GEOLOGY | THE GEOLOGICAL SOCIETY OF AMERICA®

https://doi.org/10.1130/G46491.1

Manuscript received 13 May 2019
Revised manuscript received 17 July 2019
Manuscript accepted 17 July 2019

Cold and dry outbreaks in the eastern Mediterranean 3200 years ago

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ABSTRACT

Can climate affect societies? This question, of both past and present importance, is encapsulated by the major socioeconomic crisis that affected the Mediterranean 3200 yr ago. The demise of the core civilizations of the Aegean and eastern Mediterranean during the Late Bronze Age and the early Iron Age (Dark Ages) is still controversial because it raises the question of climate-change impacts on ancient societies. Although evidence for this climate shift has gradually gained currency, recent attempts to quantify its magnitude remain equivocal. Here we focus on the northern Levant (coastal Syria) where the economic, political, and cultural changes were particularly acute. We quantify past climate changes and find that mean annual temperatures attained anomalies of – 2.3 ± 0.3 °C to – 4.8 ± 0.4 °C compared to present-day conditions. Rainfall regimes displayed an important shift in seasonality, with a 40% decrease in winter precipitation. A 300 yr period of dry and cool climate started ~3200 yr ago and was coeval with deep social changes in the eastern Mediterranean. These "Little Ice Age"–type conditions affected harvests, leading to severe food shortages that probably aggravated the sociopolitical tensions. This crisis highlights the fragility of societies, both past and present, to major climate-change episodes and their broader consequences.

INTRODUCTION

More than five decades ago, the American archaeologist Rhys Carpenter (1966) evoked a major climate shift ~3200 yr ago to explain the demise of the Mycenaean civilization. This climate hypothesis was subsequently developed using the Palmer drought index (Weiss, 1982), winter climate and hemispheric circulation patterns (Donlay, 1971; Bryson et al., 1974), and historical climatology (Neumann and Parpola, 1987; Alpert and Neumann, 1989). Debate at one point was heated (e.g., Neumann, 1985), but the idea gradually lost currency because it was not supported by any scientific data. New results from Tell Tweini in Syria (Fig. 1) have recently revived Carpenter's hypothesis. The site has provided evidence for a marked environmental shift that is chronologically correlated with the Late Bronze Age (LBA) crisis and the Dark Ages (we call the whole event "the crisis years" herein; Kaniewski et al., 2008). Since then, several records from Greece (Finné et al., 2017), Cyprus (Kaniewski et al., 2013a), Syria (Sorrel and Mathis, 2016), Lebanon (Cheng et al., 2015), Israel (Litt et al., 2012; Kaniewski et al., 2013b, 2017; Langgut et al., 2013; Schiebel and Litt, 2018), and Egypt (Bernhardt et al., 2012) depict similar trends, evoking a severe climate shift of regional extent (Kaniewski et al., 2015). Nonetheless, the quantification of changes in rainfall regime and temperature has proved challenging until now, in part owing to the scarcity of archives in Levantine coastal areas, where social changes during the LBA crisis and the Dark Ages were particularly acute.

Here, we used data from the southernmost part of the Kingdom of Ugarit (Syria), on the alluvial plain and affluent valley of the Rumailiah River, near the present-day coastal town of Jableh (Fig. 1), located west of the Jabal an Nuşayrīyah mountain range (Kaniewski et al., 2008, 2011a). The alluvial complex is overlooked by Tell Tweini (Bretschneider and Jans, 2019). We used pollen-based assemblages to quantify climate variables and probe climate and society during the LBA crisis–Dark Ages (Figs. 1–3). We compared the magnitude of this event with climate changes during the past two millennia (the Late Antiquity Little Ice Age during the Muslim Era, and the pre-industrial Little Ice Age during the Ottoman Empire).

METHODS

Pollen Samples

The pollen samples derive from two cores (termed TW-1 and TW-2; TW-1: 35°22′22.94″N, 35°56′12.49″E, 17 m a.s.l. [above sea level]; TW-2: 35°22′13.16″N, 35°56′11.36″E, 16.06 m a.s.l.; Fig. DR1 in the GSA Data Repository[1])

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[1]GSA Data Repository item 2019333, Figures DR1–DR3 and Tables DR1–DR8, is available online at http://www.geosociety.org/datarepository/2019/, or on request from editing@geosociety.org.

CITATION: Kaniewski, D., et al., 2019, Cold and dry outbreaks in the eastern Mediterranean 3200 years ago: Geology, v. 47, p. , https://doi.org/10.1130/G46491.1

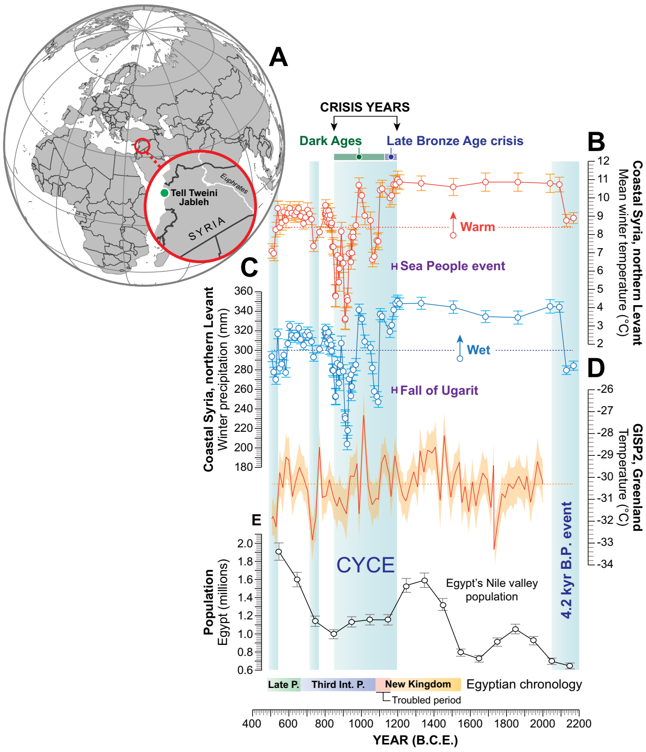

Figure 1. Winter temperature and precipitation reconstructions for Tell Tweini, coastal Syria and comparison with other proxy records. (A) Map showing location of Tell Tweini and Jableh in the northern Levant. (B,C) Winter temperature (with standard deviations) (B) and winter precipitation (with standard deviations) (C) reconstructions for the northern Levant. (D) Temperatures reconstructed from Greenland Ice Sheet Project 2 (GISP2) record (Kobashi et al., 2009); orange shading represents 1 standard deviation error. (E) Egypt's Nile valley population (Butzer, 1976) (error bars denote the standard deviation of each data point) drawn with Egyptian chronology (Shaw, 2000) (Late P.—Late Period; Third Int. P.—Third Intermediate Period). The Sea People "event" (Gilboa, 2006–2007; Killebrew and Lehmann, 2013) and the fall of the city of Ugarit (Syria; Yon, 2006) are denoted as chronological bars. Crisis Years Cooling Event (CYCE) is shaded in blue. The other blue shaded bars denote periods of climate deterioration.

retrieved with a percussion corer from the alluvial deposits (Rumailiah River and a small spring-fed valley) at the foot of Tell Tweini (Kaniewski et al., 2008, 2010, 2011a, 2011b). We added eight new samples from the bottom of the core TW-2 (from 400 to 795 calibrated years Common Era [cal. yr CE]). Samples were prepared for pollen analysis using standard procedures for clay deposits (Faegri and Iversen, 1989). Pollen grains were counted under 400× and 1000× magnification using an Olympus microscope. Pollen diagrams for the two cores are available in the literature (Kaniewski et al., 2010, 2011b). The local hygrophytes, aquatic taxa, and spores of non-vascular cryptogams were not considered in the pollen-based climate model. The cultivated species (primary anthropogenic indicators) were also excluded from the statistical analyses, in addition to the secondary anthropogenic indicators (e.g., *Plantago* [plantains or fleaworts], *Rumex* [docks and sorrels]). Olive trees (*Olea europaea*) were retained, as it has been shown that they were not cultivated at Tell Tweini and around Jableh (Kaniewski et al., 2009).

Agricultural Activities

Agricultural activities were reconstructed from the two cores using cereals (*Poaceae cerealia*) and viticulture (*Vitis vinifera*). Pollen frequencies (expressed as percentages) are based on the terrestrial pollen sum, excluding local hygrophytes, aquatic taxa, and spores of non-vascular cryptogams.

Chronology

The chronology is based on 10 accelerator mass spectrometry (AMS) ^{14}C ages (Beta Analytic [Miami, Florida, USA] and Poznan Laboratories [Poznan, Poland]). Full details are given in Table DR1 in the Data Repository. The original age models are available in the literature (Kaniewski et al., 2010, 2011a, 2011b). The robustness of our age model is corroborated by the Jeita Cave (Lebanon) δ^{18}O record (see Fig. DR2; Cheng et al., 2016), a chronological reference for the Levant, and the Mavri Trypa Cave (Greece) δ^{18}O record (Finné et al., 2017). The Greenland Ice Sheet Project 2 (GISP2) record (Kobashi et al., 2009) also served as a further chronological control (Fig. 1).

Pollen-Based Climate Model

Pollen assemblages were used to infer past climate variables (Figs. 2 and 3) and document the LBA decline and the ensuing Dark Ages (Fig. DR3; Tables DR2–DR7). Our statistical approach includes the two biases known for pollen-based climate reconstructions: (1) a fossil pollen assemblage may not have a strict modern analog (Jackson and Williams, 2004), and (2) the climate range of a species or genus may change through time (Cheddadi and Khater, 2016; Cheddadi et al., 2016). Our new method is based on the hypothesis that the co-occurrence of plant taxa in an assemblage at any time may happen only under a common suitable climate range, or an overlap of the climatic range, for all plant taxa composing that assemblage (Fig. DR3). Under such a hypothesis, two plant species should not occur simultaneously in an assemblage if their overall climatic ranges do not intersect. We assigned the fossil pollen taxa to modern species, and subsequently calculated a weighted median value and its standard deviations of the climate range encompassed by all assigned modern species. Similar approaches have been used to infer past climate variables using the mutual climatic range of insects (Elias, 1997), plant fossil remains (Mosbrugger and Utescher, 1997; Pross et al., 2000), mollusks (Moine et al., 2002), and ostracods (Horne, 2007) and to derive climate probability density functions (Kühl et al., 2002) from fossil pollen data.

Our method (Cheddadi et al., 2017) also accommodates the variability of pollen taxa in the fossil record by including a leave-one-out calculation. For each fossil sample, one known taxon is removed and a weighted median (using the pollen percentages as a weight) of all of the remaining taxa is calculated. For each sample, we calculated the weighted median as many times as there are taxa in each fossil sample. The final climatic value is the median value of all iterations. In addition, the standard deviation corresponds to the median value of all of the standard deviations.

The additional leave-one-out approach minimizes the effect of either over- or underrepresentation of some pollen species or those that show large variations in the fossil record. The code was written using the software R (R Core Team, 2014) and its various libraries (Akima and Gebhardt, 2015), RMySQL (Ooms et al., 2016), and the statistics that are part of the R software. The modern plant database used for the fossil taxa assignment includes georeferenced species distributions from the *Atlas Florae Europaeae* (Jalas and Suominen, 1973, 1979, 1980) and from the Global Biodiversity Information Facility (https://www.gbif.org). The modern climate variables were obtained from the WORLDCLIM database (https://www.worldclim.org; Hijmans et al., 2005).

Data Sharing

The data required to replicate all analyses in this study are available in the Data Repository (Tables DR1–DR8).

QUANTIFYING CLIMATE COOLING BEGINNING 3200 YR AGO

Focusing on winter, the major rainfall season in Syria, precipitation and mean temperatures began to fall ~1200 calibrated years Before Common Era (cal. yr BCE). They both reached their lowest values at ca. 1090–1060 and ca. 920–910 cal. yr BCE (Fig. 1), in phase with the lower temperatures recorded in the GISP2 record (Kobashi et al., 2009), the Agassiz (Canadian High Arctic)–Greenland record (Vin-

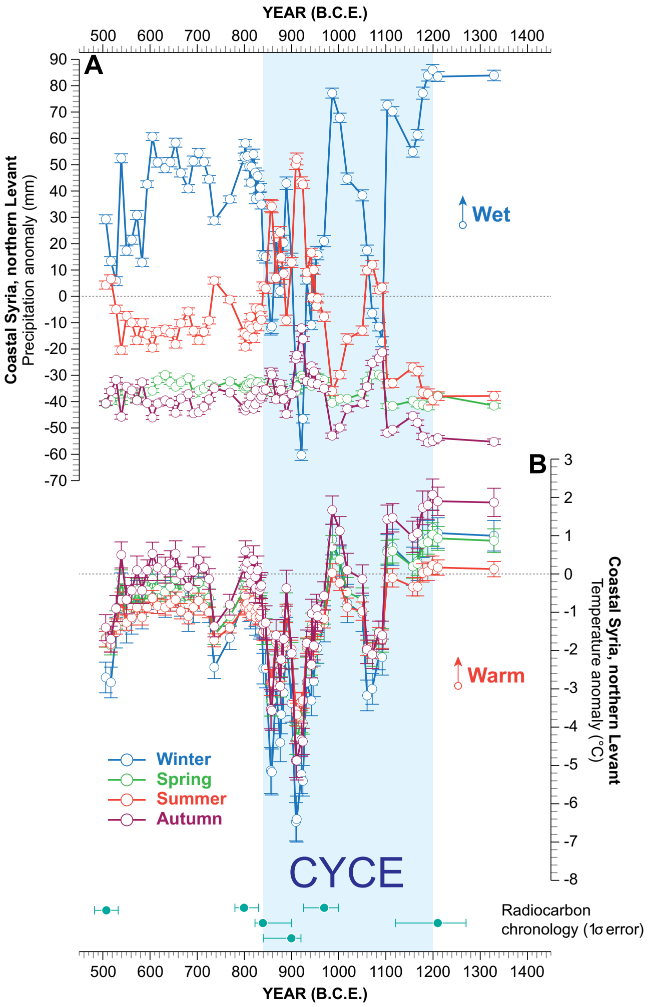

Figure 2. Seasonal precipitation and temperature anomalies for Late Bronze Age–Early Iron Age transition, coastal Syria. (A) Seasonal precipitation anomalies relative to the second half of the 20th century CE (with standard deviations). (B) Seasonal temperature anomalies relative to the second half of the 20th century CE (with standard deviations). Radiocarbon dates (^{14}C) are displayed with 1σ calibration, consistent with dated sediment layers. Crisis Years Cooling Event (CYCE) is shaded in blue.

ther et al., 2009), and in northwestern Africa (Morley et al., 2014). An initial cold event is recorded, dated to ca. 1200–1115 cal. yr BCE, but this does not display the same amplitude as the two ensuing events (Fig. 1). The first cold period (ca. 1090–1060 cal. yr BCE) is correlated with an abrupt cold episode in the North Atlantic (termed event 2), characterized by marked sea-ice advance east of Newfoundland (eastern Canada) and south of Greenland (Klus et al., 2018; Fig. 3). In coastal Syria, the period ca. 1090–1060 cal. yr BCE shows winter temperature and precipitation values of 6.6 ± 0.4 °C and 247 ± 1.9 mm, respectively (Fig. 1), while the period ca. 920–910 cal. yr BCE displays values of 3.3 ± 0.5 °C and 204 ± 2.0 mm. Temperatures below zero were not recorded. This climate oscillation is coincident with an environmental shift on the Nile Delta (Egypt; Bernhardt et al., 2012) and declining populations in Egypt (Butzer, 1976; Fig. 1).

We subsequently transformed the climate data into anomalies compared to present-day conditions (Fig. 2), using the second half of the 20th century CE as a reference point (mean annual temperature of 17.05 ± 0.35 °C and annual precipitation of 610.4 ± 22.2 mm). Focusing on winter and spring, the two main sowing seasons in Syria, temperatures cooled, relative to present, by 3.2 ± 0.4 °C (winter) and 2.0 ± 0.3 °C (spring) at ca. 1060 cal. yr BCE, and by 6.5 ± 0.5 °C (winter) and 4.3 ± 0.4 °C (spring) at ca. 910 cal. yr BCE. For both seasons, the cumulative rainfall decrease is ~47.7 ± 1.9 and 90.4 ± 1.5 mm, respectively. The mean winter rainfall amounts decreased by 26% (ca. 1090–1060 cal. yr BCE) and 40% (ca. 920–910 cal. yr BCE) compared to the end of the LBA (ca. 1350–1250 cal. yr BCE; mean value of 348.8 ± 1.3 mm). During summer, temperatures cooled, relative to present, by 1.9 ± 0.2 °C (ca. 1060 cal. yr BCE) and 3.6 ± 0.3 °C (ca. 910 cal. yr BCE). Rainfall displays positive anomalies of 43.5 ± 1.9 mm (relative to the 20th century CE) and of 91.6 ± 2 mm compared to the end of the LBA.

Seasonal temperatures (from winter to autumn) all show the same trend and depict a cooler period from ca. 1200 to ca. 850 cal. yr BCE with marked cold events (Fig. 2). The rainfall regime does not display an overall decline but manifests a clear change in seasonality compared to the present day or Bronze Age, with a noticeable drop in winter amounts and an increase in the summer when evapotranspiration increases significantly (Fig. 2). Autumn and spring precipitation were both below present-day values. Cooler temperatures and substantial interseasonal variation in rainfall may have had pronounced consequences for crop yields.

The cooling period is interrupted by an abrupt ~80 yr warming phase (ca. 1050–970 cal. yr BCE) (Fig. 3). Temperature anomalies during this phase are defined by an average value of – 0.2 ± 0.34 °C, with a highest positive anomaly of 0.8 ± 0.32 °C. A similar warming was recorded in Greenland (Vinther et al., 2009; Kobashi et al., 2011) and northwestern Africa (Morley et al., 2014), evoking teleconnections via the North Atlantic ocean-atmosphere system.

A comparison with climate changes during the past 1600 yr in the northern Levant shows that the period 1200–850 cal. yr BCE displays cooler spikes than the Late Antiquity Little Ice Age (lower anomaly: –3.2 ± 0.4 °C), the pre-industrial Little Ice Age (lower anomaly: –2.9 ± 0.2 °C), and the severe winter of 1928–1929 CE (lower anomaly: –2.9 ± 0.3 °C; Fig. 3). The cold episodes identified in coastal Syria during the period 400–1950 cal. yr CE mesh with abrupt cooling events in the Bosphorus and colder winters in Istanbul (Turkey), both identified in historical data (Yavuz et al., 2007). Because no written sources can be associated with the Dark Ages, the temperature oscillations are based on correlations with Greenland (Fig. 1), North Atlantic cold events, and northwestern African cold periods (Fig. 3).

CRISIS YEARS COOLING EVENT AND ITS SOCIETAL IMPLICATIONS

The eastern Mediterranean's cold and dry period between 1200 and 850 cal. yr BCE can be qualified as a "W"-shaped cooling event occurring ~2750 yr before the pre-industrial Little Ice Age (e.g., Jones et al., 2001) and ~1850yr before the Late Antiquity Little Ice Age (Büntgen et al., 2016). This colder period is clearly differentiated from the 4.2 kyr B.P. event (Weiss et al., 1993; Weiss, 2016), and does not correspond to a progressive deterioration of the climate between these two episodes. We propose terming this climate shift the "Crisis Years Cooling Event (CYCE)" to differentiate it from the entire 3.2 kyr B.P. event (a political and socioeconomic event) from its climate and environmental elements. Our data suggest slightly different conclusions from those published recently (Weiberg and Finné, 2018) and imply that climate had a partial impact on societies during the "crisis years", probably by affecting food resources and production. Regarding crop yields and viticulture (Table DR8), each colder period (CYCE, Late Antiquity Little Ice Age, pre-industrial Little Ice Age) is associated with an important decline in agriculture in the coastal area (Fig. 3), evoking a drop in crop yields that may have severely affected the health of northern Levantine

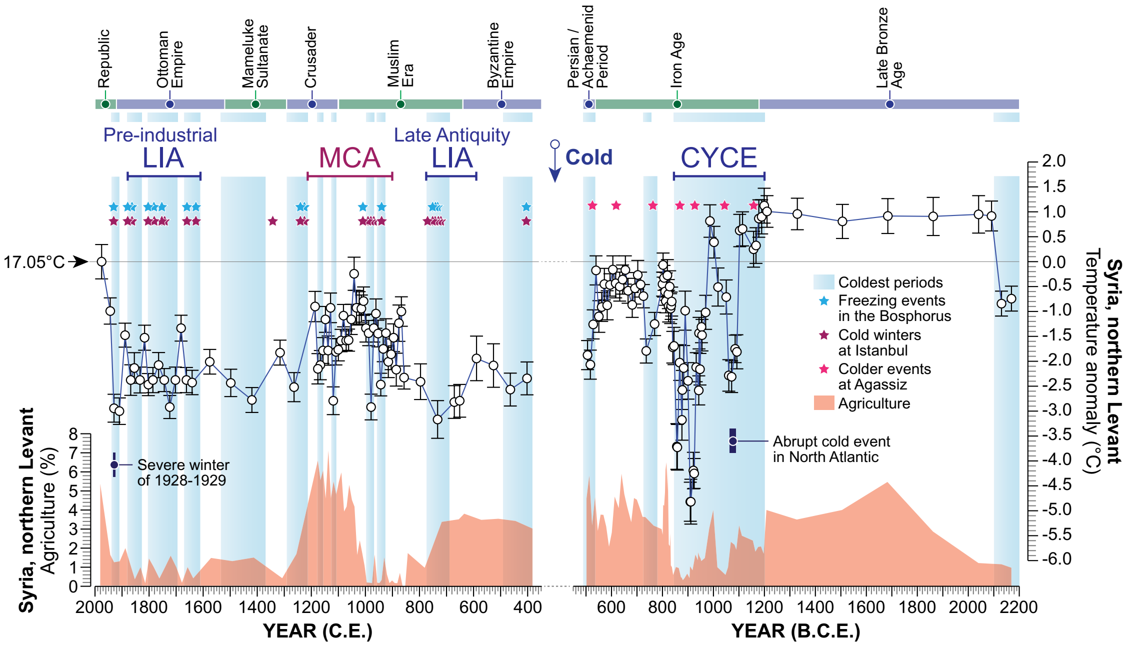

Figure 3. Reconstruction of temperature anomalies for Late Bronze Age–Persian period and Late Antiquity–20th century (with standard deviations) in Syria. Vertical blue bar highlights each cold period. Agricultural dynamics (based on cereals and viticulture) are displayed for the two periods. Percentage values are relative to the pollen sum of each sample. Blue and purple stars denote freezing events in the Bosphorus and colder winters in Istanbul (Turkey), respectively (Yavuz et al., 2007). Pink stars indicate cold events at Agassiz (Canadian High Arctic)–Greenland for the period 1200–450 BCE (Vinther et al., 2009). The abrupt cold event in the North Atlantic (event 2; Klus et al., 2018), the severe winter of 1928–1929 CE (Yavuz et al., 2007), the Late Antiquity Little Ice Age (LIA; Büntgen et al., 2016), the Medieval Climate Anomaly (MCA; Kaniewski et al., 2011a), and the pre-industrial LIA (Jones et al., 2001) are indicated. The 17.05 °C line denotes the mean annual temperature at present. Archaeological time scale has been added to the age model.

populations, and influenced the economy, acting as an amplifier of the social crisis.

SUMMARY

A major climate shift 3200 yr ago affected the Old World. Cool conditions, colder than the pre-industrial Little Ice Age and the Late Antiquity Little Ice Age, spread over the northern Levant. A fall in average annual temperatures was accompanied by a significant variation in the rainfall pattern, characterized by greater seasonality compared to the present day. This period of climate change, lasting 300 yr, was characterized by two cold events separated by a warmer and wetter phase centered on ca. 1000 cal. yr BCE. The cold and dry period, termed CYCE, seems to have impacted eastern Mediterranean populations through stresses put on food and agricultural productivity.

ACKNOWLEDGMENTS

Support was provided by the Institut Universitaire de France (CLIMSORIENT program), the University of Ghent (Department of Archaeology), and the Research Foundation Flanders (FWO, G010218N). This work is a contribution to Labex OT-Med (ANR-11-LABX-0061) and has received funding from the Excellence Initiative of Aix-Marseille University—A*MIDEX, a French “Investissements d’Avenir” project. We thank the three anonymous reviewers for helping to improve an earlier version of this manuscript.

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