SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 7, No. 3, (2021), pp. 105-116
Open Access. Online & Print

DOI: 10.5281/zenodo.4916520

SPATIAL VARIABILITY OF HUMAN SUBSISTENCE STRATEGIES DURING THE LONGSHAN PERIOD (~4.6-~3.9 KA BP) AND ITS POSSIBLE PHYSICAL ENVIRONMENTAL CONTEXTS IN THE YELLOW-HUAI RIVER AREA, EAST CHINA

Kaifeng Li[1,2], Panpan Gong[1], Hainan Hu[1], Wenyan Jia[1], Xiaoli Liu[1] and Wenhua Gao[1*]

[1]College of Geography and Environmental Science, National Demonstration Center for Environment and Planning, Henan University, Kaifeng, 475004, China
[2]Cultural Heritage Laboratory of the Yellow River, Henan University, Kaifeng 475001, China

Received: 15/07/2021
Accepted: 03/08/2021
Corresponding author: Wenhua Gao (gaowenhua@henu.edu.cn)

ABSTRACT

Remarkable spatial differentiation of human subsistence strategies existed during the Longshan period (~4.6-~3.9 ka BP) in the Yellow-Huai River Area; however, its external driving factors remain unclear due to the poor understanding of local physical environmental settings. In this study, we first compiled the information on spatial variabilities of physical environmental conditions and human subsistence strategies during the Longshan period within and around the Yellow-Huai River Area, then compared the relationships between local environmental conditions and human subsistence strategies. The results show that the mixed millet-rice farming mode was widespread during the Longshan period in the study area, but exhibiting lower (higher) proportion of rice (millet) in the circumjacent highlands than in the lowlands. In the circumjacent highlands, the persistent East Asian summer monsoon weakening during the Longshan period caused obvious water supply reduction due to the decline of monsoon-related precipitation and the shrinkage of pre-existing surface water. Consequently, prehistoric humans likely preferred to plant more less-water-requirement crops (i.e., millet) to adapt to the drier environmental conditions, resulting in the decreasing proportion of rice in human cropping structure. Whereas, although regional precipitation decline also occurred during the Longshan period in the lowlands of the study area, many regional rivers running from surrounding highlands flowed into the lowlands for their saucer-shaped topography. Subsequently, the lakes and marshes were still wide development in the lowlands, thus, there was a sufficient and steady water supply for rice farming, causing higher proportion of rice in human cropping structure during the Longshan period in the lowlands of the Yellow-Huai River Area.

KEYWORDS: Human subsistence strategies, Physical environmental contexts, Spatial variability, The Longshan period, The Yellow-Huai River Area

1. INTRODUCTION

Climate fluctuations and associated environmental changes have been repeatedly suggested to be important driving forces behind the rises and falls of prehistoric societies (e.g., Weiss et al., 1993; Binford et al., 1997; Cullen et al., 2000; Wu and Liu, 2004; Anderson et al., 2007; Buckley et al., 2010; Liu and Feng, 2010; Li, et al., 2014; Lespez et al., 2016; Liritzis et al., 2019; Shqiarat, 2019; Qin, 2021). However, archaeological research has presented that prehistoric societies are fairly resilient and flexible to changing climatic and environmental regimes by using a diverse set of coping strategies in response (Turney et al., 2006; Manning and Timpson, 2014; Liu et al., 2019; Dong et al., 2020; Li and Gao, 2021; Ren et al., 2021). Consequently, the interactions between prehistoric human societies and their surroundings are much more complex (Butzer, 2012; Dugmore et al., 2012; Dong et al., 2020; Jaffe et al., 2021; Ren et al., 2021). Subsistence strategy is one of key human factors that is sensitive to climatic and environmental variations and also could affect the spread and development of prehistoric societies (Jones, 2007; Zhao, 2014; Chen et al., 2015; Zhang et al., 2018a; Yuan, 2019; Hu et al., 2021; Portillo et al., 2021), thus, understanding the subsistence strategy and its adaptation to the environmental condition during prehistoric period is vital to reveal the patterns and mechanisms of human-environment interactions (e.g., Kay and Kaplan, 2015; Jin et al., 2016; Rendu et al., 2019; Yuan, 2019; Yuan et al., 2020; Li et al., 2020; Hu et al., 2021; Portillo et al., 2021; Yang et al., 2021).

The Longshan period from ~4.6 to ~3.9 ka BP is a crucial time of rapid change on subsistence economy characterized by diversified and intensified food production technologies in agriculture (Zhao, 2014; Yuan, 2019; Yuan et al., 2020; Chen, 2021). Previous studies show that the millet-based and rice-based agricultures are respectively distributed in the Yellow River and Yangtze River basins (Yang et al., 2016; He et al., 2017; Yuan, 2019; Li et al., 2020). In particular, a unique agricultural style of mixed millet-rice mode is widely distributed in the Yellow-Huai River Area (YHRA) (Yang et al., 2016; He et al. 2017; Wang et al., 2018; Li et al., 2020). However, remarkable spatial variability in exact proportion of rice (millet) in human cropping structure existed during the Longshan period in the YHRA, exhibiting lower (higher) proportion of rice (millet) in the circumjacent highlands than in the lowlands (Yang et al., 2016; Li, 2017; Liao et al., 2019; Yuan, 2019). Although regional differences in the physical environment conditions have been proposed to be an important external driving factor (Yang et al., 2016; Li, 2017; Liao et al., 2019; Chen, 2021), the question of how spatial differentiation of environmental conditions could have affected the human subsistence strategies remains unclear due to the poor understanding of the spatial variation in local physical environmental settings (Yang et al., 2016; Jiang et al., 2018; Wu et al., 2019). In past three decades, a great stride on the spatial-temporal patterns of Holocene paleoenvironmental changes, especially on high-resolution proxy sequences of paleoclimate, has been made within and around the YHRA (Jin, 1990; Ma et al., 2006; Hu et al., 2008; Chen et al., 2009; Dong et al., 2018; Zhang et al., 2018b; Li and Gao, 2019; Wang et al., 2019; Chen et al., 2021; Shu et al., 2021). This provides a good opportunity for exploring the specific environmental background for abovementioned remarkable spatial variations of human subsistence strategies during the Longshan period in the YHRA.

In this study, by reviewing ten available Holocene paleoclimatic and paleoenvironmental records within and around the YHRA (Figure 1a, No. 1-10), we first delineated the regional variations in East Asian summer monsoon (EASM) and monsoon-related precipitation/moisture and identified the spatial variations in local environmental conditions during the Longshan period. Then, we collected and analyzed archaeobotanical data from eight selected archaeological sites with detailed floatation results (Figure 1b, No. 11-18) and portrayed the spatial variability in human subsistence strategies during the Longshan period within the study area. At last, the relationships between human subsistence strategies and local environmental conditions are compared and examined.

2. REGIONAL SETTINGS

The YHRA referred in this study is situated in the bordering area between the lower Yellow River and the Huai River, roughly including modern eastern Henan Province, south-western and southern Shandong Province, northern Jiangsu Province and northern Anhui Province (Figure 1a). Topographically, the pre-existing terrain of the YHRA is a saucer-shaped basin before the Quaternary (Jin, 1990; Zhao, 1986; Guo et al., 2008) and is surrounded by mountains and highlands on the northeast, southwest and west (Figure 1a). Consequently, many rivers (especially the Yellow River and the Huai River) running from surrounding highlands had flowed into this saucer-shaped basin, resulting in widespread distribution of a large number of lakes and marshes in the YHRA throughout most time of Quaternary (Jin, 1990; Zou, 1993; Guo et al., 2008; Yu, 2016). However, the locations and sizes of these lakes and marshes changed dramatically during the late Holocene due to the influences of climatic fluctuation, river flooding and intensive agriculture activities (Zou, 1993; Liu, 2004; Guo et al., 2008; Yu, 2016). As a result, today most of these lakes and marshes are filled with silt and have disappeared from the landscape in the YHRA (Figure 1b).

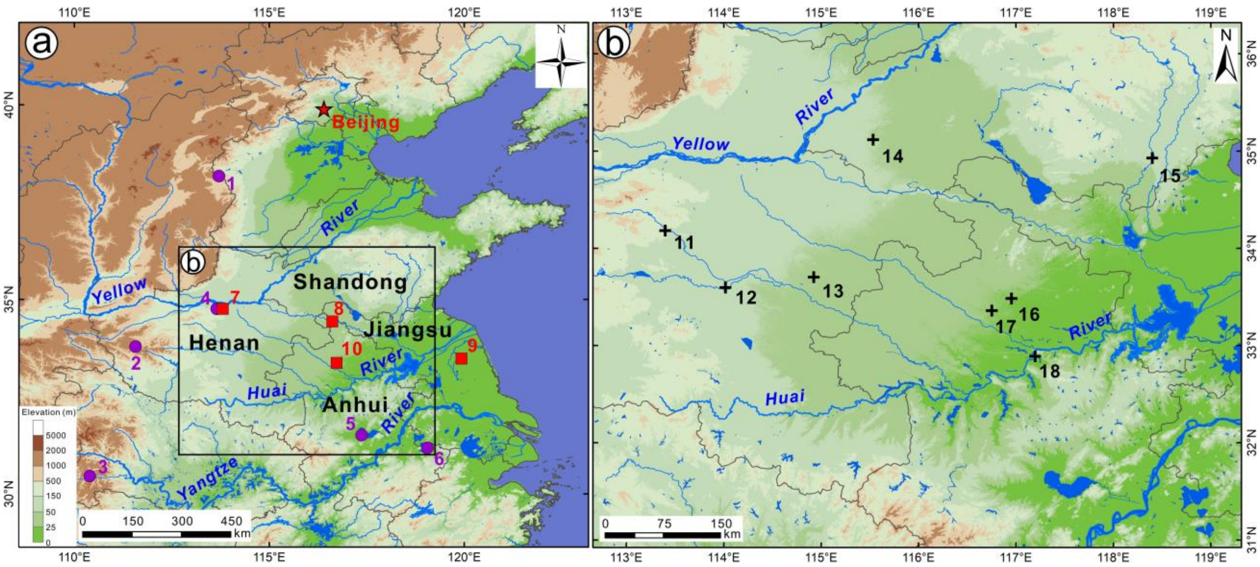

Figure 1. Study area. (a) A large-scale geographic context of the YHRA and the surrounding areas. The labeled are Holocene paleoclimatic (purple circles, No. 1-6) and paleoenvironmental (red boxes, No. 7-10) record sites mentioned in the text. And they are as follows: 1. Lianhua Cave (Dong et al., 2018), 2. Dongshiya Cave (Zhang et al., 2018b), 3. Heshang Cave (Hu et al., 2008), 4. Zheng City (Li and Gao, 2019), 5. Chaohu Lake (Chen et al., 2009), 6. Nanyi Lake (Chen et al., 2021), 7. Putian strata (Wang et al., 2019), 8. Huangkou strata (Jin, 1990), 9. Gangxi strata (Shu et al., 2021), 10. Yushici strata (Ma et al., 2006). (b) Topographic backgrounds of the YHRA and the surrounding areas, and the locations of eight selected archaeological sites (dark crosses) with detailed floatation results within the study area, and they include: 11. Wadian site (Liu et al., 2018), 12. Haojiatai site (Deng et al., 2021), 13. Pingliangtai site (Zhao et al., 2019), 14. Shilipubei site (Guo et al., 2019), 15. Dongpan site (Wang et al., 2011), 16. Luchengzi site (ARICRA et al., 2016), 17. Yuchisi site (IACASS and CBMC, 2007), 18. Yuhuicun site (IACASS and BMM, 2013).

Climatologically, the YHRA and the surrounding areas are situated in the transition between the relatively wet-warm southern China and the relatively dry-cool northern China; the East Asian monsoon system dominates this area with significance seasonal variations in temperature and precipitation (Zhao, 1986; Wang and Li, 2007). The temperature is low in winter (-1.5-0°C, January) and high in summer (27-28°C, July) with mean annual temperature between ~11°C and ~15°C; the mean annual precipitation ranges from ~700 to ~1100 mm with most rainfall occurring during the summer. Thus, the abundant rainfall is synchronous with high temperature in summer. This physical environmental condition is suitable for agricultural development. Archaeobotanical research shows that the mixed millet-rice farming mode has already appeared within and around the YHRA since the late Peiligang period (7.9-7.0 ka BP) and lasted until the Bronze Age (Zhang et al., 2012; Yang et al., 2016; Wang et al., 2018; Yuan, 2019). Furthermore, throughout the Holocene, the East Asian Monsoon has experienced complex fluctuations in the YHRA and the surrounding areas (Chen et al., 2009; Jiang et al., 2018; Li and Gao, 2019; Wu et al., 2019; Chen et al., 2021; Shu et al., 2021), its fluctuations and associated environment changes likely have impacted local prehistoric human activities (Liu, 2004; Wang et al., 2016; Wu et al., 2019; Yuan, 2019; Xu, 2020; Chen, 2021; Li and Gao, 2021).

Due to the fertile soil and water accessibility, the YHRA and the surrounding areas have been believed to be an important birthplace of Chinese civilization (Liu and Chen, 2012; Underhill, 2013). Continuing archaeological discoveries in the past decades have shown that it is a core area for cultural exchange and integration between northern and southern China during the Neolithic period (Xu, 2020). As a result, local Neolithic farming mode presents a unique mixed framing mode of millet from northern China and rice from southern China (Yang et al., 2016; He et al., 2017; Li et al., 2020; Xu, 2020). Moreover, the spatial pattern of this mixed millet-rice farming mode also exhibits obviously change in different stages of the Neolithic period (Yang et al., 2016; Yuan, 2019; Chen, 2021).

3. RESULTS

3.1. *Spatial variability of physical environmental conditions during the Longshan period in the YHRA*

3.1.1. The EASM and related moisture variations

To explore the spatial variations in local environmental conditions in the YHRA, the regional climatic change during the Longshan period should be examined first. Here we reviewed six high-resolution proxy sequences with reliable chronologies and well-accepted validities of the proxy-climate relationships within and around the YHRA (Figure 1a, No. 1-6). They include three stalagmite δ[18]O sequences from Lianhua Cave (Dong et al., 2018), Dongshiya Cave (Zhang et al., 2018b) and Heshang Cave (Hu et al., 2008), one reconstructed moisture sequence in Zhengzhou City (Li and Gao, 2019), and two pollen sequences from Chaohu Lake (Chen et al., 2009) and Nanyi Lake (Chen et al., 2021).

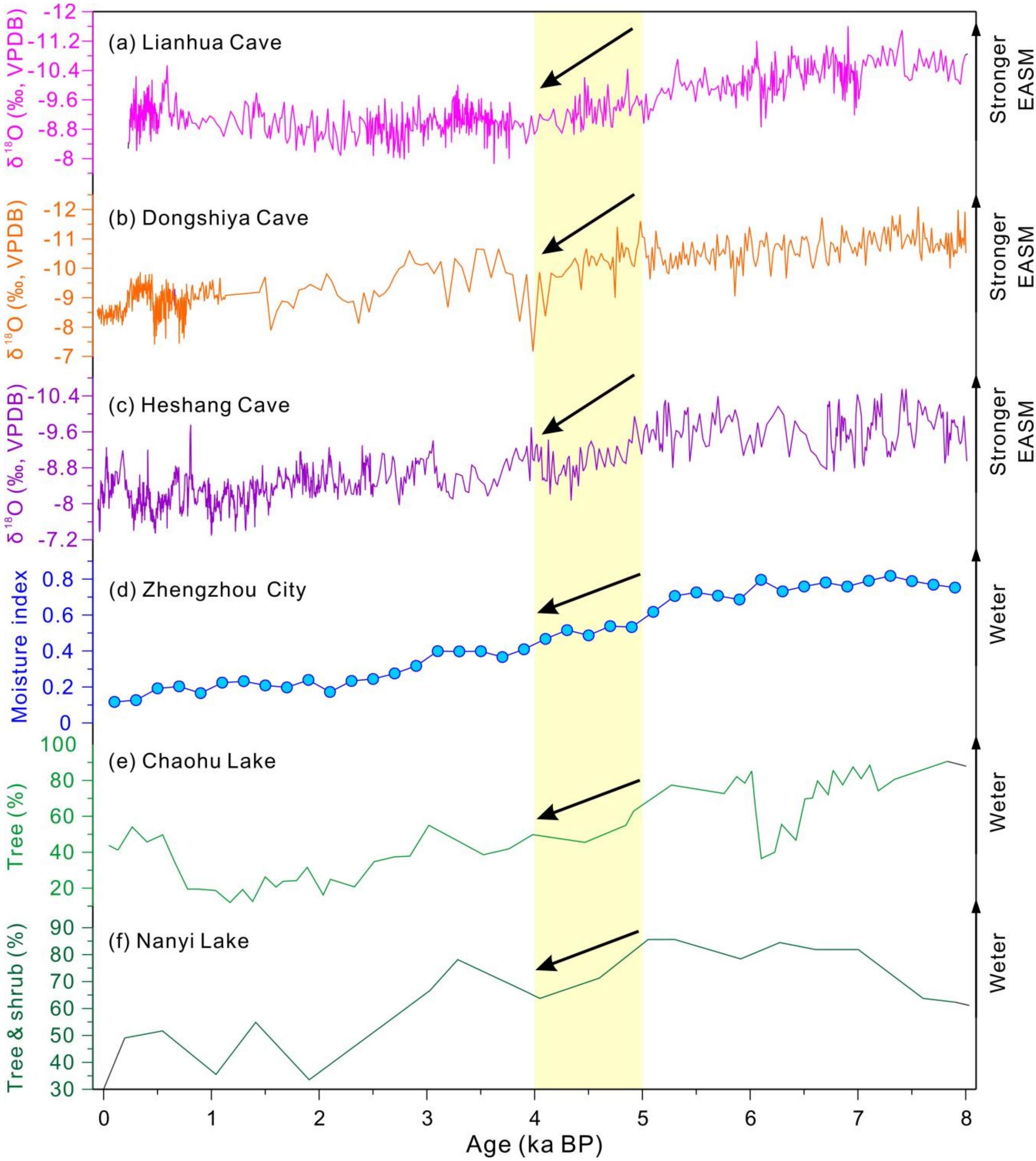

Figure 2. Proxy sequences of climatic changes within and around the YHRA in the past 8000 years. The yellow band indicates the declining interval of the EASM and monsoon-related moisture or arboreal pollen proportion from ~5.0 to ~4.0 ka BP. (a) δ[18]O sequence at Lianhua Cave (Dong et al., 2018); (b) δ[18]O sequence at Dongshiya Cave (Zhang et al., 2018b); (c) δ[18]O sequence at Heshang Cave (Hu et al., 2008); (d) reconstructed moisture index in Zhengzhou City (Li and Gao, 2019); (e) tree pollen proportion in Chaohu Lake (Chen et al., 2009); (f) tree and shrub pollen proportion in Nanyi Lake (Chen et al., 2021).

The selected stalagmite $\delta^{18}O$ curve at Lianhua Cave indicates that the EASM was intense between ~8.0 and ~5.0 ka BP, then it had weakened between ~5.0 and ~4.0 ka BP (Figure 2a). The similar trend of the EASM variations is unanimously documented from other two selected stalagmite $\delta^{18}O$ curves at Dongshiya Cave (Figure 2b) and Heshang Cave (Figure 2c). As a result, the regional moisture and vegetation present nearly synchronous variations with the EASM. The reconstructed moisture curve in Zhengzhou City distinctly shows that the time interval from ~8.0 to ~5.0 ka BP is wet following with a time interval of decreasing trend in local moisture from ~5.0 to ~4.0 ka BP (Figure 2d). At the Chaohu Lake, although there is an obvious dry interval centered at ~6.0 ka BP, a pollen-suggested wet period and a subsequent drying period exist during the timespans from ~8.0 to ~5.0 ka BP and from ~5.0 to ~4.0 ka BP, respectively (Figure 2e). The last record reviewed is from Nanyi Lake, and it presents a similar trend of climate change with Chaohu Lake between ~8.0 and ~4.0 ka BP (Figure 2f).

In brief, the reviewed six proxy sequences unanimously propose that the climate at regional scale within and around the YHRA has experienced remarkable changes of the EASM and monsoon-related moisture or vegetation, presenting a wet period from ~8.0 to ~5.0 ka BP and a subsequent increasingly drying period from ~5.0 to ~4.0 ka BP.

3.1.2. Spatial differentiation in local environmental conditions

To further uncover the spatial differentiation in local environmental conditions during the Longshan period, four stratigraphic profiles recording local paleoenvironmental evolution with relatively good age controls were selected within the YHRA (Figure 1a, No. 7-10). They include a lacustrine-swamp strata at Putian, a lacustrine-fluvial strata at Huangkou, a lacustrine-marine strata at Gangxi, and an archaeological sequence at Yuchisi.

Stratigraphically, the Putian profile features a noticeable lacustrine-swamp layer at depths from ~13.8 to ~6.4 m (Figure 3, No. 7), suggesting that the area around Putian experienced a development period of lake and marsh between ~7.0 and ~3.1 ka BP (Wang et al., 2019). Similarly, the Huangkou profile (Figure 3, No. 8) also records obvious lacustrine and lacustrine-fluvial development periods from the early Holocene at ~12.0 ka BP to the late Holocene at ~2.5 ka BP (Jin, 1990). However, the sedimentary environment at Gangxi (Figure 3, No. 9) in southeastern margin of the study area clearly presents three evolutional stages: a lacustrine development stage during ~13-~7.25 ka BP, a marine development stage during ~7.25-~6.45 ka BP and again a lacustrine development stage after 6.45 ka BP (Shu et al., 2021). As a whole, the selected three stratigraphic profiles obviously exhibit an earlier starting time and a later ending time of the lacustrine-swamp development period from the northwestern margin to the southeastern margin within the YHRA. In addition, the Yuchisi strata records two different stages in local climate variations: a wet stage before ~5000 a BP and a subsequent drying stage between ~5000 and ~4000 a BP (Figure 3, No. 10).

To sum up, the local paleoenvironmental records assuredly support that there was a lasting-drying trend of local paleoclimate during the Longshan period in the YHRA, but there is a noticeable spatial differentiation in local environmental conditions, namely, the durations of lacustrine-swamp development are longer in the low-lying regions than in the circumjacent highlands within the study area.

3.2. *Spatial variability of human cropping structures during the Longshan period in the YHRA*

As aforementioned, to compare the spatial changes in human cropping structures during the Longshan period in the study area, eight archaeological sites with detailed floatation results were selected (Table 1). They include Wadian site, Haojiatai site and Pinglinagtai site in the western part of study area, Shilipubei site and Dongpan site in the northern part of study area, and Luchengzi site, Yuchisi site and Yuhuicun site in the center of study area (Figure 1b).

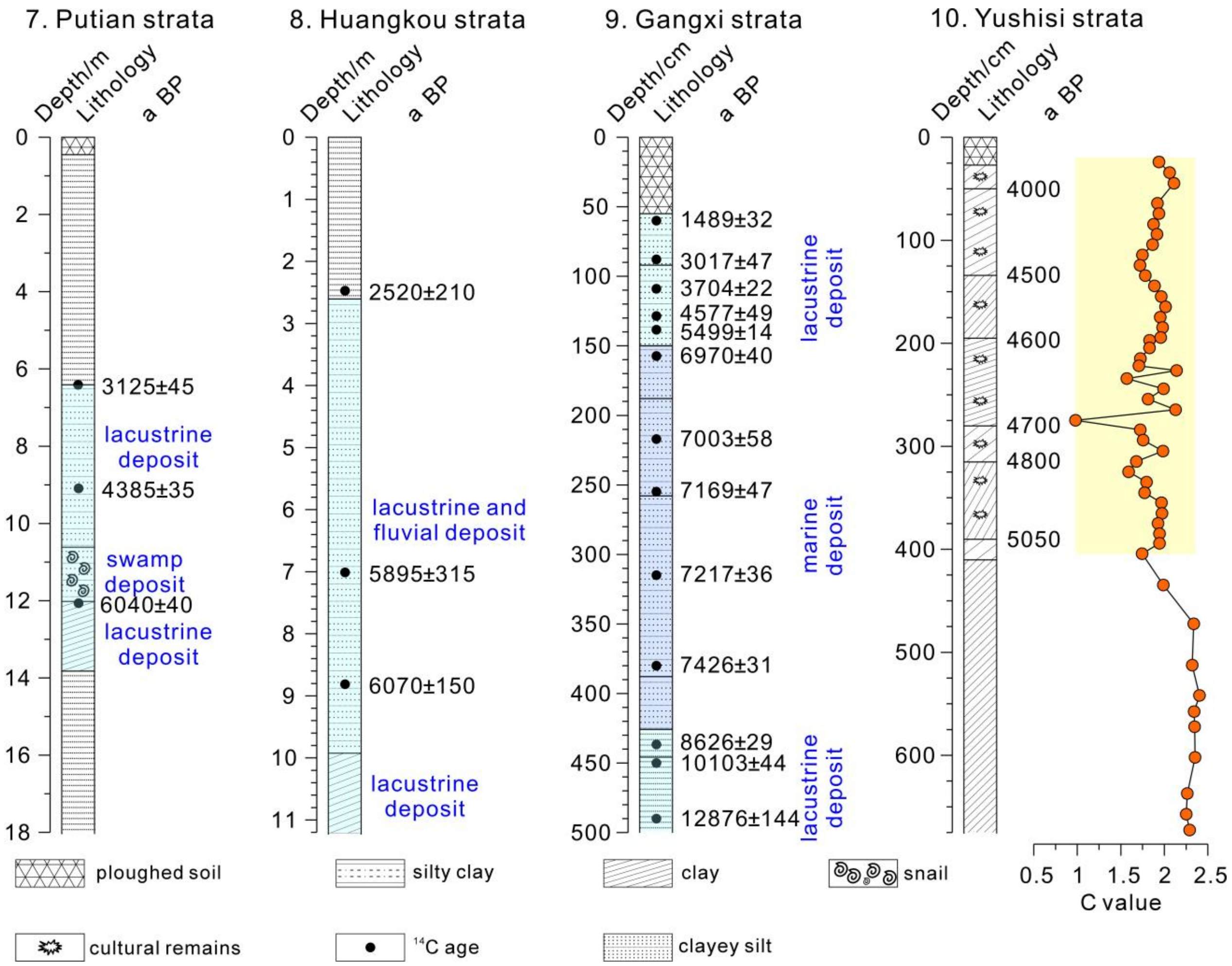

Figure 3. Local stratigraphic profiles of paleoenvironmental evolutions in the YHRA. They include: (7) Putian strata (Wang et al., 2019); (8) Huangkou strata (Jin, 1990); (9) Gangxi strata (Shu et al., 2021); (10) Yuchisi strata (Ma et al., 2006). The yellow band marks the climatic drying trend between ~5000 and ~4000 a BP by the C value (a chemical weathering index to indicate climatic variation) in the area around Yuchisi.

Table 1. The counted results of plant remains from eight selected archaeological sites in the YHRA

No.	Site name	Foxtail millet	Broomcorn millet	Rice	Wheat	Soybean	Wild plants
11	Wadian	5253	1110	1366	22	905	3099
12	Haojiatai	8509	918	59	1	130	2662
13	Pingliangtai	2876	310	2	2	80	1114
14	Shilipubei	1566	327	423	13	197	1290
15	Dongpan	37	6	359	6	0	518
16	Luchengzi	49	5	190	0	0	176
17	Yuchisi	57	5	70	0	0	6
18	Yuhuicun	2	0	33	2	18	513

Table 1 lists the detailed information of floatation results on plant remains in abovementioned eight archaeological sites. It clearly presents that sedentary agriculture is the dominant subsistence economy in seven of the eight selected archaeological sites. The exception is Yuhuicun (a sacrificial site), the possible reason for lower proportion of crop plants in floatation results is related with its function (IACASS and BMM, 2013). It also shows that the prehistoric agriculture is a mixed millet-rice farming mode during the Longshan period in the YHRA. Although there are five main types of crops, namely, foxtail millet (*Setaria italica*), broomcorn millet (*Panicum miliaceum*), rice (*Oryza sativa*), wheat (*Triticum aestivum*) and soybean (*Glycine max*), foxtail millet, broomcorn millet and rice are the dominating types of crops (Table 1). Moreover, there were obviously differences in cropping structures of these archaeological sites. Foxtail millet was the most common grain in first four archaeological sites (Table 1, No. 11-14); whereas, rice ranked first among all corps in last four archaeological sites (Table 1, No. 15-18).

Here, a special note is made to further highlight the spatial variability in cropping structures of eight selected archaeological sites. Figure 4 shows spatial distribution of cropping structures during the Longshan period in the study area. The proportions of millet (including foxtail millet and broomcorn millet) are dominant in cropping structures at archaeological sites of Wadian, Haojiatai, Pingliangtai and Shilipubei with elevation roughly higher than ~30 m (Figure 4), while the rice are dominant at archaeological sites of Dongpan, Luchengzi, Yuchisi and Yuhuicun with elevation roughly lower than ~30 m (except Dongpan site). In other words, roughly there are lower (higher) proportion of rice (millet) in the circumjacent highlands than in the lowlands during the Longshan period in the YHRA (Figure 4).

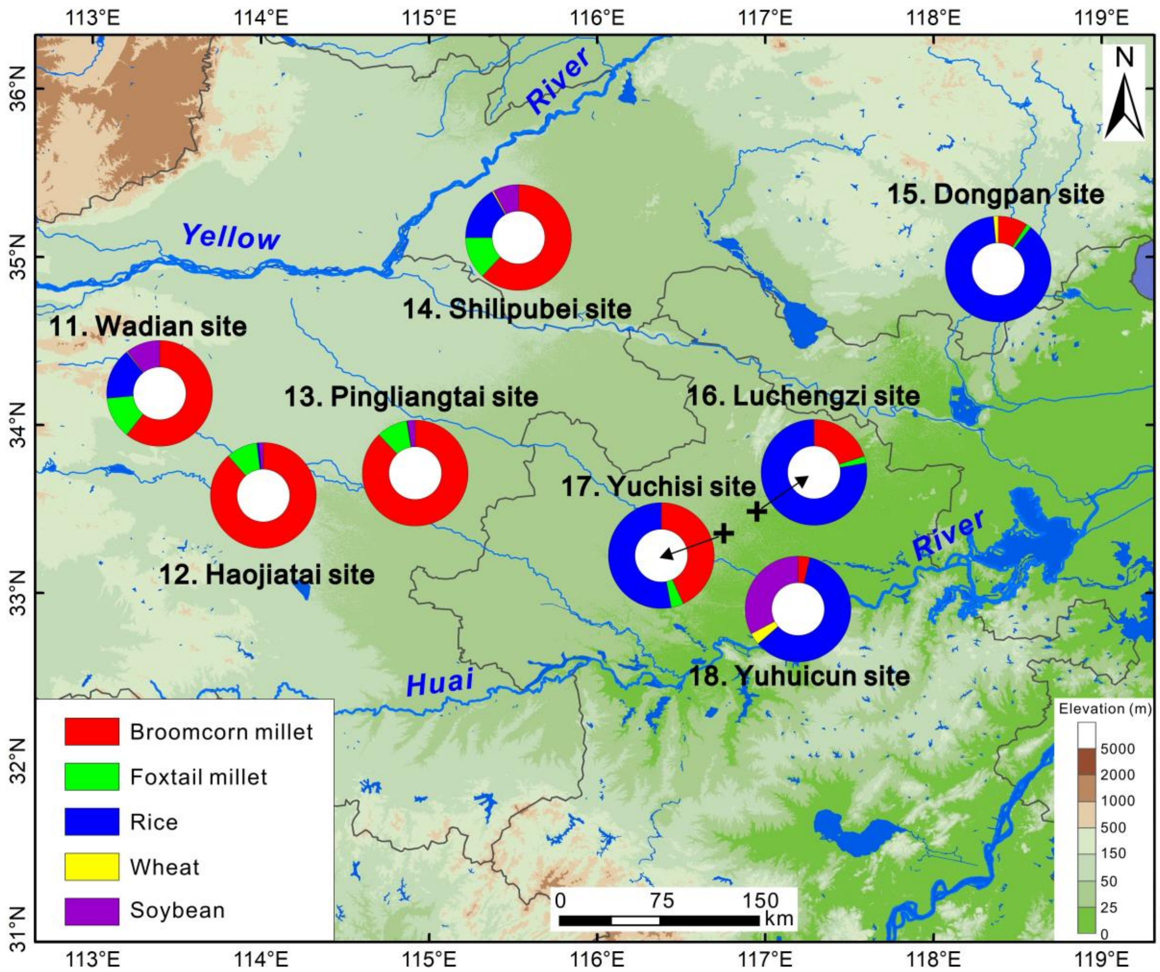

Figure 4. Spatial distribution of cropping structures during the Longshan period in the YHRA

4. DISCUSSION

4.1. *Spatial differentiation in local physical environmental conditions*

As stated earlier, the six high-resolution regional paleoclimatic records clearly present that a strong EASM and associated humid climate existed from ~8.0 to ~5.0 ka BP and a subsequent increasingly drying climate occurred from ~5.0 to ~4.0 ka BP due to the weakening EASM (Figure 2). Such regional climate variations are demonstrated by the local paleoenvironmental record at Yuchisi (Figure 3, No. 10). As a consequence, high precipitation caused widespread development of lakes and marshes during 8.0-5.0 ka BP in the low-lying regions of the YHRA (Jin, 1990; Chen, 2007; Guo et al., 2008; Wang et al., 2019; Shu et al., 2021). Besides, the surrounding piedmont plains and loess tablelands around the YHRA were also dotted sporadically with a large number of lakes and marshes (Li et al., 2015; Yu, 2016; Lu et al., 2021). This has been supported by the wide distribution of many early- and mid-Holocene limnetic facies in and around the YHRA (Guo et al., 2008; Yu, 2016; Li et al., 2019; Lu et al., 2021).

However, with the persistent weakening of the EASM and related precipitation declining since ~5.0 ka BP, the shrinkage of preexisting surface water was likely first occurred in the surrounding highlands and then in the low-lying regions of the YHRA. Two recent studies on extensive paleoenvironmental surveys on the western margin of the study area (i.e., Zhengzhou region) lead strong support to our speculation on local hydrological changes, which show that the areas of lakes and marshes in Zhengzhou region have decreased dramatically since the late Yangshao period (~5.0 ka BP) (Li et al., 2019; Lu et al., 2021). As a result, during 5.0-4.0 ka BP a large area of arable land was created in the surrounding highlands and adjacent areas, and thus was occupied by locally rapid increasing population (Li et al., 2021). Although regional precipitation declining with increasingly drying climate also occurred since ~5.0 ka BP within the study area (Figure 3, No. 10), however, many rivers (especially the Yellow River and the Huai River) running through surrounding highlands inevitably would flowed into the lowlands of the study area for its preexisting saucer-shaped topography (Figure 1), resulting in wide distribution of surface water in the low-lying regions during 5.0-4.0 ka BP (Figure 3, No. 7-9). Nonetheless, the increasingly drying climate and associated shrinking of preexisting surface water during 5.0-4.0 ka BP still influenced local environmental conditions, namely, many arable land likely outcropped scatteredly in the YHRA and provided places for prehistoric human habitation (Liu, 2004; Xu, 2020; Li et al., 2021), just like the Yuchisi. Since ~5.0 ka BP, prehistoric human began to dwell at Yuchisi (Figure 3, No. 10), and this time is consistent with the starting time of the regional drying hydroclimatic conditions (see section 3.1).

4.2. *The adaptation of Human subsistence strategies to local physical environmental changes*

Millet (broomcorn millet and foxtail millet) requires less water than rice, thus, local hydrological conditions and associated surface water supply could play important roles in cropping structures of prehistoric agriculture (Zhao, 2014; Liao et al., 2019; Yuan, 2019; Li et al., 2020; Yang et al., 2021). Under the influence of the intense EASM and associated high precipitation between 8.0 and 5.0 ka BP (Figure 2), lakes and marshes were not only widely distributed in the low-lying regions but also in the surrounding highlands in the YHRA (Chen, 2007; Guo et al., 2008; Yu, 2016; Wang et al., 2019; Lu et al., 2021). This environmental condition could provide adequate surface water supply and facilitate the development of rice farming. As a result, the mixed millet-rice farming mode was widespread in the relative highlands in and around the YHRA during this time interval (Zhang et al., 2012; He et al., 2017; Wang et al., 2018; Liao et al., 2019), and the rice farming likely was the only agricultural system in the low-lying regions of the study area (Yang et al., 2016).

However, the persistent weakening EASM and ensuing precipitation decline during 5.0-4.0 ka BP (Figure 2) caused dramatically hydrological changes in and around the YHRA (see section 4.1). The distribution pattern of surface water showed clear spatial differentiation due to different responses of local hydrological conditions within the study area (Figure 3), that is, the area of surface water was gradually decreasing from the low-lying regions to the surrounding highlands (Guo et al., 2008; Yu, 2016; Li et al., 2019). Consequently, surface water reduction was more remarkable in the surrounding highlands than in the low-lying regions during the Longshan period in the YHRA. As mentioned above, broomcorn millet, foxtail millet and rice are the main crop types in human subsistence strategy during the Longshan period in the YHRA (Table 1). With the increasingly drying of local hydroclimate in the Longshan period (Figure 2), the spatial range of mixed millet-rice farming mode had shrunk toward alluvial plains within the YHRA (Figure 4). As a result, only millet agriculture was distributed in the surrounding hills and loess tablelands (Liao et al., 2019), and the agriculture system had transformed from earlier rice farming to later mixed millet-rice farming in the low-lying regions (Yang et al., 2016).

5. CONCLUSIONS

From the discussions above, three conclusions can be drawn. First, there was distinct spatial variability in local environmental conditions (especially hydrological conditions) during the Longshan period in the YHRA. Due to the weakening EASM and consequent precipitation decline during the Longshan period, preexisting lakes and marshes had shrunk dramatically in circumjacent highlands; however, surface water was still widely distributed in the low-lying regions within the study area for the confluence of surrounding regional rivers. Second, obvious spatial variability in cropping structures of human subsistence strategy existed during the Longshan period in the YHRA. Although the mixed millet-rice farming mode was widespread in the YHRA, the proportion of rice (millet) was higher (lower) in the low-lying regions than in the surrounding highlands. Finally, the spatial distribution variability in surface water supply for prehistoric agriculture development substantially impacted spatial pattern in cropping structures of human subsistence strategy. Due to dramatically surface water reduction, the cultivation of millet crops was the primary subsistence strategy in circumjacent highlands; whereas, with more available surface water, rice occupied more prominent position in the low-lying regions within the YHRA.

By compiling the information on spatial variabilities of physical environmental conditions and human subsistence strategies during the Longshan period within and around the YHRA, the relationships between local environmental conditions and human subsistence strategies were compared and examined in this paper. However, only limited floatation results and local paleoenvironmental records are used for discussion of human cropping structures and physical environmental evolutions, no more floatation results or microfossil results and high-resolution paleoenvironmental sequences are included. Moreover, because the main purpose of this paper is to explore the possible interactions between human subsistence strategy and external environmental factor, other factors, such as agricultural technologies, cultural exchange, human activities, that could influence human cropping structures, were not involved in this paper. In future studies, more archaeobotanical data, paleoenvironemtnal sequences and other influencing factors are needed to promote a better understanding of human-environment interactions in the YHRA.

ACKNOWLEDGEMENTS

This research was jointly supported by the grants from the MOE Youth Foundation of Humanities and Social Sciences, China (No. 17YJCZH046), and the Foundation of Humanities and Social Sciences of the Department of Education, Henan Province, China (Nos. 2018-ZZJH-086; 2019-ZZJH-103).

REFERENCES

Anderson, D.G., Maasch, K.A. and Sandweiss, D.H. (2007) *Climate change and cultural dynamics: a global perspective on mid-Holocene transitions*. London: Academic Press.

APICRA (Anhui Provincial Institute of Cultural Relics and Archaeology), SMBCH (Suzhou Municipal Bureau of Cultural Heritage) and SMM (Suzhou Municipal Museum). (2016) *Luchengzi site in Suzhou*. Beijing: Cultural Relics Press (in Chinese with English abstract).

Binford, M.W., Kolata, A.L., Brenner, M., Janusek, J.W., Seddon, M.T., Abbott, M. and Curtis, J.H. (1997) Climate variation and the rise and fall of an Andean civilization. *Quaternary Research*, 47, 235-248.

Buckley, B.M., Anchukaitis, K.J., Penny, D., Fletcher, R., Cook, E.R., Sano, M., Nam, L.C., Wichienkeeo, A., Minh, T.T. and Hong, T.M. (2010) Climate as a contributing factor in the demise of Angkor, Cambodia. *Proceedings of the National Academy of Sciences of the United States of America*, 107, 6748-6752.

Butzer, K.W. (2012) Collapse, environment, and society. *Proceedings of National Academy of Sciences of the United States of America*, 109, 3632-3639.

Chen, F.H., Dong, G.H., Zhang, D.J., Liu, X.Y., Jia, X., An, C.B., Ma, M.M., Xie, Y.W., Barton, L., Ren, X.Y., Zhao, Z.J., Wu, X.H. and Jones, M.K. (2015) Agriculture facilitated permanent human occupation of the Tibetan Plateau after 3600 B.P. *Science*, 347, 248-250.

Chen, H.B. (2007) Settlements distribution and its relations with environmental changes in the Shandong-Henan-Anhui cultural region. *Archaeology*, 2, 48-60 (in Chinese).

Chen, W., Song, B., Shu, J.W., Jin, C.F. and Wang, W.M. (2021) Vegetation history with implication of climate changes and human impacts over the last 9000 years in the Lake Nanyi area, Anhui Province, East China. *Palaeoworld*, doi: 10.1016/j.palwor.2020.09.006.

Chen, W., Wang, W.M. and Dai, X.R. (2009) Holocene vegetation history with implications of human impact in the lake Chaohu area, Anhui Province, East China. *Vegetation History and Archaeobotany*, 18, 137-146.

Chen, X.L. (2021) Neolithic subsistence economy and social evolution during the Neolithic Age in the Central Plains: Reviews on the evidences of stable carbon and nitrogen isotope. *Cultural Relics in Southern China*, 1, 179-190 (in Chinese).

Cullen, H.M., deMenocal, P.B., Hemming, S., Hemming, G., Brown, F.H., Guilderson, T. and Sirocko, F. (2000) Climate change and the collapse of the Akkadian empire: evidence from the deep sea. *Geology*, 28, 379-382.

Deng, Z.H., Zhang, H., Li, W., Liang, F.W. and Cao, Y.P. (2021) A preliminary study of early agriculture practices at the Haojiatai site in Luohe city, Henan Province. *Science China Earth Sciences*, 64, 307-317.

Dong, G.H., Li, R., Lu, M.X., Zhang, D.J. and James, N. (2020) Evolution of human-environmental interactions in China from the Late Paleolithic to the Bronze Age. *Progress in Physical Geography*, 44, 233-250.

Dong, J.G., Shen, C.C., Kong, X.G., Wu, C.C., Hu, H.M., Ren, H.J. and Wang, Y. (2018) Rapid retreat of the East Asian summer monsoon in the middle Holocene and a millennial weak monsoon interval at 9 ka in northern China. *Journal of Asian Earth Sciences*, 151, 31-39.

Dugmore, A.J., McGovern, T.H., Vésteinsson, O., Arneborg, J., Streeter, R. and Keller, C. (2012) Cultural adaptation, compounding vulnerabilities and conjunctures in Norse Greenland. *Proceedings of the National Academy of Sciences of the United States of America*, 109, 3658-3663.

Guo, R.Z., Gao, M.K., Sun, M., Wang, L., Wang, S.B. and Jin, G.Y. (2019) The carbonized plant remains of pre-Qin period from Shilipubei site, Heze city, Shandong Province. *Agricultural History of China*, 5, 15-26 (in Chinese with English abstract).

Guo, S.Y., Yan, G.S., Xue, D., Zhang, E.H., Zhang, S. and Chen, C.S. (2008) *Study of stratigraphic paleontology in Henan Province (Volume seven)*. Zhengzhou: The Yellow River Water Conservancy Press (in Chinese).

He, K.Y., Lu, H.Y., Zhang, J.P., Wang, C. and Huan, X.J. (2017) Prehistoric evolution of the dualistic structure mixed rice and millet framing in China. *Holocene*, 27, 1885-1898.

Hu, C.Y., Henderson, G.M., Huang, J.H., Xie, S.C., Sun, Y. and Johnson, K.R. (2008) Quantification of Holocene Asian monsoon rainfall from spatially separated cave records. *Earth and Planetary Science Letters*, 266, 221-232.

Hu, Y.W. (2021) Human subsistence strategies and adaptations in the lower Yangtze River region during the prehistoric era. *Frontiers in Earth Science*, 9, 654416.

IACASS (Institute of Archaeology in Chinese Academy of Social Sciences) and BMM (Bengbu Municipal Museum). (2013) *Yuhuicun site in Bengbu*. Beijing: Science Press (in Chinese).

IACASS (Institute of Archaeology in Chinese Academy of Social Sciences) and CBMC (Cultural Bureau of Mengcheng County). (2007) *Yuchisi site in Mengcheng (part II)*. Beijing: Science Press (in Chinese).

Jaffe, Y.Y., Castellano, L., Shelach-Lavi, G. and Campbell, R.B. (2021) Mismatches of scale in the application of paleoclimatic research to Chinese archaeology. *Quaternary Research*, 99, 14-33.

Jiang, S.W., Luo, W.H., Tu, L.Y., Yu, Y.Y., Fang, F., Liu, X.Y., Zhan, T., Fang, L.D., Zhang, X.L. and Zhou, X. (2018) The Holocene optimum (HO) and the response of human activity: A case study of the Huai River Basin in eastern China. *Quaternary International*, 493, 31-38.

Jin, G.Y., Wagner, M., Tarasov, P.E., Wang, F. and Liu, Y.C. (2016) Archaeobotanical records of middle and late Neolithic agriculture from Shandong Province, East China, and a major change in regional subsistence during the Dawenkou Culture. *Holocene*, 26, 1605-1615.

Jin, Q. (1990) *Quaternary system of Huaibei Plain in Anhui*. Beijing: Geological Publishing House (in Chinese).

Jones, E.L. (2007) Subsistence change, landscape use, and changing site elevation at the Pleistocene-Holocene transition in the Dordogne of southwestern France. *Journal of Archaeological Science*, 34, 344-353.

Kay, A.U. and Kaplan, J.O. (2015) Human subsistence and land use in sub-Saharan Africa, 1000 BC to AD 1500: A review, quantification, and classification. *Anthropocene*, 9, 14-32.

Lespez, L., Glais, A., Lopez-Saez, J., Drezen, Y.L., Tsirtsoni, Z., Davidson, R., Biree, L. and Malanidou, D. (2016) Middle Holocene rapid environmental changes and human adaptation in Greece. *Quaternary Research*, 85, 227-244.

Li, B., Liu, H., Wu, L., McCloskey, T.A., Li, K.F. and Mao, L.M. (2014) Linking the vicissitude of Neolithic cities with mid Holocene environment and climate changes in the middle Yangtze River, China. *Quaternary International*, 321, 22-28.

Li, K.F. and Gao, W.H. (2019) Holocene climate change in Henan area: A synthesis of proxy records. *Quaternary International*, 521, 185-193.

Li, K.F. and Gao, W.H. (2021). Human settlement distribution patterns during the Longshan and Xinzhai-Erlitou periods and their hydrogeomorphic contexts in the Central Plains, China. *Catena*, 204, 105433.

Li, K.F., Gao, W.H., Wu, L., Hu, H.N., Gong, P.P., Li, S.Y., Jin, R. and Si, Y. (2021) Spatial expansion of human settlement during the Longshan period (~4.5-~3.9 ka BP) and its hydroclimatic contexts in the lower Yellow River floodplain, Eastern China. *Land*, 10, 712.

Li, K.F., Ma, C.M., Gao, W.H., Li, S.Y., Li, Z.X. and Pan, Y.F. (2015) Progress and trend of Holocene environmental archaeology in Henan Province. *Progress in Geography*, 34, 883-897 (in Chinese with English abstract).

Li, R., Lv, F.Y., Yang, L., Liu, F.W., Liu, R.L. and Dong, G.H. (2020) Spatial-temporal variation of cropping patterns in relation to climate change in Neolithic China. *Atmosphere*, 11, 677.

Li, S.Q., Ma, Y.F., Guo, Y.S., Du, J. and Wang, D.F. (2019) Relationship between distribution features of ancient settlement and changes of river and lake prior to western Zhou danasty in Zhengzhou area. *Areal Research and Development*, 38, 171-176 (in Chinese with English abstract).

Li, Z.P. (2017) Primary Study on human subsistence economy of the late and terminal Neolithic age in the lower Yellow and Huai River plain. *Cultural Relics in Southern China*, 3, 177-186 (in Chinese).

Liao, Y.N., Lu, P., Mo, D.W., Wang, H., Storozum, M.J., Chen, P.P. and Xu, J.J. (2019) Landforms influence the development of ancient agriculture in the Songshan area, central China. *Quaternary International*, 521, 85-89.

Liritzis, I., Westra, A. and Miao, C.H. (2019) Disaster geoarchaeology and natural cataclysms in world cultural evolution: An overview. *Journal of Coastal Research*, 35, 1307-1330.

Liu, C., Zhao, Z.J. and Fang, Y.M. (2018) Analysis on the flotation result of plant remains in 2007 and 2009 at Wadian site, Yuchi City, Henan Province. *Huaxia Archaeology*, 1, 95-128 (in Chinese).

Liu, F.G. and Feng, Z.D. (2010) A dramatic climatic transition at ~4000 cal. yr BP and its cultural responses in Chinese cultural domains. *Holocene*, 22, 1181-1197.

Liu, L. (2004) *The Chinese Neolithic: Trajectories to early states*. Cambridge: Cambridge University Press.

Liu, L. and Chen, X.C. (2012) *The archaeology of China: From the late Paleolithic to the early Bronze age*. Cambridge: Cambridge University Press.

Liu, L., Chen, X.C., Wright, H., Xu, H., Li, Y.Q., Chen, G.L., Zhao, H.T., Kim, H. and Lee, G.A. (2019) Rise and fall of complex societies in the Yiluo region, North China: The spatial and temporal changes. *Quaternary International*, 521, 4-15.

Lu, P., Lü, J.Q., Zhuang, Y.J., Chen, P.P., Wang, H., Tian, Y., Mo, D.W., Xu, J.J., Gu, W.F., Hu, Y.Y., Wei, Q.L., Yan, L.J., Wang, X. and Zhai, H.G. (2021) Evolution of Holocene alluvial landscapes in the northeastern Songshan region, Central China: Chronology, models and socio-economic impact. *Catena*, 197, 104956.

Ma, C.M., Zhu, C., Zhu, G.Y., Wang, J.H., Huang, R. and Gu, W.W. (2006) Magnetic susceptibility and elemental geochemistry analysis of the archaeological strata at the Yuchisi site, Anhui. *Journal of Stratigraphy*, 30, 124-130 (in Chinese with English abstract).

Manning, K. and Timpson, A. (2014) The demographic response to Holocene climate change in the Sahara. *Quaternary Science Reviews*, 101, 28-35.

Portillo, M., Morales, J., Marco, Y.C., Aouadi, N., Lucarini, G., Belhouchet, L., Coppa, A. and Peña-Chocarro, L. (2021) Changing plant-based subsistence practices among early and middle Holocene communities in eastern Maghreb. *Environmental Archaeology*, 26, 455-470.

Qin, Z. (2021) Exploring the early Anthropocene: Implications from the long-term human-climate interactions in early China. *Mediterranean Archaeology and Archaeometry*, 21, 133-148.

Ren, X.L., Xu, J.J., Wang, H., Storozum, M., Lu, P., Mo, D.W., Li, T.Y., Xiong, J.G. and Kidder, T.R. (2021) Holocene fluctuations in vegetation and human population demonstrate social resilience in the prehistory of the Central Plains of China. *Environmental Research Letters*, 16, 055030.

Rendu, W., Renou, S., Soulier, M., Rigaud, S., Roussel, M. and Soressi, M. (2019) Subsistence strategy changes during the Middle to Upper Paleolithic transition reveals specific adaptations of human populations to their environment. *Scientific Reports*, 9, 15817.

Shqiarat, M. (2019) History and archaeology of water management in Jordan through ages. *Scientific Culture*, 5, 41-54.

Shu, Q., Zhao, Y.F., Frechen, M., Zhang, J.R., Chen, Y., Liu, Y. and Yang, P.P. (2021) Chronology of a sedimentary sequence from the land-ocean interaction zone in the North Jiangsu Basin. *Quaternary International*, 580, 78-86.

Turney, C.S.M., Baillie, M., Palmer, J. and Brown, D. (2006) Holocene climatic change and past Irish societal response. *Journal of Archaeological Science*, 33, 34-38.

Underhill, A.P. (2013) *A companion to Chinese archaoelogy*. West Sussex: John Wiley & Sons.

Wang, C., Lu, H.Y., Gu, W.F., Zuo, X.X., Zhang, J.P., Liu, Y.F., Bao, Y.J. and Hu, Y.Y. (2018) Temporal changes of mixed millet and rice agriculture in Neolithic-Bronze Age Central Plain, China: Archaeobotanical evidence from the Zhuzhai site. *Holocene*, 28, 738-754.

Wang, H.Y., Liu, Y.C. and Jin, G.Y. (2011) Analysis on the carbonized plant remains from Dongpan site, 2009, Linshu County, Shandong. *East Asia Archaeology*, 8, 357-372 (in Chinese with English abstract).

Wang, J.J., Sun, L.G., Chen, L.Q., Xu, L.B., Wang, Y.H. and Wang, X.M. (2016) The abrupt climate change near 4400 yr BP on the cultural transition in Yuchisi, China and its global linkage. *Scientific Reports*, 6, 27723.

Wang, L.S., Hu, S.Y., Yu, G., Wang, X.H., Wang, Q., Zhang, Z.H., Ma, M.M., Cui, B.L. and Liu, X.B. (2019) Multiproxy studies of lake sediments during mid-Holocene in Zhengzhou region of the Henan Province, central China, and the implications for reconstructing the paleoenvironments. *Quaternary International*, 521, 104-110.

Wang, S.W. and Li, W.J. (2007) *Climate of China*. Beijing: China Meteorological Press.

Weiss, H., Courty, M.A., Wetterstrom, W., Guichard, F., Senior, L., Meadow, R. and Crunow, A. (1993) The genesis and collapse of third millennium north Mesopotamian civilization. *Science*, 261, 995-1004.

Wu, L., Zhou, H., Li, J.Y., Li, K.F., Sun, X.L., Lu, S.G., Li, L.Y., Zhu, T.X. and Guo, Q.C. (2019) Thiessen polygen analysis and spatial pattern evolution of Neolithic cultural sites (8.0-4.0 ka BP) in Huaibei Plain of Anhui, East China. *Quaternary International*, 521, 75-84.

Wu, W.X. and Liu, T.S. (2004) Possible role of the "Holocene event 3" on the collapse of Neolithic cultures around the central plains of China. *Quaternary International*, 117, 153-166.

Xu, F. (2020) *A transitional region: a research on the early social process of Lianghuai region*. Shanghai: Shanghai Classics Publishing House (in Chinese).

Yang, L., Ma, M.M., Chen, T.T., Cui, Y.F., Chen, P.P., Zheng, L.C. and Lu, P. (2021) How did trans-Eurasian exchanges affect spatial-temporal variation in agricultural patterns during the late prehistoric period in the Yellow River valley (China)? *Holocene*, 31, 247-257.

Yang, Y.Z., Cheng, Z.J., Yao, L., Li, Z.Y., Li, W.Y., Luo, W.H., Yuan, Z.J., Zhang, J. and Zhang, J.Z. (2016) The emergence, development and regional differences of mixed farming of rice and millet in the upper and middle Huai River Valley, China. *Science China Earth Sciences*, 59, 1779-1790.

Yu, G. (2016) *Sedimentology of lake-river systems and environmental evolution in Zhengzhou Region*. Beijing: Science Press (in Chinese).

Yuan, J. (2019) *Research on subsistence from the Neolithic to the Bronze Age in China*. Shanghai: Fudan University Press (in Chinese).

Yuan, J., Campbell, R., Castellano, L. and Chen, X.L. (2020) Subsistence and persistence: agriculture in the Central Plains of China through the Neolithic to Bronze Age transition. *Antiquity*, 94, 900-915.

Zhang, J.N., Xia, Z.K., Zhang, X.H., Storozum, M.J., Huang, X.Z., Han, J.Y., Xu, H., Zhao, H.T., Cui, Y.F., Dodson, J. and Dong, G.H. (2018a) Early-middle Holocene ecological change and its influence on human subsistence strategies in the Luoyang Basin, north-central China. *Quaternary Research*, 89, 446-458.

Zhang, J.P., Lu, H.Y., Gu, W.F., Wu, N.Q., Zhou, K.S., Hu, Y.Y., Xin, Y.J. and Wang, C. (2012) Early mixed farming of millet and rice 7800 years ago in the middle Yellow River region, China. *PLoS One*, 7, e52146.

Zhang, N., Yang, Y., Cheng, H., Zhao, J.Y., Yang, X.L., Liang, S., Nie, X.D., Zhang, Y.H. and Edwards, R.L. (2018b) Timing and duration of the East Asian summer monsoon maximum during the Holocene based on stalagmite data from North China. *Holocene*, 28, 1631-1641.

Zhao, S.Q. (1986) *The physical geography of China*. New York: Wiley.

Zhao, Z.J. (2014) The process of origin of agriculture in China: Archaeological evidence from the floation results. *Quaternary Sciences*, 34, 73-84 (in Chinese with English abstract).

Zhao, Z.Z., Cao, Y.P. and Jin, G.Y. (2019) Analysis of plain remains from Pinglingtai site in Longshan period. *Agricultural History of China*, 4, 19-32 (in Chinese with English abstract).

Zou, Y.L. (1993) *The history geography of Huanghuaihai Plain*. Hefei: Anhui Eduational Publishing House (in Chinese).