Regional Environmental Change (2019) 19:2287–2297
https://doi.org/10.1007/s10113-018-01460-w

ORIGINAL ARTICLE

300-year drought frames Late Bronze Age to Early Iron Age transition in the Near East: new palaeoecological data from Cyprus and Syria

David Kaniewski[1,2,3] · Nick Marriner[4] · Joachim Bretschneider[5] · Greta Jans[6] · Christophe Morhange[7,8] · Rachid Cheddadi[9] · Thierry Otto[1,2] · Frédéric Luce[1,2] · Elise Van Campo[1,2]

Received: 17 October 2018 / Accepted: 20 December 2018 / Published online: 19 January 2019
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

Abstract

In Eastern Mediterranean history, 1200 BCE is a symbolic date. Its significance is tied to the important upheavals that destabilised regional-scale economic systems, leading to the dislocation of mighty Empires and, finally, to the "demise" of a societal model (termed "the Crisis Years"). Recent studies have suggested that a centuries-long drought, of regional scale, termed the 3.2 ka BP event, could be one of the motors behind this spiral of decline. Here, we focus on this pivotal period, coupling new palaeoenvironmental data and radiocarbon dates from Syria (the site of Tell Tweini) and Cyprus (the site of Pyla-*Kokkinokremnos*), to probe whether climate change accelerated changes in the Eastern Mediterranean's Old World, by inducing crop failures/low harvests, possibly engendering severe food shortages and even famine. We show that the Late Bronze Age crisis and the following Dark Ages were framed by an ~ 300-year drought episode that significantly impacted crop yields and may have led to famine. Our data underline the agro-productive sensitivity of ancient Mediterranean societies to environmental changes, as well as the potential link between adverse climate pressures and harvest/famine.

Keywords Late Bronze Age crisis · Climate change · Drought · 3.2 ka BP event · Food shortages · Famine · Eastern Mediterranean

Introduction

The Late Bronze Age (LBA) crisis (or "collapse"/decline) is traditionally defined as a period of deep-seated change marked by a weakening of economic systems at a regional scale, the erosion of political powers and vast population movements in the Mediterranean (e.g. Weiss 1982; Neumann and Parpola 1987; Singer 1999; Killebrew 2005; Gilboa 2006–2007; Killebrew and Lehmann 2013; Driessen 2018). This event, centered on ~ 3200 BP but spanning ~ 300 years (Dark Ages), has fueled strong debates due to the period's complexity in addition to the "climate hypothesis" (3.2 ka BP event)

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10113-018-01460-w) contains supplementary material, which is available to authorized users.

✉ David Kaniewski
david.kaniewski@univ-tlse3.fr

[1] Université Paul Sabatier-Toulouse 3, EcoLab (Laboratoire d'Ecologie Fonctionnelle et Environnement), Bâtiment 4R1, 118 Route de Narbonne, 31062 Toulouse cedex 9, France

[2] CNRS, EcoLab (Laboratoire d'Ecologie Fonctionnelle et Environnement), 31062 Toulouse cedex 9, France

[3] Secteur Biologie-Médecine-Santé, Institut Universitaire de France, 103 boulevard Saint Michel, 75005 Paris, France

[4] CNRS, Laboratoire Chrono-Environnement UMR6249, Université de Franche-Comté, UFR ST, 16 Route de Gray, 25030 Besançon, France

[5] Department of Archaeology / Ancient Near East, Faculty of Art and Philosophy, Ghent University, Sint-Pietersnieuwstraat 35, 9000 Ghent, Belgium

[6] Near Eastern Studies, Faculteit Letteren, Katholieke Universiteit Leuven, Blijde-Inkomststraat 21, 3000 Leuven, Belgium

[7] CNRS, IRD, INRA, Collège de France, CEREGE, Aix-Marseille Université, Aix-en-Provence, France

[8] Recanati Institute for Maritime Studies, University of Haifa (RIMS), Mount Carmel, 31905 Haifa, Israel

[9] Université Montpellier II, CNRS-UM2-IRD, ISEM, Montpellier, France

that has been proposed to partially explain the sudden decline of powerful states and empires (e.g. Kaniewski et al. 2008; Kaniewski et al. 2010; Litt et al. 2012; Kaniewski et al. 2013a; Langgut et al. 2013, 2014, 2015; Schiebel and Litt 2018).

While numerous data and hypotheses have already been reported in two review papers (Kaniewski et al. 2015, 2017) and in the scientific literature (e.g. Cline 2014; Manning 2018) concerning the potential impact of environmental stresses on complex societies 3200 years ago, one of the main issues revolves around chronology. A recent study, based on tephrostratigraphy, has strengthened the original temporal framework (~ 3200 cal BP) by showing that drought occurred just after the FL-Etna eruption dated to ~ 3300 BP (3448–3334 cal BP according to Coltelli et al. 2000, or 3359–3171 cal BP according to Sadori and Narcisi 2001) in numerous cores from the Central Mediterranean (Zanchetta et al. 2018). This anchor point is key to precisely constraining the chronology of the 3.2 ka BP event that, until now, has been challenging.

Concerning the causes underpinning the LBA crisis, it has been argued that several anthropogenic factors, such as technological innovations (Weiss 1982) leading to changes in warfare (Drews 1993), internal downfalls due to the weakening of economic systems and rising inequalities leading to political struggles (Neumann and Parpola 1987; Weiss 1982; Bryce 2005; Driessen 2018; Jung 2018a), were some of the reasons behind the demise of the Eastern Mediterranean's core civilizations. While these various causes may all have played out at the end of the LBA, written evidence also reports widespread food shortages in the Eastern Mediterranean. Letters on clay tablets from Turkey and Syria and inscriptions from Egypt recount the "deteriorating" environmental conditions and emphasise the requests for food during a particularly harsh period (e.g. Brinkman 1968; Nougayrol et al. 1968; Butzer 1976; Bryce 2005; Cohen and Singer 2006). Based on these written documents, recent palaeoenvironmental-based studies have highlighted a centuries-long drought that was coeval with the LBA crisis (see full references in Kaniewski et al. 2015; Kaniewski and Van Campo 2017). As societies in semi-arid contexts are generally sensitive to climatic, hydrological and environmental changes, especially those that affect food production and resources (e.g. Reuveny 2007; Glaser et al. 2017), we suggest that drought may have partly contributed to the fall of the Old World 3200 years ago by sparking poor harvests and famine. The competition for increasingly scarce resources probably led to emigration towards fertile agricultural zones, creating social tensions and conflicts in receiving areas (e.g. Reuveny 2007). The Sea Peoples (e.g. Artzy 1987; Singer 2000; Gilboa 2006-2007; Killebrew and Lehmann 2013), that first overwhelmed the Aegean and Eastern Mediterranean empires and kingdoms before hitting Egypt, were probably a flow of migrants looking for new fertile lands to settle. Their ranks probably swelled in each country they crossed, also undermined by climatic stress and food shortages, during their raids in the Eastern Mediterranean (Kaniewski et al. 2011).

Even if past and present climate changes can influence human societies in various ways (potentially triggering migration or conflict; Glaser et al. 2017; Wetter et al. 2014; Camenisch et al. 2016; Pribyl 2017), trying to prove a potential link between climate pressures, poor harvests and site abandonment 3200 years ago remains challenging even in the Eastern Mediterranean. Evidence must be garnered from reliable archaeological contexts where all datasets can be connected without any distortions. While radiocarbon (^{14}C) chronologies can be obtained from reliable archaeological layers such as those at Tell Tweini (Syria) and Pyla-*Kokkinokremnos* (Cyprus), no palaeoenvironmental reconstruction has, as yet, been undertaken on these sedimentary deposits, despite their archaeological richness (e.g. Bretschneider and Van Lerberghe 2008; Bretschneider et al. 2010; Karageorghis and Kanta 2014; Bretschneider et al. 2017; Bretschneider and Jans 2019). Comparing and contrasting the data from the same sedimentary deposits at these two sites circumvents any historical distortion because the environmental indicators, ^{14}C chronology and human artefacts would all derive from the same samples.

Here, we present ^{14}C data and in situ palaeoecological reconstructions from Tell Tweini and Pyla-*Kokkinokremnos* (Fig. 1) to investigate the local environment at the end of the LBA. These two sites were selected because they were both significantly affected by the LBA crisis. We also discuss long-term climate reconstructions to explore the potential impact of environmental pressures on harvests. These large datasets offer the first testimony covering a large geographical window from local archaeological deposits to the Mediterranean basin and demonstrate that a climate shift was coeval with the 3.2 ka BP event.

Material and methods

Syria The samples originate from the coastal site of Tell Tweini (field A; Fig. 2), which probably constituted the ancient harbour of Gibala, the southernmost limit of the powerful Ugarit kingdom (Bretschneider and Van Lerberghe 2008; Bretschneider et al. 2010; Bretschneider and Jans 2019). Tell Tweini (35° 22′ 17.93″ N, 35° 56′ 12.60″ E, elevation 19 to 27 m a.s.l., surface 11.6 ha) lies east of Jableh (Syria), ~ 1.75 km from the present coastline. Quality control on sample collection for ^{14}C measurements was undertaken during excavations. Only samples from reliable contexts (with clear parallels to meaningful ceramic assemblages and occupation levels) were used. Samples were selected from primary contexts, with an emphasis placed on short-lived samples (seeds or olive stones). All botanical macro-remains were determined using optical and scanning electron microscopes. Samples

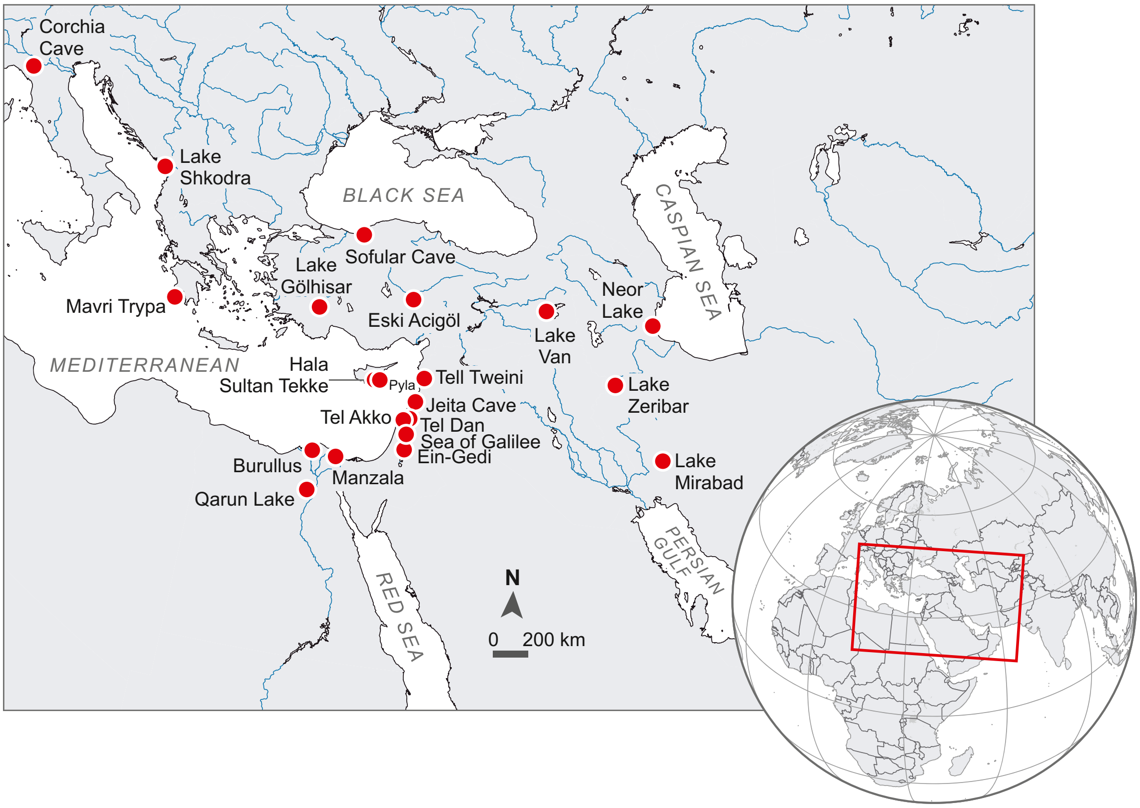

Fig. 1 Location of the main sites discussed in this study. The map denotes places where the 3.2 ka BP event is recorded (see the manuscript for full references)

were dated by Beta Analytic (Miami, Florida) and Poznan Radiocarbon Laboratory (Poznan) using standard accelerator mass spectrometry. Previously reported chronologies (Kaniewski et al. 2011) are here complemented with new and unpublished ^{14}C dates (Fig. 3; see Supplementary material).

Botanical macro-remains for ^{14}C measurements and palynological slides originated from the same samples. Samples were prepared for pollen analysis using standard procedures for clay deposits (fully detailed in Faegri and Iversen 1989). Pollen grains were counted under × 400 and × 1000 magnification using an Olympus microscope. Pollen frequencies (expressed as percentages) are based on the terrestrial pollen sum, excluding local hygrophytes, aquatic taxa and spores of non-vascular cryptogams. The average concentration is 8874 ± 98 pollen grains cm^{-3}. The mean pollen sum is 443 ± 5 pollen grains, with a minimum of 425 pollen grains. The median value is 447 pollen grains, with a 25th percentile of 428 pollen grains and a 75th percentile of 450 pollen grains. The mean number of taxa is 36 ± 3 taxa, with a minimum of 31 taxa. The median value is 36 taxa, with a 25th percentile of 35 taxa, and a 75th percentile of 37 taxa. The dataset was transformed into pollen-derived biomes (Fig. 2) according to the method developed by Tarasov et al. (1998). The biomes are displayed as boxplots (Fig. 2; see Supplementary material). Previous data have demonstrated that, at Tweini, *Olea* pollen-type originated from the wild varieties during the Bronze and Iron Ages despite archaeological evidence for olive cultivation in the northern Levant (Kaniewski et al. 2009).

Cyprus The samples originate from the coastal site of Pyla-*Kokkinokremnos* (sector 5; Fig. 2; Karageorghis and Demas 1984; Karageorghis and Kanta 2014; Bretschneider et al. 2015; Bretschneider et al. 2017), located near the village of Pyla on the southeast coast of Cyprus (Fig. 2). The site lies about 10 km east of Larnaca, ancient Kition, and some 25 km southwest of Enkomi, two major Bronze Age centres of the 13th–12th BCE, the period known as Late Cypriot IIC and IIIA. Pyla-*Kokkinokremnos* (34° 59′ 27″ N, 33° 42′ 51″ E) culminates at an altitude of ~ 83 m.a.s.l. Its summit forms a large and irregularly shaped plateau, with a surface area of ~ 6 ha and a maximum of ~ 300 m by ~ 650 m large. Samples were taken from a large rectangular shaft dug into the bedrock (Bretschneider et al. 2017). At the bottom of the shaft, a 30-cm-thick ash layer underneath an oval stone structure contained a large intact jug and an inverted open terracotta recipient filled with burnt organic material. The bottom of the shaft was also cut out of the rock. Samples were selected from this primary context, with an emphasis placed on short-lived samples (seeds or olive stones). All botanical macro-remains were determined using optical and scanning electron

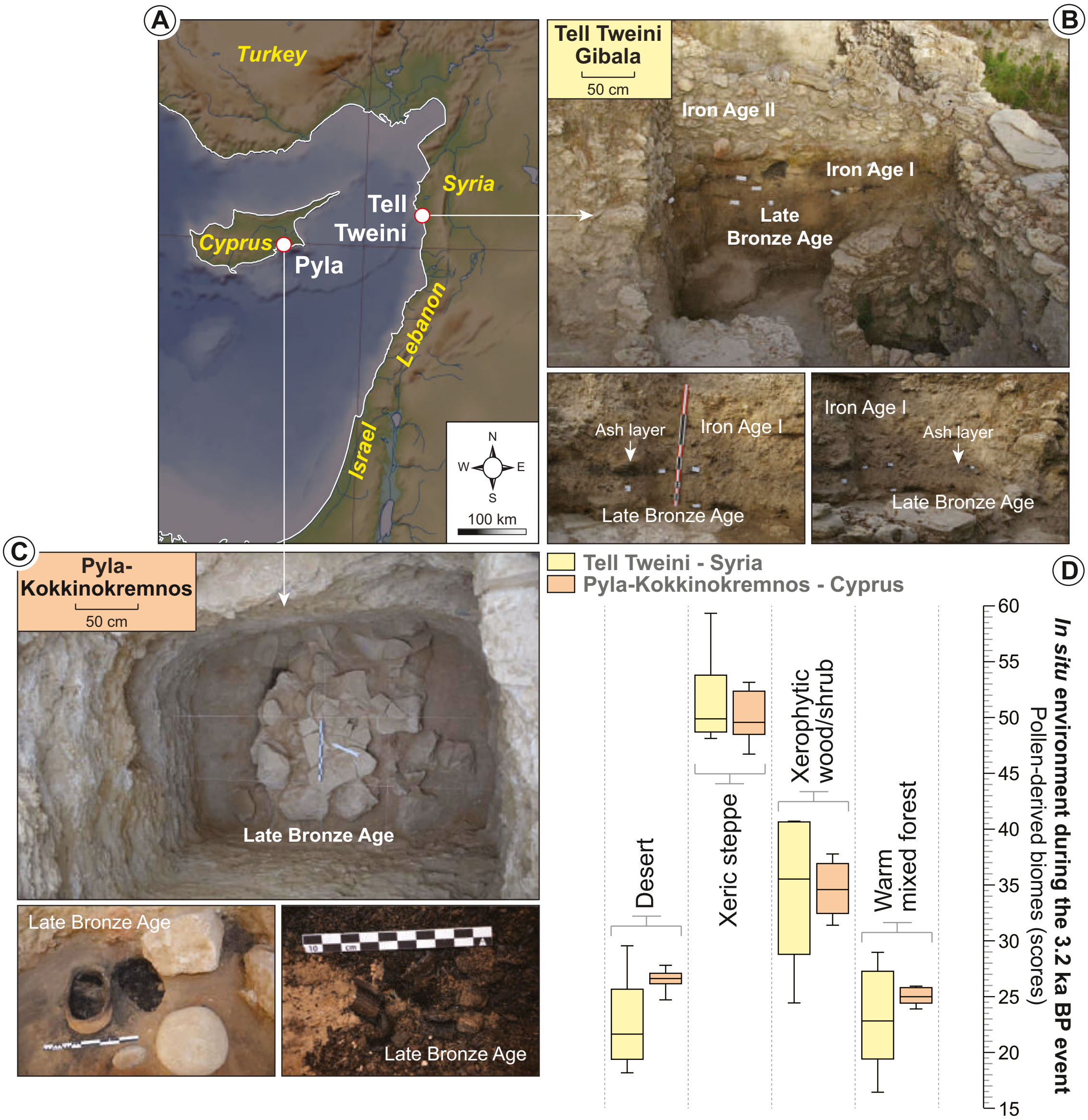

Fig. 2 Geographical location of the study area in the Eastern Mediterranean and pollen-derived biomes for the 3.2 ka BP event. **a** Map showing the location of Tell Tweini and Pyla-*Kokkinokremnos*. **b** A focus on the room where the samples were taken at Tell Tweini. **c** A focus on the large rectangular shaft where the samples were taken at Pyla-*Kokkinokremnos*. **d** In situ pollen-derived biomes for the 3.2 ka BP event. The biomes are displayed as boxplots

microscopes. Samples were dated by Beta Analytic (Miami, Florida) using standard accelerator mass spectrometry ^{14}C (Fig. 3; see Supplementary material).

Like Tell Tweini, chronological and palaeoenvironmental analyses were performed upon the same samples. The average pollen concentration was 6384 ± 129 grains cm^{-3}. The mean pollen sum was 319 ± 7 pollen grains, with a minimum of 293 pollen grains. The median value was 318 pollen grains, with a 25th percentile of 303 pollen grains and a 75th percentile of 334 pollen grains. The mean number of taxa was 32 ± 1 taxa, with a minimum of 31 taxa. The median value was 32 taxa, with a 25th percentile of 31 taxa, and a 75th percentile of 33 taxa (see Supplementary material).

Long-term climate reconstructions Datasets were selected to cover a wide geographical area (the Mediterranean basin, the Black Sea and Iran). While the emphasis was placed on Syria and Cyprus, where the two archaeological sites are located, sites from Lebanon and Israel were also added. The curves (Figs 4 and 5) were directly drawn using the initial values (when the data were available in open access repositories) or extracted from the original publications when the raw data were not available. The original datasets were extracted using the software package GraphClick. To standardise the contrasting proxies, we transformed all of the datasets into z-scores and plotted these values on a linear age-scale.

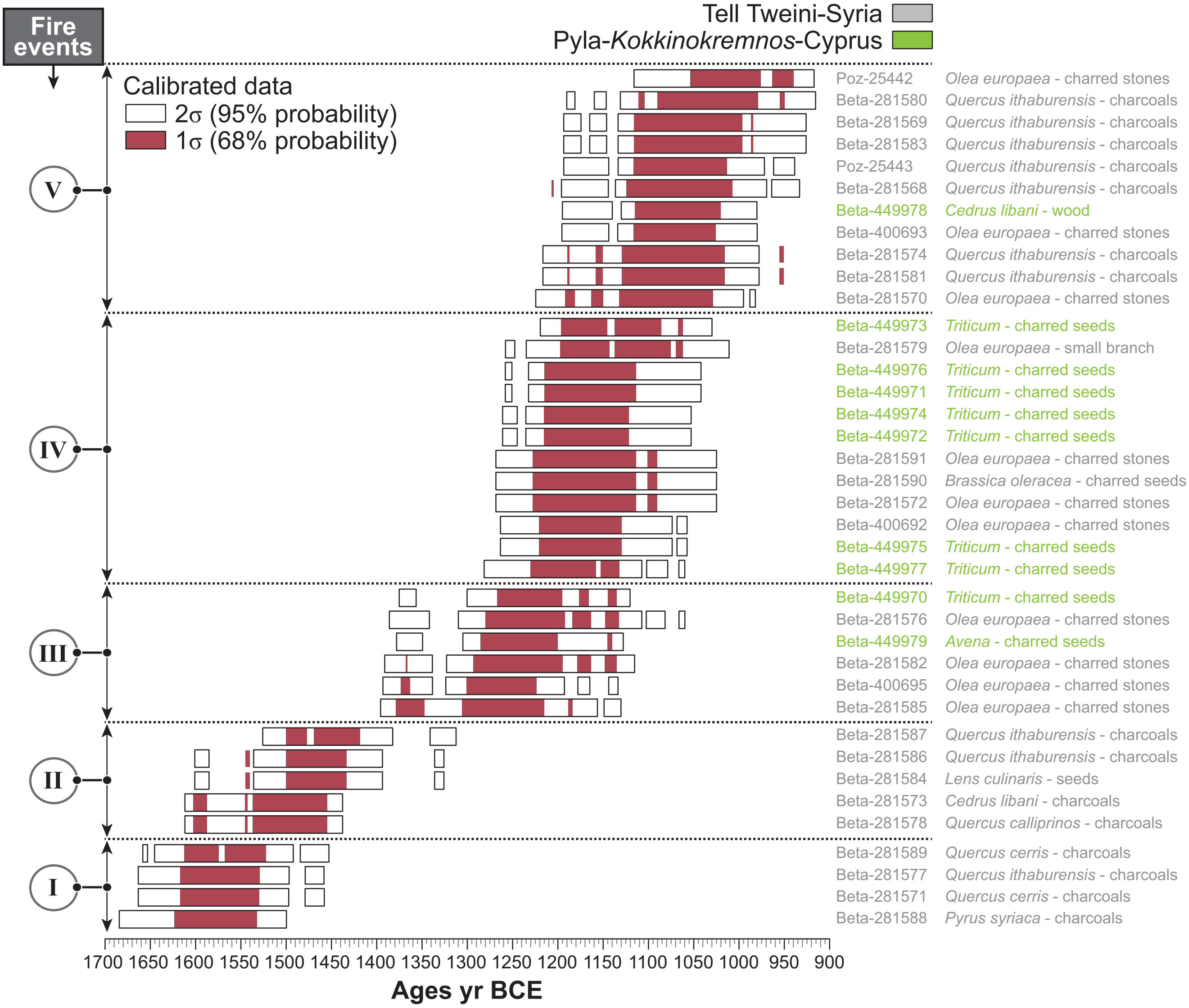

Fig. 3 Radiocarbon chronology from Tell Tweini and Pyla-*Kokkinokremnos*. The chronological data are displayed as 1*σ* and 2*σ* calibrated BCE. The data in grey correspond to Tell Tweini whereas data in green indicate Pyla-*Kokkinokremnos*. The fire events are underlined with numbers

Long-term agricultural activities Datasets (initial values) were transformed into z-scores and plotted on a linear time-scale (Fig. 6). The data sets are focused on Cyprus, Syria and Israel.

Results

In situ environmental reconstructions Samples from the archaeological sites (Fig. 2), coeval with the periods III–IV (Fig. 3), show a clear dominance of a xeric-steppe, both in Syria and Cyprus. High values of the xerophytic wood/shrub are also recorded whereas the desert and warmly mixed forest biomes display the lowest scores. The two main biomes suggest a dry environment that does not appear to result from human pressures as both sites were abandoned and agricultural activity was very low. These biomes are mainly in accordance with what was documented in the core TW-1, retrieved from the alluvial deposits of the Rumailiah river (near Tell Tweini, coastal Syria; Kaniewski et al. 2008, 2010) and in the core B22, sampled at the Larnaca Salt Lake (near Hala Sultan Tekke, coastal Cyprus; Kaniewski et al. 2013a). The cultivated species during this period correspond on average to 0.65 ± 0.14% at Tell Tweini and 0.84 ± 0.04% at Pyla-*Kokkinokremnos*. Olive trees are defined by an average of 2.65 ± 0.3% at Tell Tweini and 3.71 ± 0.12% at Pyla-*Kokkinokremnos*, similar to the scores obtained for cores TW-1 and B22 (~ 3%) at the end of the LBA.

^{14}C chronology The ^{14}C results were subdivided into five different blocks (Fig. 3), with the main phase centred on the

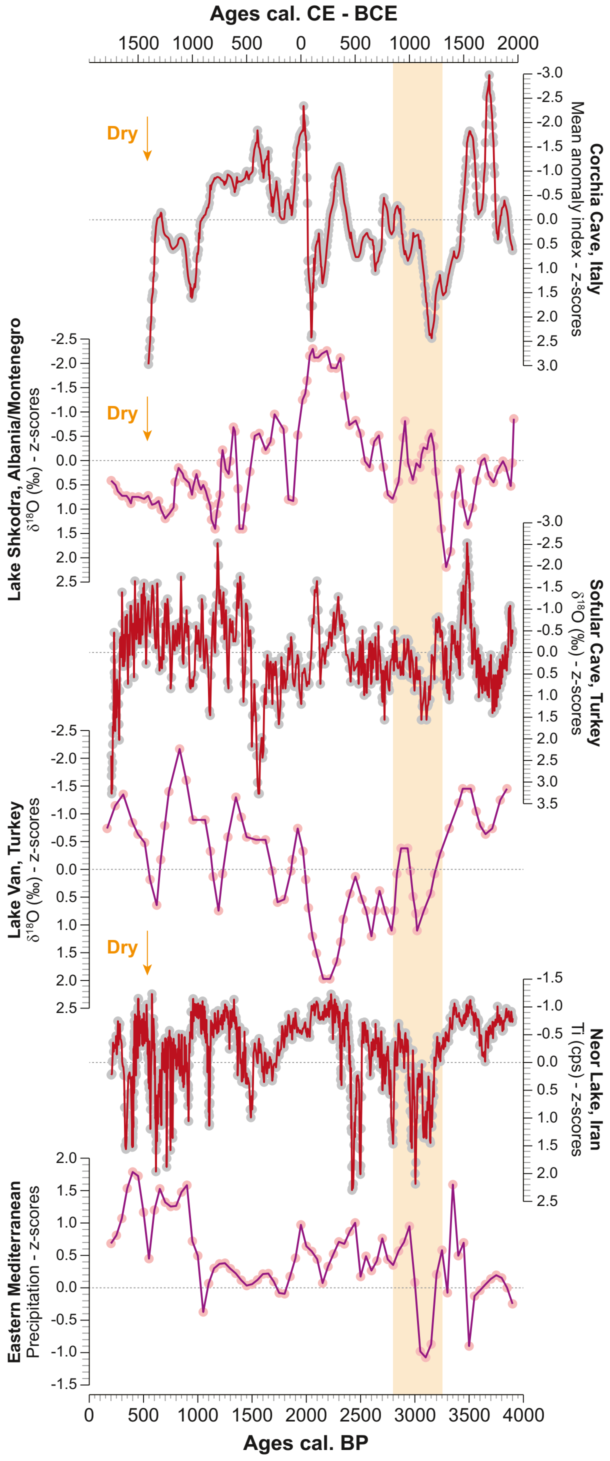

Fig. 4 Paleoclimate series (z-score transformed), with the type of climate proxy noted. The orange vertical band represents the 3.2 ka BP event. From top to bottom, Corchia Cave (Mg/Ca, δ^{13}C and δ^{18}O-based climatology, Italy, Regattieri et al. 2014), Lake Shkodra (δ^{18}O-based climatology, Albania/Montenegro, Zanchetta et al. 2012), Sofular cave (δ^{18}O-based climatology, Turkey, Göktürk et al. 2011), Lake Van (δ^{18}O-based climatology, Turkey, Wick et al. 2003), Neor Lake (Ti-based climatology, Iran, Sharifi et al. 2015) and the Eastern Mediterranean (pollen-based bioclimatology, Kaniewski et al. 2013b)

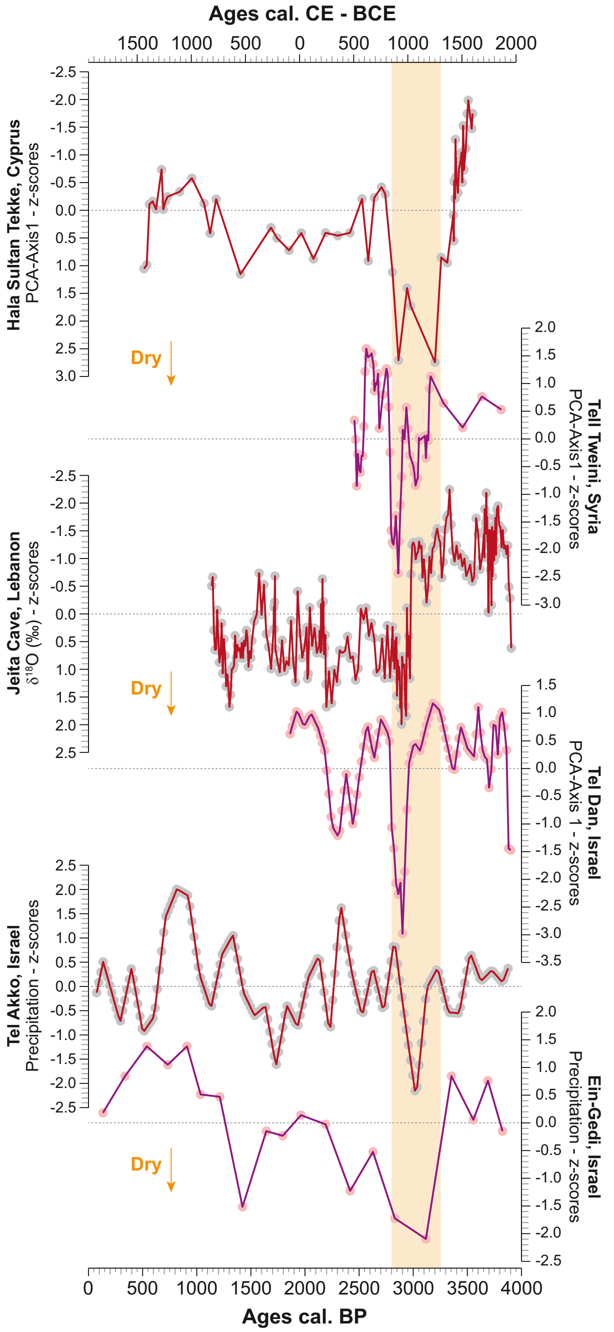

Fig. 5 Paleoclimate series (z-score transformed), with the type of climate proxy noted. The orange vertical band represents the 3.2 ka BP event. From top to bottom, Hala Sultan Tekke (pollen-based bioclimatology, Cyprus, Kaniewski et al. 2013a), Tell Tweini (pollen-based bioclimatology, Syria, Kaniewski et al. 2008), Jeita Cave (δ^{18}O-based climatology, Lebanon, Cheng et al. 2015), Tel Dan (pollen-based bioclimatology, Israel, Kaniewski et al. 2017), Tel Akko (pollen-based bioclimatology, Israel, Kaniewski et al. 2013b), and Ein-Gedi (pollen-based bioclimatology, Israel, Litt et al. 2012)

periods III–IV, which fit archaeologically with the LBA crisis. Period III is framed by a lower boundary of 3020 ± 30 ^{14}C BP [based on olive stones; 2σ calibration 3270–3140 cal BP (0.77; 1320–1190 cal BCE)] and an upper limit of 2990 ± 30

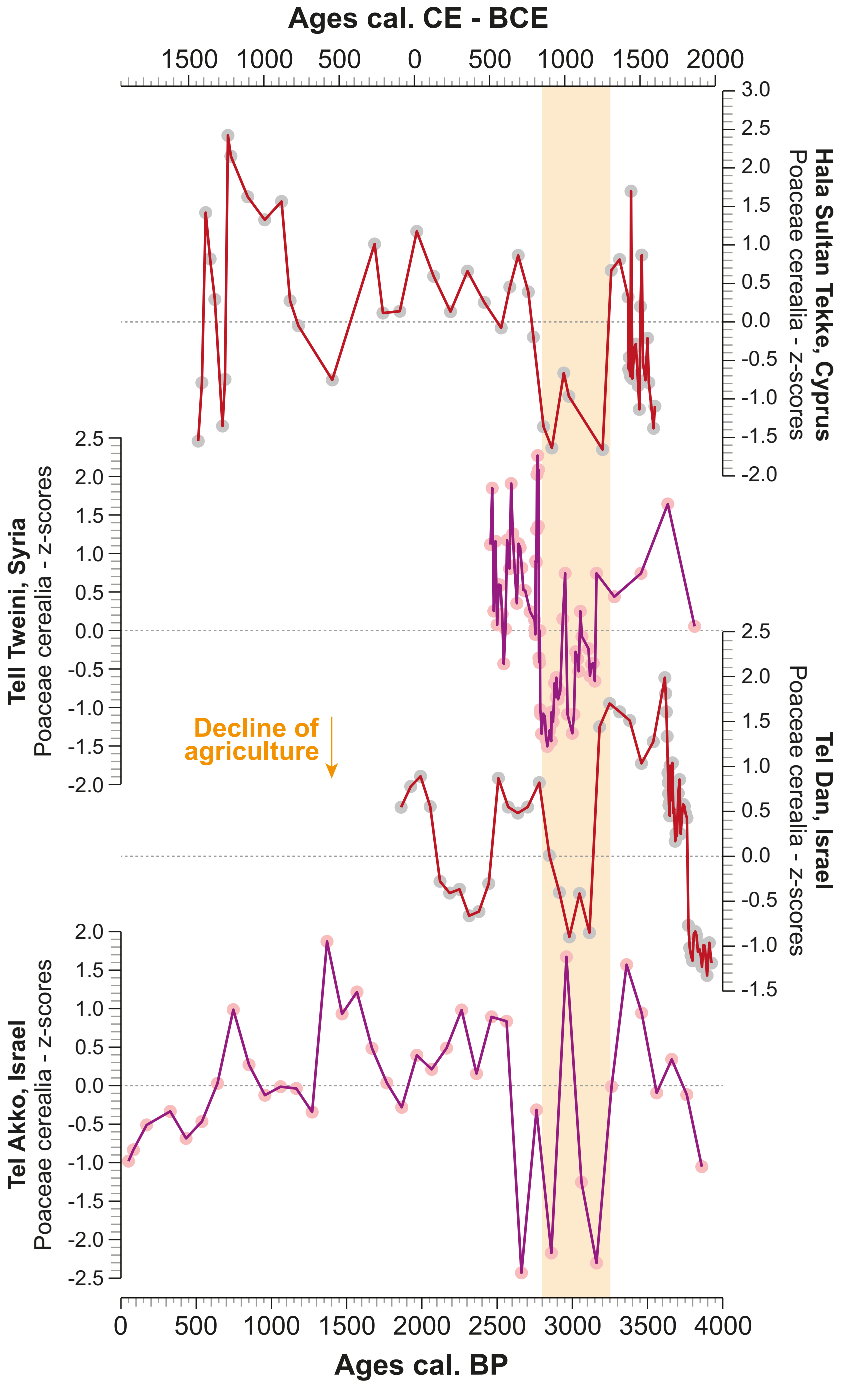

Fig. 6 *Poaceae cerealia* series (z-score transformed). The orange vertical band represents the 3.2 ka BP event. From top to bottom, Hala Sultan Tekke (Cyprus, Kaniewski et al. 2013a), Tell Tweini (Syria, Kaniewski et al. 2008), Tel Dan (Israel, Kaniewski et al. 2017) and Tel Akko (Israel, Kaniewski et al. 2013b)

^{14}C BP [based on wheat seeds; 2σ calibration 3250–3070 cal BP (0.97; 1300–1120 cal BCE)]. Period IV is defined by a lower boundary of 2970 ± 30 ^{14}C BP [based on wheat seeds; 2σ calibration 3225–3055 cal BP (0.97; 1275–1105 cal BCE)] and an upper limit of 2930 ± 30 ^{14}C BP [based on wheat seeds; 2σ calibration 3165–2975 cal BP (1.00; 1215–1025 cal BCE)]. The dry conditions, attested by the in situ environmental reconstructions, are thus framed by 2σ calibrations of 3270–3140 cal BP (1320–1190 cal BCE) and 3165–2975 cal BP (1215–1025 cal BCE).

Long-term environmental reconstructions Environmental studies from Italy (Corchia Cave; Regattieri et al. 2014), Albania/Montenegro (Lake Shkodra; Zanchetta et al. 2012), Turkey (Sofular Cave and Lake Van; Wick et al. 2003; Göktürk et al. 2011) and Iran (Neor Lake; Sharifi et al. 2015) were here considered (Figs 1 and 3). We focused on the Eastern Mediterranean (Fig. 5) with sequences from Cyprus (Hala Sultan Tekke; Kaniewski et al. 2013a), Syria (Tell Tweini; Kaniewski et al. 2008, 2010), Lebanon (Jeita Cave; Cheng et al. 2015) and Israel (Tel Akko, Tel Dan and

Ein-Gedi shore; Litt et al. 2012; Kaniewski et al. 2013b, 2017). Jeita Cave (Cheng et al. 2015), with its high chronological resolution, serves as a chronological anchor point for the other sequences dated by ^{14}C.

At the scale of the Eastern Mediterranean, one of the most striking elements of the data is the temporal alignment of the dry event at Tell Tweini, Tel Dan and Jeita Cave (Fig. 5). This suggests that the chronology of all the sites is reliable. The lowest scores at Tel Akko, indicative of a dry environment in the Central Levant, appears synchronous with the same event recorded on the shores of the Dead Sea at Ein-Gedi (Litt et al. 2012). From Italy to Iran, the event is clearly bracketed between ~ 3200 and ~ 2950 cal BP (Fig. 5) with the first drought episode culminating at ~ 3150 cal BP and the second at ~ 2950 cal BP.

The 3.2 ka BP climate event appears to be a W-shaped episode, with two dry phases framing a short-lived wetter period (at ~ 2950–3000 cal BP). The two drier periods are centred on ~ 3150 and ~ 2900/2850 cal BP in Cyprus and the northern Levant while in the Central and Southern Levant, the climate shift appears as a peak event centred on ~ 3050 cal BP, in accordance with the model simulation of Soto-Berelov et al. (2015). Several sites from the Nile Delta (Fig. 1), such as the Burullus lagoon (Bernhardt et al. 2012), Qarun Lake (Hassan 1997; Sun et al. 2019) and Manzala Lagoon (Krom et al. 2002) also show a shift to more arid conditions during the same period.

Decline of agriculture During the 3.2 ka BP event, all of the cores available from Cyprus to Israel show a clear downturn in agricultural activities (Fig. 6). The decline started at ~ 3250 cal BP, with the lowest scores at ~ 3150 and ~ 2900/2850 cal BP, in phase with the highest drought peaks (Fig. 5). A W-shaped event is also clearly depicted in the agricultural activities with a short-term rise in cereals in the middle part of the event at ~ 2950 cal BP (Fig. 6). The aridification and downturn in agricultural activities are chronologically correlated and are probably interrelated.

Discussion

The sites of Pyla-*Kokkinokremnos* and Tell Tweini were both affected by the LBA crisis, but not in the same way. Pyla-*Kokkinokremnos* was a short-lived settlement with one architectural phase dating between ~ 1230 and 1170 BCE (~ 3180–3120 BP), according to the pottery assemblages. The site was probably abandoned (thus far, there is no evidence of fire destruction) between ~ 1190 and 1170 BCE (~ 3140–3120 BP, end of the LBA in Cyprus) but "everything" was left behind or hidden, including large metal hoards. People seem to have fled the area. The youngest ceramic dates are attributed to the beginning of the Late Helladic IIIC period (first decades of the twelfth century BCE). The people who founded Pyla-*Kokkinokremnos* around 1230 BCE (around 3180 BP), occupied the site for just one to two generations, close to other important LBA settlements such as Kition, Hala Sultan Tekke and Enkomi. The abandonment of Pyla-*Kokkinokremnos* is dated to be between 2970 ± 30 (3225–3055 2σ cal BP; 1275–1105 2σ cal BCE) and 2930 ± 30 ^{14}C BP (3165–2975 2σ cal BP; 1215–1025 2σ cal BCE) by a series of ^{14}C measurements (Fig. 3).

The harbour town of Tell Tweini (possibly ancient Gibala) was a thriving Levantine trade centre in the LBA kingdom of Ugarit, integrated into a wide network of long-distance trading and cultural exchanges spanning the Aegean, Cyprus, the Levant, Egypt and Western Asia. Like the nearby capital of Ugarit and Tell Kazel to the south, Tell Tweini was partly destroyed by fire at the end of the Late Bronze Age. Stratigraphic evidence shows hints of unrest with a layer of ashes covering the ruins of various Late Bronze Age buildings at the site (Bretschneider et al. 2008; Bretschneider and Van Lerberghe 2008; Al-Maqdissi et al. 2011). The indication of the destruction levels at Tell Tweini and Tell Kazel and their positions inside the two stratigraphic sequences, as well as in the related Mycenaean pottery repertoires, allow to correlate (from an archaeological and historical point of view) the Mycenaean phase of LH IIIC Early 1 with the first regnal years of Pharaoh Ramesses III (Jung 2018a; Jung 2018b). The final period of destruction at the end of the LBA is dated from 2960 ± 30 ^{14}C BP (3210–3020 2σ cal BP; 1260–1070 2σ cal BCE) and 2950 ± 40 ^{14}C BP (3215–2975 2σ cal BP; 1265–1025 2σ cal BCE) (taking only short-lived samples as chronological markers; Fig. 3).

In both instances, the in situ palaeoenvironmental reconstructions show a dominant steppe landscape (Fig. 2) during this period, with scarce agriculture and low harvests, suggesting a harsh period. This is in accordance with the written archives (cuneiform tablets; see Kaniewski et al. 2011, 2015 for full details) from the LBA crisis that mention crop failures (Brinkman 1968; Neumann and Parpola 1987; Bryce 2005), severe food shortages, sharp increases in grain prices and famine (Singer 2000; Cohen and Singer 2006). This period also witnessed the first famine aid ever recorded, sent from Pharaoh Merenptah to the Hittite Kingdom (Warburton 2003; Bryce 2005). A parallel can be drawn with the long-term reconstructions of agricultural activities that display low cereal scores during the 3.2 ka BP event, with a first pronounced decline at ~ 3150 cal BP (~ 1200 cal BCE; Fig. 6).

The in situ environmental reconstructions also seem to be in accordance with long-term environmental studies (from Cyprus to Israel; Fig. 5) that display a dry event that started at ~ 3200 cal BP and ended at ~ 2850 cal BP, keeping Jeita Cave as a chronological anchor point

(Cheng et al. 2015). The 3.2 ka BP climate episode appears as a W-shaped event, with two drier phases interrupted by a short-lived wet episode at ~2950–3000 cal BP. This short wet phase is further attested by the recovery of agriculture (Fig. 6).

A dry event was also recorded in the Central-Southern Levant (e.g. Litt et al. 2012; Langgut et al. 2013, 2014; Schiebel and Litt 2018). Further north, the crater lake Eski Acigöl (Turkey) furnishes evidence of increasing aridity during the period 1250–850 cal BCE (Roberts et al. 2001, 2011). At Lake Gölhisar (Eastwood et al. 2007) and Sofular Cave (Göktürk et al. 2011), an important drop in precipitation occurred during the crisis years. These data are paralleled by the δ^{18}O records from Lake Mirabad and Lake Zeribar (Zagros Mountains of Iran) that also provide evidence of regional aridification during the crisis years (Stevens et al. 2006). These trends are furthermore correlated with discharge minima in the Tigris and Euphrates River (e.g. Cullen and deMenocal 2000) for the period 1150–950 cal yr. BCE (Kay and Johnson 1981; Neumann and Parpola 1987; Alpert and Neuman 1989). In Greece, the stalagmite S1 from Mavri Trypa cave also shows clear evidence of a dry period impacting crop yields (Finné et al. 2017), such as Tell Tweini and Hala Sultan Tekke (Figs 5 and 6).

Conclusions

The environmental data, mainly focused on the Eastern Mediterranean, show that the LBA crisis was framed by an ~300-year drought episode, termed the 3.2 ka BP event. This climate shift underscores the agro-productive sensitivity of ancient Mediterranean societies to environmental changes. The outcomes (crop failures and increased famine) and consequences suggest a partial link between adverse climate pressures and harvest/famine. Our new data rekindle the debate about the role of climate in shaping ancient societies and the need for a more high-resolution and archaeologically based palaeoenvironmental studies.

Funding information Support was provided by the Institut Universitaire de France, CLIMSORIENT program, the University of Ghent—Department of Archaeology and the Research Foundation Flanders (FWO, G010218 N). This work is a contribution to Labex OT-Med (n° ANR-11-LABX-0061) and has received funding from the Excellence Initiative of Aix-Marseille University—A*MIDEX, a French "Investissements d'Avenir" project.

Compliance with ethical standards

Competing interests The authors declare that they have no conflict of interest.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

Al-Maqdissi M, Van Lerberghe K, Bretschneider J, Badawi M (2011) Tell Tweini: onze campagnes de fouilles syro-belges (1999–2010). Documents d'Archéologie Syrienne, Damas

Alpert P, Neuman J (1989) An ancient correlation between streamflow and distant rainfall in the Near East. J Near East Stud 48:313–314

Artzy M (1987) On boats and Sea Peoples. Bull Am Sch Orient Res 266: 75–84

Bernhardt C, Horton BP, Stanley JD (2012) Nile Delta vegetation response to Holocene climate variability. Geology 40:615–618. https://doi.org/10.1130/G33012.1

Bretschneider J, Van Lerberghe K (2008) Tell Tweini, ancient Gibala, between 2600 BCE and 333 BCE. In: Bretschneider J, Van Lerberghe K (eds) In search of Gibala, an archaeological and historical study based on eight seasons of excavations at Tell Tweini (1999–2007) in the A and C fields. Aula Orientalis, Barcelona, pp 12–66 http://journals.openedition.org/abstractairanica/41442. Mar 2018

Bretschneider J, Van Lerberghe K, Vansteenhuyse K, Al-Maqdissi M (2008) The Late Bronze Age and Iron Age in the Jebleh region: a view from Tell Tweini. In: Kühne H, Czichon RM, Kreppner FJ (eds) Proceedings of the 4th International Congress of the Archaeology of the Ancient Near East. Harrassowitz Verlag, Wiesbaden, pp 33–46

Bretschneider J, Jans G, Van Vyve AS (2010) Les Fouilles du chantier A en 2009 et 2010. In: Al-Maqdissi M, Van Lerberghe K, Bretschneider J, Badawi M (eds) Tell Tweini: onze campagnes de fouilles syro-belges (1999–2010). Documents d'Archéologie Syrienne, Damas, pp 131–146

Bretschneider J, Kanta A, Driessen J (2015) Pyla-*Kokkinokremos*: preliminary report on the 2014 excavations. Ugarit-Forschungen 46:1–37

Bretschneider J, Kanta A, Driessen J (2017) Pyla-*Kokkinokremos* (Cyprus): preliminary report on the 2015-2016 campaigns. Ugarit-Forschungen 48:36–120

Bretschneider J, Jans G (2019) About Tell Tweini (Syria): artefacts, ecofacts and landscape. Research results of the Belgian mission. OLA Peeters, Leuven

Brinkman JA (1968) A political history of post-Kassite Babylonia, 1158–722 BC. Analecta Orientalia, Ville

Bryce T (2005) The kingdom of the Hittites. Oxford University Press, Oxford. https://doi.org/10.1093/acprof:oso/9780199281329.001.0001

Butzer KW (1976) Early hydraulic civilization in Egypt. University of Chicago Press, Chicago

Camenisch C, Keller KM, Salvisberg M, Amann B, Bauch M, Blumer S, Brázdil R, Brönnimann S, Büntgen U, Campbell BMS, Fernández-Donado L, Fleitmann D, Glaser R, González-Rouco F, Grosjean M, Hoffmann RC, Huhtamaa H, Joos F, Kiss A, Kotyza O, Lehner F, Luterbacher J, Maughan N, Neukom R, Novy T, Pribyl K, Raible CC, Riemann D, Schuh M, Slavin P, Werner JP, Wetter O (2016) The 1430s: a cold period of extraordinary internal climate variability during the early Spörer minimum with social and economic impacts in north-western and Central Europe. Clim Past 12:2107–2126. https://doi.org/10.5194/cp-12-2107-2016

Cheng H, Sinha A, Verheyden S, Nader FH, Li XL, Zhang PZ, Yin JJ, Yi L, Peng YB, Rao ZG, Ning YF, Edwards RL (2015) The climate variability in northern Levant over the past 20,000 years. Geophys Res Lett 42:8641–8650. https://doi.org/10.1002/2015GL065397

Cline EH (2014) 1177 BC: the year civilization collapsed. Princeton University Press, Princeton

Cohen Y, Singer I (2006) Late synchronism between Ugarit and Emar. In: Amit Y, Zvi EB, Finkelstein I, Lipschits O (eds) Essays on Ancient

Israel in its Near Eastern context. A tribute to Nadav Na'ama. Eisenbrauns, Winona Lake, pp 123–139

Coltelli M, Del Carlo P, Vezzoli L (2000) Stratigraphic constraints for explosive activity in the past 100 ka at Etna volcano, Italy. Int J Earth Sci 89:665–677. https://doi.org/10.1007/s005310000117

Cullen HM, deMenocal PB (2000) North Atlantic influence on Tigris-Euphrates streamflow. Int J Climatol 20:853–863. https://doi.org/10.1002/1097-0088(20000630)20:8%3C853::AID-JOC497%3E3.0.CO;2-M

Drews R (1993) The end of the Bronze Age: changes in warfare and the catastrophe ca. 1200 BC. Princeton University Press, Princeton

Driessen J (2018) The archaeology of forced migration. Crisis-induced mobility and the collapse of the 13th c. BCE Eastern Mediterranean (Aegis 15). Presses Universitaires de Louvain, Louvain

Eastwood WJ, Leng MJ, Roberts N, Davis B (2007) Holocene climate change in the eastern Mediterranean region: a comparison of stable isotope and pollen data from Lake Gölhisar, Southwest Turkey. J Quat Sci 22:327–341. https://doi.org/10.1002/jqs.1062

Faegri K, Iversen I (1989) Textbook of pollen analysis, fourth edn. Wiley, London

Finné M, Holmgren K, Shen CC, Hu HM, Boyd M, Stocker S (2017) Late bronze age climate change and the destruction of the Mycenaean palace of Nestor at Pylos. PLoS One 12:e0189447. https://doi.org/10.1371/journal.pone.0189447

Gilboa A (2006-2007) Fragmenting the Sea Peoples, with an emphasis on Cyprus, Syria and Egypt: a Tel Dor perspective. Scripta Mediterranea 27-28: 209–244

Glaser R, Himmelsbach I, Bösmeier A (2017) Climate of migration? How climate triggered migration from Southwest Germany to North America during the 19th century. Clim Past 13:1573–1592. https://doi.org/10.5194/cp-13-1573-2017

Göktürk OM, Fleitmann D, Badertscher S, Cheng H, Edwards RL, Leuenberger M, Fankhauser A, Tüysüz O, Kramers J (2011) Climate on the southern Black Sea coast during the Holocene: implications from the Sofular cave record. Quat Sci Rev 30:2433–2445. https://doi.org/10.1016/j.quascirev.2011.05.007

Hassan FA (1997) The dynamics of a riverine civilization: a geoarchaeological perspective on the Nile Valley, Egypt. World Archaeol 29:51–74 .https://doi.org/10.1080/00438243.1997.9980363

Jung R (2018a) Push and pull factors of the Sea Peoples between Italy and the Levant. In: Driessen J (ed) The Archaeology of forced migration. Crisis-induced mobility and the collapse of the 13th c. BCE Eastern Mediterranean (Aegis 15). Presses Universitaires de Louvain, Louvain, pp 279–312

Jung R (2018b) Mycenaen pottery in coastal Syria. In: Badre L, Capet E, Vitale B (eds) Tell Kazel au Bronze Récent. Études Céramiques, Beyrouth, pp 47–51

Kaniewski D, Paulissen E, Van Campo E, Al-Maqdissi M, Bretschneider J, Van Lerberghe K (2008) Middle East coastal ecosystem response to middle-to-late Holocene abrupt climate changes. Proc Natl Acad Sci U S A 105:13941–13946. https://doi.org/10.1073/pnas.0803533105

Kaniewski D, Paulissen E, Van Campo E, Bakker J, Van Lerberghe K, Waelkens M (2009) Wild or cultivated *Olea europaea* L. in the eastern Mediterranean during the middle-late Holocene? A pollen-numerical approach. The Holocene 19:1039–1047. https://doi.org/10.1177/0959683609341000

Kaniewski D, Paulissen E, Van Campo E, Weiss H, Otto T, Bretschneider J, Van Lerberghe K (2010) Late second-Early first millennium BC abrupt climate changes in coastal Syria and their possible significance for the history of the eastern Mediterranean. Quat Res 74:207–215. https://doi.org/10.1016/j.yqres.2010.07.010

Kaniewski D, Van Campo E, Van Lerberghe K, Boiy T, Vaansteenhuyse K, Jans G, Nys K, Weiss H, Morhange C, Otto T, Bretschneider J (2011) The Sea Peoples, from cuneiform tablets to carbon dating. PLoS One 6:e20232. https://doi.org/10.1371/journal.pone.0020232

Kaniewski D, Van Campo E, Guiot J, LeBurel S, Otto T, Baeteman C (2013a) Environmental roots of the Late Bronze Age crisis. PLoS One e71004:8. https://doi.org/10.1371/journal.pone.0071004

Kaniewski D, Van Campo E, Morhange C, Guiot J, Zviely D, Shaked I, Otto T, Artzy M (2013b) Early urban impact on Mediterranean coastal environments. Sci Rep 3:354. https://doi.org/10.1038/srep03540,2013b

Kaniewski D, Guiot J, Van Campo E (2015) Drought and societal collapse 3200 years ago in the eastern Mediterranean: a review. WIREs Clim Change 6:369–382. https://doi.org/10.1002/wcc.345

Kaniewski D, Van Campo E (2017) The 3.2 kyr BP event and the Late Bronze Age crisis, a climate-induced spiral of decline. In: Weiss H (ed) Megadrought and collapse. Oxford University Press, Oxford, pp 161–182. https://doi.org/10.1093/oso/9780199329199.001.0001

Kaniewski D, Marriner N, Ilan D, Morhange C, Thareani Y, Van Campo E (2017) Climate change and water management in the biblical city of Dan. Sci Adv 3:e1700954. https://doi.org/10.1126/sciadv.1700954

Karageorghis V, Demas M (1984) Pyla-Kokkinokremnos, a late 13th-century B.C. fortified settlement in Cyprus. Chr. Nicolaou & Sons LTD, Nicosia

Karageorghis V, Kanta A (2014) Pyla-Kokkinokremnos, a late 13th-century B.C. fortified settlement in Cyprus, excavatioons 2010–2011. Studies in Mediterranean Archaeology vol. CXLI - Aströms Förlag, Uppsala

Kay PA, Johnson DL (1981) Estimation of the Tigris-Euphrates streamflow from regional palaeoenvironmental proxy data. Clim Chang 3:251–263. https://doi.org/10.1007/BF00136671

Killebrew AE (2005) Biblical peoples and ethnicity: an archaeological study of Egyptians, Canaanites, Philistines, and early Israel, 1300-1100 BC. SBLABS, Atlanta. 33:59. https://doi.org/10.1111/j.1748-0922.2007.001498.x

Killebrew AE, Lehmann G (2013) The Philistines and other Sea Peoples in text and archaeology. SBLABS, Atlanta. https://doi.org/10.2307/j.ctt46n483

Krom MD, Stanley JD, Cliff RA, Woodward JC (2002) Nile River sediment fluctuations over the past 7000 yr and their key role in sapropel development. Geology 30:71–74. https://doi.org/10.1130/0091-7613(2002)030<0071:NRSFOT>2.0.CO;2

Langgut D, Finkelstein I, Litt T (2013) Climate and the Late Bronze Collapse: new evidence from the southern Levant. Tel Aviv 40: 149–175. https://doi.org/10.1179/033443513X13753505864205

Langgut D, Neumann FH, Stein M, Wagner A, Kagan EJ, Boaretto E, Finkelstein I (2014) Dead Sea pollen record and history of human activity in the Judean highlands (Israel) from the Intermediate Bronze into the Iron Ages (~ 2500–500 BCE). Palynology 38: 280–302. https://doi.org/10.1080/01916122.2014.906001

Langgut D, Finkelstein I, Litt T, Neumann FH, Stein M (2015) Vegetation and climate changes during the bronze and iron ages (~3600–600 BCE) in the southern Levant based on palynological records. Radiocarbon 57:217–235. https://doi.org/10.2458/azurc.57.18555

Litt T, Ohlwein C, Neumann FH, Hense A, Stein M (2012) Holocene climate variability in the Levant from the Dead Sea pollen record. Quat Sci Rev 49:95–105. https://doi.org/10.1016/j.quascirev.2012.06.012

Manning J (2018) The open sea: the economic life of the ancient Mediterranean world from the Iron Age to the rise of Rome. Princeton University Press, Princeton. https://doi.org/10.1002/9781444338386.wbeah06321/full

Neumann J, Parpola S (1987) Climatic change and the eleventh-tenth-century eclipse of Assyria and Babylonia. J Near East Stud 46:161–182. https://doi.org/10.1086/373244

Nougayrol J, Laroche E, Virolleaud C, Schaeffer C (1968) Ugaritica V, Nouveaux textes accadiens, hourrites et ugaritiques des archives et bibliothèques privées d'Ugarit. Mission de Ras Shamra, 16. Librairie Orientaliste Paul Geuthner, Paris

Pribyl K (2017) Farming, famine and plague, the impact of climate in Late Medieval England. Springer, Heidelberg. https://doi.org/10.1007/978-3-319-55953-7

Regattieri E, Zanchetta G, Drysdale RN, Isola I, Hellstrom JC, Dallai L (2014) Lateglacial to Holocene trace element record (Ba, mg, Sr) from Corchia Cave (Apuan Alps, Central Italy): paleoenvironmental implications. J Quat Sci 29:381–392. https://doi.org/10.1002/jqs.2712

Reuveny R (2007) Climate change-induced migration and violent conflict. Polit Geogr 26:656–673. https://doi.org/10.1016/j.polgeo.2007.05.001

Roberts N, Reed JM, Leng MJ, Kuzucuoglu C, Fontugne M, Bertaux J, woldring H, Bottema S, Black S, Hunt E, Karabiyikoglu M (2001) The tempo of Holocene climate change in the eastern Mediterranean region: new high-resolution crater-lake sediments data from Central Turkey. The Holocene 11:721–736. https://doi.org/10.1191/09596830195744

Roberts N, Eastwood WJ, Kuzucuoglu C, Fiorentino G, Caracuta V (2011) Climatic, vegetation and cultural change in the eastern Mediterranean during the mid-Holocene environmental transition. The Holocene 21:147–162. https://doi.org/10.1177/0959683610386819

Sadori L, Narcisi B (2001) The postglacial record of environmental history from Lago di Pergusa, Sicily. The Holocene 11:655–670. https://doi.org/10.1191/09596830195681

Schiebel V, Litt T (2018) Holocene vegetation history of the southern Levant based on a pollen record from Lake Kinneret (Sea of Galilee), Israel Vegetation. Hist Archaeobotany 27:577–590. https://doi.org/10.1594/PANGAEA.884740

Sharifi A, Pourmand A, Canuel EA, Ferer-Tyler E, Peterson LC, Aichner B, Feakins SJ, Daryaee T, Djamali M, Naderi A, Lahijani HAK, Swart PK (2015) Abrupt climate variability since the last deglaciation based on a high-resolution, multi-proxy peat record from NW Iran: the hand that rocked the cradle of civilization? Quat Sci Rev 123:215–230. https://doi.org/10.1016/j.quascirev.2015.07.006

Singer I (1999) A political history of Ugarit. In: Watson WGE, Wyatt N (eds) Handbook of Ugaritic Studies, vol 120. Handbuch der Orientalistik, Erste Abteilung, Leiden, pp 603–733. https://doi.org/10.2307/606647

Singer I (2000) New evidence on the end of the Hittite empire. In: Oren ED (ed) The Sea Peoples and their world: a reassessment. University of Pennsylvania, Philadelphia, pp 21–33

Soto-Berelov M, Fall PL, Falconer SE, Ridder E (2015) Modeling vegetation dynamics in the southern Levant through the Bronze Age. J Archaeol Sci 53:94–109. https://doi.org/10.1016/j.jas.2014.09.015

Stevens LR, Ito E, Schwalb A, Wright HE Jr (2006) Timing of atmospheric precipitation in the Zagros Mountains inferred from a multi-proxy record from Lake Mirabad, Iran. Quat Res 66:494–500. https://doi.org/10.1016/j.yqres.2006.06.008

Sun Q, Liu Y, Salem A, Marks L, Welc F, Ma F, Zhang W, Chen J, Jiang J, Chen Z (2019) Climate-induced discharge variations of the Nile during the Holocene: evidence from the sediment provenance of Faiyum Basin, North Egypt. Glob Planet Chang 172:200–210. https://doi.org/10.1016/j.gloplacha.2018.10.005

Tarasov PE, Cheddadi R, Guiot J, Bottema S, Peyron O, Belmonte J, Ruiz-Sanchez V, Saadi F, Brewer S (1998) A method to determine warm and cool steppe biomes from pollen data; application to the Mediterranean and Kazakhstan regions. J Quat Sci 13:335–344. https://doi.org/10.1002/(SICI)1099-1417(199807/08)13:4<335::AID-JQS375>3.0.CO;2-A

Warburton D (2003) Love and war in the Later Bronze Age: Egypt and Hatti. In: Matthews R, Roemer C (eds) Ancient perspectives on Egypt. University College of London Press, London, pp 75–100

Weiss B (1982) The decline of Late Bronze Age civilization as a possible response to climatic change. Clim Chang 4:173–198. https://doi.org/10.1007/BF02423389

Wetter O, Pfister C, Werner JP, Zorita E, Wagner S, Seneviratne SI, Herget J, Grünewald U, Luterbacher J, Alcoforado MJ, Barriendos M, Bieber U, Brázdil R, Burmeister KH, Camenisch C, Contino A, Dobrovolný P, Glaser R, Himmelsbach I, Kiss A, Kotyza O, Labbé T, Limanówka D, Litzenburger L, Nordl Ø, Pribyl K, Retsö D, Riemann D, Rohr C, Siegfried W, Söderberg J, Spring JL (2014) The year-long unprecedented European heat and drought of 1540 - a worst case. Clim Chang 125:349–363. https://doi.org/10.1007/s10584-014-1184-2

Wick L, Lemcke G, Sturm M (2003) Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. The Holocene 13:665–675. https://doi.org/10.1191/0959683603hl653rp

Zanchetta G, Van Welden A, Baneschi I, Drysdale RN, Sadori L, Roberts N, Giardini M, Beck C, Pascucci V, Sulpizio R (2012) Multiproxy record for the last 4500 years from Lake Shkodra (Albania/Montenegro). J Quat Sci 27:780–789. https://doi.org/10.1002/jqs.2563

Zanchetta G, Bini M, Di Vito MA, Sulpizio R, Sadori L (2018) Tephrostratigraphy of paleoclimatic archives in Central Mediterranean during the Bronze Age. Quat Int. https://doi.org/10.1016/j.quaint.2018.06.012