Environmental Research Letters

LETTER

Dietary shift and social hierarchy from the Proto-Shang to Zhou Dynasty in the Central Plains of China

Xin Li, Shanjia Zhang, Minxia Lu, Menghan Qiu, Shaoqing Wen and Minmin Ma

1. Introduction

Human-environment interactions were complex in prehistoric and historical periods. Climate change was an important contributing factor to societal change from the third to the first millennium BCE (Before Common Era) throughout the world (e.g. Weiss et al 1993, Staubwasser et al 2003, Wu and Liu 2004, Kuper and Kröpelin 2006). In some cases, however, ancient societies displayed a significant degree of resilience to climate change, such as in northwestern China (Ma et al 2016, Berger and Wang 2017), the Indus river basin of India (Petrie et al 2017), the Maya civilization of Central America (Dunning et al 2012), Southwest Asia (Flohr et al 2016), and areas along the historic Silk Road (Yang et al 2019a). Technological innovation and its widespread impact played an important role in social transformations and human-environment interactions during the period between the third and first millennium BCE (Diamond and Bellwood 2003, Chen et al 2015a, Dong et al 2017a).

Ancient civilization in China is one of the oldest civilizations in the world and emerged during the second millennium BCE when the Proto-Shang and Shang states developed in the Central Plains. The territory of ancient China expanded significantly during the subsequent Zhou Dynasty (1046–221 BCE), which included the Western Zhou (1046–771 BCE) and the
Eastern Zhou (770–221 BCE) dynasties. The socio-economic development from ~2000 to 221 BCE laid the foundation for the formation of imperial China in the Qin-Han era (221 BCE–220 CE). However, the spatio-temporal changes of the economic patterns in the Central Plains, as well as the underpinning mechanisms, have lacked rigorous investigation.

Human subsistence strategies during the Shang and Zhou dynasties can be inferred in part from fragmented records in historical documents, such as the ‘Shi Jing’ (詩經) and ‘Shang Shu’ (尚書); however, surviving ancient works are too scarce to reveal the complete picture of human lifestyles in these periods. Archaeometry provides viable approaches for reconstructing human subsistence strategies in both prehistoric and historical periods. For example, archaeobotanical and zoo-archaeological analysis have been used to study human strategies for plant and animal utilization (e.g. Zeder and Hesse 2000, Zhao 2011, Yuan 2015), while stable isotope analysis of human bones unearthed from Xinancheng cemetery, the bones having been identified as relics of the Western Zhou Dynasty by archaeologists. In addition, integration of the results with other archaeological data and paleoclimate records from lacustrine deposits of the Gonghai Lake and Daihai Lake in northern China (Xu et al 2010, Chen et al 2015b), enabled us to examine the spatio-temporal variation of human subsistence strategies and to evaluate the social resilience and adaptive capacity of the societies to respond to climate change in the Central Plains from ~2000 to 221 BCE.

2. Study area

2.1. Archaeological background

In this paper, the Central Plains of China include the Guanzhong Plain of Shaanxi Province, southern Shanxi and Hebei Province, western Shandong and northern Henan Province (figure 1). This region witnessed the origin and development of ancient civilization, including the Proto-Shang period (~2000–1600 BCE), the Shang Dynasty (1600–1046 BCE), the Western Zhou Dynasty (1046–771 BCE) and the Eastern Zhou Dynasty (770–221 BCE), as well as the rise of the Qin–Han Empire (221 BCE–220 CE).
In the Central Plains from isotopic data of human samples from 13 of these sites for the period ∼2000 to 221 BCE. We selected eight bone samples with high collagen yields from both upper- and lower-status individuals for accelerator mass spectrometry (AMS) radiocarbon dating at Peking University, Beijing. Conventional ages from $^{14}$C dating values were calibrated to the calendar age based on the IntCal13 calibration curve (Reimer et al 2013) using OxCal v.4.3.2 (Bronk Ramsey 2017). All ages were reported as ‘cal BCE’.

### 3.3. Radiocarbon dating

We selected eight bone samples with high collagen yields from both upper- and lower-status individuals for accelerator mass spectrometry (AMS) radiocarbon dating at Peking University, Beijing. Conventional ages from $^{14}$C dating values were calibrated to the calendar age based on the IntCal13 calibration curve (Reimer et al 2013) using OxCal v.4.3.2 (Bronk Ramsey 2017). All ages were reported as ‘cal BCE’.

### 3.4. Statistical analysis

The independent samples t-test was used to detect differences between two independent groups of samples. Statistical analysis was performed using SPSS 22.0 software.

A strict hierarchical structure in society was well-established during these periods. For instance, the burial pattern, such as the grave sizes and the type and quality of graves including the burial goods can reflect the socio-economic status of individuals in these ancient societies.

#### 2.2. Xinancheng cemetery

Xinancheng cemetery, situated in the southeast margin of the Loess Plateau, is a part of the territory of Zhangzi County, Shanxi Province (figure 1). Between 2012 and 2015, a salvage excavation project for this cemetery was carried out by the Shanxi Provincial Institute of Archaeology. Pottery ware, bronzes, jade and stone artifacts, cowries and other funerary objects were unearthed. According to the characteristics of the mortuary ritual, all the graves were dated as belonging to the mid-late Western Zhou Dynasty (Han et al 2016, Li 2017).

#### 3. Materials and methods

### 3.1. Data collection

A total of 62 human and three animal bones (two from horses and one from a dog) were collected from Xinancheng cemetery for isotopic analysis. Published isotopic data of human samples (supplementary table S1) were also scrutinized to trace human dietary shifts in the Central Plains from ∼2000 to 221 BCE.

Furthermore, isotopic data for human samples from 13 of these sites (including Xinancheng cemetery) were selected for tracing socio-economic status differences in dietary signatures in the Central Plains for the period ∼2000–221 BCE (supplementary table S1). The status level of individuals was defined as being either upper or lower level based on several criteria: (1) burials with no grave goods were classed as lower-status and burials with jade, bronze, shells, etc, were upper-status; (2) occupants of burials classed as human victims including those sacrificed were classed as lower-status otherwise upper-status; (3) burials with no container were classed as lower-status, while burials with containers as upper-status; (4) burials in small graves were classed as lower-status, while those in large/medium graves as upper-status.

#### 3.2. Collagen preparation and measurement

Carbon and Nitrogen stable isotope ratios in bone collagen reflect the long-term isotopic composition of an individual’s diet, which has been successfully applied to study past human diets and subsistence strategies (e.g. Hedges and Reynard 2007, Hu et al 2008, Ma et al 2016). Feeding experiments (e.g. Ambrose and Norr 1993) show that the collagen δ$^{15}$N values are closely associated with the trophic levels of individuals, while the δ$^{13}$C values are influenced by the ratios of C$_3$ and C$_4$ plants in their diet. In this study, we extracted bone collagen samples according to the method of Richards and Hedges (1999) with some modifications (Ma et al 2016). Stable carbon and nitrogen isotopic analyses were conducted in the Key Laboratory of Western China’s Environmental System (MOE), Lanzhou University. Collagen samples were processed in an automated carbon and nitrogen analyser linked to a Thermo Finnigan Flash DELTA-plus XL mass spectrometer. All carbon and nitrogen isotope ratio analyses were measured relative to V-PDB and AIR standard samples. The measurement analytical precision was better than 0.2‰ for both carbon and nitrogen isotopic ratios.

#### 3.3. Radiocarbon dating

We selected eight bone samples with high collagen yields from both upper- and lower-status individuals for accelerator mass spectrometry (AMS) radiocarbon dating at Peking University, Beijing. Conventional ages from $^{14}$C dating values were calibrated to the calendar age based on the IntCal13 calibration curve (Reimer et al 2013) using OxCal v.4.3.2 (Bronk Ramsey 2017). All ages were reported as ‘cal BCE’.

#### 3.4. Statistical analysis

The independent samples t-test was used to detect differences between two independent groups of samples. Statistical analysis was performed using SPSS 22.0 software.

**Table 1.** $^{14}$C ages for burial occupants in Xinancheng.

| Sample no. | Context | Lab no.     | $^{14}$C age (yr BP) | Calibrated age (cal BCE) |
|------------|---------|-------------|---------------------|--------------------------|
| SX08       | M17     | LZU1722P    | 2805 ± 25           | 1023–897                 |
| SX20       | M80     | LZU17227    | 2750 ± 25           | 972–829                  |
| SX21       | M58     | LZU17228    | 2745 ± 25           | 970–826                  |
| SX29       | M124    | LZU17229    | 2700 ± 20           | 897–814                  |
| SX38       | M32     | LZU17230    | 2755 ± 25           | 921–845                  |
| SX03       | M101    | LZU1722S    | 2750 ± 25           | 972–829                  |
| SX11       | M106    | LZU17224    | 2775 ± 25           | 996–845                  |
| SX15       | M109    | LZU17225    | 2770 ± 25           | 994–840                  |
4. Results

4.1 Chronology

The ages of the eight human collagen samples for age ranges with confidence intervals (CIs) of 68.2% and 95.4%, based on 14C dating, are shown in table 1. The dating results range from 1013 to 811 cal BCE (95.4%), the values being coincident with typological studies on cultural relics (Han et al 2016, Li 2017) and typically reflecting a period in the mid-late Western Zhou Dynasty (1046–771 BCE).

4.2 Human and animal bone results

Isotopic data and collagen quality indicators for the individual samples are presented in table 2 and figure 2, and isotopic data for the two status categories are summarized in table 3. The collagen of all samples was well preserved with C:N ratios (atomic basis) of 3.1 to 3.4. The human and animal isotopic data for samples from Xinancheng cemetery are plotted in figure 2(a). Given that the natural vegetation of northern China is composed of C3 plants (Gu et al 2003, Wang et al 2003, Auerswald et al 2009, Liu et al 2011), C4 food resources (i.e. millet) are always associated with human settlements. The δ13C value for the dog implies a C4 food-based diet, reflecting a relatively large intake of millet and/or human waste and scraps. One horse (sample SX65) with a relatively enriched δ13C value (−9.2‰) is likely to have been sustained with C4 plants (e.g. millet). However, data for another horse sample (sample SX68) suggests it ranged freely and consumed both wild (e.g. grasses and fruits) and domesticated plants (e.g. millet).

The δ13C and δ15N values for all individuals ranged from −10.8 to −7.4‰ (mean = −8.4‰ ± 0.7‰) and from 7.6 to 10.9‰ (mean = 9.0 ± 0.7‰), respectively. These values suggested that all individuals buried in Xinancheng relied on C4 foods (millet and/or millet-based animal protein). Furthermore, the δ13C values for the upper-status individuals were significantly more positive than those of the lower-status individuals (mean = −9.1‰ versus −8.2‰, p = 0.003, figures 2(b), (c) and table 3), indicating a little more reliance on C4 foods for upper-status individuals. Upper-status individuals also had higher δ15N values than lower-status individuals (mean = 9.5‰ versus 8.8‰, p = 0.001, figures 2(b), (c) and table 3), indicating a higher protein intake for upper-status individuals.

4.3. Socio-economic status differences as reflected in dietary signatures

The carbon and nitrogen isotopic values for human bones in the Central Plains reveal that there were no significant differences between the upper (n = 47) and lower (n = 102) socio-economic groups during Proto-Shang (supplementary table S3), which implies that there were no dietary differences between the upper and lower-status groups. Significant differences, however, were observed in the δ13C and δ15N values for humans during the subsequent period, that is, from Shang to Zhou (supplementary table S3). The δ13C values of the upper-status individuals (n = 64) were significantly more negative than those of the lower-status individuals (n = 121) (supplementary table S3) from Shang to Western Zhou, suggesting a little more reliance on C3 foods for the upper-status group. Furthermore, the upper-status individuals had higher δ15N values than the lower-status individuals from Shang to Western Zhou, indicating there was more consumption of animal protein. However, the δ13C values for the Eastern Zhou lower-status individuals (n = 45) were significantly more negative than those of the upper-status individuals (n = 112) (supplementary table S3), indicating more reliance on C3 foods for the lower-status group. The eastern Zhou lower-status group also had lower δ15N values than the upper-status group, suggesting those peoples ate less animal protein.

5. Discussion

5.1. Human diets and subsistence strategies in southeast Shanxi Province from 1046 to 771 BCE

For human bone collagen, the ranges of δ13C values for C4-based, C3/C4 mixed and C3-based food sources are −6‰ to −12‰, −12‰ to −18‰ and −18‰ to −23‰, respectively (Pechenkina et al 2005, Barton et al 2009, Ma et al 2014). According to the δ13C values for all individuals (−10.8 to −7.4‰) from Xinancheng cemetery, the Western Zhou individuals in the cemetery had a C4-based diet. Given that the vegetation in the Loess Plateau consisted mainly of C3 plants (Wang et al 2003), individuals from Xinancheng consumed millet as their staple crop and were heavily reliant on millet-based agriculture. Wheat (Triticum aestivum) was first introduced to China around 2500 BCE, probably through one of the three possible routes Zhao (2009) hypothesized, the Eurasian Steppe route, the Ancient Silk Road, and the Sea route. Both the wheat researchers retrieved from archaeological contexts and those traditionally cultivated by farmers are exclusively hexaploid bread wheat in China (Fuller and Lucas 2014, Stevens et al 2016). The important role of millet and the limited role of wheat and rice in the human diets for the Western Zhou period are consistent with archaeobotanical data. Archaeobotanical studies reveal that millet was the staple crop cultivated in Shanxi Province in the Neolithic period (Song et al 2019). Although there was an increase in crop species from Proto-Shang to Western Zhou, including wheat, rice and soybean (Lee et al 2007, Song et al 2019), these new plant species were supplementary crops for the overall agriculture system with millet being the staple crop in the Central Plains of China (Zhao and Fang 2007, Wu et al 2014, Zhou and Garvie-Lok 2015, Lu et al 2019).
Table 2. Carbon and nitrogen isotopic data for humans and animals from Xinancheng.

| Sample  | Context | δ¹³C (‰) | δ¹⁵N (‰) | C%  | N%  | C/N | Species | Status |
|---------|---------|-----------|-----------|------|------|------|---------|--------|
| SX07 M15 | −10.4   | 10.8      | 43.2      | 16   | 3.2  | Human | Upper   |
| SX08 M17 | −9.3    | 9.4       | 42.5      | 15.6 | 3.2  | Human | Upper   |
| SX67 M18 | −9      | 10.9      | 43.7      | 15.7 | 3.2  | Human | Upper   |
| SX02 M59 | −8.4    | 8.7       | 43.4      | 15.9 | 3.2  | Human | Upper   |
| SX17 M64 | −9.8    | 9.4       | 43.7      | 16   | 3.2  | Human | Upper   |
| SX19 M25 | −8.6    | 9.6       | 42.6      | 15.5 | 3.2  | Human | Upper   |
| SX20 M80 | −9.2    | 9.9       | 42.5      | 15.3 | 3.2  | Human | Upper   |
| SX21 M58 | −10.8   | 8.2       | 43.2      | 15.7 | 3.2  | Human | Upper   |
| SX29 M124| −8.5    | 9.4       | 42.4      | 15.4 | 3.2  | Human | Upper   |
| SX57 M74 | −8      | 7.6       | 44        | 16.2 | 3.2  | Human | Upper   |
| SX58 M32 | −9      | 10.2      | 42.5      | 15.5 | 3.2  | Human | Upper   |
| SX59 M84 | −8      | 10.1      | 42        | 15.5 | 3.2  | Human | Lower   |
| SX63 M24 | −9.9    | 9.5       | 42        | 15.5 | 3.2  | Human | Lower   |
| SX03 M101| −8.2    | 7.8       | 43.1      | 15.9 | 3.2  | Human | Lower   |
| SX04 M99 | −8.6    | 9         | 42.6      | 15.5 | 3.2  | Human | Lower   |
| SX06 M63 | −8.2    | 7.8       | 40.1      | 14.5 | 3.2  | Human | Lower   |
| SX09 M103| −8.6    | 9.8       | 41.3      | 14.8 | 3.2  | Human | Lower   |
| SX11 M106| −8.3    | 8.9       | 41.6      | 15.1 | 3.2  | Human | Lower   |
| SX12 M111| −7.4    | 8.9       | 43.4      | 16   | 3.2  | Human | Lower   |
| SX13 M112| −8.8    | 9         | 43.2      | 15.7 | 3.2  | Human | Lower   |
| SX14 M100| −8.6    | 8.7       | 42.2      | 15.2 | 3.2  | Human | Lower   |
| SX16 M26 | −8.8    | 7.7       | 43.1      | 15.4 | 3.3  | Human | Lower   |
| SX18 M92 | −8.1    | 9.4       | 43.2      | 15.6 | 3.2  | Human | Lower   |
| SX22 M120| −9.4    | 9.3       | 43        | 15.8 | 3.2  | Human | Lower   |
| SX23 M41 | −7.7    | 9.1       | 41.8      | 15.3 | 3.2  | Human | Lower   |
| SX24 M20 | −9.5    | 8         | 42.3      | 15   | 3.3  | Human | Lower   |
| SX25 M118| −8.2    | 8.8       | 43        | 15.6 | 3.2  | Human | Lower   |
| SX26 M51 | −8.3    | 8.8       | 43.7      | 15.9 | 3.2  | Human | Lower   |
| SX27 M66 | −8.1    | 7.9       | 43        | 15.6 | 3.2  | Human | Lower   |
| SX28 M67 | −7.6    | 8         | 42.8      | 15.6 | 3.2  | Human | Lower   |
| SX30 M61 | −8.2    | 9         | 41.4      | 15   | 3.2  | Human | Lower   |
| SX31 M79 | −8.1    | 9         | 43.4      | 16.1 | 3.1  | Human | Lower   |
| SX32 M102| −8.3    | 9.8       | 42.9      | 15.8 | 3.2  | Human | Lower   |
| SX33 M86 | −8.2    | 9.2       | 41.6      | 15   | 3.2  | Human | Lower   |
| SX34 M77 | −8.2    | 8.7       | 41.3      | 15.1 | 3.2  | Human | Lower   |
| Sample | Context | δ¹³C (‰) | δ¹⁵N (‰) | C%  | N%  | C/N | Species | Status |
|--------|---------|----------|----------|-----|-----|-----|---------|--------|
| SX35   | M21     | −7.8     | 7.9      | 43.1| 15.8| 3.2 | Human   | Lower  |
| SX36   | M36     | −7.8     | 9.3      | 42.9| 15.8| 3.2 | Human   | Lower  |
| SX37   | M83     | −8       | 8.7      | 41.2| 15   | 3.2 | Human   | Lower  |
| SX38   | M119    | −8.5     | 9.2      | 41.6| 15.2| 3.2 | Human   | Lower  |
| SX39   | M114    | −8       | 8.1      | 43.5| 16   | 3.2 | Human   | Lower  |
| SX40   | M85     | −7.7     | 8.7      | 42   | 15.4| 3.2 | Human   | Lower  |
| SX41   | M69     | −8.3     | 8.9      | 42.1| 15.4| 3.2 | Human   | Lower  |
| SX42   | M46     | −7.9     | 9.9      | 43.4| 16.1| 3.2 | Human   | Lower  |
| SX43   | M71     | −8.1     | 8.9      | 42.5| 15.7| 3.2 | Human   | Lower  |
| SX44   | M54     | −9       | 9.8      | 42.8| 15.6| 3.2 | Human   | Lower  |
| SX45   | M65     | −8.3     | 8.7      | 41.4| 15.1| 3.2 | Human   | Lower  |
| SX46   | M94     | −7.9     | 9.2      | 42.5| 15.6| 3.2 | Human   | Lower  |
| SX47   | M23     | −7.9     | 9.5      | 39.8| 14.6| 3.2 | Human   | Lower  |
| SX48   | M89     | −8.2     | 9.2      | 42.5| 15.6| 3.2 | Human   | Lower  |
| SX49   | M117    | −8.6     | 9.2      | 39.5| 14.4| 3.2 | Human   | Lower  |
| SX50   | M104    | −8       | 9.2      | 44   | 16.2| 3.2 | Human   | Lower  |
| SX51   | M115    | −7.5     | 8.3      | 41.1| 15   | 3.2 | Human   | Lower  |
| SX52   | M97     | −8.6     | 8.2      | 41.5| 15.2| 3.2 | Human   | Lower  |
| SX53   | M60     | −8.2     | 8.2      | 37.9| 14   | 3.2 | Human   | Lower  |
| SX54   | M95     | −8.8     | 9.2      | 42.7| 15.6| 3.2 | Human   | Lower  |
| SX55   | M90     | −7.9     | 8.8      | 43.8| 16.2| 3.1 | Human   | Lower  |
| SX56   | M88     | −7.7     | 9.9      | 43.3| 15.9| 3.2 | Human   | Lower  |
| SX60   | M48     | −8.4     | 9.2      | 42.3| 15.5| 3.2 | Human   | Lower  |
| SX61   | M42     | −7.8     | 9.4      | 43.3| 16   | 3.2 | Human   | Lower  |
| SX62   | M116    | −8       | 8.4      | 43.6| 15.9| 3.2 | Human   | Lower  |
| SX64   | M34     | −8.1     | 8.5      | 44   | 15.7| 3.3 | Human   | Lower  |
| SX65   | M108    | −8.7     | 8.9      | 40.3| 14.3| 3.3 | Human   | Lower  |
| SX66   | M43     | −9.2     | 9.4      | 42.4| 14.7| 3.4 | Horse   | Lower  |
| SX68   | M62     | −16.1    | 4.4      | 42.2| 14.7| 3.4 | Horse   | Lower  |
The number \((n = 3)\) and species \((n = 2)\) of animal remains at Xinancheng (table 2) was too small to predict how much animal protein contributed to human diets. However, previous research has indicated that human \(\delta^{15}N\) values could be correlated with social status and/or gender (e.g. Ambrose et al 2003, Linderholm et al 2008, Zhang et al 2012, Zhang 2015, Dong et al 2017b). The range of human \(\delta^{15}N\) values was relatively wide \((7.7‰–10.9‰)\) at Xinancheng cemetery, indicating that humans consumed varying amounts of protein. The \(\delta^{15}N\) values for the upper-status individuals were significantly higher than that of the lower-status individuals \((p = 0.001\), table 3 and figure 2(b)), indicating that the upper-status individuals consumed slightly more meat and/or milk. The human \(\delta^{13}C\) values for the upper-status individuals were also significantly more negative than that of the lower-status individuals \((p = 0.003\), table 3 and figure 2(c)), implying that upper-status individuals had more C3-food intake (most likely wheat and/or C3-based animal protein). The same phenomenon was also reported for sites at Shang and Western Zhou in the adjacent area of Henan Province (Cheung et al 2017b, Dong et al 2017b, Zhang et al 2017). This similarity in dietary consumption implies that upper-status individuals in the Central Plains might have consumed slightly more exotic C3 staples (i.e. wheat) in the period \(\sim 1600–771\) BCE, given that wheat was difficult to procure and/or required higher labor input to produce when it was introduced in China at an early stage (Chen 2016, Long et al 2018).

### 5.2. Spatio-temporal variation of subsistence patterns

To investigate potential dietary changes in the Central Plains from Proto-Shang to Eastern Zhou, the present results were compared with other stable carbon isotope ratio data for human bones unearthed from sites dating to the period \(\sim 2000\) and \(221\) BCE (figure 3). In general, humans had a C4-dominant diet (including millet and C4-based animal protein) and were heavily reliant on millet-based agriculture during the period from Proto-Shang to Western Zhou, a fact supported by archaeobotanical evidence and historical documentary records. Archaeobotanical and documentary records show that millet was the most important crop in the Central Plains from Proto-Shang to Western Zhou, while other crops, including wheat and rice, were supplementary crops (Zhao and Fang 2007, Wu et al 2014, Yang et al 2017, Zhong et al 2018). Furthermore, ancient peoples used millet and millet by-products to feed livestock (Barton et al 2009). For instance, not only

---

**Table 3. Summary of isotopic data for individuals and significance testing at Xinancheng.**

| Status | N | Mean (‰) | SD | Range | \(p\) | Mean (‰) | SD | Range | \(p\) |
|-------|---|----------|----|-------|------|----------|----|-------|------|
| Upper | 13 | -9.1     | 0.9| -10.8 to -8.0 | 0.003* | 9.5     | 0.9| 8.2 to 10.9 | 0.001* |
| Lower | 49 | -8.2     | 0.4| -9.5 to -7.4  |      | 8.8     | 0.6| 7.7 to 9.9  |      |

* The mean difference is significant at the 0.05 level.
did pigs and dogs eat a large amount of millet and millet by-products, but sheep, goats and cattle also consumed some millet and millet by-products based on the results of stable carbon isotope analysis (Hou et al 2013, Dai et al 2016, Ma et al 2016), giving further evidence to the fact that human societies were heavily reliant on millet-based agriculture in the Central Plains from Proto-Shang to Western Zhou.

It can be seen that the range of human $\delta^{13}C$ values expanded and shifted towards $C_3$ plants during Eastern Zhou ($p = 0$, supplementary table S2 and figure 3(a)), which probably implies an increased consumption of wheat during the Eastern Zhou. An increased consumption of wheat in the Eastern Zhou (Dong et al 2017b, Zhou et al 2017) diet is consistent with the archaeobotanical data, which shows a rapid increase in the frequency and/or ubiquity of wheat in the crop assemblages during this period (e.g. Liu et al 2017, Ma 2017, Deng et al 2019). And historical documentary records also support this increase. For example, wheat cultivation was supported by governments during the Eastern Zhou period according to ancient Chinese books such as ‘Zuo Zhuang’ (左传) and ‘Zhan Guo Ce (战国策).’ Human dietary patterns and subsistence strategies, however, were inconsistent in different regions of the Central Plains from Proto-Shang to Eastern Zhou (figure 3). Humans shifted their diets from predominantly $C_4$ to mixed $C_3$ and $C_4$ in Henan Province during Eastern Zhou (figure 3(b)), while individuals of Shanxi and Shaanxi Provinces were sustained by a predominantly $C_4$ diet during Eastern Zhou (figures 3(c), (d)). This suggests that human diets changed in the Central Plains during Eastern Zhou, but the change was more apparent in the core region (i.e. northern Henan Province) of the Central Plains.

5.3. Social resilience and adaptive capacity in the context of climate change

The subsistence patterns of humans could shift as a result of changes in climate and society. Climate change has been identified as an important factor in influencing the evolution of human subsistence patterns in the past (Ma et al 2016, Gong et al 2019). When natural resources become unavailable and induced by climate deterioration and/or population pressures, humans may change their subsistence strategies to increase social resilience and adaptive capacity.

Foord, millet and broomcorn millet, which were domesticated in northern China, were the staple crops in the Central Plains before Eastern Zhou (figure 3). Furthermore, wheat, an exotic crop, played a limited role in the overall subsistence system before Eastern Zhou in the Central Plains (Chen 2016), although...
wheat, first domesticated in West Asia, was introduced into the Central Plains around 2000 BCE (Lee et al. 2007, Zhao 2014, 2015), when trans-Eurasia cultural exchanges gradually intensified. Subsequently, the peoples of the Central Plains consumed more wheat during Eastern Zhou, and spatial differentiation of human dietary changes was observed for different regions of the Central Plains, according to stable carbon and nitrogen isotopic data (figure 3).

The dietary shift toward more wheat consumption in the Central Plains most likely was associated with the deteriorating climate from the late Shang to the early Eastern Zhou dynasties. An oxygen isotope record of Greenland suggests that globally, the climate was cooling during this period (figure 4(f)). Wang (2011) also shows that dry events increased during 2.8–2.6 ka BP along with a decrease in temperature. Although climate patterns in China were more complex (Wanner et al. 2011), its general trend was also similar. The weakening Asian summer monsoon recorded by speleothem δ18O from Dongge Cave appears to be consistent with a general cooling and drying climate condition from the late Shang to the early Eastern Zhou dynasties (figure 4(f)). Regionally, three paleoclimatic records from the Gonghai and Daihai Lakes all suggest a declining trend in temperature and precipitation in the Central Plains during this period (figures 4(c)–(e)). Two high-resolution pollen records from the Gonghai and Daihai Lakes further illustrate that an extremely cold episode occurred at the turn of the Western and Eastern Zhou Dynasties, which is consistent with the weakest episode of the Asian summer monsoon (figure 4(f)). The Warring States period (475–221 BCE) chronicle ‘Zhushu Jinian’ (竹书纪年) recorded that ‘Peaches and apricots ripen in September (circa October in Gregorian Calendar)’ (‘九月，桃杏实’) and ‘Frost occurred in June (circa July in Gregorian Calendar)’ (‘夏六月，隠霜’) in the Central Plains, also indicating an unusually cold climate during the reign of King You (795–771 BC), the last king of the Western Zhou.

Given that millet was drought-tolerant but not cold-resistant (Wang 1994), the grain yield of millet-based agriculture might have started to decrease with the deterioration of climate since the late Shang Dynasty (figure 4). This form of agriculture probably eventually lost its viability during the extremely cold and dry episode that lasted from the late Western Zhou to early Eastern Zhou dynasties. The food supply would have been at risk and could not feed the large population (20 million) because an agricultural system based on only one crop would have been vulnerable to a changing environment. Responding to the climatic pressure, the society of the Central Plains showed its resilience and adaptive capacity by incorporating cold-resistant wheat in the traditional millet-based agricultural system to supplement and vary the agricultural system. Furthermore, wheat is much more high-yielding than millet (Peng 2010), probably facilitating, in part, the rapid increase of population from 10 million to 20 million (Lu and Teng 2000) in the Central Plains from 1046 to 771 BCE, which might in turn have promoted a dependency by society on wheat production, especially in Henan, the core area of the Eastern Zhou government. Even in the Han Dynasty (202 BCE–220 CE), the importance of wheat in the food assemblage slightly exceeded that of millet (Hou et al. 2012, Deng et al. 2019).

To investigate potential dietary changes between the upper- and lower-status individuals, the δ13C and δ15N values are plotted for the respective status categories (figures 4(a), (b)). It can be seen that the upper-status individuals ate more C3 foods than the lower-status individuals from Shang to Western Zhou (figure 4(b), supplementary table S3), including wheat and C3-based animal protein. Given that wheat would have been difficult to procure and/or would have required higher labor input to produce when it was introduced in China at an early stage, upper-status individuals might have consumed more exotic crops (i.e. wheat) from Shang to Western Zhou. With the adoption and expansion of wheat cultivation in the Central Plains (Ma 2017, Tang et al. 2018, Zhong et al. 2018, Deng et al. 2019), wheat would have gradually increased in the daily diet and would have assumed increasing agricultural importance for all individuals during Eastern Zhou, but especially for the lower-status individuals (supplementary table S3, figures 4(a), (b)). This could have occurred because wheat was not scarce, and although it tasted bad in comparison to millet, the people in the Central Plains before the end of the Han Dynasty (Zeng 2005) would have opted to steam or boil the whole grain.

Human societies adopted a wide variety of strategies to adapt to environmental changes and extreme climatic events. Migration and subsistence strategy changes are two of them that have received the most attention (Kuper and Kröpelin 2006, Flohr et al. 2016, Lespez et al. 2016, Dong et al. 2019). However, along with the developing civilization, the adaptive capacity of human communities in response to the environmental pressures also developed. Our analysis reveals that the agricultural communities in the Central Plains responded to the environmental stress during the Zhou Dynasty by changing their crop structures rather than radically changing their subsistence strategies. Specifically, they started to plant more wheat to adapt to environmental and population pressure. Researchers have also reported similar phenomena in northwestern China (Ma et al. 2016, Yang et al. 2019b), India (Pokharia et al. 2017), and Italy (Primavera et al. 2017). This implies that collapse of a society was not the only way for ancient societies to respond to climate change, thus, in some instances humans could increase their resilience and adaptive capacity through alteration of their agricultural practices and strategies in response to the environmental pressures. Since then, the rise and fall of civilizations is likely to have been
dominated by human society itself instead of climate change as a result of further improvements in the capacity of humans to adapt to environmental change.

6. Conclusion

The isotopic and radiocarbon dating results presented suggest that humans consumed a great amount of C4 foods (millet and/or C4-based animals’ protein) during the period between ~1000 and 800 BCE, while the diets of different hierarchical groups were clearly varied. Upper-status individuals consumed more animal protein and more C3 crops (most likely wheat) than lower-status individuals. From integration of isotopic data from human bones with archaeobotanical data of the Central Plains, it was confirmed that human diets and subsistence strategies changed significantly such that more wheat was consumed during Eastern Zhou, as evidenced by the increased intake of C3 staples for lower-status individuals.
The aggravation of survival stress induced by climate deterioration around the late western Zhou—early eastern Zhou Dynasty could have been an important contributing factor to socio-economic change during the Zhou Dynasty (1046–221 BCE). The mixed millet and wheat agricultural system developed in the Central Plains during Eastern Zhou to respond to environmental and population pressures, implied that the socio-economic system of the Eastern Zhou Dynasty displayed a certain degree of resilience to climate change. The combined climate change, human isotopic data and burial patterns presented in this study can be applied more widely to prehistoric and historical periods in China and other countries to shed light on the resilience of human societies and their relationships with environmental change.

Acknowledgments

This research was supported by the National Key R&D Program of China (Grant no.: 2018YFA0606402), the Strategic Priority Research Program of Chinese Academy of Sciences, Pan–Third Pole Environment Study for a Green Silk Road (Pan–TPE) (Grant no.: XDA20040101), the National Natural Science Foundation of China (Grant no.: 41871076). We sincerely thank two anonymous reviewers for valuable comments, as well as Zhiping Zhang (Lanzhou University) for his advice on processing the paleoclimate data.

Data availability statement

The data that support the findings of this study are included within the article.

ORCID iDs

Shanjia Zhang https://orcid.org/0000-0003-1324-7929

References

Ambrose S H and Norr L 1993 Isotopic composition of dietary protein and energy versus bone collagen and apatitic: purified diet growth experiments Molecular Archaeology of Prehistoric Human Bone (Prehistoric Human Bone-Archaeology at the Molecular Level) ed J B Lambert and G Gruepe (Berlin: Springer)
Ambrose S H, Buikstra J and Krueger H W 2003 Status and gender differences in diet at Mound 72, Cahokia, revealed by isotopic analysis of bone J. Anthropol. Archaeol. 22 217–26
Auerwald K, Wittmer M H O M, Männel T T, Bai Y F, Schäufele R and Schneidler H 2009 Large regional-scale variation in C3/C4 distribution pattern of Inner Mongolia steppe is revealed by grazer wool carbon isotope composition Biogeosciences 6 795–805
Barton L, Newsome S D, Chen F H, Wang H, Guilderson T P and Bettinger R L 2009 Agricultural origins and the isotopic identity of domestication in northern China Proc. Natl Acad. Sci. 106 5523–8
Berger E and Wang H 2017 Bioarchaeology of adaptation to a marginal environment in bronze age western China Am. J. Human Biol. 29 e22956
Bronk Ramsey C 2017 OxCal version 4.3.2 (https://c14.arch.ox.ac.uk/oxcal.html)
Chen F H et al 2015a Agriculture facilitated permanent human occupation of the Tibetan plateau after 3600 B.P. Science 347 248–50
Chen F H et al 2015b East Asian summer monsoon precipitation variability since the last deglaciation Sci. Rep. 5 11186
Chen X 2016 A archaeological perspective on scale of wheat cultivation during the Chinese early Bronze Age (in Chinese) Agric. Hist. China 3 3–9
Cheung C, Jing Z C, Tang J G, Weston D A and Richards M P 2017b Diets, social roles, and geographical origins of sacrificial victims at the royal cemetery at Yinxu, Shang China: new evidence from stable carbon, nitrogen, and sulfur isotope analysis J. Anthropol. Archaeol. 48 28–45
Cheung C, Jing Z C, Tang J G, Yue Z W and Richards M P 2017a Examining social and cultural differentiation in early Bronze Age China using stable isotope analysis and mortuary patterning of human remains at Xin’anzhuang, Yinxu Archaeol. Anthropol. Sci. 9 799–816
Dai L I, Li Z P, Zhao C Q, Yuan J, Hou L L, Wang C S, Fuller B T and Hu Y W 2016 An isotopic perspective on animal husbandry at the Xinzhai site during the initial stage of the legendary Xia Dynasty (2070–1600 BC) Int. J. Osteoarchaeol. 26 685–96
Deng Z H, Fuller D Q, Chu X L, Cao Y P, Jiang Y C, Wang L Z and Lu H Y 2019 Assessing the occurrence and status of wheat in late Neolithic central China: the importance of direct AMS radiocarbon dates from Xiazhai Veg. Hist. Archaeobot. 26 61–73
Diamond J and Bellwood P 2003 Farmers and their languages: the first expansions Science 300 597–603
Dong G H, Liu F W and Chen F H 2017a Environmental and technological effects on ancient social evolution at different spatial scales Sci. China Earth Sci. 60 2067–77
Dong G H, Li R, Lu M X, Zhang D J and James N 2019 Evolution of human–environmental interactions in China from the late Paleolithic to the Bronze Age Proc. Phys. Geog. 9 030913331987680
Dong Y, Morgan C, Chinenov Y, Zhou L G, Fan W Q, Ma X L and Pechenkina K 2017b Shifting diets and the rise of male-biased inequality on the Central Plains of China during Eastern Zhou Proc. Natl. Acad. Sci. 114 932–7
Dunning N P, Beach T P and Luzzadder-Beach S 2012 Kax and kol: technological effects on ancient social evolution at different spatial scales Prog. Phys. Geog. 36 485–508
Fahmideh F, Zareh M, Tahan R, Nourizadeh B and Shirhadi S A 2019 The effect of physical education on blood lipid profile in patients with type 2 diabetes Mellitus: a randomized controlled trial J. Family Med. Prim. Care 8 1048–53
Flohr P, Fleitmann D, Matthews R, Matthews W and Black S 2016 Steppe is revealed by grazer wool carbon isotope composition in C3 plants Quat. Sci. Rev. 114 203–15
Fukuyama S, Nakamura Y, Goto H, Kameyama Y and Shimura T 2011 Effects of prolonged fasting on polycyclic aromatic hydrocarbons and polychlorinated biphenyls in human blood plasma Sci. Total Environ. 409 5399–4004
Gu Z Y, Liu Q, Xu B, Han J M, Yang S L, Ding Z L and Liu T S 2003 Climate as the dominant control on C3 and C4 plant abundance in the Loess Plateau: organic carbon isotope evidence from the last glacial–interglacial loess–soil sequences Chin. Sci. Bull. 48 1271–8
Han B H, Li B, Yang L Z and Li S Q 2016 The excavation report of Liujiazhuang sites, Jinan, Shandong Province in Chinese Z. Archäol. 31 127–139
Hedges R E M and Reynard L M 2007 Nitrogen isotopes and the trophic level of humans in archaeology J. Archaeol. Sci. 34 1240–51
Hou L L, Wang N, Lv P, Hu Y W, Song G D and Wang C S 2012 Transition of human diets and agricultural economy in Shenmingpu Site, Henan, from the Warring States to Han Dynasties Sci. China Earth Sci. 55 973–82

Hou L L et al 2013 Human subsistence strategy at Liuzhuang site, Henan, China during the proto-Shang period (c. 2000–1600 BC) by stable isotopic analysis J. Archaeol. Sci. 40 2344–51

Hu Y W, Wang S G, Luan F S, Wang C S and Richards M P 2008 Stable isotope analysis of humans from Xiaojingshan site: implications for understanding the origin of millet agriculture in China J. Archaeol. Sci. 35 2960–5

Kohn M J 1999 You are what you eat Science 283 335–6

Kuper R and Kroppelin S 2006 Climate-controlled Holocene occupation in the Sahara: motor of Africa’s evolution Science 313 803–7

Lee G, Wang G D, Liu L and Chen X 2007 Plants and people from the early Neolithic to Shang periods in North China Proc. Natl. Acad. Sci. 104 1087–92

Lespez L, Glais A, Lopez-Saez J A, Le Drezen Y, Tsirtsoni Z, Davidson R, Biree L and Malamidou D 2016 Middle Holocene rapid environmental changes and human adaptation in Greece Quat. Res. 85 227–44

Li Z 2017 A Research on the Human Skeletons of the Xizhou Dynasty from Xinancheng Graveyard in Yangrou Country, Shannxi Province (in Chinese) Jilin University

Linderholm A, Jonson C H, Svensk O and Liden K 2008 Diet and status in Birka: stable isotopes and grave goods compared Antiquity 82 446–61

Liu H, Song G D, Gong Y W, Jiang H E and Wang C S 2017 A Preliminary Analysis of the botanical remains from the Shenmingpu Site in Xichuan, Henan (in Chinese) Huaxia Archaeol. 1.54–61

Liu L, Zhou X, Yu Y Y and Guo Z T 2011 The natural vegetations on the Chinese Loess Plateau: the evidence of soil organic carbon isotope in Chinese Quat. Sci. 31 506–13

Long T W, Leipe C, Jin G Y, Wagner M, Guo R Z, Schroeder O and Tarasov P E 2018 The early history of wheat in China from 13C dating and Bayesian chronological modelling Nat. Plants 4 272–9

Lu Y and Teng Z Z 2000 General Population History of China (in Chinese) (Uinan, China: Shandong People’s Publishing House)

Lu M X, Wang J X, Liu R L, Yang Y, Wei M and Dong G H 2019 A brief history of wheat utilization in China Front. Agr. Sci. Eng. 6 288–95

Ma F Q 2017 Archaeological Research at the City of Zhu State from Eastern Zhou to Western Han Periods with the Perspective of Palaeoethnobotany: A Case Study Based on Macromains in 2015 (in Chinese) (Uinan, China: Shandong University)

Ma M M, Dong G H, Jia X, Wang H, Cui Y F and Chen F H 2016 Dietary shift after 3600 cal yr BP and its influencing factors in northwestern China: evidence from stable isotopes Quat. Sci. Rev. 143 557–70

Ma M M, Dong G H, Lightfoot E, Wang H, Liu Y Y, Jia X, Zhang K R and Chen F H 2014 Stable isotope analysis of human and faunal remains in the Western Loess Plateau, approximately 2000 cal BC Archaeometry 56 237–55

Ma Y, Fuller B T, Wei D, Shi L, Zhang X Z, Hu Y W and Richards M P 2016 Isotopic perspectives (δ13C, δ15N, δ34S) of diet, social complexity, and animal husbandry during the proto-Shang period (ca. 2000–1600 BC) of China Am. J. Phys. Anthropol. 160 433–45

Pechenkina E A, Ambrose S H, Ma X L and Benfer R A Jr 2005 Reconstructing northern Chinese Neolithic subsistence practices by isotopic analysis J. Archaeol. Sci. 32 1172–89

Pokharia A K, Agnihotri R, Sharma S, Baijup S, Nath J, Kumaran R N and Negi B C 2017 Altered cropping pattern and cultural continuity with declined prosperity following abrupt and extreme arid event at ~4200 yrs BP: Evidence from an Indus archaeological site Khirsara, Gujarat, western India PLoS One 12 e0185864

Peng W 2010 Re-discussion on the extension of wheat in Han Dynasty (in Chinese) Res. Cltn. Econ. Hist. 463–71

Petrie C A et al 2017 Adaptation to variable environments, resilience to climate change: investigating land, water and settlement in Indus Northwest India Curr. Anthropol. 58 1–30

Primavera M, D’Oronto C, Muntoni I M, Radina F and Fiorentino G 2017 Environment, crops and harvesting strategies during the II millennium BC: resilience and adaptation in socio-economic systems of Bronze Age communities in ETRUSCUM (SE Italy) Quat. Int. 436 83–95

Reimer P J et al 2013 IntCal 13 and marine13 radiocarbon age calibration curves 0–50,000 Years cal BP Radiocarbon 55 1689–87

Richards M P and Hedges R E M 1999 Stable isotope evidence for similarities in the types of marine foods used by late Mesolithic humans at sites along the Atlantic coast of Europe J. Archaeol. Sci. 26 717–22

Song X, Wang L Z and Fuller D Q 2019 A regional case in the development of agriculture and crop processing in northern China from the Neolithic to Bronze Age: archaeobotanical evidence from the Shushui River survey, Shanxi province Archaeol. Anthropol. Sci. 11 667–82

Staubwasser M, Sirico F, Grootes P M and Segl M 2003 Climate change at the 4.2 ka BP termination of the Indus valley civilization and Holocene south Asian monsoon variability Geophys. Res. Lett. 30 71–4

Stevens C J, Roibeyr A, Lucas L, Silva F and Fuller D Q 2016 Between China and South Asia: A Middle Asian corridor of crop dispersal and agricultural innovation in the Bronze Age Archaeol. Sci. 26 1541–55

Tang M, Wang X Y, Hou K and Hou L L 2018 Carbon and nitrogen stable isotope of the human bones from the Xiaonanhuang cemetery, Jinhzhong, Shanxi, a preliminary study on the expansion of wheat in ancient Shanxi, China (in Chinese) Acta Anthropol. Sin. 37 518–30

Vinther B M et al 2009 Holocene thinning of the Greenland ice sheet Nature 461 385

Wang H P, Chen J H, Zhang S D, Zhang D D, Wang L Z, Xu Q H, Chen S Q, Wang S J, Kang S C and Chen F H 2018 A chironomid-based record of temperature variability during the past 4000 years in northern China and its possible societal implications Clim. Past 14 383–96

Wang G A, Han J M and Liu D S 2003 The carbon isotope composition of C3 herbaceous plants in loess area of northern China Sci. China Ser. D-Earth Sci. 46 1069–76

Wang S W 2011 Holocene Climate Change (in Chinese) (Beijing: Meteorological Press)

Wang X Y 1994 Common Millets in China (in Chinese) (Beijing: China Agricultural Press)

Wang Y, Cheng H, Edwards R L, He Y Q, Kong X G, An Z S, Wu J Y, Kelly M J, Dykoski C A and Li X D 2003 The Holocene Asian monsoon: links to solar changes and the Atlantic climate Science 308 854–7

Wanner H, Solomina O, Grosjean M, Ritz S P and Petit R M 1999 The collapse of Neolithic Cultures around the Central Plain of China Cul. Rel. Central China 45 109–17

Wu W X and Liu T S 2004 Possible role of the Atlantic climate in the collapse of Neolithic Cultures around the Central Plain of China Quat. Res. 61 153–66

Xu Q H, Xiao J L, Li Y C, Tian F and Nakagawa T 2010 Pulsen-based quantitative reconstruction of Holocene climate changes in the Daxihai Lake area, Inner Mongolia, China J. Clim. 23 8256–68

Yang S S, Ren L L, Dong G H, Cui Y F, Liu R L, Chen G K, Wang H, Wilkins S and Chen F H 2019b Economic Change in the prehistoric Hexi Corridor (4800–2200 BP), North-West China Archaeometry 61 957–76

Yang Y Z, Yuan J Z, Zhang Q J, Cheng Z J, Xuan H L, Fang F, Zhang J Z and Gu W F 2017 Characteristics and development
of agriculture during Xia and Shang Dynasties based on carbonized plant analysis at the Dongzhao site, Central China (in Chinese) Acta Anthropol. Sin. 36 119–30
Yang L E, Bork H R, Fang X and Mischke S 2019a Socio-Environmental Dynamics along the Historical Silk Road (Heidelberg: Springer-Nature)
Yuan J 2015 Zooarchaeology of China (in Chinese) (Beijing: Cultural Relics Press)
Yuan J and Flad R 2005 New zooarchaeological evidence for changes in Shang Dynasty animal sacrifice J. Anthropol. Archaeol. 24 252–70
Zeder M A and Hesse B 2000 The initial domestication of goats (Capra hircus) in the Zagros mountains 10,000 years ago Science 287 2254–7
Zeng X S 2005 On the spread of wheat in ancient China (in Chinese) J. Chin. Dietary Cul. 1 99–135
Zhang G W 2015 Stable isotope analysis of carbon and nitrogen for social class differentiation embodied in Tombs (in Chinese) Cul. Rel. Southern China 3 161–8
Zhang X L, Qiu S H, Zhong J and Liang Z H 2012 Stable carbon and nitrogen analysis on the human remains from the Qianzhangda cemetery at Shandong, China (in Chinese) Archaeology 9 83–96
Zhang X L, Xu G D, He Y L and Qiu S H 2017 The analysis of carbon and nitrogen stable isotopes of human bone of M54 tombs at Yinxu (in Chinese) Archaeology 3 100–9
Zhao Z J 2011 New archaeobotanic data for the study of the origins of agriculture in China Curr. Anthropol. 52 S295–306
Zhao Z J 2014 The process of origin of agriculture in China: archaeological evidence from flotation results (in Chinese) Quat. Sci. 34 73–84
Zhao Z J 2015 The study of wheat was introduced into China–The data of plant archaeology (in Chinese) Cul. Rel. Southern China 3 44–52
Zhao Z J and Fang Y M 2007 Floatation results and analysis of Dengfeng Wangchenggang site (in Chinese) Huaxia Archaeol. 2 78–89
Zhao Z J 2009 Eastward spread of wheat into China–New data and new issues Chin. Archaeol. 9 1–9
Zhong H, Li S T, Li H F and Zhao Z J 2018 Floatation results and analysis on Xiaoshuangqiao ruins, Zhengzhou City, Henan Province (in Chinese) Cul. Rel. Southern China 2 163–9
Zhou L G and Garvie-Lok S J 2015 Isotopic evidence for the expansion of wheat consumption in northern China Archaeol. Res. Asia 4 25–35
Zhou L G, Garvie-Lok S J, Fan W Q and Chu X L 2017 Human diets during the social transition from territorial states to empire: stable isotope analysis of human and animal remains from 770 BCE to 220 CE on the Central Plains of China J. Archaeol. Sci. Rep. 11 211–23