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Charcoal evidence for environmental change ca. 3.5 ka and its influence on ancient people in the West Liao River Basin of northeastern China

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Abstract

Fossil charcoals from archaeological sites provide direct evidence for the relationship between environmental change and ancient peoples' livelihoods in the past. Our identification of 5811 fossil charcoal fragments from 84 samples suggested temperate deciduous and mixed conifer-broadleaved forests as the dominant vegetation at the Erdaojingzi site in northeastern China ca. 3500 cal yr BP; the major representative taxa were *Quercus*, *Pinus*, and *Ulmus*. Four woody plants probably supplied humans with food resources at the Erdaojingzi site, including *Quercus*, *Ulmus*, *Amygdalus/Armeniaca*, and *Ziziphus*. The nuts of *Quercus* were utilized as staple foods because of their rich starch content. The leaves of *Ulmus* may have been used by humans because of their massive dietary fibre. *Amygdalus/Armeniaca* and *Ziziphus* probably provided fruits for humans. Based on the coexistence approach (CA) used on the fossil charcoals, we found that the MAT anomaly was 7.9 ± 5.9°C at ca. 3500 cal yr BP, which is almost the same as the modern one (7.8°C), while the MAP was halved from 772 ± 301 mm at ca. 3500 cal yr BP to 370 mm currently. The wet climate might have facilitated significant development of rain-fed agriculture, promoted the emergence of large settlements, and eventually facilitated the birth of civilization.

Keywords: Archaeobotany; Civilization origin; Subsistence strategy; Vegetation; Fruit; *Quercus*; Xiajiadian

INTRODUCTION

Exploring the relationship between environmental change and human adaptation during the Holocene is crucial to a better understanding of ancient human-environment interactions (Butzer, 2012; Hsiang et al., 2013). The rapid climatic deterioration ca. 4200 cal yr BP has been termed the "Holocene Event 3" (Perry and Hsu, 2000), and its significant effect on ancient civilizations has gained worldwide attention (Weiss et al., 1993; Cullen et al., 2000; deMenocal, 2001; Staubwasser et al., 2003; Wu and Liu, 2004; Lawler, 2007; Sun et al., 2019). Almost all prehistoric archaeological cultures in border regions in China declined during this climate event (Wang, 2004; Wu and Liu, 2004; An et al., 2005; Chen et al., 2005; Wu et al., 2014; Jia et al., 2017; Xu et al., 2017; Guo et al., 2018a; Sun et al., 2019). However, three dominant civilization centers emerged after the "Holocene Event 3" in northern China (Zhang, 1997), including the Erlitou Culture in the Central Plain (3800–3500 cal yr BP) (Zhang et al., 2019), the Yueshi Culture in the Haidai region (3800–3450 cal yr BP) (Fang, 1998), and the Lower Xiajiadian Culture in the West Liao River Basin (4000–3500 cal yr BP) (Shelach, 1994; Shelach et al., 2011).

The West Liao River Basin was one of the centers of the origin of Chinese civilization. The site of Xinglongwa is considered to be one of the earliest broomcorn millet cultivation sites (7800 cal yr BP) (Jones and Liu, 2009; Zhao 2014). The finely carved jades that were excavated from the Hongshan Culture Niuheliang site first appeared ca. 5500 yr BP (Lawler,

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2009). Ultimately, an advanced society was founded during the Lower Xiajiadian period, defined by the construction of stone cities such as the Sanzuodian site (Shelach, 1994; Shelach et al., 2011). Previous research has shown that there was a 500 year cycle of human activity intensity, which was driven by climate changes in northeastern China during the Neolithic and Bronze ages (Xu et al., 2019). The warm and wet climate facilitated cultural prosperity and population growth, including the Xinglongwa, Hongshan, and Lower Xiajiadian cultures (Xia et al., 2000; Jin and Liu, 2001; Q. Xu et al., 2002; Li et al., 2006; Jia et al., 2017; D. Xu et al., 2019). The prosperity of the Lower Xiajiadian Culture has been attributed to the development of millet agriculture in the warm and wet climate (Jia et al., 2016a, 2017). Nevertheless, in the West Liao River Basin, only scattered qualitative paleoclimate records exist that cover the Lower Xiajiadian period (Xu et al., 2002; Li et al., 2006; Mu et al., 2016; Guo et al., 2018b; Zhao et al., 2018), and these are inadequate for us to explore the ancient human-environment relationships in the region.

As the key component of biodiversity, plant diversity plays a vital role in the conservation and sustainable growth of habitats around the world (Wilson and Ehrlich, 1991; Pimm et al., 1995; Thomas et al., 2004). Based on plant microfossils (pollen, phytoliths, starch granules), plant macrofossils (seeds, charcoal, wood), and biomarkers (aromatic hydrocarbons), it is possible to reconstruct the past vegetation composition, ancient agricultural evolution, and climate change (Piperno, 1988; Birks and Line, 1992; Shackleton and Prins, 1992, Wang and Lu, 1993; Piperno and Pearsall, 1998; Odgaard, 1999; Jérémy et al., 2008; Zhao, 2014; Matthias et al., 2015; Chen et al., 2015a, b; Li et al., 2020; Zhou et al., 2020). The investigation of ancient human-environment relationships requires a precise chronology of paleoclimate changes and human activities. However, there are often inconsistencies between the paleoclimate records obtained from sediments and the human activity records obtained from archaeological sites. For example, the lake and loess sediment records provide a large number of quantitative paleoclimate reconstructions (Chen et al., 2015a; Cao et al., 2017; Herzschuh et al., 2019; Zhang et al., 2020), but due to the reservoir effect, it is difficult to obtain accurate chronological frameworks (Geyh et al., 1997; Christine et al., 2001; Stein et al., 2013, Long et al., 2015).

First-hand paleoclimate records reconstructed from materials in archaeological sites are likely to help solve the age non-correspondence problems. Fortunately, since humans have been able to manipulate fire, large amounts of fossil charcoals remain in archaeological sites. Owing to the incomplete combustion of wood (McGinnes et al., 1974), plenty of fossil charcoals that have retained their anatomical characteristics can be retrieved from the archaeological sites. In addition, reconstructions based on fossil charcoals are more responsive to local environmental conditions, owing to the immobility of large pieces of charcoal (Blackford, 2000). Furthermore, in prehistoric periods, human activities were likely confined to 5 km or 1 hour walking distance from the settlement (Shackleton and Prins, 1992; Rodríguez, 2004; Fontenari et al., 2005; Li et al., 2013). This also ensures that fossil charcoal, the by-product of human activities, reflects local scales of human-environment interactions (Vita-Finzi, 1969). Therefore, the fossil charcoals from archaeological sites were ideal materials for local vegetation reconstruction. They provide ideal materials for revealing paleo-vegetation, paleoclimate, and past human activities (Figueiral and Mosbrugger, 2000; Cui et al., 2002; Asouti and Austin, 2005; Asouti and Fuller, 2008; Sun and Li, 2012; X. Li et al., 2013; An et al., 2014; Wang et al., 2016; H. Li et al., 2017; Liu et al., 2019a, b). However, there have been only four cases of quantitative reconstructions of paleoclimate from fossil charcoals in western China (Sun and Li, 2012; Li et al., 2013; N. Sun et al., 2014, 2016; Wang et al., 2016), and none located in eastern China, particularly in places where Chinese civilization originated, such as the Central Plain, the Haidai Region, and the West Liao River Basin.

The use of paleoenvironmental reconstructions based on fossil charcoal obtained from archaeological sites in the pivotal areas and periods of civilization origin is of great significance for exploring the environmental background and its influence on civilization. In this study, we reconstructed the vegetation and paleoclimate at the Erdaojingzi site using fossil charcoals. Combined with other archaeological materials unearthed from this site, we explored the ancient human-environment interactions in the West Liao River Basin (i.e., the eastern part of the agricultural-pastoral zone in northern China) during the Lower Xiajiadian period.

STUDY AREA

The Erdaojingzi site (119.08°N, 42.17°E, 617 m above sea level [a.s.l.]) is located in the Hongshan District to the southeast of Chifeng City, Inner Mongolia (Figure 1). Five thousand two hundred square meters were uncovered, and 305 archaeological features were unearthed, including city walls, surrounding ditches (moats), courtyards, house foundations, paths, cellars, ash pits and burials. In addition, the site contained 1000 excavated items filled with pottery wares, stone and bone implements, jades, and other artifacts (Cao et al., 2010). The excavation at the Erdaojingzi site provided sufficient materials to examine the human-environment relationships during a crucial stage of the origin of civilization.

Chifeng is located in the southeast portion of Inner Mongolia, the eastern part of the farming-pastoral zone, in northeast China. This area also contains extensive loess accumulations, with loess tableland, hills, valleys, and other landform types. The West Liao River joins the upper branches of the Xar Moron River and the Laoha River (Figure 1), and feeds into the Liao River, ultimately flowing into the Bohai Sea. Uplift of the Great Khingan Mountains resulted in higher topography west of the West Liao River Basin. The average elevation ranges from 2833 m a.s.l. in the west to 280 m a.s.l. in the east, with mountains gradually giving way to hills and eventually to plains. The precipitation diminishes from the southeast (500 mm) to northwest (200 mm) owing to the characteristics

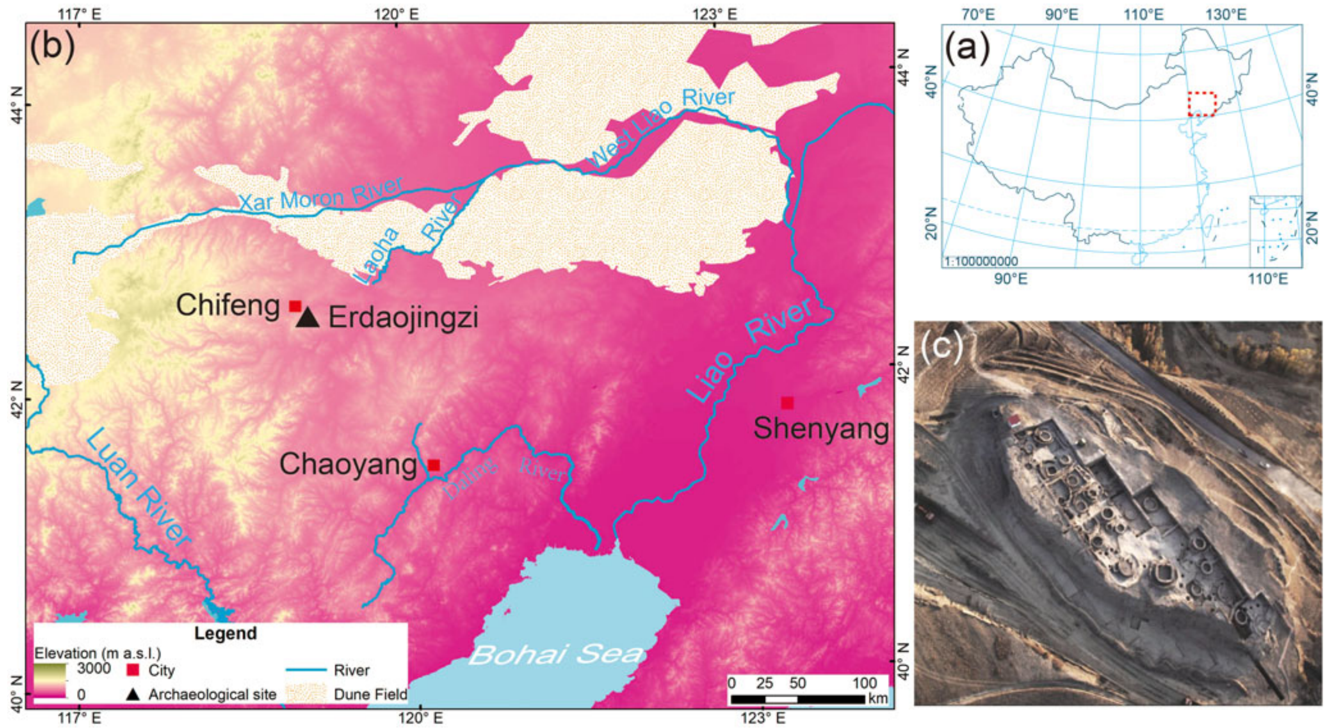

Figure 1. (color online) Location of the Erdaojingzi site in Chifeng, Inner Mongolia, northeast China. (a) Map of China; (b) location of the Erdaojingzi site; (c) landscape of the Erdaojingzi site.

of the East Asian monsoon, which likewise lessens from southeast to northwest (An et al., 2000). According to the meteorological data provided by the Chifeng Weather Station (http://data.cma.cn/), the average annual temperature is 7.8°C (with an annual extreme maximum and minimum temperature of 40.4 and −27.8°C, respectively), the average annual precipitation is 370 mm, and the average annual relative humidity is 50%. The temperate semi-humid and semi-arid continental monsoon climate promotes the vegetation of the temperate grassland in this area.

Today, shrub meadow dominates the vegetation around the Erdaojingzi site, which is situated in the Loess hills and lower hilly areas of southeastern Chifeng. The main shrubs include *Lespedeza bicolor* Turcz., *Vitex negundo* Linn., *Ziziphus jujube* var. *spinose* (Bunge) Hu, *Hoppophae* Linn., *Armeniaca sibirica* (Linn.) Lam., among others. Some sporadic trees are distributed on the shrub grassland, including *Pinus tabularformis* Carr., *Ulmus pumila* Linn., *Sophora japonica* Linn., and *Populus* Linn. (Local History Compilation Committee of Chifeng, 1996).

METHODS

Radiocarbon dating

Two carbonized seed samples collected from the archaeological sites were dated with accelerator mass spectrometry (AMS) by Beta Analytic in Miami, Florida, USA. The IntCal20 curve (Reimer et al., 2020) and the Libby half-life of 5568 years were used in calculating all ages, with the calibration performed using the OxCal 4.4 program (https://c14.arch.ox.ac.uk/oxcal/OxCal.html). All ages reported are relative to AD 1950 (referred to as "cal yr BP").

Plant flotation and fossil charcoal identification

The application of flotation and the identification of plant remains have greatly promoted the study of the subsistence strategies of prehistoric societies in recent years (Zhao, 2010). Eighty-four soil samples with a total volume of 405 liters were collected for flotation. Carbonized plant remains were obtained using a sieve with #80 mesh (aperture size of 0.2 mm) and then dried in the shade and sorted. Five thousand eight hundred eleven fossil charcoals were collected with a sieve with an aperture size of 2 mm. A metallographic microscope (Nikon LV150) was employed to identify the microstructure of the fossil charcoals using the cross, radial, and tangential sections, and the plant taxa were identified based on wood anatomy atlases (Cheng et al., 1992; Yao, 1988). The fossil charcoals with obvious morphological characteristics were adhered to an aluminum sample stage and were overgilded on the sample surface by an ion-sputtering instrument. Then, they were scanned by a Quanta 650 electron microscope. Based on the results of the identification of the fossil charcoals, the percent abundance ratio and frequency of each taxon were calculated. All samples were identified in the Archaeobotany Laboratory, Institute of Archaeology, Chinese Academy of Social Sciences.

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Table 1. ^{14}C dates from the Erdaojingzi site.

Sample No.	Lab No.	Methods	Material	$^{13}C/^{12}C$ (%)	^{14}C age (yr BP)	Calibrated age (yr BP)	
						1σ range	2σ range
EDJZ -H8	Beta-558960	AMS	foxtail millet	−8.5	3330 ± 30	3531 ± 42	3551 ± 85
EDJZ -H64	Beta-558959	AMS	foxtail millet	−9.0	3340 ± 30	3553 ± 63	3583 ± 102

Quantitative reconstruction of the paleoclimate

The coexistence approach (CA) is based on the assumption that fossil plants have similar climatic requirements as their nearest living relative species. The CA provides a quantitative estimate of past climate by setting out the climatic tolerances of individual species, and then identifying the range of climatic conditions under which all species in a fossil assemblage could co-exist today (Mosbrugger and Utescher, 1997). The coexistence approach (CA) was employed to quantitatively reconstruct the paleoclimate in the Erdaojingzi site associated with the Lower Xiajiadian Culture. Based on the similar living environment of modern plants, the climatic tolerance ranges of every taxon of the fossil charcoals were derived from Fang et al. (2009), including the maximum and minimum of the mean annual temperature (MAT), mean annual precipitation (MAP), and index of moisture content in the soil (IM) (Fang and Yoda, 1990), respectively.

RESULTS

Radiocarbon dating

Systematic archaeological excavation confirmed that the Erdaojingzi site is an archaeological site that belongs in the Lower Xiajiadian period, and no remains indicate that it fits other periods (Cao et al., 2010). The age range of Lower Xiajiadian Culture is 3900–2800 cal yr BP, based on 32 radiocarbon dates in the West Liao River Basin (Jia et al., 2017). The two calibrated ^{14}C ages of the Erdaojingzi site are within the range of 3600–3500 cal yr BP. The calibrated ^{14}C ages from charcoals collected in the Erdaojingzi site are shown in Table 1.

Fossil charcoals

Five thousand eight hundred eleven charcoal fragments were identified, and 21 different taxa were identified in 84 samples from the Erdaojingzi site (Fig. 2, Table 2). The three most

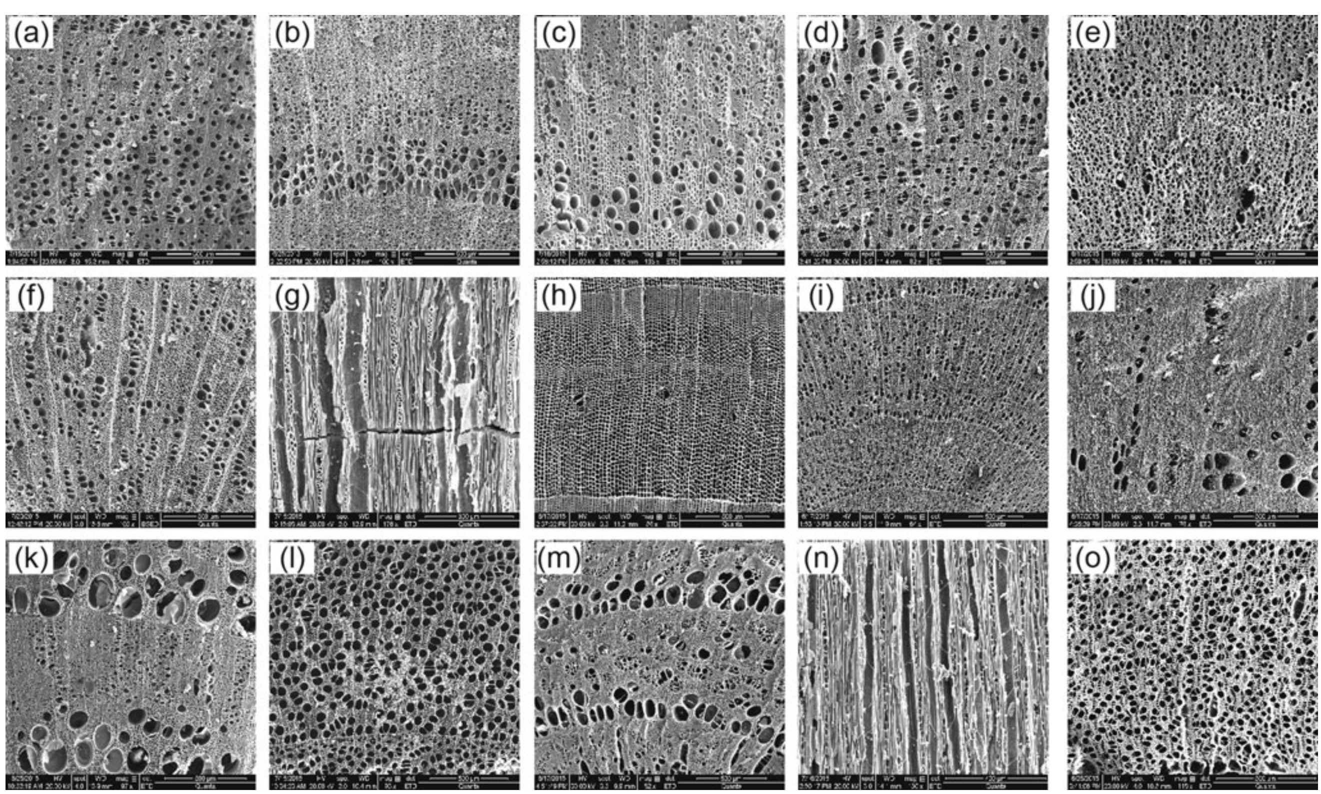

Figure 2. Microstructures of charcoal from the Erdaojingzi site; (g) and (n) are tangential sections, others are cross-sections. (a) *Acer* sp.; (b, c) *Amygdalus* sp./*Armeniaca* sp.; (d) *Betula* sp.; (e) *Cotoneaster* sp.; (f) *Ostrya* sp.; (g) *Phellodendron* sp.; (h) *Pinus* sp.; (i) *Populus* sp.; (j, k) *Quercus* sp.; (l) *Salix* sp.; (m) *Ulmus* sp.; (n) *Ziziphus* sp.; (o) unknown 4.

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Table 2. The fossil charcoal assemblages from the Erdaojingzi site.

Taxa	Absolute fragment count	Abundance ratio (%)	Ubiquity	Frequency (%)
Acer sp.	23	0.40	6	8.22
Alnus sp.	9	0.15	5	6.85
Amygdalus sp.	134	2.31	23	31.51
Armeniaca sp.	56	0.96	14	19.18
Betula sp.	191	3.29	21	28.77
Cotoneaster sp.	128	2.20	21	28.77
Fraxinus sp.	2	0.03	1	1.37
Koelreuteria sp.	3	0.05	1	1.37
Ostrya sp.	1	0.02	1	1.37
Phellodendron sp.	159	2.74	12	16.44
Pinus sp.	1477	25.42	20	27.40
Populus sp.	270	4.65	24	32.88
Quercus spp.	2031	34.95	63	86.30
Rhamnus sp.	3	0.05	1	1.37
Salix sp.	102	1.76	18	24.66
Tilia sp.	271	4.66	19	26.03
Ulmus sp.	852	14.66	47	64.38
Ziziphus sp.	19	0.33	7	9.59
Unknown1	65	1.12	5	6.85
Unknown2	1	0.02	1	1.37
Unknown3	12	0.21	3	4.11
Unknown4	2	0.03	2	2.74
Total	5811	100.00	73	86.90

abundant types of fossil charcoals made up 75.03% of the total, including *Quercus* (2031, 34.95%), *Pinus* (1477, 25.42%), and *Ulmus* (852, 14.66%). There were also seven types of fossil charcoals with more than 100 pieces, including *Tilia* (271, 4.66%), *Populus* (270, 4.65%), *Betula* (191, 3.29%), *Amygdalus/Armeniaca* (190, 3.27%), *Phellodendron* (159, 2.74%), *Cotoneaster* (128, 2.20%), and *Salix* (102, 1.76%). There were also seven types that appeared sporadically, including *Acer* (23, 0.40%), *Ziziphus* (19, 0.33%), *Alnus* (9, 0.15%), *Koelreuteria* (3, 0.05%), *Rhamnus* (3, 0.05%), *Fraxinus* (2, 0.03%), and *Ostrya* (1, 0.02%). Four different types of fossil charcoals could not be identified.

With the exception of *Pinus*, a temperate evergreen conifer, most of the woody plants in China are broad-leaved deciduous taxa, including *Quercus*, *Ulmus*, *Tilia*, *Populus*, *Betula*, *Amygdalus*, *Armeniaca*, *Phellodendron*, *Cotoneaster*, *Salix*, *Acer*, *Ziziphus*, *Alnus*, *Koelreuteria*, *Rhamnus*, *Fraxinus*, and *Ostrya* (Wu, 1980). Thus, the fossil charcoal assemblage at Erdaojingzi indicates the presence of temperate deciduous and mixed conifer-broadleaved forests ca. 3500 cal yr BP, distinct from the shrub meadow vegetation found there today.

Quantitative reconstruction of paleoclimate

The climatic factors were obtained by applying CA based on 21 fossil charcoal taxa from the Erdaojingzi site (Table 3). The results indicated that MAT was 2.0–13.8°C, MAP was 471–1073 mm, and IM was -28.7–74.1 (Fig. 3).

DISCUSSION

Paleovegetation and paleoclimate

Because plant species have particular climate tolerances (Thornthwaite, 1948; Fang and Yoda, 1990; Wang, 1992), plant composition from sedimentary records or archaeobotanical assemblages can indicate climate history (Piperno, 1988; Birks and Line, 1992; Shackleton and Prins, 1992; Wang and Lu,

Table 3. The climate ranges (from Fang et al., 2009) of individual plant taxa in the Erdaojingzi site.

	MAT/°C		MAP/mm		IM	
Taxa	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Acer sp.	0.2	17.1	304	1689	48.6	105.7
Alnus sp.	5.8	13.8	404	1073	28.7	74.1
Amygdalus sp.	0.8	24.8	471	1997	35.9	132.1
Armeniaca sp.	1.3	21	225	1751	65.1	121.7
Betula sp.	5.8	15.5	132	1358	80.1	128.6
Cotoneaster sp.	5.5	17.5	63	1214	84.9	128.6
Fraxinus sp.	5	15.2	341	1200	46.6	83.5
Koelreuteria sp.	2	21.4	349	1997	51.5	147
Ostrya sp.	2.2	15.5	373	1478	43.4	125.9
Phellodendron sp.	2.9	21.1	392	1770	43.4	112.2
Pinus sp.	4.1	16.4	127	1502	81.2	182.6
Populus sp.	5.8	22.2	58	2208	90.8	128.6
Quercus spp.	5.8	15.5	132	1077	80.1	121.7
Rhamnus sp.	1.2	24.1	137	2759	77.5	246.5
Salix sp.	3.6	24.8	35	2037	94.9	147
Tilia sp.	5.8	14.2	367	1073	40.9	74.1
Ulmus sp.	5.8	21.6	21	1770	97.3	112.2
Ziziphus sp.	4.3	24.8	21	1893	97.3	129.9

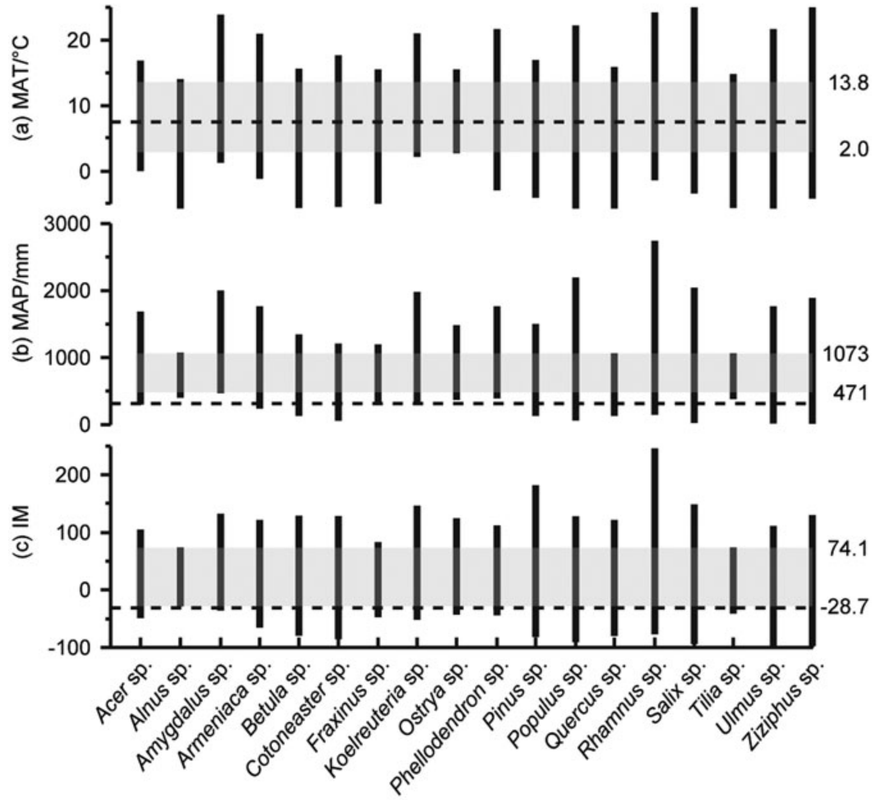

Figure 3. Coexistence intervals for the Erdaojingzi site (shadow represents the overlapping climate range, dotted line represents the modern climate in the areas).

1993; Odgaard, 1999; Matthias et al., 2015; Chen et al., 2015a; Cao et al., 2017; Xu et al., 2017; Li et al., 2020). Pollen-based vegetation and climate reconstructions typically reflect the paleoenvironmental conditions in a wide area due to the long distance of pollen dispersion (Xu et al., 2015). The pollen of herbaceous plants dominated the pollen assemblage (60–80%) from the Wangxianggou profile in this area during the Lower Xiajiadian period, including *Artemisia*, *Chenopodiaceae,* and *Fagopyrum* (Li et al., 2006). Furthermore, 30% of the area was covered with woody plants (Li et al., 2020), including temperate broadleaved trees such as *Quercus*, *Ulmus*, *Betula*, *Juglans*, *Alnus*, *Castanea*, *Celtis*, *Anacardiaceae*, *Pterocarya*, *Tilia*, and *Salix,* and temperate coniferous trees such as *Pinus* (Li et al., 2006). However, there are some differences in pollen assemblage between the archaeological sites and the natural profiles. A large number of pollen specimens in the Dadianzi and Chengzishan sites in the Lower Xiajiadian period were identified as *Pinus* (Kong et al., 1991; Zhao et al., 2009). Our pollen records, which were obtained from the natural sand-dune profiles in the West Liao River Basin, indicated that temperate grassland was the dominant vegetation in this area during the Lower Xiajiadian period (Jia et al., 2017). Such a difference may be attributable to secondary accumulation in the archaeological strata.

Fortunately, the woody plants that were completely recovered by the fossil charcoals obtained from the Erdaojingzi site can make up for the deficiency of pollen in grassland vegetation. There were 21 different woody plants growing near the Erdaojingzi site ca. 3500 cal yr BP, including *Quercus*, *Pinus*, *Ulmus*, *Tilia*, *Populus*, *Betula*, *Phellodendron*, *Amygdalus*/*Armeniaca*, *Cotoneaster*, *Salix*, *Acer*, *Ziziphus*, *Alnus*, *Koelreuteria*, *Rhamnus*, *Fraxinus*, *Ostrya*, and four unknown plants (Table 2). However, six species of woody plants that were found in this area 3500 cal yr BP are not distributed here today, including *Phellodendron*, *Cotoneaster*, *Alnus*, *Koelreuteria*, *Fraxinus*, and *Ostrya*. Three types of woody plants probably were the dominant species, including *Quercus* (34.95%), *Pinus* (25.42%), and *Ulmus* (14.66%). Seven other woody plants probably appeared around the site because their percent abundance ratio all exceed 1%, including *Populus* (4.65%), *Amygdalus*/*Armeniaca* (3.27%), *Cotoneaster* (2.20%), *Betula* (3.29%), *Salix* (1.76%), *Tilia* (4.66%), and *Phellodendron* (2.74%). Also, some woody plants appeared sporadically, as indicated by their small amount of charcoal remains, such as *Acer* (0.40%), *Ziziphus* (0.33%), *Alnus* (0.15%), *Koelreuteria* (0.05%), *Rhamnus* (0.05%), *Fraxinus* (0.03%), and *Ostrya* (0.02%). The unearthed percent ubiquity refers to the percentage of a specific taxon of charcoal in all samples. It was employed to reflect the combination of woody vegetation around the site in the corresponding period (Salisbury and Jane, 1940). As reflected by both the percentage of absolute number and unearthed percent ubiquity, *Quercus* (34.95%, 86.3%) and *Ulmus* (14.66%, 64.38%) were likely to be the dominant woody plants distributed around the Erdaojingzi site ca.

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3500 cal yr BP. Most woody plants are temperate broadleaved deciduous taxa, except the evergreen coniferous plants of *Pinus*.

Therefore, the assemblages of fossil charcoal at the Erdaojingzi sites reflected that temperate deciduous and mixed conifer-broadleaved forests were found near the site ca. 3500 cal yr BP. Similar vegetation types occur in the middle and lower mountain areas in the Songnen Plain and the Liaohe Plain, as well as the low-elevation area of the Changbai Mountains in the east nowadays (Wu, 1980).

Almost all climate records from soil/sand-dune profiles (Ren, 1998; Xia et al., 2000; Jin and Liu, 2001; Xu et al., 2002; Yang et al., 2012; Zhao et al., 2018; Xue et al., 2020), lakes (Li et al., 2006), and archaeological samples (Kong et al., 1991) indicated a wet climate in the West Liao River Basin ca. 3500 BP. Because previous studies only qualitatively describe the climate in our study area, we made an attempt to use fossil charcoals obtained from the Erdaojingzi site to reconstruct the past climate. Based on CA, the MAT ca. 3500 cal yr BP was 7.9 ± 5.9°C, which is very similar to the present one (7.8°C), while MAP was almost halved, from 772 ± 301 mm at ca. 3500 cal yr BP to 370 mm currently (Fig. 3). Also, the moisture index reduced sharply from 22.7 ± 51.4 at ca. 3500 cal yr BP (Fig. 3) to -30 ± 10 nowadays (Fang et al., 2009). The charcoal assemblage at the Erdaojingzi site indicated a relatively wetter climate for the temperate zone in the West Liao River Basin. This echoes previous results about the past climate in our study area (Ren, 1998; Xia et al., 2000; Jin and Liu, 2001; Xu et al., 2002; Li et al., 2006; Yang et al., 2012; Zhao et al., 2018; Xue et al., 2020). The past forest was dominated by temperate deciduous and mixed conifer-broadleaved species, such as *Quercus*, *Pinus*, and *Ulmus*.

Human utilization of wood resources

Timber is one of the main resources for humans and is closely related to human activities identified by archaeological remains (Shackleton and Prins, 1992). There were four main purposes for human utilization of woody plant resources: building materials, making tools, fuelwood, and food. In addition to being used as firewood, almost all woody plants in the Erdaojingzi site could be utilized as construction and tool-making materials.

Archaeobotanical studies of carbonized seeds have shown that ancient people were engaged in dry farming of predominantly foxtail millet at the Erdaojingzi site (Y. Sun et al., 2014). Apart from agriculture, fossil charcoals indicate that local people may also have engaged in some gathering activities (Y. Sun et al., 2014). Four woody plants have also been used as food today, including *Quercus*, *Ulmus*, *Amygdalus/Armeniaca*, and *Ziziphus*. *Quercus* probably was dominant in the gathering, comprising the most fossil charcoals identified from the Erdaojingzi site (Table 2). Acorns, which are the nuts of *Quercus*, are considered to be an important component of gathering because they were often found in the archaeological sites of China (Zhao, 2006; Fuller et al., 2007; Sun et al., 2007; Yang et al., 2009; Fuller and Qin, 2010; Ma et al., 2016). The acorns also have been processed by humans since the Neolithic Age in the West Liao River Basin (Ma et al., 2016), and were probably chosen as a useful supplement for food resources in the Erdaojingzi site due to their rich starch content. The second-largest number of fossil charcoals comes from *Ulmus*. Owing to the edibility of the tender leaves, *Ulmus* could provide a certain amount of food resources in the spring when food is relatively scarce. Utilization of the leaves of *Ulmus* was also reflected by a clay pot discovered at the Shigu site in Henan (Xu, 1996). Apart from serving as primary food resources, some fruit-bearing woody plants were selected as supplementary food sources in ancient times, such as *Amygdalus/Armeniaca* and *Ziziphus* (42.47% and 9.59% of the unearthed percent ubiquity, respectively).

Implications for Lower Xiajiadian Culture

The relatively wet climate may represent a warm temperate humid climate in the West Liao River Basin ca. 3500 cal yr BP, which is significantly different from the middle temperate semi-humid and semi-arid climate today. Climate change has not only caused the transition of regional forest grassland vegetation ca. 3500 cal yr BP to today's retama bushland vegetation, but also facilitated the significant development of rain-fed agriculture. The main subsistence strategies transformed from a mixture of multiple survival patterns during the Neolithic Age (before 4000 cal yr BP) (Jia et al., 2016b, 2017) to millet-dominated agriculture during the Lower Xiajiadian period (Zhao et al., 2009; Y. Sun et al., 2014; Jia et al., 2016a, 2017). Developed agriculture provided stable food resources for human beings, promoted the emergence of large settlements, such as Sanzuodian and Erdaojingzi (Cao et al., 2010; Shelach et al., 2011), and further facilitated the birth of advanced civilization. However, good times did not last long: the 500 year cycle of climate deterioration destroyed the agricultural system in the West Liao River Basin after 3500 BP (Jia et al., 2016a, 2017; Xu et al., 2019). Subject to the influence of the East Asian summer monsoon, the precipitation gradually decreased from the southeast to the northwest. The agricultural groups of the Lower Xiajiadian Culture probably followed the precipitation change and migrated southward to the North China Plain, then moved southward and integrated with the cultural system in central China.

CONCLUSION

The fossil charcoals indicate that temperate deciduous and mixed conifer-broadleaved forests were the dominant vegetation near the Erdaojingzi site at ca. 3500 cal yr BP. The three major woody plants discovered are *Quercus*, *Pinus*, and *Ulmus*, representative species of the warm temperate forest-steppe.

In addition to the use of woody plants for building materials, making tools, and fuel, there were four woody plants that probably supplied food for ancient humans in the Erdaojingzi site. The nuts of some woody plants such as *Quercus* were taken as staple foods because of their rich starch or cellulose content. The tender leaves of *Ulmus* might have served as supplementary food sources for humans in spring when food was relatively scarce. The other two woody plants, namely *Amygdalus*/*Armeniaca* and *Ziziphus,* probably provided fruits to humans.

The CA results of the quantitative reconstruction indicate that MAT was 7.9 ± 5.9°C and MAP was 772 ± 301 mm. The past environment was significantly wetter than that today. The wet climate facilitated significant development of rain-fed agriculture, the emergence of large settlements such as Sanzuodian and Erdaojingzi, and the birth of advanced civilization. Also, subject to the influence of the East Asian summer monsoon, precipitation change likely caused the agricultural groups of the Lower Xiajiadian Culture to migrate southward to the North China Plain, and then to move southward and integrate with the cultural system in central China.

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