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The 4.2 ka event and its resulting cultural interruption in the Daihai Lake basin at the East Asian summer monsoon margin

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ABSTRACT

The 4.2 ka event has attracted worldwide interest since it was suggested to be a possible cause for the collapse of ancient civilizations. With the accumulation of proxy records, however, both the nature of the 4.2 ka event itself and the manner of societal responses to climate change have become controversial. Here we present a climatic record of Daihai Lake spanning 5–3 cal ka BP, together with a cultural series for the lake basin around 4 cal ka BP, to explore the regional nature of the 4.2 ka event and the relationship between climatic variation and cultural evolution. The climatic record reflects a dry event at the interval of 4060–3690 cal yr BP that could be a regional manifestation of the 4.2 ka event. The cultural series suggests an interruption between two different cultures during the period of 4300–4000 cal yr BP. Taking into consideration the dating errors and especially the uncertainties resulting from dating cultural layers of the archaeological sections, we suggest that the cultural interruption in the Daihai Lake basin might have been caused by a monsoon-related dry event. Humans primarily engaged in agriculture likely left the lake basin because the drainage basin became unsuitable for agrarian activities as the climate became too dry, thus leaving a cultural vacancy of several centuries in the lake basin. A significant decline in the intensity of the East Asian summer monsoon on centennial to multi-decadal timescales could be associated with dramatic cooling of surface waters of both the North Atlantic and western tropical Pacific.

1. Introduction

The 4.2 ka event has been identified as a possible contributor to the collapse of ancient civilizations in the Euphrates and Tigris floodplains of western Asia (Weiss et al., 1993) and in the Yucatán Peninsula of Mesoamerica (Hodell et al., 1995). Years later, two articles (Weiss and Bradley, 2001; deMenocal, 2001) have demonstrated that the drought that occurred 4.2 ka ago could explain the societal collapse of Old World civilizations based on data from existing archaeological and paleoclimatic studies. This point of view motivated extensive investigations into the causal relationship between cultural evolution and climate change on representative archaeological records and also promoted researches aimed at the 4.2 ka event using high-resolution paleoclimatic records. With the accumulation of proxy records, however, both the nature of the 4.2 ka event (Marchant and Hooghiemstra, 2004; Magny et al., 2009) and the manner of societal responses to climate change (Drysdale et al., 2006; Staubwasser and Weiss, 2006) have become increasingly controversial.

Researches on the 4.2 ka event and its impact on cultural evolution in China have been encouraged by Hsü's view (1998) that famines and mass migrations have occurred in the past. In ancient China, these could have resulted from regional droughts related to global cooling. Wu and Liu (2004) synthesized data from paleoclimatic records in eastern China and suggested that the climatic anomaly that occurred ~4.2 ka ago produced a drought in the north and flooding in the south, which was responsible for the collapse of Neolithic cultures in the central plain of China during the late third millennium BC. Recently Liu and Feng (2012) examined the newly published data of paleoclimatic and archaeological records spanning the transition from the middle to late Holocene and offered a different interpretation from that of Wu and

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Liu (2004). In brief, an abrupt climatic shift occurred in northern China at ~4 cal ka BP; while in southern China the ~4 cal ka event had several effects. With the associated climatic drying at ~4 cal ka BP, Chinese Neolithic cultures in the north and in the south collapsed; while the Longshan Culture in the central plain thrived. A high-resolution paleoclimatic record with a well-documented archaeological record from the same locale can resolve these two conflicting views.

Towards this end, we present a climatic record of a sediment core at Daihai Lake in central southern Inner Mongolia together with a cultural record of archaeological sites in the lake basin. Daihai Lake is located at the northern margin of the East Asian summer monsoon that represents a climatically sensitive region and a cultural transition zone. The multi-proxy paleoclimatic data from the core sediments of the lake and the abundant cultural relics from archaeological excavations in the lake basin would provide new insights into the 4.2 ka event and the relationship between the event and regional cultural responses. The aim of the present study is to explore the nature and mechanism of the 4.2 ka event occurring in the Daihai Lake region and its possible role in the interruption of local cultures developed in the lake basin.

2. Study area

Daihai Lake (40°29′ to 40°37′N, 112°33′ to 112°46′E), a hydrologically closed lake, lies ~10 km east of Liangcheng County, Inner Mongolia, China (Fig. 1). It lies in an inland, fault-depression basin that was formed in the Late Pliocene to Early Pleistocene (Li, 1979; Song et al., 1986). It has an area of 134 km^2, a maximum water depth of 16 m, and an elevation of 1221 m a.s.l. (measurements in July 1986; Wang et al., 1990). The lake basin is bordered by the Manhan Mountains (highest peak: 2305 m a.s.l.) on the north and the Matou Mountains (highest peak: 2035 m a.s.l.) on the south. Hills and low mountains are distributed on the east and lacustrine plains extend from the western shore. The lake has a catchment of 2289 km^2. Two rivers from the east and west and three intermittent streams from the south supply water for the lake, but no rivers drain the lake (Fig. 1).

Daihai Lake is located at the transition from semi-humid to semi-arid areas of the middle temperate zone of China (Fig. 1). The climate of the lake's region is influenced by the East Asian summer and winter monsoons (Chinese Academy of Sciences, 1984; Zhang and Lin, 1985). During the summers, the warm, moist southeasterly air-masses interact with cold air from the northwest and produce rainstorms. During winter, cold, dry northwesterly air generates strong winds and cold weather. The mean annual temperature in the lake region is 5.1 °C with a July average of 20.5 °C and a January average of −13.0 °C. Mean annual precipitation is 423 mm, and ~80% of the annual precipitation falls in June–September with a peak value of 122 mm in August. Mean

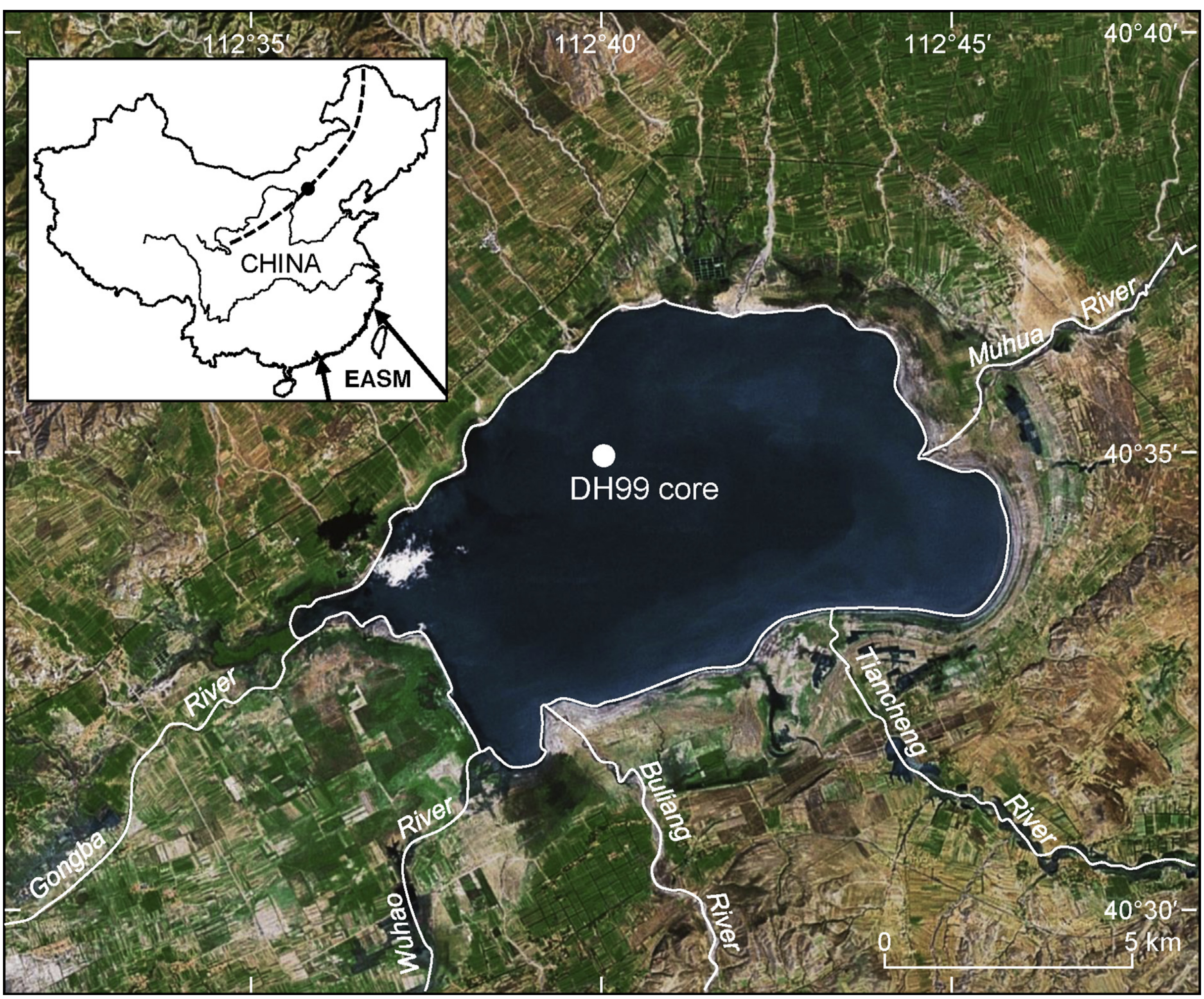

Fig. 1. Map of Daihai Lake (from http://www.maps.google.com) showing the location of the DH99 core. Mountains border the lake on the north and south; hills are distributed on the east; and lacustrine plains extend from the western shore. Five rivers supply water for the lake, but no rivers drain the lake. The inset gives a sketch map of China showing the current northern limit of the East Asian summer monsoon (dashed line) defined as the 400-mm isohyet of mean annual precipitation (Chinese Academy of Sciences, 1984; Zhang and Lin, 1985) and the location of Daihai Lake (solid circle). EASM shown in the inset stands for the East Asian summer monsoon.

annual evaporation reaches 1162 mm, which is ~3 times the annual precipitation. The lake is covered with ~60 cm of ice from November to March.

The modern natural vegetation of the lake basin belongs to the southern temperate steppe (Compilatory Commission of Vegetation of China, 1980; Wu et al., 1993). Forests are distributed on the north slopes of the mountains, accompanied by mesophilous scrubs and herbs under the trees. Alpine meadows are developed in the mountainous areas above 1900 m a.s.l. Grasses and herbs cover the hilly areas; whereas halophilic meadows and patches of boggy meadow dominate the lakeshore plain and the distal parts of alluvial fans.

3. Climatic variation in the Daihai Lake basin around 4.2 cal ka BP

3.1. DH99 core at Daihai Lake

Drilling was conducted at a water depth of 13.1 m in the central part of Daihai Lake in the summer of 1999 (Fig. 1), using a Japanese-made TOHO drilling system (Model D1–B). A sediment core was extracted to a depth beneath the lake floor of 11.96 m and is designated DH99 (40°35.165′N, 112°40.057′E; Fig. 1). The core was collected in half-split polyethylene tubes using a piston corer. Sediment recovery reached 98.5%. The core section was split, photographed and described on site and then cut into 2-cm segments, resulting in 598 samples for laboratory analyses.

The sediments of the DH99 core are composed of homogeneous silt and silty clay and can be divided into two parts at core depth of 6.65 m: 1) a greenish-grey to greyish-black upper part with burrows at depths of 2.10–5.70 m, and 2) a light to dark grey, laminated lower part (Fig. 2).

Eight bulk samples were collected from organic-rich horizons of DH99 core sediments (Fig. 2; Table 1) (Xiao et al., 2004) and dated with a HVE Tandetron AMS-II system at the Center for Chronological Research, Nagoya University, Japan. Organic carbon was extracted from each sample and dated following the method described by Kitagawa et al. (1993) and Nakamura et al. (2000). The ^{14}C dates of all the samples from the DH99 core were determined with a half-life of 5568 yr.

In the previously published paper (Xiao et al., 2004), carbon reservoir effects on radiocarbon dating of the bulk organic matter of the lake sediments were not considered for the chronology of the sediment core. Xiao et al. (2004) declared that the presented AMS ^{14}C ages might be ~360 yr older based on the close relation between the age and depth of the upper 10 m of the sediment core as well as the linear extrapolation of ^{14}C ages. To construct a precise age–depth model for the DH99 core in the present study, calibrations are performed on the carbon reservoir-free ^{14}C dates.

As shown in Fig. 2, the relation between the ^{14}C age and depth of 6 samples from the upper 9.9 m of the DH99 core is quite close, which implies that the sedimentation rate of the upper 9.9 m is nearly uniform. From this linear relation, the age of the surface of the lake sediments (i.e., age of the horizon at core depth of 0 m) can be extrapolated to ~366 ± 124 yr. This anomalously old age can be considered to result from carbon reservoir effects on radiocarbon dating of the bulk organic matter of Daihai Lake sediments. To produce a new age–depth model for the DH99 core, we first subtracted the carbon reservoir age of 366 ± 124 yr from all the original ^{14}C dates, assuming that it is constant through the core, and then performed calibrations on the carbon reservoir-free ^{14}C dates. The conventional ages were converted to calibrated ages using the OxCal4.3 radiocarbon age calibration program (Bronk Ramsey, 2017) with the IntCal13 calibration data (Reimer et al., 2013) (Fig. 2; Table 1). The age–depth model indicates that the DH99 core covers the last ~12,000 yr (Fig. 2). Ages of sampled horizons of the sediment core were derived by linear interpolation between radiocarbon-dated horizons using the mean values of 2σ ranges of calibrated ages.

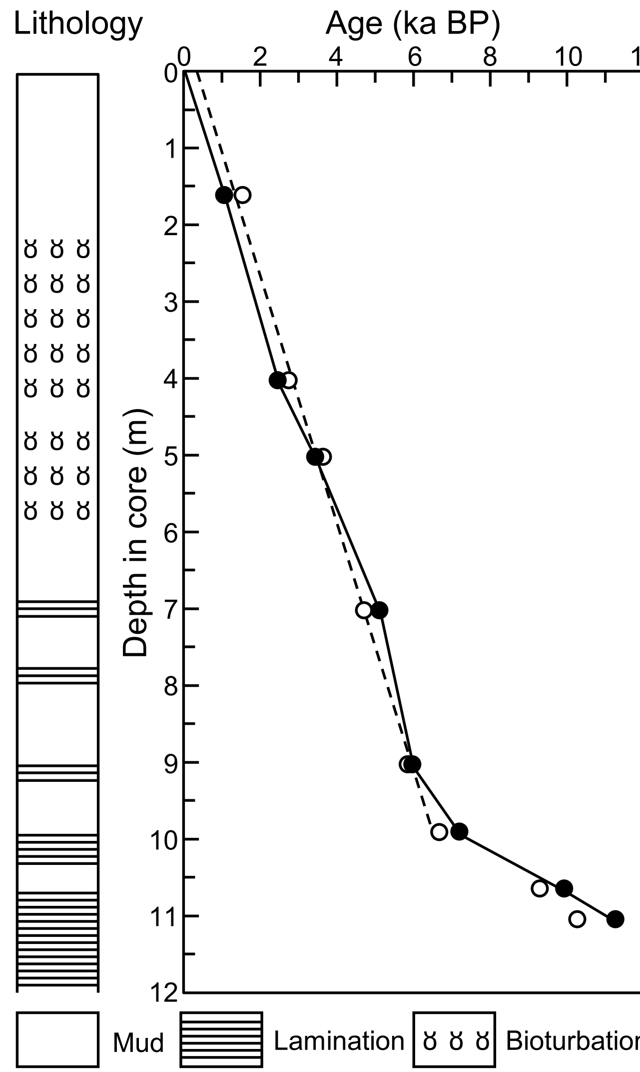

Fig. 2. Lithological log and age–depth model of the DH99 core recovered in the central part of Daihai Lake. Hollow circles represent AMS radiocarbon dates, and solid circles represent the mean values of 2σ ranges of calibrated ages of carbon reservoir-corrected radiocarbon dates. The carbon reservoir correction factor is 366 ± 124 yr, age of the surface of the lake sediments derived from the upper 6 radiocarbon dates by linear extrapolation as indicated by the dashed line.

3.2. Proxy sequences of the DH99 core

The DH99 core has been analysed at 2- to 4-cm intervals for multiple proxies including grain-size distribution (Peng et al., 2005), carbon concentration (Xiao et al., 2006) and pollen assemblage (Xiao et al., 2004) in order to investigate the history of changes in climate in the lake region during the Holocene. Based on the pollen profile (Xiao et al., 2004) and the pollen–climate transfer function for temperate eastern Asia (Wen et al., 2013), in addition, Xiao et al. (2013) quantitatively reconstructed the history of changes in the regional precipitation for the Holocene. The above multi-proxy data for the period between 5 and 3 cal ka BP (corresponding to the segment of the sediment core between 695 and 463 cm at core depth) were re-examined in the present study in order to explore the detailed process of climate changes on centennial to multi-decadal scales in the Daihai Lake basin around 4.2 cal ka BP (Fig. 3).

3.2.1. Silt fraction content

The content of the silt fraction in the core sediments during the

Table 1
AMS radiocarbon dates of samples from the DH99 core recovered in the central part of Daihai Lake.

Laboratory number[a]	Depth interval (cm)	Dating material	$\delta^{13}C$ (‰)	AMS ^{14}C age (yr BP)	Corrected ^{14}C age[b] (yr BP)	Calibrated ^{14}C age (2σ) (cal yr BP)
NUTA2-2954	159–161	Organic matter	–25.1	1434 ± 28	1068 ± 127	744–1262
NUTA2-2864	401–403	Organic matter	–26.8	2688 ± 27	2322 ± 127	2060–2735
NUTA2-2868	500–502	Organic matter	–25.2	3531 ± 28	3165 ± 127	3056–3693
NUTA2-2719	700–702	Organic matter	–24.8	4729 ± 32	4363 ± 128	4781–5319
NUTA2-2721	900–902	Organic matter	–24.3	5809 ± 33	5443 ± 128	5335–6477
NUTA2-2724	988–990	Organic matter	–25.1	6593 ± 34	6227 ± 129	6846–7421
NUTA2-2877	1062–1064	Organic matter	–25.5	9175 ± 34	8809 ± 129	9552–10187
NUTA2-2725	1102–1104	Organic matter	–24.7	10,171 ± 39	9805 ± 130	10,760–11,652

[a] Laboratory code of Center for Chronological Research, Nagoya University, Japan.
[b] The reservoir correction factor is 366 ± 124 yr, age of the surface of the lake sediments derived from the upper 6 ^{14}C ages by linear extrapolation.

period of 5000–3000 cal yr BP shows lower-than-average values at the interval of 4250–3790 cal yr BP (core depth: 605–551 cm) with an average of 71.6% and a minimum of 62.8% (Fig. 3). The silt fraction occupies 70% to 90% of clastic materials of the sediment core; and decreases in the content of silt fraction were generally accompanied by increases in that of sand fraction during the Holocene (Peng et al., 2005). Therefore decreases in the silt fraction content were interpreted to indicate decreases in the water level of Daihai Lake (Peng et al., 2005). We thus infer that lower values of the silt fraction content at the interval of 4250–3790 cal yr BP imply a lower lake level at that time.

3.2.2. Total organic carbon concentration

The concentration of total organic carbon in the core sediments during the period of 5000–3000 cal yr BP shows lower-than-average values at the interval of 4100–3760 cal yr BP (core depth: 587–547 cm) with an average of 2.0 and a minimum of 1.4 (Fig. 3). The organic matter in the sediments of Daihai Lake is mainly derived from terrestrial plants growing in the lake catchment because the lacustrine organic matter has atomic C/N ratios greater than 10 (Xiao et al., 2006). Therefore decreases in the total organic carbon concentration were interpreted to indicate decreases in the surface runoff of the lake catchment because the terrestrial organic matter entering the lake would be transported by rivers and streams from the lake catchment (Xiao et al., 2006). We thus infer that lower values of the total organic carbon concentration at the interval of 4100–3760 cal yr BP would denote a weakened catchment surface runoff at that time.

3.2.3. Tree pollen percentage

The percentage of tree pollen in the core sediments during the period of 5000–3000 cal yr BP shows lower-than-average values at the interval of 4060–3690 cal yr BP (core depth: 583–539 cm) with an average of 17.6 and a minimum of 7.4 (Fig. 3). Changes in the percentage of tree pollen in the sediments of Daihai Lake were closely related to changes in the coverage of woody plants growing in the lake catchment (Xiao et al., 2004). Therefore decreases in the tree pollen percentage were interpreted to indicate decreases in the forest coverage in the lake region (Xiao et al., 2004). Because the growth of plants in the semi-arid area of north China is more sensitive to precipitation than to temperature (Xiao et al., 2004), we infer that lower values of the tree pollen percentage at the interval of 4060–3690 cal yr BP imply decreased precipitation in the lake region at that time.

3.2.4. Mean annual precipitation

The precipitation history in the Daihai Lake region during the Holocene was quantitatively reconstructed (Xiao et al., 2013) based on a pollen profile from the same sediment core (Xiao et al., 2004), using a

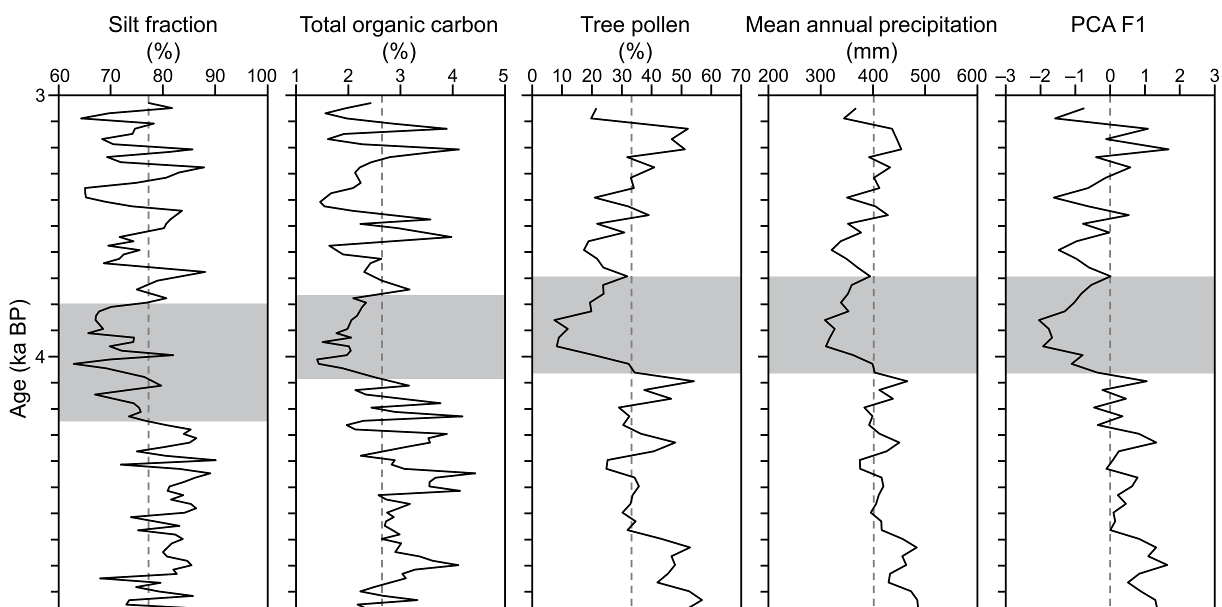

Fig. 3. Time series of silt fraction (%), total organic carbon (%), tree pollen (%) and mean annual precipitation (mm) from the DH99 core spanning the period between 5 and 3 cal ka BP as well as the PCA F1 obtained from the aforementioned four proxies. The chronology was derived from the carbon reservoir-corrected age–depth model; ages of sampled horizons were determined by linear interpolation between radiocarbon-dated horizons using the mean values of 2σ ranges of calibrated ages. Vertical dashed lines show the averages of each proxy data as well as the average of PCA F1 values during the period between 5 and 3 cal ka BP. The shaded bars mark the intervals around 4.2 cal ka BP at which the proxy or PCA F1 has lower-than-average values.

pollen–climate transfer function for temperate eastern Asia (Wen et al., 2013). As shown in Fig. 3, the mean annual precipitation in the lake region during the period of 5000–3000 cal yr BP shows lower-than-average values at the interval of 4060–3690 cal yr BP (core depth: 583–539 cm) with an average of 342.8 mm and a minimum of 308.1 mm. These data indicate that the climate of the lake region became dry at the interval of 4060–3690 cal yr BP.

3.3. Climatic records of the DH99 core

The lowered lake level at the interval of 4250–3790 cal yr BP registered by the silt fraction content in the core sediments and the weakened catchment surface runoff at the interval of 4100–3760 cal yr BP registered by the total organic carbon concentration in the core sediments suggest decreased precipitation, i.e., a relatively dry climate in the lake region during those time intervals. The decreased regional precipitation at the interval of 4060–3690 cal yr BP shown by the percentage of tree pollen in the core sediments and by the pollen-reconstructed mean annual precipitation both indicate a dry condition in the lake region at that time. These data of different proxies are in good agreement with each other during the period of 5000–3000 cal yr BP and especially around 4.2 cal ka BP (Fig. 3).

In order to detect the pattern of temporal changes in the regional wet–dry condition during the period of 5000–3000 cal yr BP, principle component analysis (PCA) was performed to analyze the time series of data of the silt fraction content, total organic carbon concentration, tree pollen percentage and the mean annual precipitation. All the raw data of the 4 proxies were standardized, and then PCA was conducted on the standardized data with the proxies as variables. F1, F2 and the first three factors of PCA capture 62.0%, 22.8% and 99.6% of the total variance within the data set, respectively. As shown in Fig. 3, PCA F1 with an average value of 0 during the period of 5000–3000 cal yr BP displays lower-than-average values at the interval of 4060–3690 cal yr BP with an average of −1.3 and a minimum of −2.0. These data indicate that PCA F1 reflects the common characteristics of the 4 proxies for the prominent dry event at the interval of 4060–3690 cal yr BP. We thus suggest that the dry event occurring in the Daihai Lake basin could be the regional manifestation of the 4.2 ka event.

4. Cultural evolution in the Daihai Lake basin around 4.2 cal ka BP

4.1. Cultural sites

In the 1970s and 1980s, archaeologists from the Inner Mongolia Autonomous Institute of Cultural Relics and Archaeology carried out extensive excavations in the Daihai Lake basin in order to investigate the origin of nomads of northern China and the response of human activities to changes in the environment of the transitional zone of agriculture and pastoralism. A great number of Neolithic relics were unearthed from a total of 36 sites in the lake basin (Fig. 4). Archaeological studies suggested that these relics represent 3 different cultures, i.e., the Haishengbulang Culture (10 sites) corresponding to the Yangshao Culture, the Laohushan Culture (23 sites) to the early Longshan Culture and the Zhukaigou Culture (3 sites) to the late Longshan Culture (Fig. 4) (Tian, 1993, 2000). Among these cultures, the Laohushan Culture and Zhukaigou Culture appeared in the lake basin around 4.2 cal ka BP.

4.2. Cultural series

Studies on the unearthed relics indicated that the Laohushan Culture and Zhukaigou Culture are different from each other in at least 3 cultural aspects (Table 2) (Tian, 1993, 2000; Tian and Guo, 2004). First, potteries of the Laohushan Culture are characterized by plain-surface, flat-bottomed pots with 1 or 2 handlebars and by the ornaments of both basket and rope figures; while the Zhukaigou Culture is characterized by jars with 3 bag-shaped legs and 1 or no handlebar, and by the ornaments dominated by rope figures. Second, funerary goods of the Laohushan Culture contain jawbones of pigs; while those of the Zhukaigou Culture include bones of sheep. And third, some tribes of the Laohushan Culture are surrounded by stonewalls, denoting sedentary habits; while nor tribes of the Zhukaigou Culture surrounded by stonewalls, implying migratory habits. These data suggest that humans of the Laohushan Culture might be engaged in farming and those of the Zhukaigou Culture engaged in grazing (Tian, 1993, 2000; Tian and Guo, 2004).

4.3. Cultural chronology

Radiocarbon dating of bulk samples collected from cultural layers and soil strata of the archaeological sections was conducted to identify the appearance of different cultures in the lake basin (Tian, 1993, 2000). The data indicate that the Laohushan Culture developed during the period of 4800–4300 cal yr BP and the Zhukaigou Culture developed during the period of 4000–3500 cal yr BP (Fig. 5; Table 2) (Tian, 1993, 2000). It is obvious that a cultural vacancy of ∼300 yr exists between the earlier Laohushan Culture and the later Zhukaigou Culture.

5. Discussion

The Laohushan Culture and Zhukaigou Culture developed in the Daihai Lake basin around 4.2 cal ka BP as two distinct cultures. The former was a sedentary, agricultural culture, and the latter a migratory, nomadic culture (Tian, 1993, 2000; Tian and Guo, 2004). The Laohushan Culture first appeared ∼4800 cal yr ago and disappeared ∼4300 cal yr ago; while the Zhukaigou Culture first appeared ∼4000 cal yr ago and disappeared ∼3500 cal yr ago (Tian, 1993, 2000). These data indicate that the Laohushan Culture was interrupted at ∼4300 cal yr BP and the Zhukaigou Culture did not appear in the lake basin until ∼4000 cal yr BP, denoting a cultural interruption of ∼300 yr in the Daihai Lake basin.

As shown in Fig. 5, the cultural interruption occurring in the Daihai Lake basin can be correlated with the regional dry event revealed by multiple proxies of the lake sediments, even though both chronologies do not show an ideal correspondence. It is worthwhile to mention that the age spans of most cultural layers were delimitated by linear interpolation between radiocarbon-dated horizons of the soil strata of the archaeological sections (Tian, 1993, 2000), leading to relatively larger uncertainties for the delimitation of different cultures. We thus suggest that the cultural interruption in the Daihai Lake basin can be explained by the drought occurring in the lake region.

In northern China, the development of primitive agriculture was closely related to the climatic condition represented by regional rainfall (Yan, 1997). During the period of the Laohushan Culture, the mean annual precipitation in the Daihai Lake region remained over 400 mm (Fig. 3), providing a necessary condition required for farming. Thereafter humans primarily engaged in agriculture likely left the lake basin because the drainage basin became unsuitable for agrarian activities as the climate became too dry, thus leaving a cultural vacancy of several centuries in the lake basin. After the dry event when the Zhukaigou Culture developed, the mean annual precipitation in the lake region decreased to ∼350 mm (Fig. 3) which was probably not in favor of agriculture production. People might have been forced by the dry climate to change the land-use strategy, leaving the rain-fed agriculture for the potential stockbreeding. In addition, the vegetation in the Daihai Lake basin was part of the typical steppe during the period of the Zhukaigou Culture that was different from the forest steppe occurring during the period of the Laohushan Culture (Fig. 3) (Xiao et al., 2004). The expansion of grasslands would contribute to the development of nomadic herding in which humans of the Zhukaigou Culture were engaged.

Fang and Sun (1998) first attributed the interruption of the

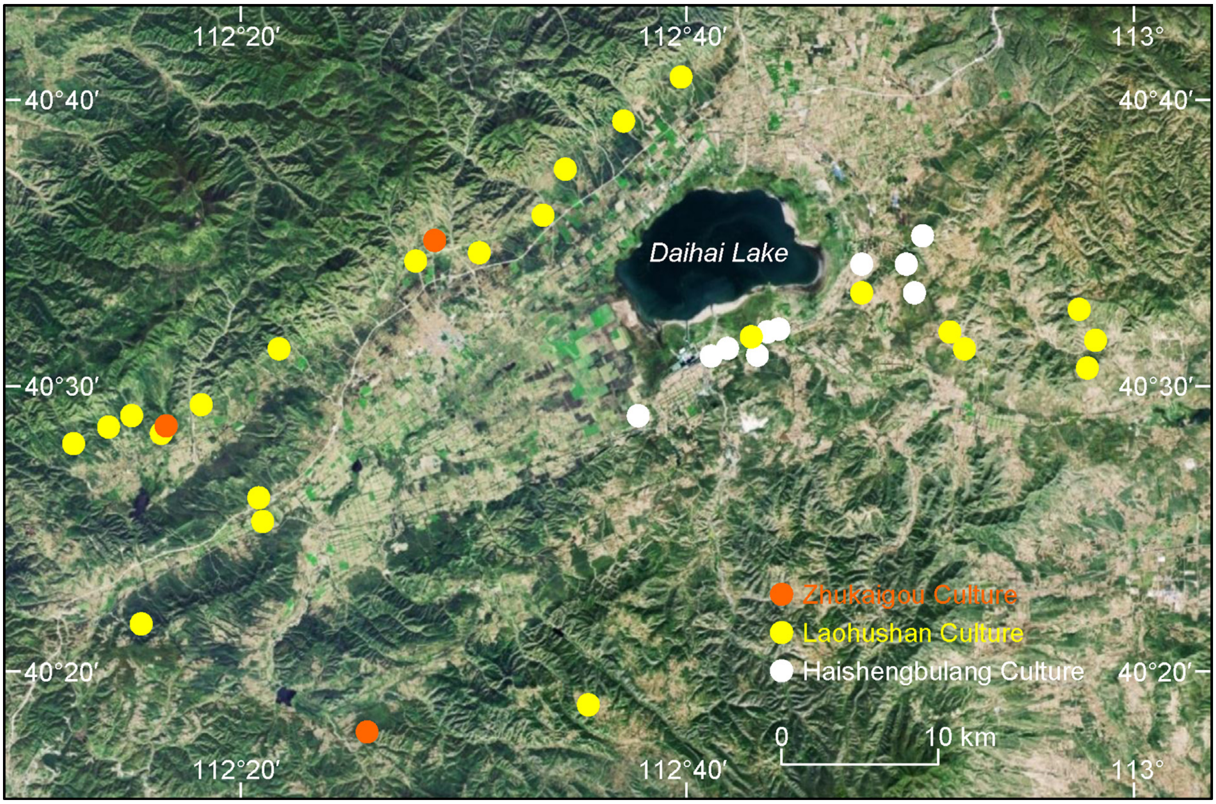

Fig. 4. Map of the Daihai Lake basin (from http://www.maps.google.com) showing the distribution of archaeological sites of the Haishengbulang, Laohushan and Zhukaigou Cultures. The Haishengbulang Culture (10 sites, 5800–5000 cal yr BP) corresponds to the Yangshao Culture, the Laohushan Culture (23 sites, 4800–4300 cal yr BP) to the early Longshan Culture and the Zhukaigou Culture (3 sites, 4000–3500 cal yr BP) to the late Longshan Culture. After Tian (2000) and Tian and Guo (2004).

Table 2
Comparison between cultural features of the Laohushan Culture and Zhukaigou Culture (after Tian (2000) and Tian and Guo (2004)).

Factors	Zhukaigou Culture	Laohushan Culture
Potteries	Plain-surface, flat-bottomed pots with one or two handlebars	Jars with three, bag-shaped legs with one or no handlebar
	Ornaments of basket and rope figures	Ornaments dominated by rope figure
Funerary goods	Jawbones of pigs	Bones of sheep
Settlement	Tribes surrounded by stone wall (sedentary)	Tribes not surrounded by stone wall (migratory)
Way of living	Agrarian farming	Nomadic herding
Number of sites	23	3
Chronology	4800–4300 cal yr BP	4000–3500 cal yr BP

Laohushan Culture to climatic cooling based on the impacts of ≥10 °C cumulative temperature decreases on frost-free period in the lake region and of a temperature drop to agricultural production in areas along the Great Wall during the historical period. This interpretation has been followed by Tian (2000) and Tian and Guo (2004). As stated above, our multi-proxy data imply a decrease in regional precipitation rather than temperature. In particular, decreases in the input of terrestrial materials, including clastic silts and organic matter, to the lake have nothing to do with decreasing air temperature. Consequently we do not agree with the inference of a cold event as the possible cause of the cultural interruption in the Daihai Lake basin around 4.2 cal ka BP.

Modern observations indicate that more than 80% of the annual precipitation falls in summer in the Daihai Lake region when the rainbelt of the East Asian summer monsoon (EASM) migrates to its northern margin (Chinese Academy of Sciences, 1984; Zhang and Lin, 1985) (cf. Fig. 1). These data imply that past changes in the precipitation of the lake region would be closely related to variations in the strength of the EASM. We thus infer that the dry event occurring in the Daihai Lake region at 4060–3690 cal yr BP implies a large decline of the EASM.

6. Conclusions

The multiple proxies of a sediment core at Daihai Lake reveal a prominent dry event occurring in the lake region at the interval of 4060–3690 cal yr BP that could be the manifestation of the 4.2 ka event in the northern margin of the EASM. The drought related to a remarkable decline of the EASM could cause the interruption of the local culture in the lake basin. The EASM variability on centennial to multidecadal scales would be physically linked with the ocean–atmosphere interactions occurring in the North Atlantic and in the tropical Pacific.

Differences in timing between the regional climatic drying and the local cultural interruption would be derived from the dating errors and especially the uncertainties resulting from the chronology of archaeological sections. Future studies should pay more attention to the reliability of dating cultural layers in order to explore the causal relationship between climatic changes and human activities.

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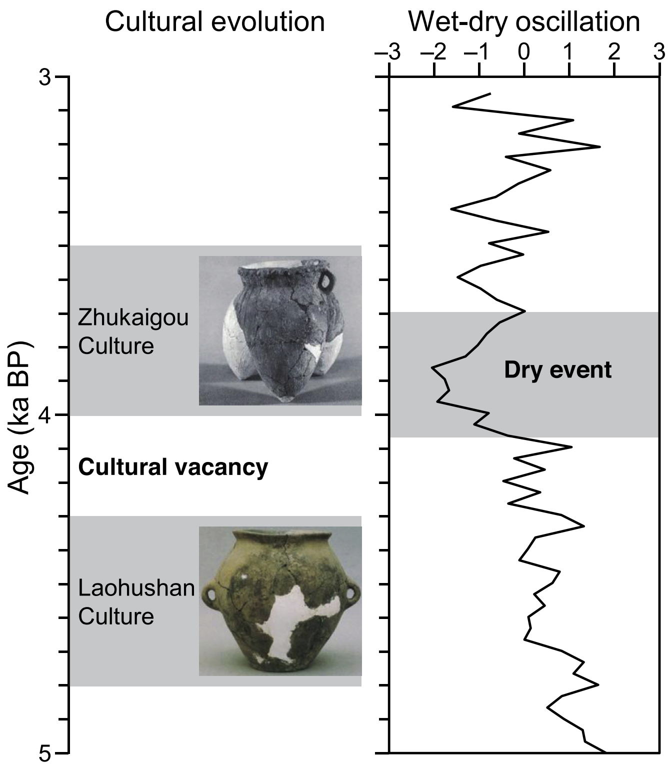

Fig. 5. The series and chronology of cultural evolution in the Daihai Lake basin around 4.2 cal ka BP, compared with wet–dry oscillation in the lake region denoted by the PCA F1 factor from the four proxies of the DH99 core. The chronologies of the Laohushan Culture and Zhukaigou Culture were derived from radiocarbon dating of bulk samples collected from cultural layers and soil strata of the archaeological sections and expressed in calendar ka BP (Tian, 1993, 2000). The chronology for the wet–dry oscillation in the lake region was derived from the carbon reservoir-corrected age–depth model in the present study. The shaded bar in the panel of wet–dry oscillation marks an interval of dry event occurring in the lake region at 4060–3690 cal yr BP.

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