainfall series was constructed using measurements from the Old City of Jerusalem between 1846 and 1973, and since 1974 from the roof of the Generali building in the centre of west Jerusalem. The data was homogenized by linear regression on the overlapping period between 1950 and 1973.

Even for this relatively short period within human history, annual rainfall varies considerably. Extremely wet years (1991, 1877 and 1873) received above 1000 mm, which is double the period average of 540 mm, and nearly five times that of the driest years (1998, 1962, 1959). This year-to-year variation is not always balanced on a decadal scale. For instance, the ten-year span from 1924–1933 recorded 42% less rainfall than the decade of 1888–1897. Analysis of the rainfall record for the entire period reveals that on average the years 1846–1919 witnessed 15% more rainfall than the years 1920–2015 (significant with P-value = 0.001, Student's two-tailed t test). This change is similar in magnitude to the reduction in precipitation projected by the Intergovernmental Panel on Climate Change (IPCC) to take effect by 2100 in the region, due to anthropogenic climate change.

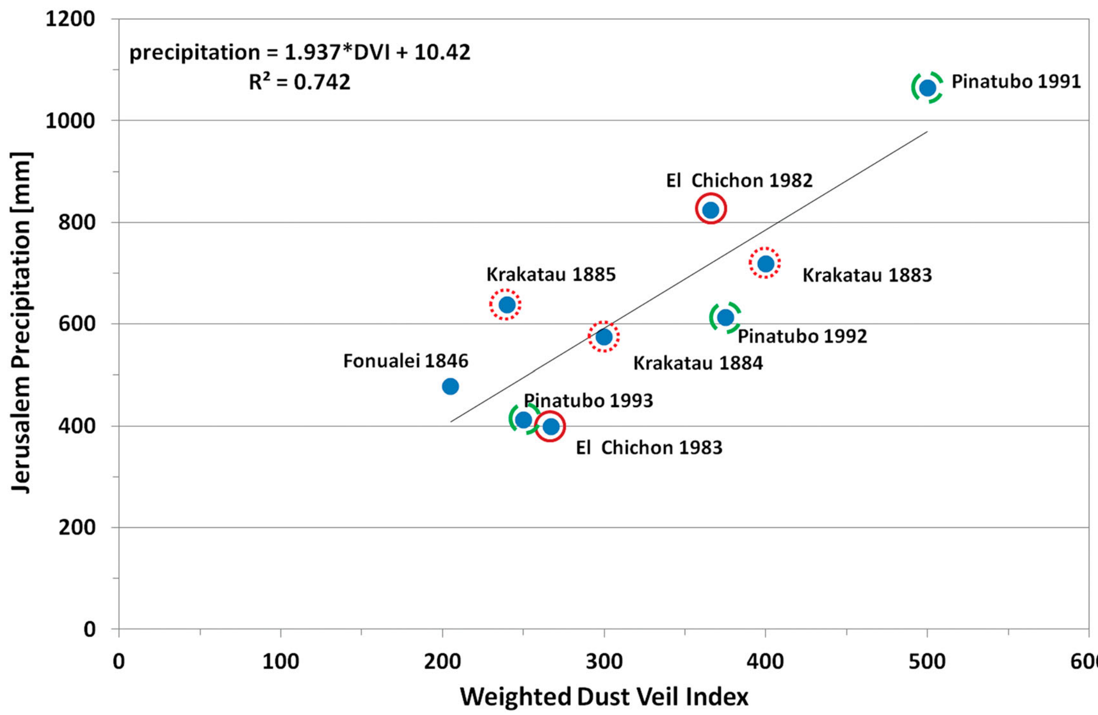

Figure 7. Rainfall in Jerusalem as a function of the northern hemisphere weighted Dust Veil Index (DVI) for years where the DVI values were above 200. Data points for consecutive years of the same volcanic eruption are encircled by the same pattern.

Out of the three wettest years, only 1991 coincided with a high weighted DVI, as indicated by the squares in Fig. 6. However, Fig. 7 shows that a strong correlation exists between rainfall and DVI in years where the weighted DVI is above 200. The average rainfall in years with weighted DVI values above 200 is 22% higher than in other years (significant with P-value = 0.034, Student's two-tailed t test). This indicates that when the concentration of dust in the stratosphere is high, there is a strong probability of a wet year, but not vice versa, as additional factors may induce wet years. Following the two largest eruptions of the past 150 years (Krakatau in 1883 and Pinatubo in 1991), the dust remained in the stratosphere for four years and coincided with relatively high rainfall in the first years after the eruption. These findings may have important implications for the influence of climate on the history of the southern Levant, particularly the 536 AD dust veil.

Discussion

The 5th century

In putting together the historical-archaeological and climatic data presented above, a convergence emerges between the decline in 5th century coin finds and extensive 5th century drought in the southern Levant and Roman East. Is this merely a coincidence or is there a causal relationship? It is our contention that while not deterministically related, there is a causal connection between these climatic changes and economic/demographic responses.

Safrai (1998) originally attributed the apparent 5th century economic decline primarily to the Barbarian invasions and the deterioration of the western Roman Empire (Safrai 1998: 109–27, 130). More recently, the local palaeoclimatic evidence for extensive drought suggests an even more compelling cause (Safrai 2011–2014). However, these two explanations, one climatic and the other cultural, are not mutually exclusive. Cook (2013) has proposed that the 5th century drought evidenced by tree-rings in China may well have affected the Asian steppes, catalysing the Hunnic invasion. Meanwhile, a long 5th century drought in Asia Minor, the centre of the eastern Roman Empire, would surely have had dire economic consequences.

On the supply side, the decline in precipitation must have caused a decrease in agricultural output for both the southern Levant and Asia Minor. This multi-regional drought would have put particular strain on the Empire's buffering capacity through trade. On the demand side, decreased agricultural output combined with the Barbarian invasions could have caused population decline, which in 5th century Rome was acute (Twine 1992). This decline, combined with the disruption of trade brought on by the Barbarian invasions (Morrisson and Sodini 2002: 172; Stathakopoulos 2007), must have harmed demand for Levantine exports, as originally suggested by Safrai (1998). Such downward shifts of supply and demand would have led directly to a drop in quantities sold and traded, and hence in the number of incidental coin finds for the period.

The 5th century has been singled out as a watershed of divergent climate patterns between central Europe and central Asia, perhaps explaining the differing fates of the eastern and western Roman Empires (McCormick *et al.* 2012). It has been proposed that these climatic patterns reflect a shift from a more positive to a more negative North Atlantic Oscillation (NAO) (Harper 2017a; see also Manning 2013: 160). Our analysis suggests that this explanation based on a wide-reaching climatic mechanism is inapplicable to the southern Levant. Black (2011) has shown that a correlation exists between NAO positive winters and the chance of very high precipitation in Israel, but not between NAO negative conditions and drought. Harper's (2017a) proposition of a more positive NAO in the early 5th century does not line up with the evidence presented here for drought. It is likely that other climatic mechanisms were more influential in the 5th century southern Levant.

The 6th century

The correlation between the weighted Dust Veil Index (DVI) and precipitation in Jerusalem suggests a strong likelihood that the 536 AD dust veil would have caused heightened rainfall in the southern Levant. This prediction is borne out by the Soreq Cave speleothem palaeoclimatic reconstructions (Bar-Matthews *et al.* 2003; Orland *et al.* 2009; Figs 4, 5) as well as Dead Sea levels (Enzel *et al.* 2003; Migowski *et al.* 2006; Fig. 5). Additional evidence derives from ephemeral stream sedimentation records. In northern Jordan, Late Byzantine sediments dominated by pseudoplastic debris flows, including large boulders, attest to extreme flash flooding in Wadi Queilbeh at the site of Abila, and in nearby Beit Ras (Lucke *et al.* 2012). These were radiocarbon-dated to 521–667 AD, although insufficient bleaching of quartz grains hindered precise dating (Lucke and Schmidt 2017). It has been suggested that the onset of this sedimentation coincided with the 536 AD event (Lucke 2014; Lucke and Schmidt 2017; Lucke *et al.* 2012). In southern Jordan, in and around Petra, there is also evidence for rapid Late Byzantine sedimentation (Lucke, pers. comm.). In the Negev, Greenbaum *et al.* (2000: 961) identify the Late Byzantine–Early Islamic period (1380–880 BP) as one marked by numerous high magnitude floods in Nahal Zin. Throughout the Mediterranean, sedimentation records portray the 6th century as a peak period of flooding (Luterbacher *et al.* 2012: 109, 111, 115–16).

The evidence from the southern Levant for heightened precipitation and extreme flash flooding complements the evidence from Europe for drought during the same period; both were the result of global cooling in the immediate aftermath of the dust veil and during the Late Antique Little Ice Age. The question is, were these rains a blessing or a curse for the southern Levant? In this sub-humid to arid region, extra rainfall is usually a boon for agriculture and may have had a positive effect on Palestine in the short term (*c.* 536–545 AD). The localized rise in rainfall could have improved local yields just when other parts of the Empire were dealing with drought and crop failure. Historical sources relate that in the aftermath of the dust veil, Italy imported food from Histria in present-day Romania (Arjava 2005); it is possible that Palestine was another such source of emergency food imports. However, this scenario depends on relatively moderate rainfall intensity. Although the sudden 6th century hike in reconstructed precipitation from Soreq Cave speleothems does not yield particularly extreme levels on the millennial time scale, this data fails to reflect the intensity of rain events. The sedimentation evidence suggests extreme flash flooding which could have been devastating for agricultural yields and infrastructure (Lucke 2011: 593). However, it is not yet clear how geographically widespread these floods were within the southern Levant.

Thus, more evidence is needed to determine whether the immediate aftermath of the 536 AD dust veil was the first in a series of disasters, or a boost of vitality preceding them. Either way, it is likely that after a few years the immediate climatic effects of the dust veil would have worn off, superseded by Justinianic plague, earthquakes and Persian conquest (Harper 2017b: 254). Of course, the economic and demographic consequences of these events have also been debated (Kennedy 2007; Meier 2016; Morrisson and Sodini 2002: 193–95). Sarris (2006: 224) has suggested that in the aftermath of the plague, peasants and labourers benefited economically from the population decrease that left their services in low supply. Notwithstanding, by the 560s AD the entrenchment of aristocratic power led to the failure of Justinian's reforms, a reversal of the trend of improved living standards, heightened social tensions, and the weakening of Asia Minor in the face of military threat (Sarris 2006: 228–34). Indeed, throughout the Byzantine Empire there are signs of economic and demographic decline, manifest in construction, urban design and trade, beginning in the second half of the 6th century (Morrisson and Sodini 2002: 186, 189–91, 211–12, 219–20). However, evidence for settlement decline in the southern Levant during this period has thus far been somewhat sparse (e.g. Ariel 2002: 299–300; 2013; Briend and Humbert 1980; Hirschfeld 2007).

This raises the challenge of detecting economic changes during this period, which may be met with recourse to the archaeological sciences. The economic effects of the dust veil should be detectable in the form of precision-dated changes in archaeobotanical and archaeozoological records. For instance, trends in the relative quantities of cash crops, such as wine grapes in archaeobotanical assemblages, may be an important gauge of economic growth and decline. Evidence for this sort of fluctuation in commercial-scale viticulture will play a critical role in the debate on the source of the Byzantine Gaza wine, and its response to the Late Byzantine perturbations (Decker 2009: 138–39; Mayerson 1985; McCormick 2012: 69–70; Jon Seligman pers. comm.). Similar considerations may be applied to other types of agricultural crops, such as wheat and barley (Fuks *et al.* 2016). Meanwhile, the known chronological specificity of the dust veil event should facilitate isolation of the climate variable in historical-economic reconstructions of the 6th century. This requires that a high-resolution chronology be attained for the archaeological evidence.

The 7th century?

A natural continuation of this presentation of proposed palaeoclimatic and historical consiliences might be the Persian and Islamic conquests of the 7th century. This is tempting considering the apparent rainfall decline of the 7th century (Figs 4, 5b), the decline in olive pollen (Neumann *et al.* 2007b; 2010), and the pressure that aridification places on nomadic pastoralists mentioned above (Shmueli 1980; see also Koder 1996: 277–78; McCormick *et al.* 2012: 190, 197). Indeed, border disputes in ancient Greece (Howe 2008: 77–98), the Hun and Avar migrations into the western Roman Empire (McCormick *et al.* 2012: 203), and the later Turkish and Mongol invasions in the East (Kennedy 1986: 347; Khazanov 1994: 234–36; Xoplaki *et al.* 2016: 247), have all been attributed to the drought-exacerbated search for rangeland by nomadic pastoralists (see also discussion in Halsall 2007: 417–54). Much the same could be argued for the Arabian tribes united by Muhammad, but that would be beyond the scope of the present article. Applying a simple climatic explanation to such an earth-shattering and complex historical event as the Islamic conquest would perforce be deterministic (Butzer 2012; Butzer and Endfield 2012; McAnany and Yoffee 2010). By contrast, the historical processes discussed above differ in at least two important respects.

First, the local economic/demographic effects of the 5th century numismatic decline and the 6th century dust veil can be more easily established than those of the 7th century Sasanid and Islamic conquests. In the case of the 5th century, the chronological period is limited to one century, and the numismatic and climatic data presented are relatively straightforward. The 6th century dust veil, although of global proportions, is very chronologically specific, which facilitates isolation of the climate variable in high-resolution palaeoclimatic and archaeological proxy data. This is very difficult to do for the 7th century, at which time both conquest and climate change coincided in the southern Levant.

Second, in line with the ‘intensification and abatement’ model (Avni 2014: 16, 352; Horden and Purcell 2000: 263–70; LaBianca 1990), these cases contribute to a more complex, rather than monolithic, picture of the period. The notion of extended and uniform economic expansion in the Byzantine southern Levant is no longer tenable, nor, it seems, is the paradigm of protracted decline in the post-Byzantine period (Avni 2011; 2014; Magness 2003; Walmsley 2007; Whittow 2003). That said, the 7th century conquests may have caused long-term disruptions in some regions, and the new regimes did alter state structures, military dispositions and political allegiances (e.g. Haldon 2010; Kennedy 1985). Coinage for this century in the southern Levant displays regional complexity, with monetary continuity in some sites, monetary weakening in others, and demonetarization in still others (Walmsley 2010). The economic history of the 7th-century Byzantine-Islamic transition is both too complex and insufficiently researched to identify meaningful climatic consiliences at present.

Conclusion

As climate becomes an ever-larger issue in the study of the human past, the identification of converging trends in history and climate is an increasingly important task. In this article, we identified three instances of such correlations in the southern Levant, during each of the 5th, 6th and 7th centuries. For the first two cases, causal connections were argued for.

Regarding the 5th century, our re-examination of Safrai's 'missing century' hypothesis demonstrates that economic decline interpretations and purely fiscal explanations of the numismatic trends are not mutually exclusive. Neither is the economic decline approach refuted by other evidence. Rather, the 'missing century' hypothesis is valid and has explanatory value both on the centennial and multi-centennial scale. In light of current evidence for drought during the same period in the southern Levant and other regions, notably Anatolia, we suggest a climatic ultimate cause for this proposed economic decline. Proximate causes may still include Barbarian invasions in the western Roman Empire, demographic decline and altered imperial fiscal policies.

Regarding the 6th century, previous studies have provided evidence for cooling and drought in Europe following the extreme volcanic eruptions of the 530s/540 AD. Here we add a Levantine perspective which predicts increased rainfall following the same volcano-induced cooling — a forecast supported by a strong correlation between the weighted Dust Veil Index (DVI) and annual precipitation in Jerusalem. This prediction is borne out by palaeoclimatic re-constructions from Soreq Cave speleothems and Dead Sea levels, as well as evidence for extreme flash flooding in riverbed sediments in Transjordan and the Negev. Drought in Europe and flooding in the Middle East are both expected outcomes of global cooling during volcanic winters, such as those described in historical accounts of the 530s AD. The economic and demographic repercussions of the volcano-induced precipitation rise in the southern Levant are less clear-cut. After a few years, however, the combined effects of plague, earthquakes and war likely overshadowed the short-term impact of the dust veil.

In the 7th century, a trend toward aridification is coeval with the Sasanid and Islamic conquests. The possibility of a causal connection cannot be ruled out, but neither can it be easily established at present. This raises a final point. Identifying consilience requires good data and careful interpretation. Arjava (2005: 74) has noted the 'danger of hastily dating all suitable economic change precisely to the middle of the sixth century' or any 'predetermined crisis point' in local archaeological studies.

Here, the most up-to-date and relevant data available were employed and inferences were drawn carefully. Nevertheless, it is certain that the evidence will be greatly enhanced in coming years. This will not only include more and improved regional and micro-regional palaeoclimatic data (Burstyn *et al*. 2016; Luterbacher *et al*. 2016), but also historical and archaeological inquiries spurred by the desire to test empirically the types of predictions and hypotheses presented here. A good example of the latter is the Byzantine Bio-Archaeology Research Program of the Negev (BYBAN), which brings together the range of archaeological sciences to answer historical questions on sustainability, collapse and resilience (Fuks *et al*. 2016; Tepper *et al*. 2015; 2017). By focusing on processes that have been largely overlooked in archaeological and historical studies of the Byzantine southern Levant, it is hoped that this article will encourage new lines of future research.

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