Climate Change and Social Unrest: A 6,000-Year Chronicle From the Eastern Mediterranean

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Key Points:
- A 6,000-year climatic reconstruction from Cyprus suggests that cold conditions have affected past societies as much as drought events
- Five important cold periods were identified at 5250 ± 20, 4215 ± 40, 3200 ± 90, 1400 ± 70, and 620 ± 20 year BP
- Each cold period is consistent with a significant instability in precipitation, mainly for winter and spring seasons

Supporting Information:
- Supporting Information S1
- Data Set S1

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Climate Change and Social Unrest: A 6,000-Year Chronicle From the Eastern Mediterranean

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Abstract The history of the Eastern Mediterranean is punctuated by major crises that have influenced many of the region's established socioeconomic models. Recent studies have underscored the role of drought and temperature oscillations in driving changes but attempts to quantify their magnitude remain equivocal, hindering long-term assessments of the potential interplay between climate and society. Here, we fill this knowledge gap using a 6,000-year pollen-based reconstruction of temperature and precipitation from Hala Sultan Tekke, Cyprus. We find that major social changes and plague outbreaks often occurred in tandem with cooler climate conditions, with anomalies ranging from −3 ± 0.4 °C to −1 ± 0.5 °C, coupled with changing precipitation patterns. We suggest that major climate changes may weaken societies by affecting primary livelihood systems. This long-term view highlights recurrent cold periods in the Eastern Mediterranean's climate history and advocates that, despite frequent adversity and pandemics, Near Eastern populations adapted and were ultimately resilient to major climate changes.

Plain Language Summary During the last 6,000 years, the Eastern Mediterranean's climate has been characterized by several periods of marked climate deterioration and cooling. Many of these cooler phases were punctuated by historical crises and outbreaks of plague, suggesting that climate may partially influence social unrest and the spread of scourges. Drought has always been a significant component of past climate changes, but temperature deviations also appear to be as important in fully comprehending the complex interplay between climate and societies.

1. Introduction

Climate, complex societies, and civilizations have been closely intertwined throughout the history of the Near East (Bar-Matthews & Ayalon, 2011; deMenocal, 2001; Weiss et al., 1993). In Egypt, the Old Kingdom ended around 4150 BP (Shaw, 2000) when the country sank into a roughly 100-year period of disorder termed the First Intermediate Period (onset 2263–2145 cal year BCE; Bronk Ramsey et al., 2010). The demise of the Old Kingdom has been partly attributed to major changes in annual flooding and Nile flow failure (Stanley et al., 2003). During the same period (~4200 BP), on the northern Mesopotamian Plains of Habur, widespread desertion of the Akkadian landscape played out (Weiss, 2016, 2017; Weiss et al., 1993). For instance, in the rain-fed Tell Leilan region, population numbers fell dramatically with ~70% of sites being abandoned. The total occupied area declined by >90% (Staubwasser & Weiss, 2006). This desertion played out during a ~300-year period of severe drought, which engendered an aridification of rain-fed plains and an acute increase in dust inputs that has led scholars to evoke a "megadrought" (Weiss, 2017). A similar event was recorded in the Eastern Mediterranean at Soreq Cave, where the acme of a long dry phase occurred during the period 4200–4050 BP (Bar-Matthews & Ayalon, 2011).

A thousand years earlier (~5200 BP), across Greater Mesopotamia, the abrupt collapse of Late Uruk settlements (from the Zagros Mountains to Syria) is also associated with a period of drought (Weiss & Bradley, 2001), dated to 5250–5170 BP in Soreq Cave (Bar-Matthews & Ayalon, 2011). The amount of rainfall in these regions of rain-fed cereal agriculture fell to below sustainable thresholds. The contemporaneous drop in Anatolian precipitation, the main source of Tigris-Euphrates waters (Cullen & deMenocal, 2000), also strongly affected irrigation agriculture down to southern Mesopotamia.

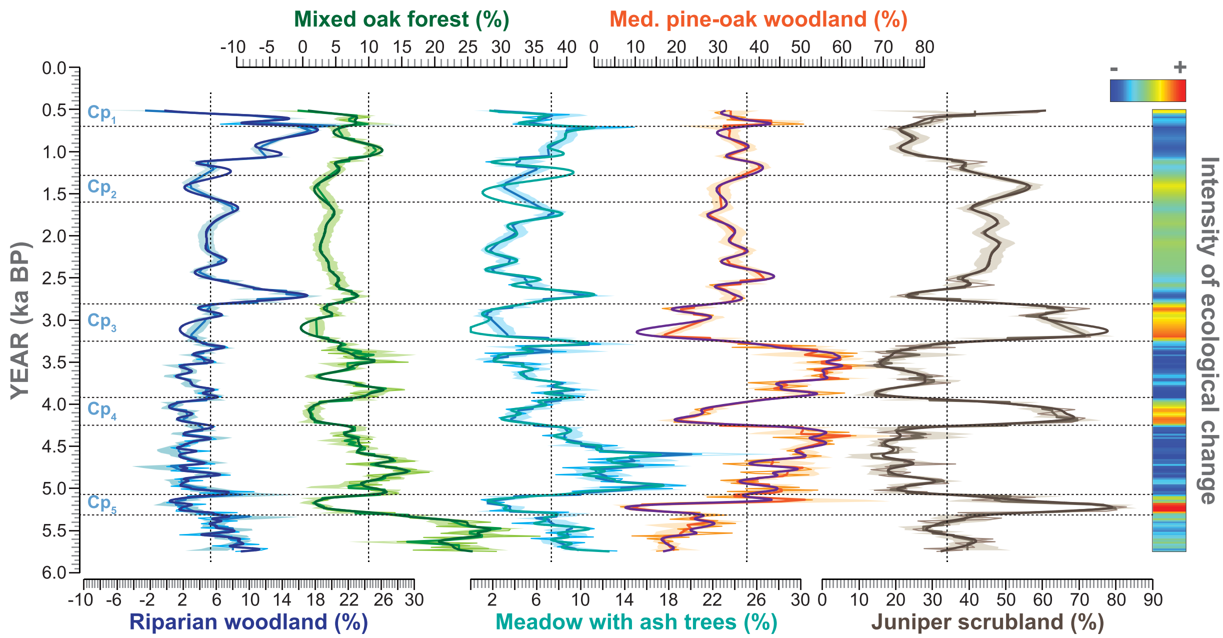

Figure 1. Pollen-derived vegetation patterns and ecosystem dynamics. The pollen-derived vegetation time series (riparian woodland, mixed oak forest, Meadow with ash trees, Mediterranean pine-oak woodland, and Juniper scrubland) are plotted on a linear time scale. The cold periods are highlighted with dotted lines and referenced by a number (**Cp_1** to **Cp_5**).

At the end of the thirteenth to the twelveth centuries BCE, many societies from the Peloponnesus to the Levant were severely affected by the collapse of social and political structures, migration of people, and transformations in the elaborate network of international trade that had built up regional prosperity (Fischer & Bürge, 2017a; Kaniewski et al., 2008, 2015). These developments, henceforth termed the "Sea Peoples phenomenon" (see Fischer & Bürge, 2017a), led to the collapse of the Late Bronze Age (LBA), the first "international period" in human history. It has been hypothesized that drought may have contributed to the collapse of the LBA world by inducing crop failures/low harvests, leading to food shortages and possibly even famine (Kaniewski et al., 2008, 2015).

Historical events show that drought, when concurrent with political and social unrest, could have been a motor of change during some of the crises that hit the Mediterranean world. Even if temperature instability has previously been evoked as one of the drivers for these crises (deMenocal, 2001; Weiss, 2016), the data mostly derive from Sea Surface Temperatures (SSTs), not from local terrestrial reconstructions in proximity to key archeological sites, limiting the robustness of correlations between climate change and historical events.

This study probes 6,000 years of temperature changes in Cyprus, an island located at the heart of ancient Eastern Mediterranean trade routes and cultural exchanges. Pollen-derived data (Figure 1) were used to quantify both temperature and precipitation (Figures 2 and 3). These results were subsequently used to assess the role of climate shifts in mediating agricultural production (Figure 4) and to evaluate to what extent climate anomalies were coeval with social changes.

2. The Site: Hala Sultan Tekke-Larnaca Salt Lake

Larnaca Salt Lake constitutes a network of four highly saline seasonal lakes located south of the city of Larnaca (Cyprus). The area exhibits a typical Mediterranean climate with hot dry summers (from mid-May to mid-September) and cool wet winters (from November to mid-March). These two main seasons are separated by short autumn and spring seasons characterized by rapid changes in weather conditions. The lakes fill during the winter months, fed by precipitation that mainly originates from eastwardly propagating, mid-latitude cyclones generated in the North Atlantic and in the Eastern Mediterranean Sea. During spring/summer, the area is influenced by the subtropical high-pressure system, which almost completely

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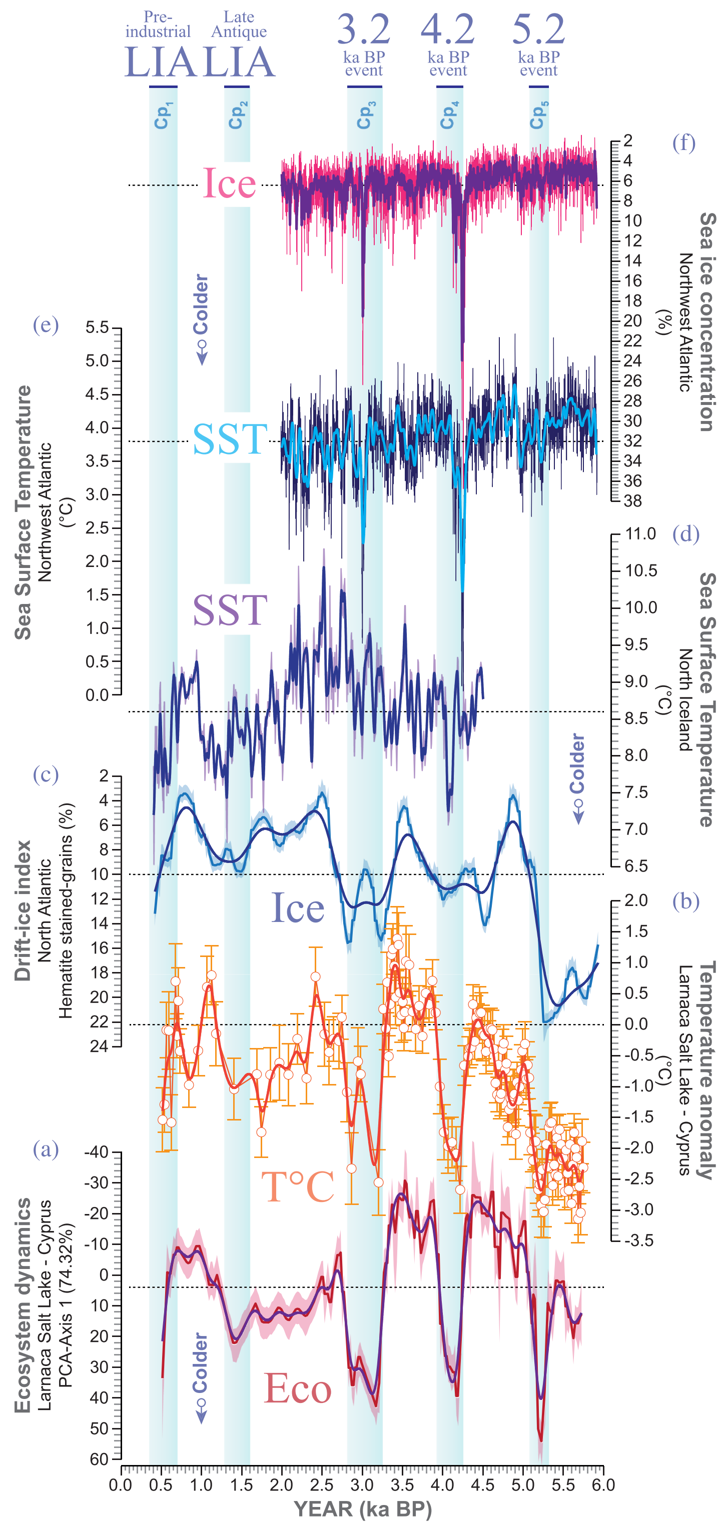

Figure 2. Six thousand years of ecosystem dynamics and temperature anomalies from Hala Sultan Tekke, coastal Cyprus. (a) Ecosystem dynamics shown as a PCA-Axis1 filtered by a LOESS smoothing (with the 2.5th and 97.5th percentiles). The trends are highlighted by a smoothing spline. (b) Temperature anomalies (T°C) displayed with the standard deviations; the trends are underlined by a smoothing spline. (c) Drift-ice index reconstructed from the North Atlantic (Bond et al., 2001). (d) Sea surface temperature from Northern Iceland (Sicre et al., 2008). (e) Sea surface temperature (°C) in the Northwest Atlantic (Klus et al., 2018). (f) Sea-ice concentration (%) in the Northwest Atlantic (Klus et al., 2018). The cold periods are shaded in blue and denoted by a number (**Cp_1** to **Cp_5**).

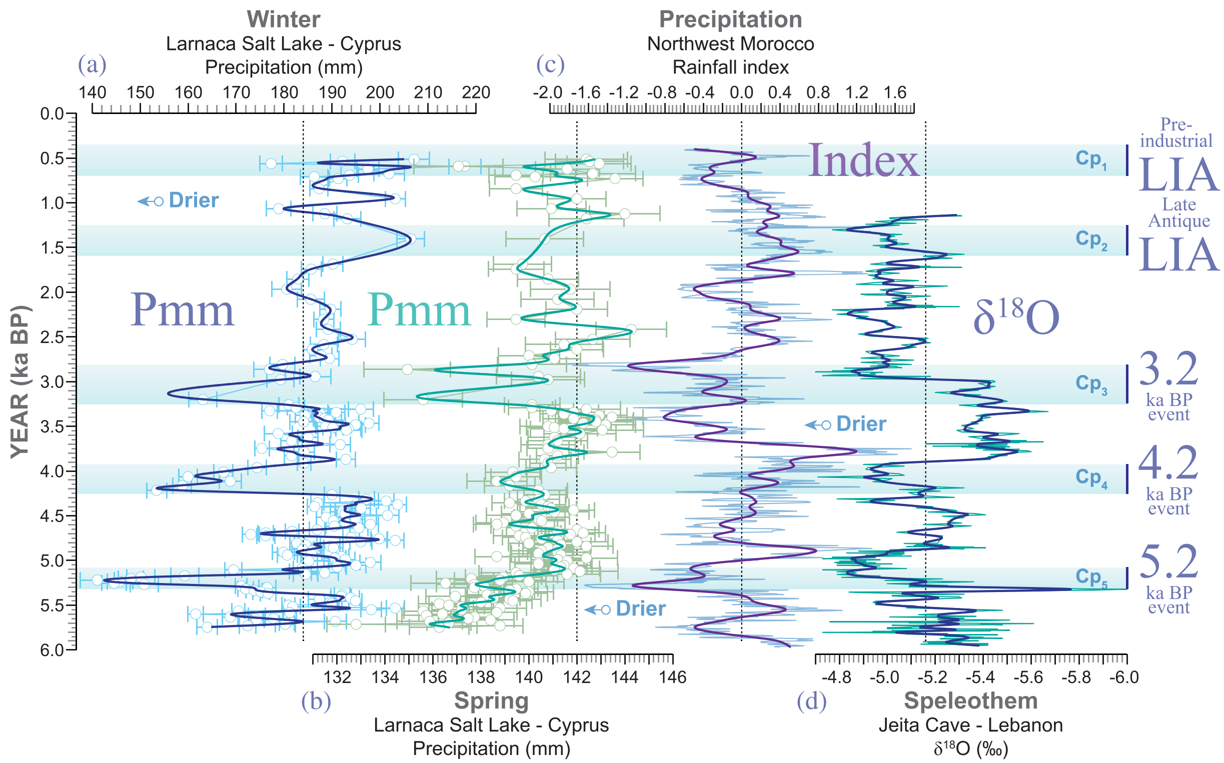

Figure 3. Six thousand years of seasonal precipitation (winter and spring) from Hala Sultan Tekke, coastal Cyprus. (a) Winter and (b) spring precipitation (Pmm) are displayed with the standard deviations; the trends are highlighted by smoothing splines. (c) Rainfall index from Northwest Morocco (Wassenburg et al., 2016). D $\delta^{18}O_{speleothem}$ from Jeita Cave, Lebanon (Cheng et al., 2015). The cold periods are shaded in blue and referenced by a number (**Cp_1** to **Cp_5**).

inhibits rainfall. As a consequence, the lake water evaporates, leaving a crust of salt and gray dust. Located on the west bank of the Larnaca Salt Lake, the shrine Hala Sultan Tekke (Mosque of Umm Haram) is the fourth holiest place for Muslims after Mecca, Medina, and Jerusalem. The area of Hala Sultan Tekke was a large city, attaining an area of more than 25 ha, and was occupied from the Middle Cypriot III/Late Cypriot IA period (~1650 BCE: ~3600 BP) to near the end of the LBA (~1150 BCE: ~3100 BP) (Fischer & Bürge, 2017b). Material remains from the city and the cemetery, one of the richest on the island, confirm vast intercultural connections including Sardinia, the Mycenaean and Minoan cultures, Anatolia, Egypt, the Levant and the Near East, and maybe even Scandinavia (Fischer, 2019). After the abandonment of the Bronze Age city, around 1150 BCE (~3100 BP), the area was never reoccupied with the exception of seasonal populations. At present the entire area of the ancient city, the mosque, and the natural habitat of the Larnaca Salt Lake with its flamingos is on UNESCO's tentative list to become a World Heritage Site.

3. Materials and Methods

3.1. Cores and Radiocarbon Chronology

In 2011 and 2016, several cores were drilled in the Larnaca Salt Lake (see supporting information Figure S1), close to the Mosque of Umm Haram. Two continuous cores, termed B22 (34°52′51.15″N, 33°36′43.68″E; 830 cm depth; 2 m a.s.l.; Kaniewski et al., 2013) and HST1 (34°53′08.17″N, 33°36′45.12″E; 575 cm depth; 0 m a.s.l.), were selected because they furnished undisturbed sediment sequences. Core B22 is chronologically framed by six radiocarbon (^{14}C) dates performed on short-lived samples (seeds and small leaves; three dates are published in Kaniewski et al, 2013). Core HST1 is constrained by nine ^{14}C dates also performed on short-lived samples (seeds and small leaves; Beta and Poznan laboratories; see Figure S2). A composite core was subsequently constructed based on chronological (^{14}C dates), sedimentological, and paleoecological (pollen analysis) correlations to create a unique sequence covering the period ~6,000 ± 20–500 ± 50 cal year BP (see Figure S3).

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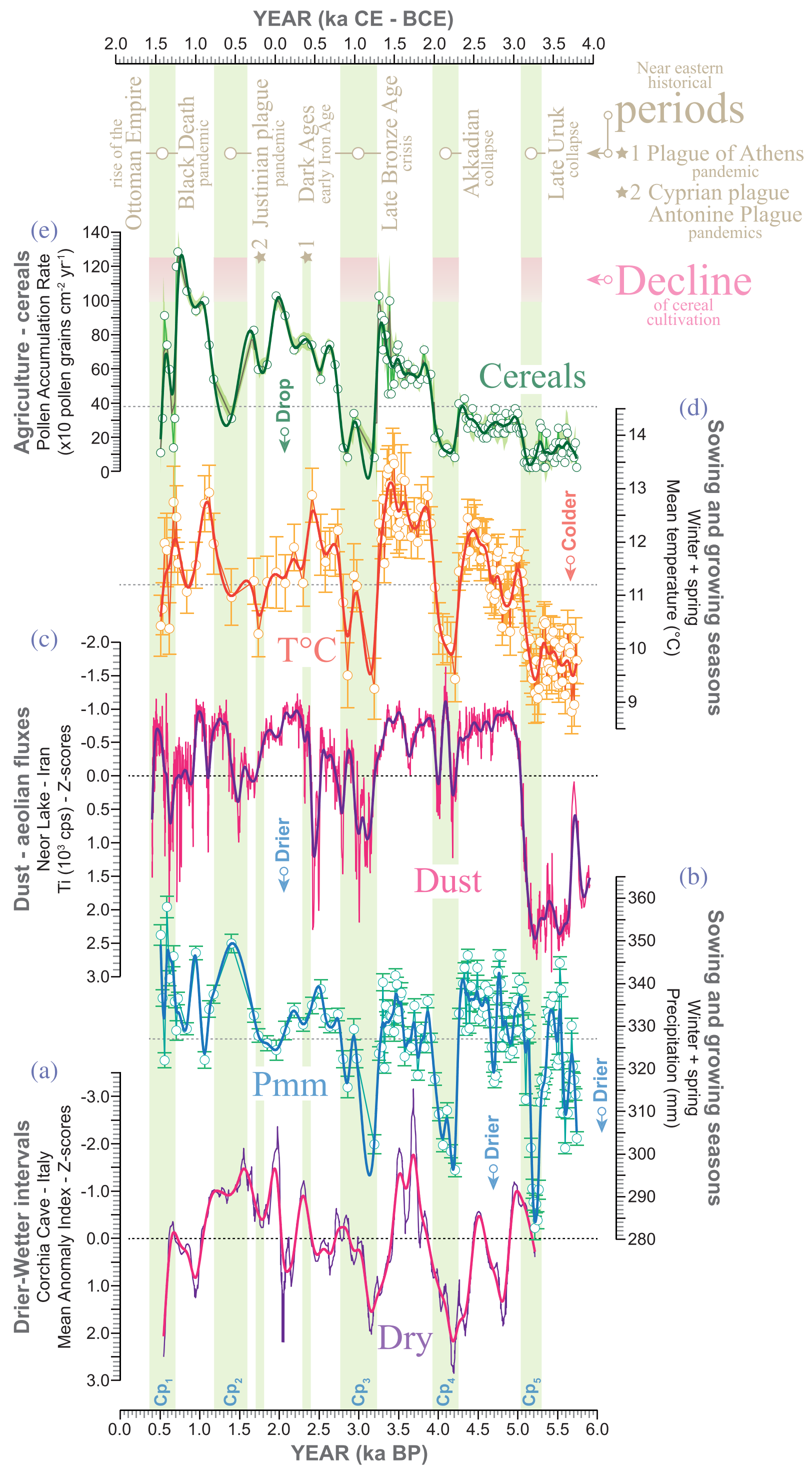

Figure 4. Reconstruction of temperatures and precipitation for the sowing-growing seasons shown alongside proxies for agricultural activities. (a) Mean anomaly index in precipitation from Corchia Cave, Italy (Regattieri et al., 2014). (b) Precipitation for the winter + spring seasons and their standard deviations; the trends are highlighted by a smoothing spline. (c) Dust index (Eolian flux) from Neor Lake, Iran (Sharifi et al., 2015). (d) Mean temperatures (T°C) for the winter + spring seasons shown with the standard deviations; the trends are highlighted by a smoothing spline. (e) Agriculture activities depicted as a cereal curve (pollen accumulation rate). The data have been filtered using a LOESS smoothing (with the 2.5th and 97.5th percentiles) and the trends underlined by a smoothing spline. The cold periods are shaded in light green and are denoted by a number (**Cp_1** to **Cp_5**). The decline of cereal cultivation is highlighted by rose shading. Some of the main historical periods in the Near East are mentioned.

3.2. Palaeoecological Data

A total of 150 samples (34 samples from the core B22 and 116 samples from the core HST1) were prepared for pollen analyses using standard palynological procedures. The 34 samples from the core B22 derive from a previous study (Kaniewski et al., 2013). Pollen grains were counted using an Olympus microscope. The mean pollen sum was 281 ± 60 pollen grains. The median value was 286 pollen grains, with a 25th percentile of 229 pollen grains and a 75th percentile of 324 pollen grains. Pollen frequencies (%) are based on the total pollen sum excluding local hygrophytes-hydrophytes and the spores of nonvascular cryptogams (for the pollen diagram, see Figures S4A and B). Aquatic taxa frequencies were calculated by adding local hygrophytes-hydrophytes to the terrestrial pollen sum. Agricultural activities were reconstructed using cereals (Poaceae cerealia). The pollen accumulation rates (PAR, also termed Influx) for cereals were calculated using pollen concentrations and sedimentation rates. PAR is defined as the number of pollen grains accumulated per unit of sediment surface area and per unit of time (grains cm^{-2} $year^{-1}$).

3.3. Statistical Analysis

Pollen data were transformed into pollen-derived vegetation patterns (PdVs) based on a Neighbor Joining clustering (with correlation as similarity measure and final branch as root; see Figure S5). Pollen types from each cluster were summed to create PdV time series (Figure 1). The PdVs were tested using a principal component analysis (PCA) to assess major changes in ecosystem dynamics for the last six millennia (based on PdV-frequencies). The resulting PCA-Axis1 (74.32% of the total variance), which mainly portrays the ecological shifts at a regional scale, has been plotted on a linear time scale (Figure 2).

3.4. Pollen-Based Climate Model

The model used to reconstruct both the temperatures and precipitation (Figures 2–4) is fully described in the literature (Cheddadi et al., 2016, 2017; Cheddadi & Khater, 2016; Kaniewski et al., 2019a). Because no continuous data set (temperatures and precipitation) is available for Larnaca for the period 1900–2000 CE, we used data from the coastal city of Limassol (~50 km west of the Larnaca Salt Lake; Petrakis et al., 2012). Warming on the south coast was 2.3 °C during the twentieth century CE at Limassol. As the average temperature for the period 1981–1990 at Larnaca is 18.9 °C, we subtracted 2.3 °C from the 18.9 °C average and used 16.6 °C as a benchmark for the anomalies (temperature at the onset of the twentieth century). We then transformed the data set into temperature anomalies (Figure 2).

4. Results and Discussion

4.1. Climate Instability

Several cold periods were recorded in Cyprus during the last 6,000 years (Figure 2), with the main anomalies centered on the 5.2 ka BP (Renssen et al., 2006; Zanchetta et al., 2014), 4.2 ka BP (Weiss, 2017), and 3.2 ka BP (Kaniewski et al., 2008, 2019a-2019b) events. The cold periods reconstructed in the present study also match cooler phases in Europe including the Late Antique Little Ice Age (LIA) (Büntgen et al., 2011, 2016) and the onset of the pre-industrial LIA (also termed Late Medieval; Jones et al., 2006; Figure 1). Each cold period corresponds to an important shift in ecosystem dynamics (Figures 1 and S4A,B) and echoes a significant instability in precipitation (Figure 3). Mean annual temperatures cooled by 3 ± 0.4 °C at 5250 ± 20 cal year BP [termed cold period 5 ($\mathbf{Cp_5}$)], 2.7 ± 0.3 °C at 4215 ± 40 cal year BP ($\mathbf{Cp_4}$), 2.6 ± 0.5 °C and 2.3 ± 0.6 °C at 3200 ± 90 and 2865 ± 90 cal year BP, respectively, ($\mathbf{Cp_3}$), 1 ± 0.5 °C at 1400 ± 70 cal year BP ($\mathbf{Cp_2}$), 1.6 ± 0.4 °C and 1.5 ± 0.5 °C at 600 ± 50 cal year BP and 510 ± 50 cal year BP, respectively, ($\mathbf{Cp_1}$) compared to present-day conditions (onset of the twentieth century CE). These colder phases are correlated with increases in the North Atlantic drift-ice index (Bond et al., 2001) and, for the period 4,500–500 cal year BP, with cooler SSTs in North Iceland (Sicre et al., 2008). Two periods, $\mathbf{Cp_4}$ and $\mathbf{Cp_3}$, are also linked with a marked decrease in SSTs and an expansion of sea-ice in the Northwest Atlantic (Klus et al., 2018; Figure 2). For winter and spring seasons (crop sowing and growing seasons), cumulative rainfall decreased during the first cold periods (Figure 3), with an effective loss of 54.2 ± 2.1 mm ($\mathbf{Cp_5}$), 50.3 ± 1.5 mm ($\mathbf{Cp_4}$), and 38 ± 2.1 mm ($\mathbf{Cp_3}$) related to precipitation levels recorded before each event (Figure 4). From the Roman era onwards, the events remained cold but became abnormally wetter (Figure 3), with an increase in cumulative rainfall during the sowing and growing seasons of crops of 16.9 ± 1.9 mm ($\mathbf{Cp_2}$) and 29.4 ± 2.1 mm ($\mathbf{Cp_1}$) (Figure 4). This instability occurred concurrently with a weakening/strengthening of precipitation

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in Morocco (Wassenburg et al., 2016) and drier/wetter conditions in both Lebanon (Cheng et al., 2015; Figure 3) and Italy (Regattieri et al., 2014; Figure 4). The drier periods also mirror dust peaks in Iran (Sharifi et al., 2015; Figure 4). The temperatures during the sowing and growing seasons follow the mean annual temperature anomalies (Figure 4).

4.2. Climate Instability and Socioeconomic Changes

Cold-dry periods (**Cp_5** to **Cp_3**) have hit the Eastern Mediterranean several times during the past 6,000 years. These phases are juxtaposed (according to our well-resolved age model) with major crises in the Near East and seemingly weakened populations by impacting harvests (Figure 4) via a loss of irrigation capacity, the development of uncultivable dry areas, and the persistence of cooler temperatures during the sowing and growing seasons. These phases of climate deterioration occurred concurrently with the decline of large cities and settlements that were significantly depopulated or even completely abandoned. Around 5200 BP (~**Cp_5**), the Late Uruk colonies of northern Mesopotamia were abandoned and deserted (Weiss, 2003), whereas the urban areas in Sumer (southern Mesopotamia) were depopulated (Postgate, 1992). A similar decline played out a thousand years later, around 4200 BP (~**Cp_4**), in the Levantine cities of Ebla, Halawa, Jerablus Tahtani, Selenkahiyeh, Sweyhat, and Umm al-Marra. During this phase, the Akkadian Empire in Mesopotamia (Weiss, 2017) and the Old Kingdom in Egypt (Stanley et al., 2003) collapsed. Around 3200 BP (~**Cp_3**), LBA societies declined and finally disintegrated, affected by both internal conflicts and migrations (the Sea Peoples phenomenon), leading to deep-seated sociocultural changes that lasted roughly 300 years. While this crisis was essentially rooted in political struggles and socioeconomic tensions, recent studies have suggested that a centuries-long drought and climate cooling underpinned the decline (Kaniewski et al., 2008, 2019a-b).

During each of these cold-dry periods, cities deteriorated or were abandoned, with, by contrast, the rise of isolated villages in rural areas (Kaniewski et al., 2015). These crises suggest that, while climate may not have been the primary agent behind the unrest, it acted as an amplifying factor, causing food shortages that weakened populations through malnutrition and forced migrations.

4.3. Climate Instability and Outbreaks of Plague

The two cold spikes (2380–2300 ± 70 cal year BP and 1800–1700 ± 70 cal year BP) and the cold-wet periods (**Cp_2** and **Cp_1**) mirror pandemics in Europe and in the Eastern Mediterranean. The Plague of Justinian during Late Antiquity (Wagner et al., 2014) is a pandemic (persisting from 541 to 750 CE: 1409–1200 BP; Little, 2007) that affected the areas rimming the Mediterranean Sea and eventually extended as far east as Persia (Sarris, 2007). The scourge was still present during the Muslim conquest of the Roman-Byzantine army in the Levant and at the onset of Islamic rule in 638 CE (1312 BP). While climatic conditions are believed to be secondary in the outbreaks of the bubonic and pneumonic forms of the plague, it has been argued that climate change has the capacity to further weaken afflicted populations by inducing food shortages, famines, and starvation (Dooley, 2007; Figure 3). Sallares (2007), moreover, noted that colder conditions/harsher winters promote the congregation of humans in poorly ventilated rooms, thus facilitating the exchange of pneumonic forms of the disease. During history, it has also been observed that increased rainfall or periods of above-normal precipitation (Figures 3 and 4) have facilitated increases in plague outbreaks due to a trophic cascade: A surge in sustenance at lower levels of the food chain (McCormick, 2007) leads to an explosion in rodent populations, including gerbils and rats (Sallares, 2007).

Before the Plague of Justinian, other scourges hit the Mediterranean world. Although resulting from diverse pathogens, the Plague of Athens (430–426 BCE: 2380–2376 BP), the Antonine plague (165–180 CE: 1785–1770 BP), and the Cyprian plague (250 CE: 1700 BP; McMichael, 2012) all occurred during colder periods (Figure 4). This suggests that populations could have been weakened via climate-induced food shortages (Figure 4) engendering malnutrition and worsening living conditions. Populations would have progressively become less resistant to pathogens.

The Black Death (1345–1350 CE: 605–600 BP in Eastern Mediterranean), one of the most devastating pandemics in human history (Schmid et al., 2015), occurred at the onset of the LIA, a period of harsh winters in Europe and the Mediterranean. Climate was not responsible for the emergence of the scourge but probably favored the outbreaks by weakening the populations. Climate changes since ~600 ± 50 cal year BP

(Figure 2) may have acted as an amplifier of the scourge, impacting food harvests (Figure 4) and populations during the Mameluke Sultanate.

4.4. Cold Conditions Versus Periods of Drought

To probe the respective role of cold conditions versus drought periods on the food-shortage episodes during the period 6000–500 BP, cross-correlations were calculated (see Figure S6). Positive correlation coefficients are considered, focusing on the Lag_0 value, with +0.50 as the significant threshold. The test, applied to cold periods versus decline in cereals, shows a significant correlation ($Lag_0 = 0.65$, $P_{value} < 0.001$), while the same test, based on drought periods versus decline in cereals, is less significant ($Lag_0 = 0.35$, $P_{value} < 0.001$). Cold conditions seem to prevail during periods of low harvests between 6000 to 500 BP. Drought probably amplified the process initiated by the decline in temperatures, particularly during the phases $\mathbf{Cp_5}$ to $\mathbf{Cp_3}$.

4.5. Islands versus the Mainland

Cyprus is an island close to Anatolia and the northern Levant. To establish a link between the populations living on an island with populations from the mainland, we focus on the LBA collapse for which numerous data are available. The climate reconstruction from Tell Tweini, coastal Syria (mainland), closely mirrors the data from Hala Sultan Tekke for the period 3500–2500 BP (Kaniewski et al., 2019a). In situ bioarcheological studies from Pyla-*Kokkinokremnos* (~15 km from Hala Sultan Tekke, Cyprus) and Tell Tweini (~220 km to the northwest) support this correlation as similar dry environments were recorded during the LBA collapse (Kaniewski et al., 2019b). On Cyprus, populations were able to overcome summer drought by pumping freshwater from the aquifers of the Tremithos River (Ploethner et al., 1986; Ghilardi et al., 2011) as the lake only fills during winter time, fed by precipitation. At Tell Tweini, the inhabitants did the same by using freshwater from the Rumailiah River and the southern springs that surrounded the tell (Kaniewski et al., 2010). At ~3200 BP, Hala Sultan Tekke, Pyla-*Kokkinokremnos*, and Tell Tweini recorded an important fall in harvests and a major shift in the environment. These three cities were finally abandoned, probably as a result of the Sea Peoples phenomenon (Fischer, 2017; Kaniewski et al., 2015). Because these sites lay close to permanent freshwater sources, which would have partially offset the drought, crop failure appears to have resulted from colder conditions during the sowing and growing seasons.

5. Conclusions

The history of civilizations in the Eastern Mediterranean and Near-Middle East appears to have been partially affected by climate by contributing to social unrest, mass migrations, and outbreaks of plagues. When occurring coevally, climate and socioeconomic factors were probably important drivers of major crises. During plague outbreaks, for instance, climate deterioration acted to further weaken already fragile populations.

Conflict of Interest

The authors declare no competing interest.

Acknowledgments
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