



The Spatiotemporal Pattern of Cultural Evolution Response to Agricultural Development and Climate Change From Yangshao Culture to Bronze Age in the Yellow River Basin and Surrounding Regions, North China

Lin Wang^{1†} and Yifu Cui^{2,3*†}

¹School of Architecture, Huaqiao University, Xiamen, China, ²College of Tourism, Huaqiao University, Quanzhou, China, ³Max Planck Institute for the Science of Human History, Jena, Germany

OPEN ACCESS

Edited by:

Jade D'Alpoim Guedes,
University of California, San Diego,
United States

Reviewed by:

Elizabeth Berger,
University of California, Riverside,
United States
Fahu Chen,
Institute of Tibetan Plateau Research
(CAS), China

*Correspondence:

Yifu Cui
cuiyifu09@hqu.edu.cn

[†]These authors have contributed
equally to this work

Specialty section:

This article was submitted to
Quaternary Science, Geomorphology
and Paleoenvironment,
a section of the journal
Frontiers in Earth Science

Received: 22 January 2021

Accepted: 19 May 2021

Published: 15 June 2021

Citation:

Wang L and Cui Y (2021) The
Spatiotemporal Pattern of Cultural
Evolution Response to Agricultural
Development and Climate Change
From Yangshao Culture to Bronze Age
in the Yellow River Basin and
Surrounding Regions, North China.
Front. Earth Sci. 9:657179.
doi: 10.3389/feart.2021.657179

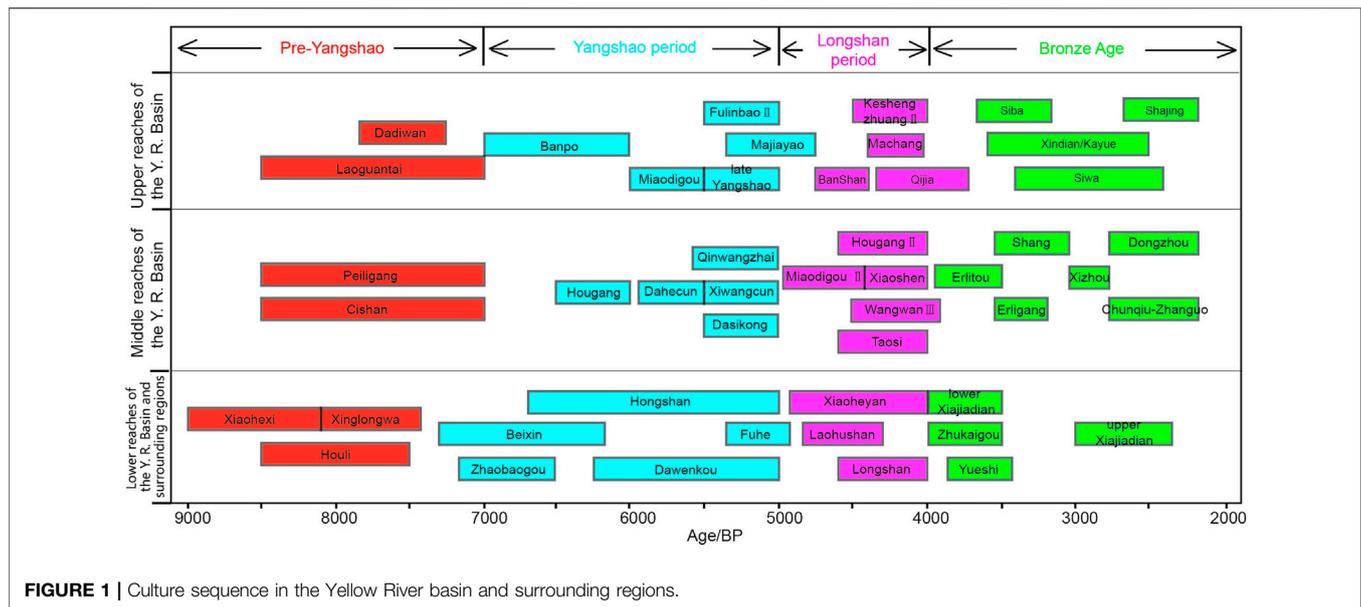
The processes and mechanisms of cultural evolution provide helpful insights into the origin and development of civilizations. This study analyses data from the national archaeological survey using kernel density analysis, a geospatial tool provided by ArcGIS10 software, to explore the spatiotemporal pattern of cultural evolution from the beginning of the Yangshao cultural period to the Bronze Age in the Yellow River basin. Agricultural development and the environmental background of this region were reconstructed using published flotation materials and high-resolution paleoclimate records. The results indicate that cultural expansion and differentiation from Yangshao (7000–5000 BP) to Longshan period (4600–4000 BP) are responding to the establishment and strengthening of millet-based agriculture and the appearance of multiple subsistence strategies in the context of environmental deterioration. To the Bronze Age, the center of sites accumulates to the Central Plains and Shandong, in contrast to the continuous cultural expansion and differentiation. The opposite circumstance may result from early urbanization along with the formation of a social system with high centralization of power.

Keywords: cultural evolution, agricultural development, climate change, kernel density analysis, urbanization, Yellow River basin

INTRODUCTION

The process and influencing factors of cultural evolution have been widely studied (Weiss et al., 1993; DeMenocal et al., 2001; Dong et al., 2012; Dong et al., 2013; Kennett et al., 2012; Medina-Elizalde and Rohling, 2012; Cui et al., 2018). The Neolithic is one of the most pivotal periods to examine cultural evolution because of the major changes associated with the development of food-producing economies and growing population unseen in prior periods. By studying the spatiotemporal pattern of cultural evolution and its influencing factors, we can better understand the origin and changing mechanisms of a civilization.

Much attention is given to the study of Chinese civilization. The Yellow River basin is the cradle of Chinese civilization. The earliest Neolithic sites are distributed along the Yellow River basin from east



to west, including the Houli site in Shandong Province, the Donghulin site in Beijing, the Cishan site in Hebei Province, the Peiligang site in Henan Province, the Laoguantai site in Shaanxi Province, and the Dadiwan site in Gansu Province. The modern Chinese civilization however was established during the Bronze Age as seen by the founding of several dynasties during this period, including the Xia, Shang, and Zhou. These dynasties were centered in the middle and lower reaches of the Yellow River basin.

Neolithic culture in the Yellow River basin (**Figure 1**) can be broadly divided into three periods: pre-Yangshao period (9000–7000 BP), Yangshao period (7000–5000 BP), and post-Yangshao period (5000–4000 BP). During pre-Yangshao period, cultural groups include, Xiaohexi culture (9000–8200 BP), Houli culture (8500–7500 BP), Xinglongwa culture (8200–7400 BP), Cishan culture (8000–7000 BP), Peiligang culture (8500–7000 BP), Laoguantai culture (8200–7000 BP), and Dadiwan culture (7800–7300 BP). Several cultures including Banpo (7000–5900 BP), Miaodigou (6000–5500 BP), Xiwangcun (5600–5000 BP), Qinwangzhai (5600–5000 BP), early Dahecun (5900–5500 BP), Beixin (7300–6200 BP), early to mid Dawenkou (6300–5000 BP), and early Majiyao (5300–4800 BP) belong to the Yangshao period. The post-Yangshao period in the Neolithic is also known as the Longshan period and includes the Shandong Longshan (4600–4000 BP), Miaodigou II (4900–4300 BP), Wangwan III (4500–3900 BP), Keshengzhuang II (4500–4000 BP), Hougang II (4600–4000 BP), Taosi (4600–400 BP), Caiyuan (4800–4200 BP), and early Qijia (4300–4000 BP) cultural sites which are found in a different area of the Yellow River basin during this period. Different cultural sites of the Bronze Age have begun to be parsed in other parts of the Yellow River basin. Several cultural sites such as Siba (3700–3200 BP), Xindian (3600–2500 BP), Kayue (3600–2500 BP), Siwa (3400–2400

BP), and Shijing (2700–2100 BP) have been discovered in the upper Yellow River basin. Other Bronze Age cultural sites including Erlitou–Erligang (3900–3000 BP), Yueshi (3800–3400 BP), and Lower Xiajiadian (4300–3600 BP) are found in the middle and lower reaches of the Yellow River basin. At the same time, many archaeological remains associated with the Shang and Zhou dynasties have been found in this area. It should be noted that cultures what we talked about are material culture complexes and not genetic groups or political formations.

According to the second national relic survey (Bureau of National Cultural Relics, 1991; Bureau of National Cultural Relics, 1996; Bureau of National Cultural Relics, 1998; Bureau of National Cultural Relics, 2002; Bureau of National Cultural Relics, 2003; Bureau of National Cultural Relics, 2006; Bureau of National Cultural Relics, 2009; Bureau of National Cultural Relics, 2010; Bureau of National Cultural Relics, 2011a; Bureau of National Cultural Relics, 2011b; Bureau of National Cultural Relics, 2013; Mei and Kong, 2008), approximately 147 pre-Yangshao period sites have been identified in the Yellow River basin and its surrounding region. These sites are relatively small and usually consist of less than a 1000 square meters. Most of these sites appear to be dispersed and exhibit mutual independence from each other, although there may be some evidence of faint links among the Peiligang, Laoguantai, Cishan, and Houli cultures, as shown by Han (2015). This study examines the spatiotemporal pattern of sites from the Yangshao period, Longshan period, and Bronze Age in the Yellow River basin with the use of kernel density analysis, a geospatial software tool. In addition, this study simultaneously compares two methods of inputting data into this analysis tool and the usefulness of the results. These results are discussed by reviewing previous evidence from archaeological excavations in the region to highlight the results' potential connection to agricultural development and geopolitics.

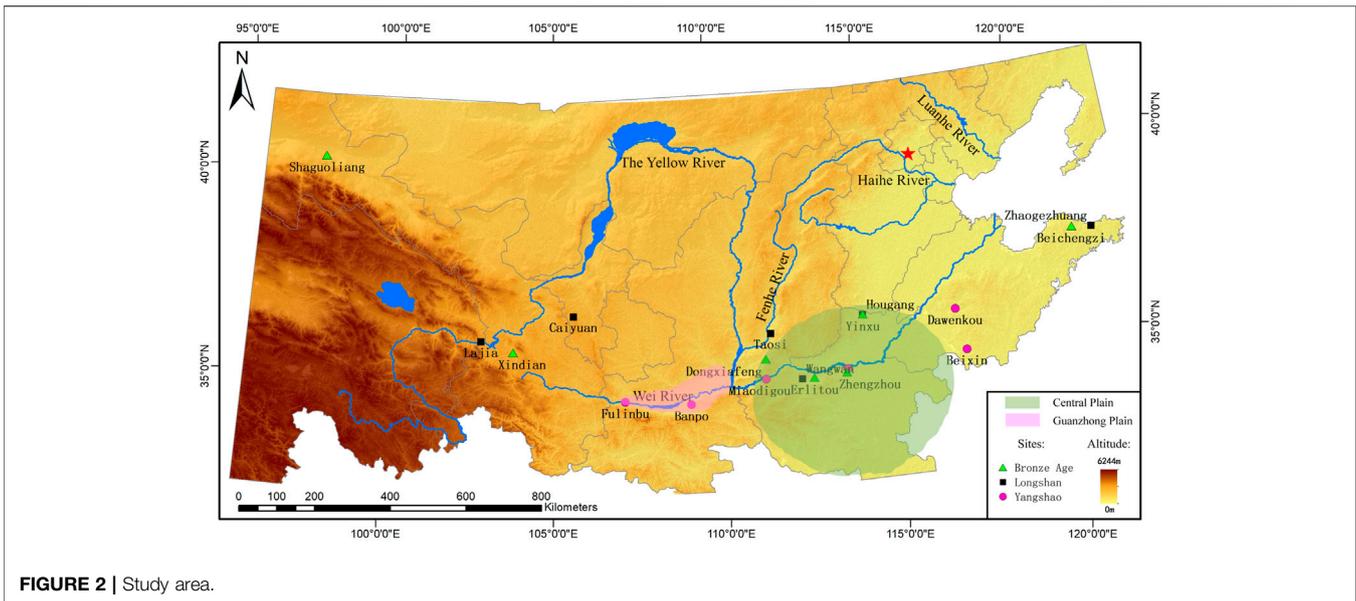


FIGURE 2 | Study area.

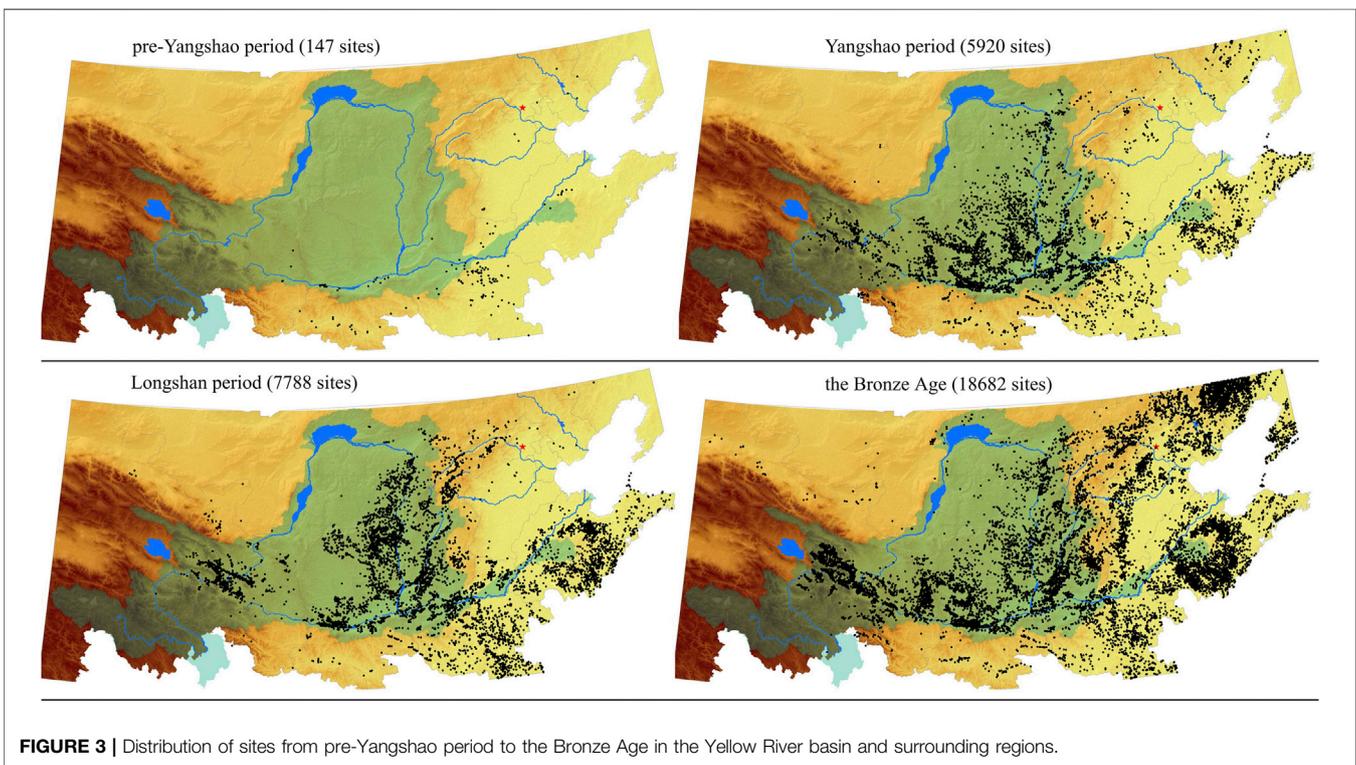


FIGURE 3 | Distribution of sites from pre-Yangshao period to the Bronze Age in the Yellow River basin and surrounding regions.

STUDY AREA

The study area (95.8°E–122.7°E, 32.1°N–41.8°N) covers the Yellow River drainage basin and its surrounding regions in northern China, stretching approximately 2300 km from the Hexi Corridor in the west to the Shandong Peninsula in the east. This area encompasses all of Ningxia, Shaanxi, Shanxi, Henan, Tianjin, Beijing, and Shandong provinces and part of Qinghai, Gansu,

Inner Mongolia, Hebei, and Liaoning provinces. The Yellow River and its two main tributaries (the Weihe River and the Fenhe River), the Luanhe River, and the Haihe River flow through these regions (Figure 2). The Yellow River is approximately 5464 km long, with its drainage basin covering 795,000 km² and its altitude decreasing 4480 m from west to east. The mean annual temperature ranges from −4 to 14°C, and the mean annual precipitation ranges from 80 to 1200 mm. As the

cradle of Chinese civilization, the Yellow River basin was the cultural and economic center of ancient China until the dynasties of South Song and Yuan. Several prehistoric sites are distributed within this study area, including 5920 Yangshao sites, 7788 Longshan sites, and 18682 Bronze Age sites (**Figure 3**, Bureau of National Cultural Relics, 1991; Bureau of National Cultural Relics, 1996; Bureau of National Cultural Relics, 1998; Bureau of National Cultural Relics, 2002; Bureau of National Cultural Relics, 2003; Bureau of National Cultural Relics, 2006; Bureau of National Cultural Relics, 2009; Bureau of National Cultural Relics, 2010; Bureau of National Cultural Relics, 2011a; Bureau of National Cultural Relics, 2011b; Bureau of National Cultural Relics, 2013; Mei and Kong, 2008). Several typical sites belonging to these three cultural periods display along the Yellow River basin and surrounding regions; among them, Beixin, Dawenkou, Miaodigou, Banpo, Fulinbu are classified as Yangshao period sites (**Figure2**, pink points); Zhaogezhuang, Hougang, Wangwan, Taosi, Caiyuan, and Lajia belong to Longshan period sites (**Figure2**, dark squares); and Beichengzi, Yinxu, Zhengzhou Shang, Dongxiafeng, Xindian, and Shaguoliang are considered as Bronze Age sites (**Figure2**, green triangles).

MATERIAL AND METHODS

Material

The archaeological site information is collected from published “Atlas of Chinese Relics” of 10 provinces and two municipalities (Bureau of National Cultural Relics, 1991; Bureau of National Cultural Relics, 1996; Bureau of National Cultural Relics, 1998; Bureau of National Cultural Relics, 2002; Bureau of National Cultural Relics, 2003; Bureau of National Cultural Relics, 2006; Bureau of National Cultural Relics, 2009; Bureau of National Cultural Relics, 2010; Bureau of National Cultural Relics, 2011a; Bureau of National Cultural Relics, 2011b; Bureau of National Cultural Relics, 2013; Mei and Kong, 2008). The information (including site location, area, and cultural attribute) is used to indicate the distributional pattern of site in north China. This “Atlas of Chinese Relics” was published after the second national archaeological survey conducted in 1981–1985, which was organized by the Provincial Administration for Cultural Heritage. The data shown in the “Atlas of Chinese Relics” use a unified format and mapping standard. We digitized these atlases to collect the geographic coordinates, cultural attributes, and site size data in order to investigate kernel density.

Methods

By using the kernel density tool provided by ArcGIS10, the site distribution patterns of the three phases are tested and compared. As a method of converting a group of points into gratings, kernel density calculates the density of point elements around each output grating cell. In this process, a smooth surface is fitted at each point. The surface value is highest at the point and decreases as the distance from the point gets larger. It reaches zero at the distance from the search radius of the point. The kernel function is used to determine how the curvature decreases. In this case, we

use the quartic kernel function. The volume under the surface is equal to the fill field value of the point, or 1 if no value is specified. Then, the density of each output grating cell is calculated by adding the values of all the core surfaces covering the center of the grating cell. In our example, the population field is specified by the site size to reasonably increase the weight of large sites. Without considering the influence of the site size, we also generate the kernel density without specifying the population field representing the distribution pattern. Conceptually, each site is like a hilltop surrounded by decreasing altitude values, and the nuclear density is used to restore a continuous surface. The search radius (or bandwidth) determines the smoothness of the surface: the larger the search radius, the wider the accumulation on the smooth surface; the smaller the search radius, the narrower the accumulation on the concave convex surface. The default search radius recommended by ArcGIS is calculated by dividing the smaller of the width or height of the input range by 30, which in our case is about 35 km. Considering the large sample area, the method of twice the default value of 70 km is used to distinguish the three-phase distribution pattern. To ensure the comparability of the final results, the uniform search radius is specified to analyze all the nuclear densities, and the highest peak value is adjusted reasonably to keep the high consistency of the results represented by ArcScene (**Figure 4**).

$$K_2(x) = \begin{cases} 3\pi^{-1}(1-x^2)^2 & \text{if } x < 1 \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

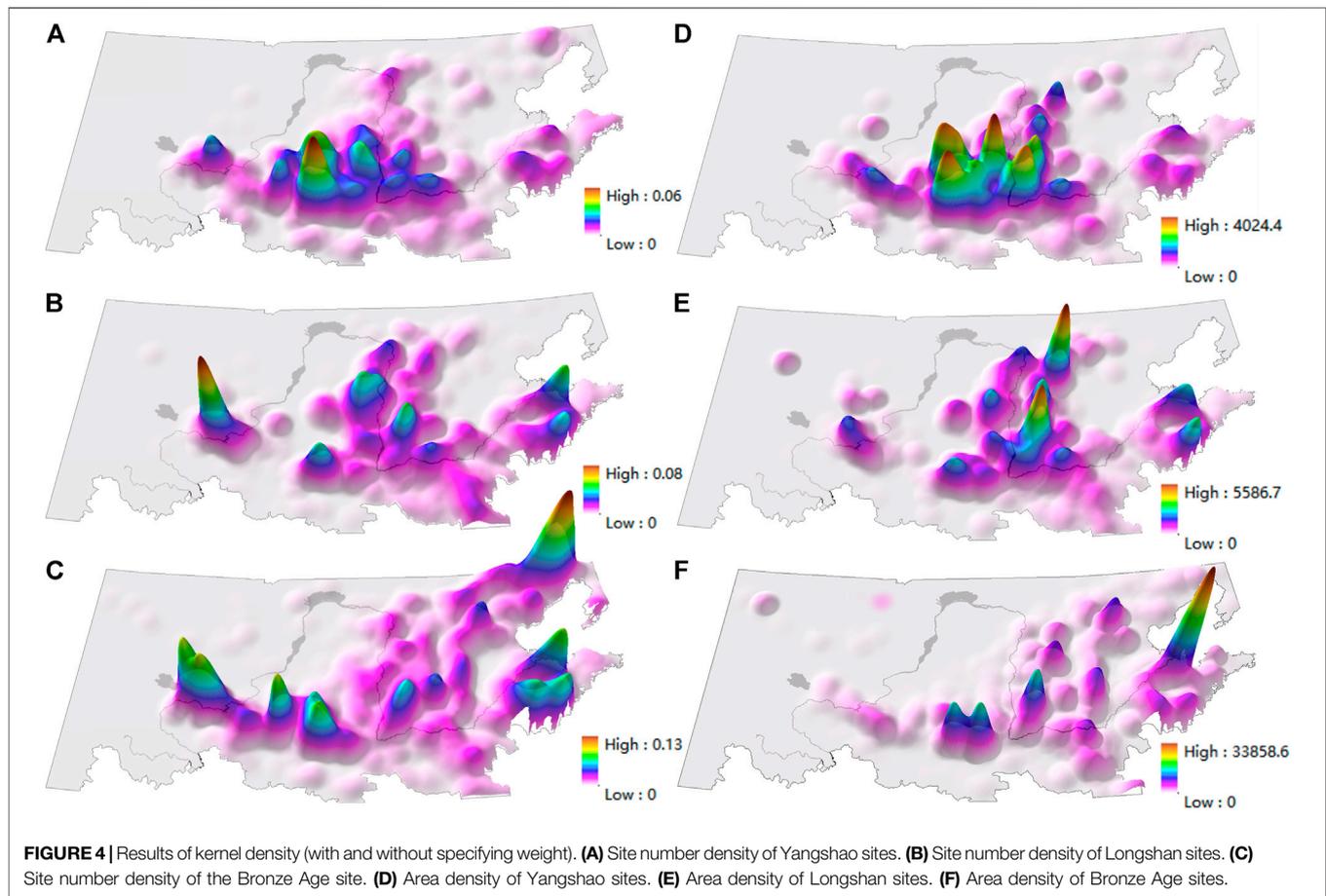
(Silverman, 1986)

RESULT

Kernel Density Analyses Without Specifying Weight (or Site Number Density)

A spatial pattern of the relative site density for each period was created using kernel density analysis without specifying a weight (or in this case without considering site size). These results are shown in **Figure 4**. Most Yangshao sites are distributed in the valleys of the upper and middle Yellow River and its main tributaries including, the Weihe River, the Fenhe River, the Taohe River, and the Huangshui River. The largest clustering of sites appears to be centered in the Guanzhong basin, Shaanxi Province (**Figure 4A**).

During the Longshan period, site density on the landscape changes and expands to several regions along the Yellow River basin. Numerous Qijia cultural sites dating to this period are found in the Huangshui River and Taohe River valleys. Miaodigou II, Wangwan III, Keshengzhuang II, Hougang II, Taosi, and Caiyuan cultural sites have been found widely distributed on both sides of the middle Yellow River. Shandong Longshan cultural sites are known from the region downstream of the Yellow River. In addition to being distributed along the river valley, Longshan period sites are also found in higher elevations among the foothills and mountains surrounding the Yellow River basin including sites found in north Shaanxi, northeast Henan, southwest Shandong, and



north Shanxi provinces (Bureau of National Cultural Relics, 1991; Bureau of National Cultural Relics, 1998; Bureau of National Cultural Relics, 2006; Bureau of National Cultural Relics, 2011a; Bureau of National Cultural Relics, 2013). Site density during the Longshan period differs from the Yangshao period, instead of high site density being found in one central location on the landscape, and multiple centers begin to appear located in east Gansu, south and central Shaanxi, south Shanxi, and west Shandong provinces (Figure 4B).

The number of sites in this region continues to expand during the Bronze Age. While site densities are higher, they appear to aggregate in many of the same locations as they did during the Longshan period, with the exception of new clusters found in the Haihe and Luanhe River valleys (Figure 4C).

Kernel Density Analyses With Specified Weight (or Area Density)

The results of kernel density with specified weight (or area density) show practical unanimity. A spatial pattern of relative site density was again created for each time period but utilizing the second method, kernel density with specified weight (taking into consideration site size using total area).

In the Yangshao period, the result of size density shows practical unanimity with that of site number density. The

center of gravity located in the valleys of the upper and middle Yellow River and its main tributaries (Figure 4D). To the Longshan period, the center of gravity has an eastward and northward transfer to west Henan and north Shanxi provinces, when compared with the Yangshao period. And several sites with a large area appeared in west Shandong Province during this period (Figure 4E). During the Bronze Age, this is what the map shows very different when compared with the Longshan period. The gravity in the middle reach of the Yellow River has a southward transfer to Henan Province, the same as the Yangshao period. Otherwise, there are sites with a huge area distributed in west Shandong Province, and it makes a really high peak lift in there (Figure 4F).

DISCUSSION

Limitations of Using Atlas of Cultural Relics as Data Source

As we mentioned before, the archaeological site information is collected from published “Atlas of Chinese Relics” of 10 provinces and two municipalities (Bureau of National Cultural Relics, 1991; Bureau of National Cultural Relics, 1996; Bureau of National Cultural Relics, 1998; Bureau of National Cultural Relics, 2002; Bureau of National Cultural Relics, 2003; Bureau of National

Cultural Relics, 2006; Bureau of National Cultural Relics, 2009; Bureau of National Cultural Relics, 2010; Bureau of National Cultural Relics, 2011a; Bureau of National Cultural Relics, 2011b; Bureau of National Cultural Relics, 2013). The survey was conducted in 1981–1985, and in the process of investigation, the criteria for judging the basic information of the site are not detailed in the publications, which will cause some doubts about the scientific validity of the data sources (Jaffe et al., 2020). For example, the Shimao site, which is a super large center settlement site that has been continuously excavated in recent years. The site area on the cultural relics atlas is 900000 square meters, and the latest information shows that the site area is more than four million square meters (Sun et al., 2020). In the process of digitizing, we also recorded some abnormal data possibly due to clerical errors in Atlas of Cultural Relics. For example, there are more than 10 sites in Shandong Province, each covering an area of more than 10 million square meters in the Bronze Age. Among them, there are even two sites with an area over 48 million square meters (Goutou site with 78 million square meters and Xigeng site with 48 million square meters). Meanwhile, in the Central Plains, there are only two sites with an area of more than 10 million square meters (Yinxu ruin with 30 million square meters and a Zhenghangucheng site with 23 million square meters). When verifying the accuracy of the site area information, we found that the two aforementioned sites with an extremely large size in Shandong Province were resurveyed in 2009, and the sizes were only recorded as 2400 and 15000 square meters on the website of Dongying Museum (<http://www.dymuseum.cn/>). Therefore, the abnormal peak of area density of Bronze Age sites observed in Shandong Province may be biased due to those clerical errors (Figure 4F). To avoid biased data revision and keep the standard unified, we kept all the records from the original Atlas of Cultural Relics when mapping them. The settlement distribution characteristics in problematic area like Shandong can be further discussed when the latest and more accurate data of the third cultural relics census are published in the future.

Despite the existing accuracy problems, our work based on enormous samples (more than 30,000) is still meaningful. Different from other smaller scale regional studies, our work focuses on summarizing the evolutionary site distributional pattern from a macroscopic spatiotemporal scale. Considering topics like agricultural diversification and climate change also happens in a similar spatiotemporal scale, and the corresponding cultural response is more suitable to be examined from a macroscopic perspective. Meanwhile, other regional studies could be more accurate on dataset and superior in manifesting cultural response to regional events like micro-landform change and rapid environmental incidents (e.g., An et al., 2005; Li et al., 2017; Liu et al., 2019; Drennan et al., 2014).

A Comparison of the Results Between Site Number Density and Area Density Analyses

If we consider that large peaks on the map equal core areas of occupation, we believe the comparison of the two results (with or without the population field specified by the site size) will indicate when and where significant site size hierarchy (or early

urbanization) appears through intuitive cartographic representation.

Using the first method, we see that there is one core area located there (east Shaanxi and Henan provinces) with occupation, and it becomes less dense as we spread outward during Yangshao period. This single core area shifts to two core areas in the Longshan period, and we see core areas in the east (west Shandong Province) and west (east Gansu Province), while the previous core area shifts to a less dense occupation. During the Bronze Age, we find an expansion of core areas across the landscape (“multi-core” distribution along the Yellow River basin from west to east).

Using the second method, we see that there is one core area located there (east Shaanxi, Henan Provinces) with occupation, and it becomes less dense as we spread outward during the Yangshao period. This is similar to what we saw in the first method. This single core area shifts to two core areas in the Longshan period, similar to what we saw with first method, but the location of the core areas are different (Henan and Shanxi provinces) and the core area from the previous period appears to shift northeast. The Bronze Age shows a vastly different core area using this model. There are two main core areas, one is located in the Central Plains and the other one located in the east (west Shandong Province), and other previous core areas of occupations show a less dense occupation.

Considering model 1 through time, it shows a single core which shifts to two different cores at opposite ends of the landscape and then results in many core areas of occupation during the Bronze Age. Conversely, model 2 through time suggests a single core area shift to multiple core areas in the same region and then results in one center of occupation in the east, demonstrating an eastward propagation toward Shanxi Province through the periods. When comparing the two models, the results correspond to the Yangshao period (Figures 4A,D). While considering the Longshan period, the results changed and centralization trend strengthened in the Central Plains, and many marginal small peaks appear in Figure 4E when compared with those in Figure 4B. Considering the Bronze Age, several marginal high peaks replaced by small peaks and a more strong center appeared when ignoring the abnormal peak in Shandong Province (the reason behind appearance of this abnormal peak is discussed in the previous part).

By taking into consideration the size information (or area) of sites, area density analysis not only represents the distribution of sites but is able to reveal the regional settlement pattern (Liu, 2007; Ma et al., 2012), further adding to our understanding of social complexity (Drennan and Uribe, 1987). Large settlement sites with areas larger than a million square meters corresponding to town sites have been found, during both the Yangshao and Longshan periods; however, the ratio of large settlements and town sites is still very low when compared to the number of smaller sites (Qian, 2001). Using the site number density analysis obscures this information because it does not consider where larger sites are on the landscape. During the Bronze Age, several large town sites appeared in the Central Plains of China, of them Yinxu ruin is the most famous town site. This transfers the center

of sites from west and east sides to the central part of the study area. The appearance of many large town sites has consanguineous relationship with the establishment of Shang and Zhou dynasties in the Central Plains of China. The establishment of dynasties reflects the formation of a social system with high centralization of power and leads to the Central Plains becoming the core area of north China.

Possible Influencing Factors to the Spatiotemporal Pattern of Cultural Evolution From the Yangshao Period to the Bronze Age in the Yellow River Basin

The results of the site number density analysis and area density analysis provide a clearer picture of the spatiotemporal pattern of cultural evolution during the Yangshao, Longshan, and Bronze Age periods in the Yellow River basin. The number of sites and their density on the landscape expand through time, while the core areas of occupation change from a single location to multiple locations after the Yangshao period.

The strengthening of agriculture is considered as the most important impetus of cultural expansions during the prehistoric period (Diamond and Bellwood, 2003; An et al., 2005; An et al., 2010; Barton et al., 2009; Kennett et al., 2012; Dong et al., 2016a), and it provides convenience for prehistoric people to expand their active area (Chen F. H. et al., 2015a). Archaeobotanical studies of macro- and micro-plant remains found in several pre-Yangshao sites indicate that millet-based agriculture originated in the Yellow River around 10,000 BP (Lee et al., 2007; Lu et al., 2009; Yang et al., 2012; Zhao, 2011; Zhao, 2014) and dated the establishment of millet-based agriculture in the Loess Plateau (Zhao, 2011; Zhao, 2014) to the early Yangshao period and Shandong area to the Beixin period (8200–7800 BP). After this time period, millet-based agriculture rapidly expanded to the Yellow River basin (Zhao, 2014; Chen F. H. et al., 2015a; Han, 2015). A small number of charred rice seeds were identified using flotation at the Yuhuazhai site which dates to the early Yangshao period (Zhao, 2014). The number of recovered rice remains increased in several late Yangshao sites, including Nanjiaokou, Xinjie, and Baligang (Wei et al., 2000; Deng and Gao, 2012; Zhong et al., 2015). Millet is a type of a dry farming crop, whose output is highly influenced by precipitation (Yang and Li, 2015). The Yangshao period experienced a relatively wet climate according to the reconstructed mean annual precipitation determined using Gonghai Lake sediments (Chen F. et al., 2015b). Suitable climate conditions can provide a wider space for human survival, which is conducive to increase the yield of crop cultivation, and also increase population and promote the prosperity of culture (Dong et al., 2012). The warm and humid climate of the Yangshao culture ensured the broad and flat loess platform in the Yellow River Valley, which was suitable for millet agriculture. Millet-based agriculture became the most important subsistence strategy in most areas of the Yellow River basin in the Yangshao period, which promoted the Yangshao culture to become the most influential mainstream culture in the Neolithic Age of north China (Dong et al., 2016b).

During the Longshan period, obvious regional differentiation of culture is demonstrated by the appearance of multi-core zones of sites densities (Figures 2, 4). Archaeobotanical evidence from the flotation at 31 Longshan period sites allows for a greater understanding of plant utilization during this period (Supplementary Table S1). Millet-based agriculture was still the main subsistence strategy, and rice agriculture is further developed. Wheat also appeared in a few late Longshan period sites including Dongpan, Liangchengzhen, Xijincheng, and Yuhuicun. The temperature and precipitation during the early Longshan period (5000–4500 BP) decreased significantly according to the northern hemisphere (30–90°N) temperature record compared to 1961–1990 instrumental mean temperature (Marcott et al., 2013) and reconstructed mean annual precipitation based on Gonghai Lake sediments (Chen F. et al., 2015b). The development of rice agriculture, further strengthening of millet-based agriculture, and the appearance of wheat during the late Longshan period indicate that agriculture subsistence strategies diversified to confront the deteriorating climate. The deterioration of climate compelled the farmers to change their subsistence strategies (Dong et al., 2013). The transformation of human diets from simplification to diversification is reflected in the results of stable carbon isotope studies in human bones as well (Ma et al., 2014).

Regional differentiation of culture and areas of occupation continue to expand into the Bronze Age according to the site number density analysis (Figure 4C). However, the area density analysis suggests that the core of Bronze Age sites are concentrated in the Central Plains because of the appearance of several large town sites (Figure 4F). Influenced by the long-distance exchange of plants across Eurasia during the second millennium BC (Dodson et al., 2013; Spengler et al., 2014; Dong et al., 2017), agriculture subsistence strategies diversified in local contexts. With the introduction of wheat, domesticated in Southwest Asia, reliance on millet-based changed to a greater reliance on wheat, barley, and millet or a mixed agriculture in the upper Yellow River valley and its adjacent areas during the Bronze Age (Liu et al., 2014; Miller et al., 2014; Ma et al., 2016). However, there is also evidence for increasing reliance on animal husbandry during this period (An et al., 2003; An et al., 2005). On the Central Plains, millet-based agriculture was still the main subsistence strategy of farmers during Erlitou, Erligang, Shang, and Zhou periods. Archaeobotanical evidence suggests that there was a decrease in the use of rice, and wheat-based agriculture increased (Chen et al., 2012; An et al., 2014; Wu et al., 2014; Yang et al., 2017). The climate became much colder and drier after 4000 BP (Cai et al., 2010; Zhou et al., 2010; Duan et al., 2012; Marcott et al., 2013), which may suggest that the adjustment of subsistence strategies in different regions are in response to the further deteriorating climate. The changing location of core occupation on the landscape may not relate directly to climate change during this period. It is possible that the changing core concentrations of occupation through the three periods indicates the beginning of urbanization in north China as vast numbers of large town sites emerged along with

the formation of dynasties or social systems with high centralization of power.

CONCLUSION

In the past, the study of settlement evolution mostly used the method of site number density analysis. In this study, by comparing site number density and area density made possible by the kernel density tool and by placing the results in context of the archaeological evidence, we can provide preliminary insights into the spatiotemporal pattern of cultural evolution taking place in China during its formative periods. Comprehensive consideration of the number and area of sites can better express the characteristics of settlement evolution. Conducive climate and the establishment and strengthening of millet-based agriculture contributed to the success of Yangshao cultures in the Yellow River basin. During the Longshan period, climatic conditions deteriorated. Differential cultural responses were found to be regionally based and subsistence strategies appear to have diversified. Site numbers on the landscape continue to expand, yet the number of larger sites become increasingly centered in the Central Plains and Shandong during the Bronze Age. This transition to a more centralized core area with larger sites seen in the results of the area density analysis may be highlighting the beginning of urbanization in China that is linked to this period.

REFERENCES

- An, C.-B., Tang, L., Barton, L., and Chen, F.-H. (2005). Climate Change and Cultural Response Around 4000 Cal Yr B.P. In the Western Part of Chinese Loess Plateau. *Quat. Res.* 63 (3), 347–352. doi:10.1016/j.yqres.2005.02.004
- An, C. B., Feng, Z. D., and Tang, L. Y. (2010). Environmental Change and Cultural Response between 8000 and 4000 Cal Yr BP in the Western Loess Plateau, Northwest China. *J. Quat. Sci.* 19 (6), 529–535.
- An, C., Feng, Z., Tang, L., and Chen, F. (2003). Environmental Changes and Cultural Transition at 4 Cal. Ka BP in Central Gansu. *J. Geographical Sci.* 58 (5), 743–748. (In Chinese).
- An, J. P., Dong, W. B., Guo, R. Z., and Jin, G. Y. (2014). Analysis of Carbonized Plant Residues in the Tangye Site of Jinan, Shandong Province. *Nongyekaogu* 6, 7–21. (In Chinese).
- 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 (14), 5523–5528. doi:10.1073/pnas.0809960106
- Bureau of National Cultural Relics (2011b). *Atlas of Chinese Cultural Relics-Fascicule of Gansu Province*. Beijing: Surveying and Mapping Publishing House. (In Chinese).
- Bureau of National Cultural Relics (2013). *Atlas of Chinese Cultural Relics-Fascicule of Hebei Province*. Beijing: Cultural Relics Press. (In Chinese).
- Bureau of National Cultural Relics (1991). *Atlas of Chinese Cultural Relics-Fascicule of Henan Province*. Beijing: Sinomap press. (In Chinese).
- Bureau of National Cultural Relics (2003). *Atlas of Chinese Cultural Relics-Fascicule of Inner Mongolia Autonomous Region*. Xi'an: Xi'an Cartographic Publishing House. (In Chinese).
- Bureau of National Cultural Relics (2009). *Atlas of Chinese Cultural Relics-Fascicule of Liaoning Province*. Xi'an: Xi'an Cartographic Publishing House. (In Chinese).
- Bureau of National Cultural Relics (2010). *Atlas of Chinese Cultural Relics-Fascicule of Ningxia Hui Autonomous Region*. Beijing: Cultural Relics Press. (In Chinese).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, and further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

FUNDING

This work was funded by "Xiamen Key Laboratory of Ecological Building Construction" and "Promotion Program for Young and Middle-aged Teacher in Science and Technology Research of Huaqiao University (No. ZQN-PY310)".

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feart.2021.657179/full#supplementary-material>

- Bureau of National Cultural Relics (1996). *Atlas of Chinese Cultural Relics-Fascicule of Qinghai Province*. Beijing: Sinomap press. (In Chinese).
- Bureau of National Cultural Relics (2011a). *Atlas of Chinese Cultural Relics-Fascicule of Shandong Province*. Beijing: Surveying and Mapping Publishing House. (In Chinese).
- Bureau of National Cultural Relics (1998). *Atlas of Chinese Cultural Relics-Fascicule of Shaanxi Province*. Xi'an: Xi'an Cartographic Publishing House. (In Chinese).
- Bureau of National Cultural Relics (2006). *Atlas of Chinese Cultural Relics-Fascicule of Shanxi Province*. Beijing: Sinomap press. (In Chinese).
- Bureau of National Cultural Relics (2002). *Atlas of Chinese Cultural Relics-Fascicule of Tianjin*. Beijing: Encyclopedia of China Publishing House. (In Chinese).
- Cai, Y., Tan, L., Cheng, H., An, Z., Edwards, R. L., Kelly, M. J., et al. (2010). The Variation of Summer Monsoon Precipitation in central China since the Last Deglaciation. *Earth Planet. Sci. Lett.* 291 (1-4), 21–31. doi:10.1016/j.epsl.2009.12.039
- Chen, F. H., Dong, G. H., Zhang, D. J., Liu, X. Y., Jia, X., An, C. B., et al. (2015a). Agriculture Facilitated Permanent Human Occupation of the Tibetan Plateau after 3600 B.P. *Science* 347, 248–250. doi:10.1126/science.1259172
- Chen, F., Xu, Q., Chen, J., Birks, H., Liu, J., Zhang, S., et al. (2015b). East Asian Summer Monsoon Precipitation Variability since the Last Deglaciation. *Scientific Rep.* 5, 11186. doi:10.1038/srep11186
- Chen, W. W., Zhang, J. Z., and Cai, Q. F. (2012). Analysis of Carbonized Plant Residues in the Guchengzhai City Site in Xinmi, Henan Province. *Huaxiakaoqu* 1, 54–62. (In Chinese).
- Cui, Y., Liu, Y., and Ma, M. (2018). Spatiotemporal Evolution of Prehistoric Neolithic-Bronze Age Settlements and Influencing Factors in the Guanting Basin, Northeast Tibetan Plateau. *Sci. China Earth Sci.* 61 (02), 31–44. doi:10.1007/s11430-017-9138-8
- Demenocal, P. B. (2001). Cultural Responses to Climate Change during the Late Holocene. *Science* 292, 667–673. doi:10.1126/science.1059827
- Deng, Z., and Gao, Y. (2012). Analysis of Plant Remains Unearthed from Baligang Site in Dengzhou. *Henan Province* 1, 156–163. (In Chinese).

- Diamond, J., and Bellwood, P. (2003). Farmers and Their Languages: the First Expansions. *Science* 300 (5619), 597–603. doi:10.1126/science.1078208
- Dodson, J. R., Li, X., Zhou, X., Zhao, K., Sun, N., and Atahan, P. (2013). Origin and Spread of Wheat in China. *Quat. Sci. Rev.* 72 (2), 108–111. doi:10.1016/j.quascirev.2013.04.021
- Dong, G., Jia, X., An, C., Chen, F., Zhao, Y., Tao, S., et al. (2012). Mid-holocene Climate Change and its Effect on Prehistoric Cultural Evolution in Eastern Qinghai Province, China. *Quat. Res.* 77 (1), 23–30. doi:10.1016/j.yqres.2011.10.004
- Dong, G., Jia, X., Elston, R., Chen, F., Li, S., Wang, L., et al. (2013). Spatial and Temporal Variety of Prehistoric Human Settlement and its Influencing Factors in the Upper Yellow River valley, Qinghai Province, China. *J. Archaeological Sci.* 40 (5), 2538–2546. doi:10.1016/j.jas.2012.10.002
- Dong, G., Liu, F., Yang, Y., Wang, L., and Chen, F. (2016a). Cultural Expansion and its Influencing Factors during Neolithic Period in the Yellow River valley, Northern China. *Chin. J. Nat.* 38 (4), 248–252. (In Chinese).
- Dong, G., Yang, Y., Han, J., Wang, H., and Chen, F. (2017). Eastern and Western Cultural Exchange from the Perspective of Crops. *Sci. China Earth Sci.* 47 (5), 530–543. (In Chinese).
- Dong, G., Zhang, S., Yang, Y., Chen, J., and Chen, F. (2016b). Agricultural Intensification and its Impact on Environment during Neolithic Age in Northern China. *Chin. Sci. Bull.* 61, 2913–2925. (In Chinese). doi:10.1360/n972016-00547
- Drennan, R., Peterson, C., Lv, X., Zhu, D., and Hou, S. (2014). Settlement and Social Dynamics in the Upper Daling and Chifeng Regions of Northeast China. *Asian Archaeology* 2, 50–76.
- Drennan, R., and Uribe, C. (1987). Chiefdoms in the Americas. *Am. Indian Q.* 13 (1).
- Duan, K., Yao, T., Wang, N., Xu, B., and Thompson, L. (2012). The Unstable Holocene Climatic Change Recorded in an Ice Core from the central Tibetan Plateau. *Sci. China Earth Sci.* 42, 1441–1449. (In Chinese).
- Han, J. (2015). Early China: The Making of the Chinese Cultural Sphere. Shanghai: Shanghai Classics Publishing House, 282. (In Chinese).
- Jaffe, Y., Castellano, L., Shelach-Lavi, G., and Campbell, R. (2020). Mismatches of Scale in the Application of Paleoclimatic Research to Chinese Archaeology[J]. *Quat. Res.* 99, 1–20. doi:10.1017/qua.2020.60
- Kennett, D. J., Breitenbach, S. F. M., Aquino, V. V., Asmerom, Y., Awe, J., Baldini, J. U. L., et al. (2012). Development and Disintegration of Maya Political Systems in Response to Climate Change. *Science* 338 (6108), 788–791. doi:10.1126/science.1226299
- Lee, G.-A., Crawford, G. W., Liu, L., and Chen, X. (2007). Plants and People from the Early Neolithic to Shang Periods in north china. *Pnas* 104 (3), 1087–1092. doi:10.1073/pnas.0609763104
- Li, H., Liu, F., Cui, Y., Ren, L., Storozum, M. J., Qin, Z., et al. (2017). Human Settlement and its Influencing Factors during the Historical Period in an Oasis-Desert Transition Zone of Dunhuang, Hexi Corridor, Northwest china. *Quat. Int.* 458 (6), 113–122. doi:10.1016/j.quaint.2016.11.044
- Liu, L., Chen, X., Wright, H., Xu, H., Li, Y., Chen, G., et al. (2019). Rise and Fall of Complex Societies in the Yiluo Region, North China: The Spatial and Temporal Changes. *Quat. Int.* 521, 4–15. doi:10.1016/j.quaint.2019.05.025
- Liu, L. (2007). *China's Neolithic Age - the Road to the Early Country*. Beijing: Cultural relics publishing house. (In Chinese).
- Liu, X., Lightfoot, E., O'Connell, T. C., Wang, H., Li, S., Zhou, L., et al. (2014). From Necessity to Choice: Dietary Revolutions in West China in the Second Millennium BC. *World Archaeology* 46 (5), 661–680. doi:10.1080/00438243.2014.953706
- Lu, H., Zhang, J., Liu, K.-b., Wu, N., Li, Y., Zhou, K., et al. (2009). Earliest Domestication of Common Millet (panicum Miliaceum) in East Asia Extended to 10,000 Years Ago. *Proc. Natl. Acad. Sci.* 106 (18), 7367–7372. doi:10.1073/pnas.0900158106
- Ma, M., Dong, G., Jia, X., Wang, H., Cui, Y., and Chen, F. (2016). Dietary Shift after 3600 Cal Yr BP and its Influencing Factors in Northwestern china: Evidence from Stable Isotopes. *Quat. Sci. Rev.* 145, 57–70. doi:10.1016/j.quascirev.2016.05.041
- Ma, M., Dong, G., Jia, X., and Zhang, Z. (2012). Analysis on the Settlement Pattern and its Influencing Factors of Neolithic-Bronze Age in Hualong County, Qinghai Province. *Quat. Res.* 32, 209–218. (In Chinese).
- Ma, M. M., Dong, G. H., Lightfoot, E., Wang, H., Liu, X. Y., Jia, X., et al. (2014). Stable Isotope Analysis of Human and Faunal Remains in the Western Loess Plateau, Approximately 2000 Calbc. *Archaeometry* 56, 237–255. doi:10.1111/arcm.12071
- Marcott, S. A., Shakun, J. D., Clark, P. U., and Mix, A. C. (2013). A Reconstruction of Regional and Global Temperature for the Past 11,300 Years. *Science* 339 (6124), 1198–1201. doi:10.1126/science.1228026
- Medina-Elizalde, M., and Rohling, E. J. (2012). Collapse of Classic Maya Civilization Related to Modest Reduction in Precipitation. *Science* 335, 956–959. doi:10.1126/science.1216629
- Mei, N., and Kong, F. (2008). *Atlas of Chinese Cultural Relics-Fascicule of Beijing*. Beijing: Science Press. (In Chinese).
- Miller, A., Usmanova, E., Logvin, V., Kalieva, S., Shevnina, I., Logvin, A., et al. (2014). Subsistence and Social Change in central Eurasia: Stable Isotope Analysis of Populations Spanning the Bronze Age Transition. *J. Archaeological Sci.* 42 (1), 525–538.
- Qian, Y. (2001). *Research on Prehistoric City Sites and Civilization Origins in China*. Xi'an: Northwest University Press. (In Chinese).
- Silverman, B. W. (1986). *Density Estimation for Statistics and Data Analysis*. New York: Chapman & Hall. doi:10.1007/978-1-4899-3324-9
- Spengler, R., Frachetti, M., Doumani, P., Rouse, L., Cerasetti, B., Bullion, E., et al. (2014). Early Agriculture and Crop Transmission Among Bronze Age mobile Pastoralists of central Eurasia. *Proc. R. Soc. B.* 281 (1783), 20133382. doi:10.1098/rspb.2013.3382
- Sun, Z., Shao, J., and Di, N. (2020). New Archaeological Discoveries of Huangchengtai Location of Shimao Site in 2016-2019. *Kaoguyuwenwu* 04, 3–11.
- Wei, P., Kong, Z., and Liu, C. (2000). "Large in Size and a High Degree of Government Administration" Should Not Be the Direction of Higher Educational Reform (Part II). *Chin. Education Soc.* 33, 77–83. (In Chinese). doi:10.2753/ced1061-1932330177
- Weiss, H., Courty, M.-A., Wetterstrom, W., Guichard, F., Senior, L., Meadow, R., et al. (1993). The Genesis and Collapse of Third Millennium north Mesopotamian Civilization. *Science* 261 (5124), 995–1004. doi:10.1126/science.261.5124.995
- Wu, W., Zhang, J., and Jin, G. (2014). Archaeobotanical Evidence from Erlitou to Han Dynasty in Nanwa Site, Dengfeng, Henan Province. *Zhongyuanwenwu* 1, 109–117. (In Chinese).
- Yang, Q., and Li, X. (2015). Carbon Isotope Characteristics of Millets in the Loess Plateau and its Influencing Factors. *Org. Geochem.* 11, 1683–1697. (In Chinese).
- Yang, X., Wan, Z., Perry, L., Lu, H., Wang, Q., Zhao, C., et al. (2012). Early Millet Use in Northern china. *Proc. Natl. Acad. Sci.* 109 (10), 3726–3730. doi:10.1073/pnas.1115430109
- Yang, Y., Yuan, Z., Zhang, J., Chen, Z., Jian, L., and Fang, F. (2017). Agricultural Characteristics and Development Process of Carboniferous Plant Remains in Zhengzhou Dongzhao Site during Xia and Shang Period. *J. Anthropol.* 36 (1), 119–130. (In Chinese).
- Zhao, Z. (2011). New Archaeobotanical Data for the Study of the Origins of Agriculture in china. *Curr. Anthropol.* 52 (S4), S295–S306. doi:10.1086/659308
- Zhao, Z. (2014). The Formation Process of Ancient Chinese Agriculture- Evidence of Surviving Plants in Flotation. *Quat. Res.* 34 (1), 73–84. (In Chinese).
- Zhong, H., Yang, Y., Shao, J., and Zhao, Z. (2015). Study on the Remains of Carbonized Plants in Xinjie Site, Lantian County, Shaanxi Province. *Nanfangwenwu* 3, 36–43. (In Chinese).
- Zhou, A., Sun, H., Chen, F., Zhao, Y., An, C., Dong, G., et al. (2010). High-resolution Climate Change in Mid-late Holocene on Tianchi lake, Liupan Mountain in the Loess Plateau in central china and its Significance. *Chin. Sci. Bull.* 55 (20), 2118–2121. doi:10.1007/s11434-010-3226-0

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2021 Wang and Cui. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.