

Cultural evolution and spatial-temporal distribution of archaeological sites from 9.5–2.3 ka BP in the Yan-Liao region, China

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Abstract: With basic information from 8353 archaeological sites, this study describes a holistic spatial-temporal distribution pattern of archaeological sites of the prehistoric culture sequence from 9.5 ka BP (ka BP = thousands of years before 0 BP, where “0 BP” is defined as the year AD 1950) to 2.3 ka BP in the region that extends from the Yanshan Mountains to the Liaohe River Plain (i.e., the Yan-Liao region) in northern China. Based on spatial statistics analysis – including the spatial density of the sites and Geographic Information System nearest-neighbour analysis, combined with a review of environmental and climatic data – this paper analyses cultural evolution, the spatial-temporal features of the archaeological sites and human activities against the backdrop of climatic and environmental changes in this region. The results reveal that prehistoric cultural evolution in the Yan-Liao region is extensively influenced by climatic and environmental changes. The Xinglongwa, Zhaobaogou and Fuhe cultures, which primarily developed during a habitable period from 8.5 ka BP to 6.0 ka BP with strong summer monsoons, have similar maximum density values, spatial patterns and subsistence strategies dominated by hunting-gathering. Significant changes occurred in the Hongshan and Lower Xiajiadian cultures, with a significant increase in numbers and densities of sites and a slump in average nearest-neighbour ratio when the environment began to deteriorate starting in 6.0 ka BP. Additionally, with the onset of a weak summer monsoon and the predominance of primitive agriculture, sites of these two cultures present a different type of concentric circle-shaped pattern in space. As the environment continuously deteriorated with increasing aridity and the spread of steppe, more sites were distributed towards the south, and primitive agriculture was replaced by livestock husbandry in the Upper Xiajiadian culture. The most densely populated areas of the studied cultures are centralized within a limited area. The Laohahe River and Jiaolaihe River basins formed the core area in which most archaeological sites were distributed during the strong summer monsoon period and the first few thousand years of the weak summer monsoon period.

Keywords: prehistoric cultural evolution; archaeological site; spatial-temporal distribution; climate and environmental change; Yanshan Mountains; Liaohe River Plain

Received: 2017-04-18 **Accepted:** 2017-10-16

Foundation: National Natural Science Foundation of China, No.41371148; Major Program of National Social Science Fund of China, No.13&ZD082

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1 Introduction

In recent years, archaeological, geographical and geological data and methods have been extensively used to study prehistoric cultural evolution, migration, the trajectory of prehistoric society, and interactions between humans and the environment (Brantingham and Gao, 2006; Tarasov *et al.*, 2006; Zhang *et al.*, 2007; Harrower, 2010). With the development and application of Geographic Information System (GIS) technology, attempts have been made to integrate site-based archaeology with a broader landscape-scale analysis (Qiao, 2007; Han *et al.*, 2008; Dong *et al.*, 2012b; Guo *et al.*, 2013; Xu *et al.*, 2016), offering a novel approach to the study of human-environment interactions and cultural development from the standpoint of spatial analysis. In addition, studies combined with archaeobotanical and stratigraphic analysis have made valuable contributions to reconstructing the palaeoenvironment and understanding how human individuals and cultures responded to its changes (Zhang *et al.*, 2010; Zhang *et al.*, 2011; Dong *et al.*, 2013; Knitter *et al.*, 2013). These studies demonstrated that a combination of archaeological data, geographical information and GIS analysis is useful for exploring human activities and developments in prehistoric cultures in connection with the impact of environmental changes. However, most recent studies have been focused on the intra-site or sub-regional scale (e.g. Zhang *et al.*, 2011; Li *et al.*, 2012; Li *et al.*, 2014). Systematic, quantitative analysis on a broader regional scale (e.g., Wagner *et al.*, 2013) has been lacking.

In China, the Xar Moron and the Liaohe river plains are important regions where several prehistoric cultures originated. Until now, studies in this area have primarily focused on specific archaeological sites, cultures or geographical units (e.g., Xiao *et al.*, 2006; Wang *et al.*, 2010). Comprehensive studies on the entire region and the influence of climatic and environmental changes on the evolution and distribution characteristics of the entire prehistoric culture sequence (e.g., Wang *et al.*, 2016) are rare. This paper seeks to contribute to this area. The study describes holistic spatial-temporal patterns of site distribution of the prehistoric culture sequence developing during 9.5–2.3 ka BP (ka BP = thousands of years before 0 BP, where “0 BP” is defined as the year AD 1950) in the region that extends from the Yanshan Mountains to the Liaohe River Plain (referred to here as the Yan-Liao region) in North China. Cultural evolution, site distribution patterns and correlations among human, environment and climate change are discussed from a broader regional and cultural perspective, with a comprehensive quantitative analysis of spatial statistics and environmental data. The methods adopted in the research can be applied into the study of other prehistoric cultures and the regional environment.

2 Study area

The study area (Figure 1) extends about 1000 km from the Yanshan Mountains to the Liaohe River Plain (the Yan-Liao region). It consists of low-elevated alluvial and loess plains, coastal lowlands surrounding the Liaodong Bay and a chain of mountain ridges and plateaus elevated from –200 m to 3000 m. The region is located on the northwestern margin of the East Asian summer monsoon area. The mean annual temperature is approximately 0–6°C in the semi-arid northwestern part (Chifeng city and Tongliao city) with annual precipitation of

300–500 mm. Coastal mountains and plains in the semi-humid south-eastern part receive more precipitation (450–600 mm) with higher annual temperature (6–9°C). Farther from the sea, the amount of precipitation decreases substantially. Approximately 60%–70% of the precipitation occurs from June to August as the summer monsoon intensifies. Due to rainfall variability and frequent cold waves in winter, the region is vulnerable to climate change (CAS, 1984). Human activities and settlements were largely limited by water availability. According to the vegetation atlas of China (Hou, 2001), alluvial and loess plains are primarily used for crops, vegetation and fruit production, while the gentle slopes are exploited for soy, corn, sorghum, millet and wheat cultivation. During the prehistoric period, the dry western and northern plains covered with herbaceous vegetation were more suitable for pasture, while the eastern and southern plains could support agriculture with their more stable water supply.

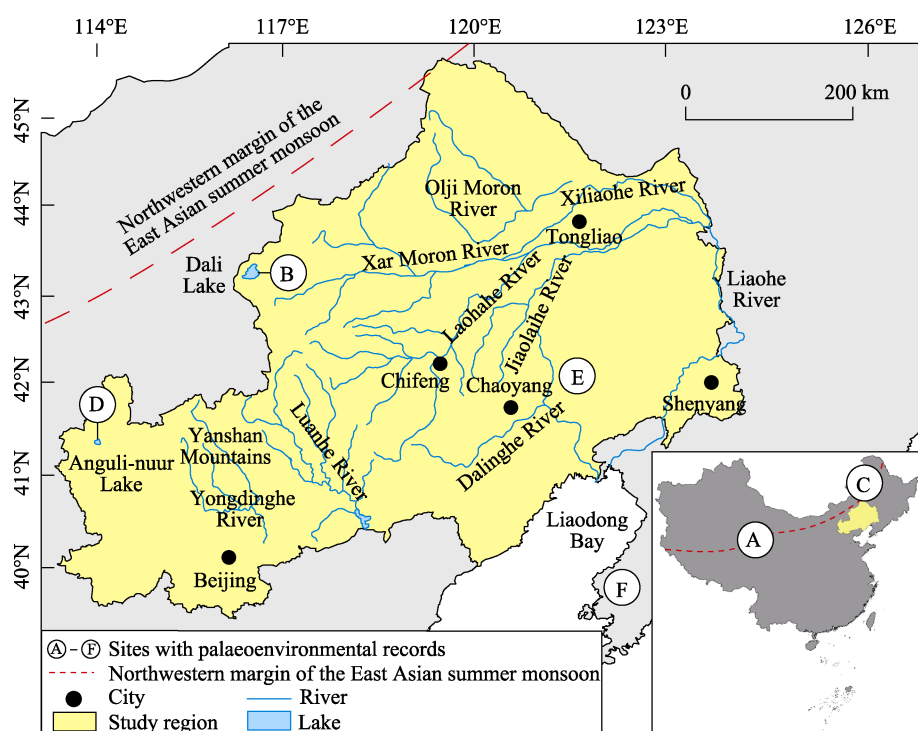


Figure 1 Location map of the Yan-Liao region with major river systems and cities. The white circles with the letters A – F indicate sites with palaeoenvironmental records discussed in the text: A – Dunde Ice Core, B – Dali Lake, C – Hulun Lake, D – Anguli-nuur Lake, E – Chahai Site, and F – South Liaoning (39°30'N, 122°E).

3 Materials and methods

3.1 Collection of the archaeological data

The published results of three national systematic archaeological field surveys in China, which were performed in 1956, 1981 and 2007, provide the original archaeological information used in this study. In the surveys, the archaeological sites of all prehistoric and historical periods were registered. The State Administration of Cultural Heritage compiled the basic information such as location, culture type and size into the series *Atlas of Chinese Cultural*

Relics by provinces, with coarse chronologies of the sites mainly based on ceramic typology. The data of archaeological sites examined in this study were extracted from the following Atlas of Chinese Cultural Relics: Inner Mongolia Autonomous Region Volume (2003), Beijing Volume (2008), Liaoning Volume (2009) and Hebei Volume (2013). The chronology of and quantitative changes in the archaeological sites of the prehistoric culture sequence studied in this paper are summarized and presented in Figure 2. Although there are still some deficiencies, such as controversial periods of certain culture, rough site chronology, omission of undiscovered sites and inaccurate location of certain site, the long time span and large number of sites guarantee that most of the results and conclusions in this study are reliable.

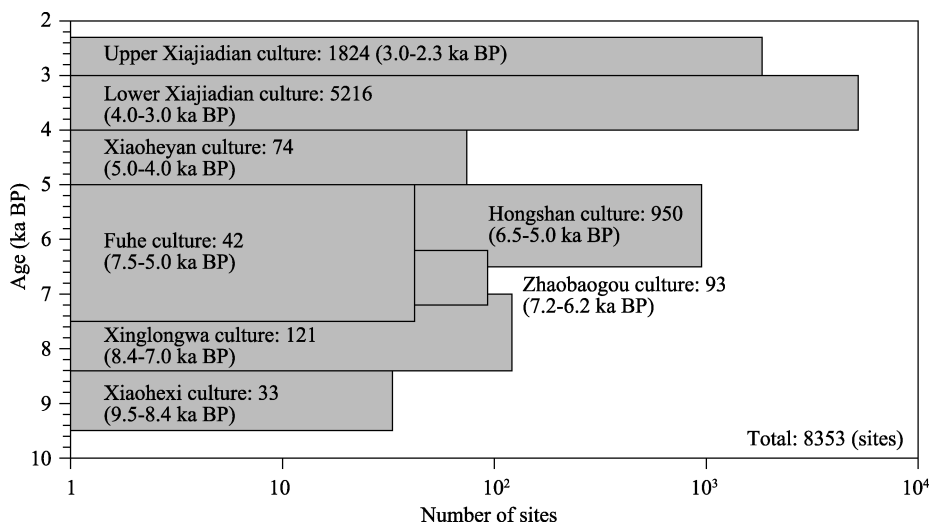


Figure 2 Quantitative changes in the number of archaeological sites of the studied prehistoric cultures with a chronological sequence

3.2 Geospatial data

3.2.1 Primary coverage and mapping of sites

The primary topographic coverage in this study is a 30 m digital elevation model of the research area that was extracted from an Aster satellite image and slightly adjusted based on known ground control points. The major rivers and lakes were extracted from the China Historical Geographic Information System project (CHGIS, 2007). After preparation work, the archaeological and geographical data of all sites were imported into GIS. With the longitude and latitude data, the sites were plotted as points on the map in GIS. The coordinate system of each layer was adjusted according to the World Geodetic System 1984 (WGS 1984).

3.2.2 Spatial density

Since the purpose of this paper is to study the evolution and spatial-temporal distribution patterns of archaeological sites of different cultures, and the sites are small compared to the entire study region, the sites can be regarded and calculated as points scattered in space. An archaeological site represents a settlement where human lived and can be regarded as a basic unit of archaeological analysis (Chang, 1967). Thus, the density of sites indicates population

density to an extent and can be used to estimate population size (Han *et al.*, 2008; Dong *et al.*, 2012b). The Point Density tool in GIS calculates a magnitude per unit area from point features that fall within an area around each cell. The spatial density features of sites were obtained with this tool.

3.2.3 Nearest-neighbour analysis

Spatial density analysis provides the average value of point density in a certain area but cannot show cluster features. Therefore, nearest-neighbour analysis is required. The value of the average nearest-neighbour (ANN) ratio indicates whether points are clustered (< 1), random ($= 1$) or dispersed (> 1) in space. It is calculated based on the average distance from each point to its nearest neighbouring point. The calculation formulas are as follows:

$$ANN = \frac{\bar{D}_O}{\bar{D}_E}$$

$$\bar{D}_O = \frac{\sum_{i=1}^n d_i}{n}$$

$$\bar{D}_E = \frac{0.5}{\sqrt{n/A}}$$

where \bar{D}_O is the observed mean distance between each point and its nearest neighbour, and \bar{D}_E is the expected mean distance for the point given in a random pattern. In the preceding equations, d_i is the distance between point i and its nearest neighbouring point, A is the area of a minimum enclosure and n is the total number of points.

The ANN tool in GIS, calculates not only the ANN ratio of each culture, but also the p-value – representing probability – and the z-score – representing standard deviation. The p-value and z-score are measures of statistical significance used to ascertain whether to reject the hypothesis of complete spatial randomness. The smaller that the p-value is and the larger the absolute value of the z-score is, the less likely the observed spatial pattern is the result of a random process. If the p-value is less than 0.01 and the absolute value of the z-score is larger than 2.58 (i.e., < -2.58 or $> +2.58$), the confidence level would be over 99% (ArcGIS, 2016).

4 Results

In total, 8353 archaeological sites of the studied prehistoric culture sequence were digitalized (Figure 3). From Figure 2, which shows quantitative changes in the number of sites in addition to the chronological and cultural sequence, it is obvious that the number of archaeological sites increased rapidly in the Hongshan culture and Lower Xiajiadian culture. Moreover, the sites of these two cultures and the Upper Xiajiadian culture are distributed across a broader area than those of the other cultures.

4.1 Spatial density

The density analysis results reveal that the Lower Xiajiadian culture has the largest maximum density value, followed by the Hongshan culture (Table 1). The Xiaohexi, Xinglongwa,

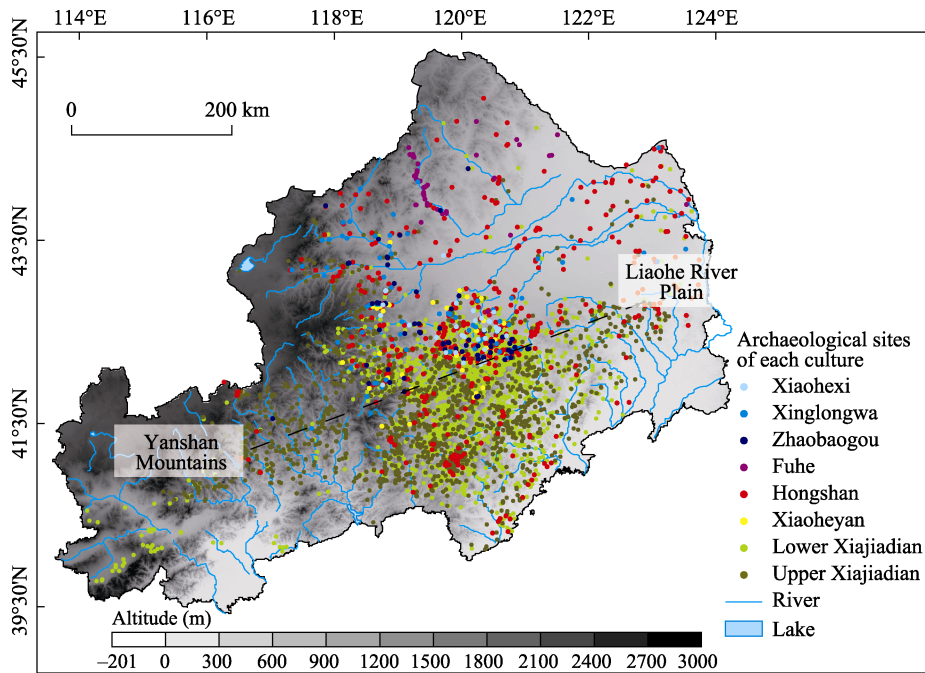


Figure 3 Spatial distributions of the archaeological sites of the studied prehistoric culture sequence.

Zhaobaogou and Fuhe cultures have similar maximum density values (approximately 0.037 site/km²). Additionally, spatial density maps (Figure 4) were drawn for each culture. The spatial density values were classified into five classes under a unified standard with geometric intervals, which ensures that each class range has approximately the same number of sites and that the change between intervals is relatively consistent. In Figure 4, three types of spatial distribution pattern can be observed. The first type consists of the Xiaohexi, Xinglongwa, Zhaobaogou, Fuhe and Xiaoheyang cultures. The Hongshan and Lower Xiajiadian cultures represent the second type while the Upper Xiajiadian culture represents the third type. The characteristics and dynamic mechanisms of the revealed spatial distribution patterns are further investigated in the following.

Table 1 Maximum density value of archaeological sites of each culture

Culture	Xiaohexi	Xinglongwa	Zhaobaogou	Fuhe
Maximum density (sites/km ²)	0.0359	0.0388	0.0367	0.0371
Culture	Hongshan	Xiaoheyang	Lower Xiajiadian	Upper Xiajiadian
Maximum density (sites/km ²)	0.1515	0.0491	0.5630	0.0853

4.2 Nearest-neighbour analysis

Using the ANN tool in GIS, the ANN value, p-value and z-score of each culture were calculated (Table 2). According to their critical values, the archaeological sites of all cultures exhibit clustering with the confidence levels over 99% except the Xiaohexi culture, whose sites tend to be randomly distributed. Among all cultures, the Lower Xiajiadian culture has the highest level of clustering with the highest confidence level. The Hongshan and Upper Xiajiadian cultures come second.

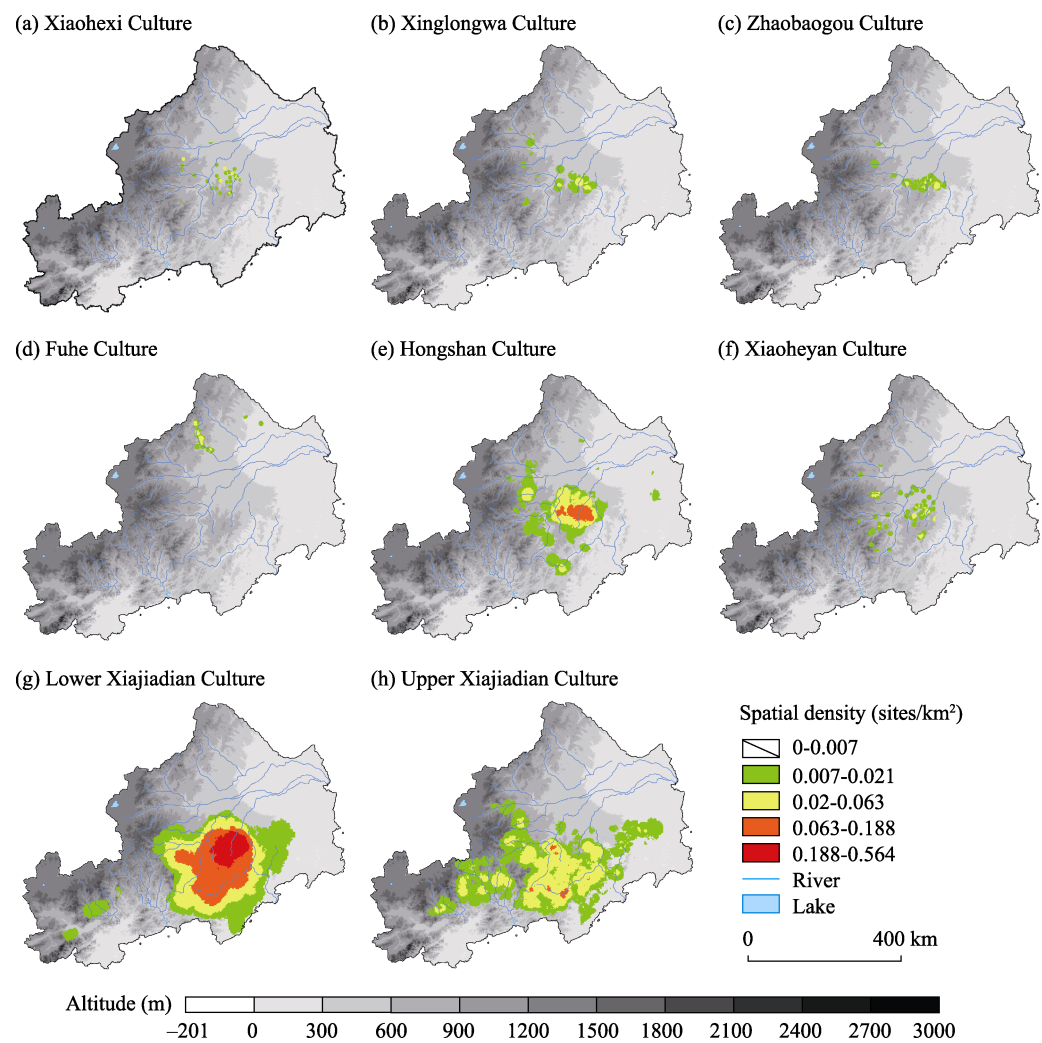


Figure 4 Spatial density map of archaeological sites of each culture

Table 2 Results of nearest-neighbour analysis of archaeological sites of each culture

Culture	Xiao-hexi	Xing-longwa	Zhaobaogou	Fuhe	Hongshan	Xiaoheyang	Lower Xiajiadian	Upper Xiajiadian
ANN	0.966	0.616	0.596	0.735	0.405	0.725	0.159	0.474
p-value	0.710	0.000	0.000	0.001	0.000	0.000	0.000	-0.000
z-score	-0.372	-8.079	-7.463	-3.279	-35.069	-4.518	-116.207	-42.993

5 Discussion

5.1 Climate and environmental change between 10.0–2.0 ka BP in the Yan-Liao region

The prehistoric culture sequence studied here includes the entire Holocene Megathermal period. Because of the sensitivity of the environment to climate in this area and the drastic fluctuations in precipitation and temperature during the Holocene Megathermal period in

North China (Shi *et al.*, 1992; Yancheva *et al.*, 2007; Avni *et al.*, 2010), the development of local prehistoric cultures and human activities were extensively influenced by climatic and environmental changes (Xia *et al.*, 2000; Mu *et al.*, 2014). The significant impact of such changes on the evolution of ancient cultures in other areas has been demonstrated (Hoelzmann *et al.*, 2001; Gao *et al.*, 2007; Wu *et al.*, 2010; Dong *et al.*, 2012a). Thus, outlining the Holocene climate fluctuations in North China and environmental changes in the Yan-Liao region contributes to a better understanding and further discussion. Pollen, sedimentary and geochemical archives for this region provide background information.

Studies have demonstrated that the Holocene Megathermal in northern China began at approximately 8.5 ka BP, before which the climate was cold and dry (Feng *et al.*, 2006). Temperature and rainfall increased dramatically since 8.5 ka BP and then gradually stabilized to a more easily habitable level (Cui and Kong, 1992; Shi *et al.*, 1992). The variation in $\delta^{18}\text{O}$ values (Figure 5a) collected from the Dunde Ice Core (Site A in Figure 1) records from the Qilianshan Mountains represents credible evidence of climate changes in northern China and in the Northern Hemisphere (Thompson *et al.*, 1989; Thompson *et al.*, 1990). The records indicate strong summer monsoons prior to 5.0 ka BP, succeeded by weak monsoon events with a decrease in temperature and precipitation in northern China. The concentrations of total organic carbon (TOC, %) and total inorganic carbon (TIC, %) of a sediment core recovered in the depocenter of Dali Lake (Site B in Figure 1) denote the balance between the water input to the lake and the evaporation of the lake water, indicating fluctuations of precipitation and humidity in the Dali Lake area (Xiao *et al.*, 2008). Drought events, depicted as shaded bars in Figure 5b (6.6–5.8, 5.1–4.85, 4.45–3.75, 3.15–2.65 ka BP), coincide with the weak summer monsoon period in Figure 5a. Pollen data from Hulun Lake (Site C in Figure 1), northeast to the study region, suggest that drought events also occurred in relatively cold intervals (Wen *et al.*, 2010). Pollen records from the Anguli-nuur Lake (Site D in Figure 1) in northern Hebei Province illustrate changes in the ratios of arboreal plants (AP) pollen to non-arboreal plants (NAP) pollen (Figure 5c). From approximately 6.8 ka BP to 2.0 ka BP, the pollen of conifers, primarily *Pinus*, and herbs was generally abundant, whilst pollen of *Chenopodiaceae* and *Artemisia* gradually increased, indicating a drop of water level. Correspondingly, the pollen of deciduous broad-leaved trees was sparse (Wang *et al.*, 2010). Flora remains in the Chahai Site (Site E in Figure 1) prove that many deciduous broadleaved forests were present in this region before 7.0 ka BP (IALP, 2012a), indicating an increase in the number of trees during warm, humid, strong summer monsoon periods (before 6.5 ka BP and approximately 5.8–5.1 ka BP) and the expansion of steppe during cool, arid, weak summer monsoon periods (after 5.1 ka BP) in this region. The ^{14}C dating data and geological analysis of northern China also demonstrated that the environment became colder and drier in 6.0–4.0 ka BP (Mo *et al.*, 2003). A reconstruction of the deviation from the present mean aridity and temperature of southern Liaoning (Figure 5d), derived from sediment and spore-pollen assemblages (39°30'N, 122°E, Site F in Figure 1), demonstrates that the humidity and temperature increased dramatically in 8.0 ka BP and gradually decreased after 6.5 ka BP, with an extreme low temperature event after 3.0 ka BP (GIG, 1977). Although these palaeoenvironmental records are from different sites in the study region or the neighbouring area, the environmental conditions they reflect represent the condition of a

fairly large area. Furthermore, the coherence of these records implies that their integration characterizes the environmental conditions of the Yan-Liao region.

Line graphs of the total number, maximum density and ANN value of archaeological sites are appended here to show their correspondences with environmental changes. Total number and maximum density have increased slightly since 8.5 ka BP, with slight decreases in the ANN value (Figure 5e). This trend is in line with the changes in environmental conditions, which were humid and warm when the Xinglongwa, Zhaobaogou and Fuhe cultures rose and developed. However, the peak in the number and maximum density of archaeological sites and the valley in the ANN value occur in the Lower Xiajiadian culture period between 4.0–3.0 ka BP, when it was drier and colder than the previous period. Additionally, the second peak and valley in Figure 5e between 6.5–5.0 ka BP also occurred in a relatively dry and cool period, which corresponds to the Hongshan culture. To understand the potential causal factors, the subsistence strategies, spatial patterns and evolution process of this culture sequence are discussed with the previously described calculations.

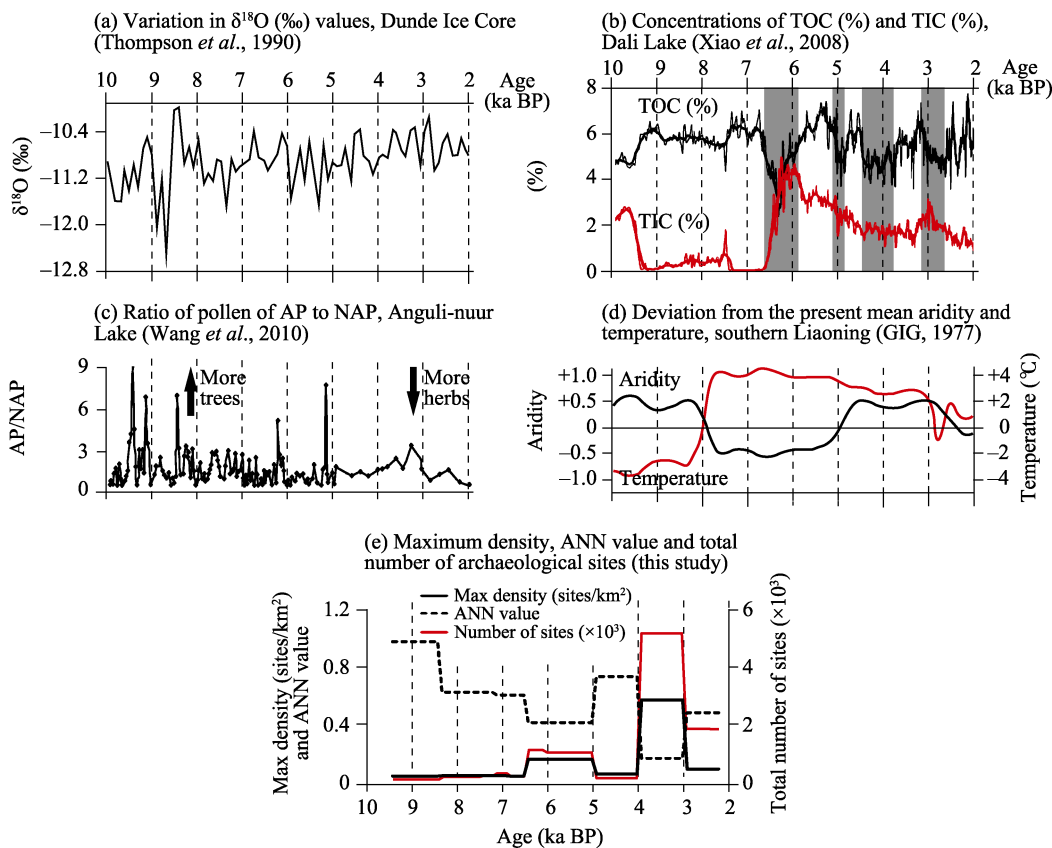


Figure 5 Comparisons of the palaeoenvironmental and archaeological records: (a) the variation in $\delta^{18}\text{O}$ (‰) values from the Dunde Ice Core; (b) the concentrations of total organic carbon (TOC, %) and total inorganic carbon (TIC, %) of the sediment core from Dali Lake; (c) the ratio of pollen of arboreal plants (AP) to that of non-arboreal plants (NAP) in the Anguli-nuur Lake; (d) the reconstruction of deviation from the present mean aridity and temperature in South Liaoning; (e) the changes in the maximum density, ANN value and total number of archaeological sites

5.2 Evolution and subsistence strategies of cultures

The Xiaohexi culture was the first Neolithic culture in the Yan-Liao region. Because of climate fluctuation and primitive level of technology, Xiaohexi has the smallest number of sites (33 sites). The subsequent Xinglongwa, Zhaobaogou and Fuhe cultures developed during a period of relatively comfortable climate conditions. However, the numbers of these sites only increased slightly. Flora and fauna remains from archaeological studies on the Zhaobaogou (IACASS, 1997), Xinglongwa (Liu, 2001), Xinglonggou (Zhao, 2004), Baiyinchanghan (IAIMAR, 2004) and Chahai (IALP, 2012a) sites demonstrated that hunting-gathering was the primary survival strategy of these four cultures, albeit primitive agriculture emerged in the Xinglongwa culture period. The turning point appeared in the Hongshan culture. Archaeological surveys and studies on a number of large sites from the Hongshan culture demonstrate that hunting-gathering remained the primary subsistence strategy in the early stage. However, in the late Hongshan stage, when the climate deteriorated, primitive agriculture was predominant while hunting-gathering was a supplementary activity (IALP, 2012b). Environmental archaeology demonstrates that the temperature decrease in the late Hongshan period was not dramatic. Because of the presence of rivers and their branch streams in the area, the temperature and water supply could support the adoption and development of primitive agriculture, despite the environmental deterioration (IACASS, 1996; IALP, 2012b; Sun and Zhao, 2013). Cohen (1977) demonstrated that only when hunting-gathering cannot provide enough food supplementation, do people adopt agriculture as their primary subsistence strategy to resolve the crisis of food shortages and starvation through cultivation and domestication of plants and animals. Figures 2 and 5 show that the Hongshan culture developed in a relatively dry and cool period with the expansion of steppe. The climate and environment were more favourable for cultivators than hunter-gatherers with respect to obtaining sufficient food. Since the main distribution area of the Hongshan culture is the same as that of the Xinglongwa and Zhaobaogou cultures (Figures 4b, 4c and 4e), the climate change that occurred in this period was likely a primary contributor to the adoption of agriculture. Hunting-gathering was no longer able to provide enough food for the population, which increased during the habitable period. The additional food provided by agriculture resulted in further population growth, as indicated by the remarkable increase in the number and density of Hongshan sites. The lower ANN value is also consistent with the higher clustering level of agriculture. Additionally, the environment in this area during the Xinglongwa and Zhaobaogou cultures was suitable for human habitation, and the food provided by hunting-gathering was abundant such that people were not sufficiently motivated to turn to agriculture, which requires more labour.

Agriculture declined in the Xiaoheyuan culture (Han, 2010) when there was another drought event (Figure 5b). The subsequent Lower Xiajiadian culture developed in a relatively humid period between two drought events, with a significant increase in site number and density that was interpreted as the zenith of the human occupation of this region (Shelach *et al.*, 2011). Fieldwork has revealed that primitive agriculture was more widespread in the Lower Xiajiadian culture than in the Hongshan culture (IACASS, 1996), which is also verified by ANN values. However, because of the vulnerability of primitive agriculture to aridity and low temperatures, the Lower Xiajiadian culture was replaced by the Upper Xia-

jiadian culture with a major shift in subsistence strategies from primitive agriculture to pasturing (IAIMAR and LMNC, 2009) as a result of the large amplitude of aridity and cooling after 3.0 ka BP (Figures 5b-d). Pasturing requires greater living space but can support a smaller population. Therefore, the number, density and clustering level of sites decrease noticeably in the Upper Xiajiadian culture.

5.3 Spatial distribution patterns of archaeological sites

The spatial distribution patterns of archaeological sites can reveal important information on human cultures and the environment. The ANN values (Table 3) reveal that all cultures appear to cluster in space except the Xiaohe culture, which tends to be a random distribution. The density map of the Xiaohe culture (Figure 4a) also indicates that its archaeological sites are scattered evenly across space. Although the Xiaohe, Xinglongwa, Zhaobaogou and Fuhe cultures have approximate maximum density values and their spatial density maps exhibit similar patterns, their ANN values vary. Among these cultures, the Zhaobaogou culture has the smallest ANN value, which indicates the highest clustering level. Based on different catchments and human activities divided between hunting-gathering and agriculture, the sites where these two survival methods were practised present different spatial features. Consequently, the similar spatial density characteristics of the Xiaohe, Xinglongwa, Zhaobaogou, and Fuhe cultures indicate that their survival strategies were similar, while primitive agriculture occupies a relatively high proportion of food-based activity in the Zhaobaogou culture. This inference is supported by archaeological evidence (IACASS, 1997; IAIMAR, 2004; Liu, 2006; IALP, 2012a).

The Fuhe culture is exceptional because of its larger maximum density value and ANN value. The Fuhe sites are primarily distributed along the Olji Moron River, where the terrain is dominated by hills. Archaeological research has demonstrated that the Xinglongwa culture might be an important origin of the Fuhe culture, and connections have been drawn between the Zhaobaogou culture and Fuhe culture (IALP, 2012a). However, evidence of agriculture was scarcely found in the Fuhe sites. The larger maximum density and ANN value indicate that Fuhe sites are distributed more evenly and randomly. One can conclude that hunting-gathering was dominant in Fuhe culture and that the environmental conditions of the Olji Moron River might not have been suitable for primitive agriculture to develop during that period. The Xiaoheyuan culture has a similar ANN value to that of the Fuhe culture but a larger maximum density. This outcome indicates that more sites of the Xiaoheyuan culture were distributed evenly in a smaller area (Figure 4f). A colder climate and the improvement of survival skills (Chen, 2009) may be the main contributors to this development.

The areas with the highest density of the studied cultures are centralized within a limited area and surrounded by areas of low density (Figure 4). The decrease in the ANN value and the increase in density imply that more sites were distributed in high-density areas with fewer sites in surrounding areas. This outcome means increasingly more people inhabited the highly populated areas, while marginal areas had increasingly fewer residents. This trend is apparent in the Hongshan culture with a smaller ANN value of 0.405 and in the Lower Xiajiadian culture, with the smallest ANN value of 0.159. Adoption of primitive agriculture is a crucial causal factor of this trend. The high-density areas on their density maps are obvious (and coloured orange and red, respectively, in Figures 4e and 4g). Patterns of concen-

tric rings appear. However, there are differences between them. In the Hongshan culture, the marginal area with lower site density primarily expands towards the west and north, particularly along the Xar Moron River. In contrast, the marginal area expands more towards the south in the Lower Xiajiadian culture, with more sites along the Dalinghe River and fewer sites along the Xar Moron River. A trend for people to move south in response to colder and drier climate conditions is evident.

A different pattern than that of previous cultures occurs for the Upper Xiajiadian culture due to the adoption of pasturing. Compared to agriculture, pasturing is more active pursuit and more resilient to difficult environments, and requires a larger space. However, its capacity to support a human population is smaller than that of agriculture (Han, 2010). This different pattern elucidates why the Upper Xiajiadian culture has more sites, a larger ANN value and a smaller density value than the Hongshan culture. The Upper Xiajiadian sites are distributed more evenly in space, with several core areas of relatively high density (Figure 4h). These core areas are distributed extensively along river basins, including the Laohahe River, the Jiaolaihe River, the Dalinghe River, the Luanhe River and branches of the Xiliaohe River. This development coincides with characteristics of nomadic production, in which herdsman prefer areas with adequate water and grass. This development also implies pasturing's noticeable position among subsistence strategies in the Upper Xiajiadian culture and the spread of steppe in this region.

The most densely populated areas of these cultures, except the Fuhe culture, all overlap along the Laohahe and Jiaolaihe river basins. Because of the predominance of hunting-gathering before the Hongshan culture and the preference of hunter-gatherers for geographical environment (Yang *et al.*, 2015), the available flora and fauna resources in this area were more sufficient than in other areas in the Yan-Liao region at 9.5–6.5 ka BP. Primitive agriculture progressed and the relative population index reached a high level in the Hongshan and Lower Xiajiadian cultures (CICARP, 2003). Thus, the proportion of primitive agriculture practised at sites distributed along the Laohahe and Jiaolaihe river basins was also larger than that in other areas. This inference is supported by archaeological evidence of stone implements and remains (Yang *et al.*, 2000; IAIMAR, 2004; Suo *et al.*, 2005; IALP, 2012a; Sun and Zhao, 2013). Considering the thousands of years of continual occupation by human beings and the high density of the Hongshan and Lower Xiajiadian archaeological sites in this area, the population capacity of this basin must have been much higher than that of other areas, which also means a habitable environment in the prehistoric period.

6 Conclusions

This paper has described and interpreted the holistic spatial-temporal patterns of archaeological sites that belong to a sequence of prehistoric cultures in the region from the Yanshan Mountains to the Liaohe River Plain during 9.5–2.3 ka BP. With the basic information of 8353 sites and GIS technology, several characteristic values were calculated and a series of maps were created. The integration and analysis of climatic and regional environmental records as well as calculations, including density calculation and the nearest-neighbour analysis, have provided a broad long-term perspective on cultural evolution, the spatial-temporal distribution features of the archaeological sites and human activities against the backdrop of

environmental and climatic changes.

Four main conclusions are drawn from the results. First, prehistoric cultural evolution and subsistence strategies in the Yan-Liao region were extensively influenced by climatic and environmental changes, particularly the deterioration of the environment in 6.6–5.8 ka BP and 3.15–2.65 ka BP. Second, the Xinglongwa, Zhaobaogou and Fuhe cultures primarily developed during a climatically comfortable period during the strong summer monsoon phase in 8.5–6.0 ka BP, with higher temperatures and greater precipitation. These three cultures and the Xiaohexi culture exhibit similar subsistence strategies dominated by hunting-gathering and similar spatial distribution patterns. Third, significant changes occurred in the survival strategies of the Hongshan, Lower Xiajiadian and Upper Xiajiadian cultures when the summer monsoon began to weaken and the environment began deteriorating after 6.0 ka BP. Primitive agriculture predominated during the late stage of the Hongshan culture and the entire Lower Xiajiadian culture and was replaced by pasturing in the Upper Xiajiadian culture as a result of the sudden decrease in temperature, the increase in aridity and the spread of steppe. The rapid increase in the number and clustering level of Hongshan and Lower Xiajiadian archaeological sites and their concentric circle-shaped distribution pattern are likely the results of the development of primitive agriculture. Last, the most densely populated areas of the studied cultures are centralized within a limited area and surrounded by less densely populated areas. The Laohahe and Jiaolaihe river basins formed the core area where most archaeological sites were distributed during the strong summer monsoon period and the first few thousand years of the weak summer monsoon period.

References

- ArcGIS, December 2016. What is a z-score? What is a p-value? Environmental Systems Research Institute (ESRI), California. [http://resources.arcgis.com/en/help/main/10.1/index.html#/What_is_a_z_score_What_is_a_p_value/005p0000000600000000/](http://resources.arcgis.com/en/help/main/10.1/index.html#/What_is_a_z_score_What_is_a_p_value/005p000000060000000/).
- Avni Y, Zhang J F, Shelach G *et al.*, 2010. Upper Pleistocene-Holocene geomorphic changes dictating sedimentation rates and historical land use in the valley system of the Chifeng region, Inner Mongolia, northern China. *Earth Surface Processes and Landforms*, 35(11): 1251–1268.
- Brantingham P J, Gao X, 2006. Peopling of the northern Tibetan Plateau. *World Archaeology*, 38(3): 387–414.
- Chang K C, 1967. Rethinking Archaeology. New York: Random House, 32–48.
- Chen G Q, 2009. Analysis on the mutual movement relation between Xiaohexi culture and other archaeology culture. *Research of China's Frontier Archaeology*, 36–46. (in Chinese)
- CHGIS, 2017. CHGIS Version 4. Cambridge: Harvard Yenching Institute and Fudan Center for Historical Geography. <http://dx.doi.org/10.7910/DVN/PDGOZ0>.
- Chinese Academy of Sciences (CAS), 1984. Physical Geography of China: Climate. Beijing: Science Press, 158. (in Chinese)
- Chifeng International Collaborative Archaeological Research Project (CICARP), 2003. Regional Archaeology in Eastern Inner Mongolia: A Methodological Exploration. Beijing: Science Press. (in Chinese)
- Cohen M N, 1977. The Food Crisis in Prehistory: Overpopulation and the Origins of Agriculture. New Heaven: Yale University Press, 18–70.
- Cui H T, Kong Z C, 1992. A preliminary analysis about the climatic fluctuation of Holocene Megathermal in the centre and eastern part of Inner Mongolia. In: Shi Y F (ed.). The Climates and Environments of Holocene Megathermal in China. Beijing: China Ocean Press, 72–79. (in Chinese)
- Dong G H, Jia X, An C B *et al.*, 2012a. Mid-Holocene climate change and its effect on prehistoric cultural evolu-

- tion in eastern Qinghai Province, China. *Quaternary Research*, 77(1): 23–30.
- Dong G H, Jia X, Elston R *et al.*, 2013. Spatial and temporal variety of prehistoric human settlement and its influencing factors in the upper Yellow River valley, Qinghai Province, China. *Journal of Archaeological Science*, 40(5): 2538–2546.
- Dong G H, Yang Y, Zhao Y *et al.*, 2012b. Human settlement and human-environment interactions during the historical period in Zhuanglang County, western Loess Plateau, China. *Quaternary International*, 281: 78–83.
- Feng Z D, An C B, Wang H B, 2006. Holocene climatic and environmental changes in the arid and semi-arid areas of China: A review. *Holocene*, 16(1): 119–130.
- Gao H Z, Zhu C, Xu W F, 2007. Environmental change and cultural response around 4200 cal. yr BP in the Yishu River Basin, Shandong. *Journal of Geographical Sciences*, 17(3): 285–292.
- Guiyang Institute of Geochemistry, Academia Sinica (GIG), 1977. Evolution of natural environments in last 10,000 yrs in southern Liaoning Province. *Scientia Sinica*, (6): 603–614. (in Chinese)
- Guo Y Y, Mo D W, Mao L J *et al.*, 2013. Settlement distribution and its relationship with environmental changes from the Neolithic to Shang-Zhou dynasties in northern Shandong, China. *Journal of Geographical Sciences*, 23(4): 679–694.
- Han M L, 2010. A study on settlements and environment of prehistoric times in the West Liaohe River Valley. *Acta Archaeologica Sinica*, 1: 1–20. (in Chinese)
- Han M L, Zhang Y, Fang C *et al.*, 2008. Location and environment of the settlements and man-land relationship in West Liaohe River Basin since Holocene. *Geographical Research*, 27(5): 1118–1128. (in Chinese)
- Harrower M J, 2010. Geographic Information Systems (GIS) hydrological modeling in archaeology: An example from the origins of irrigation in Southwest Arabia (Yemen). *Journal of Archaeological Science*, 37(7): 1447–1452.
- Hoelzmann P, Keding B, Berke H *et al.*, 2001. Environmental change and archaeology: Lake evolution and human occupation in the Eastern Sahara during the Holocene. *Palaeogeography Palaeoclimatology Palaeoecology*, 169(3/4): 193–217.
- Hou X Y, 2001. Vegetation Atlas of China (1:1000000). Beijing: Science Press. (in Chinese)
- Institute of Archaeology of Chinese Academy of Social Sciences (IACASS), 1996. Report of Archaeological Excavation of Settlement Sites and Tombs of Dadianzi Site of Lower Xiajiadian Culture. Beijing: Science Press. (in Chinese)
- Institute of Archaeology of Chinese Academy of Social Sciences (IACASS), 1997. Zhaobaogou Site, the Neolithic Settlement Site in Aohan Banner. Beijing: Encyclopedia of China Publishing House. (in Chinese)
- Institute of Archaeology of the Inner Mongolia Autonomous Region (IAIMAR), 2004. Report of Archaeological Excavation of the Neolithic Settlement, Baiyinchanghan Site. Beijing: Science Press. (in Chinese)
- Institute of Archaeology of the Inner Mongolia Autonomous Region (IAIMAR) and Liaozhongjing Museum in Ningcheng County (LMNC), 2009. Report of Archaeological Excavation of Xiaoheshigou Settlement Site of Upper Xiajiadian Culture. Beijing: Science Press. (in Chinese)
- Institute of Archaeology of Liaoning Province (IALP), 2012a. Report of Archaeological Excavation of the Neolithic Settlement, Chahai Site. Beijing: Cultural Relics Press. (in Chinese)
- Institute of Archaeology of Liaoning Province (IALP), 2012b. Report of Archaeological Excavation of Niuheliang Settlement Site of Hongshan Culture, from 1983 to 2003. Beijing: Cultural Relics Press. (in Chinese)
- Knitter D, Blum H, Horejs B *et al.*, 2013. Integrated centrality analysis: A diachronic comparison of selected Western Anatolian locations. *Quaternary International*, 312: 45–56.
- Li C H, Zheng Y F, Yu S Y *et al.*, 2012. Understanding the ecological background of rice agriculture on the Ningshao plain during the Neolithic age: Pollen evidence from a buried paddy field at the Tianluoshan cultural site. *Quaternary Science Reviews*, 35: 131–138.
- Li T Y, Mo D W, Kidder T *et al.*, 2014. Holocene environmental change and its influence on the prehistoric culture evolution and the formation of the Taosi site in Linfen basin, Shanxi province, China. *Quaternary International*, 349: 402–408.

- Liu G X, 2001. A preliminary probing into the settlement pattern of Xinglongwa culture. *Archaeology and Cultural Relics*, (6): 58–67. (in Chinese)
- Liu G X, 2006. Comparative research on the Xinglongwa culture and the Fuhe culture. *Northern Cultural Relics*, (2): 1–10. (in Chinese)
- Mo D W, Wang H, Li S C, 2003. Effects of Holocene environmental changes on the development of archaeological cultures in different regions of north China. *Quaternary Sciences*, 23(2): 200–210. (in Chinese)
- Mu Y, Qin X G, Zhang L *et al.*, 2014. A preliminary study of Holocene climate change and human adaptation in the Horqin Region. *Acta Geologica Sinica-English Edition*, 88(6): 1784–1791.
- Qiao Y, 2007. Development of complex societies in the Yiluo region: A GIS based population and agricultural area analysis. In: Bellwood P *et al.* (ed.). *Bulletin of the Indo-Pacific Prehistory Association*: 27: 61–75.
- Shelach G, Raphael K, Jaffe Y, 2011. Sanzuodian: The structure, function and social significance of the earliest stone fortified sites in China. *Antiquity*, 85(327): 11–26.
- Shi Y F, Kong Z C, Wang S M *et al.*, 1992. The climate changes and important events during the Holocene Megathermal in China. *Science in China (Series B)*, (12): 1300–1308. (in Chinese)
- State Administration of Cultural Heritage (SACH), 2003. Atlas of Chinese Cultural Relics: Inner Mongolia Autonomous Region Volume. Xi'an: Xi'an Cartographic Publishing House. (in Chinese)
- State Administration of Cultural Heritage (SACH), 2008. Atlas of Chinese Cultural Relics: Beijing Volume. Beijing: Science Press. (in Chinese)
- State Administration of Cultural Heritage (SACH), 2009. Atlas of Chinese Cultural Relics: Liaoning Volume. Xi'an: Xi'an Cartographic Publishing House. (in Chinese)
- State Administration of Cultural Heritage (SACH), 2013. Atlas of Chinese Cultural Relics: Hebei Volume. Beijing: Cultural Relics Press. (in Chinese)
- Sun Y G, Zhao Z J, 2013. A synthetic study of floral remains of Weijaiwopu Site of Hongshan culture. *Agricultural Archaeology*, 3: 1–5. (in Chinese)
- Suo X F, Li S B, Ma F L, 2005. A brief report of archaeological excavation of Shuiquan Site in Linxi County in the Inner Mongolia Autonomous Region. *Archaeology*, (11): 19–29. (in Chinese)
- Tarasov P, Jin G Y, Wagner M, 2006. Mid-Holocene environmental and human dynamics in northeastern China reconstructed from pollen and archaeological data. *Palaeogeography Palaeoclimatology Palaeoecology*, 241(2): 284–300.
- Thompson L G, Thompson E M, Davis M E *et al.*, 1989. Holocene-late Pleistocene climatic ice core records from Qinghai-Tibetan Plateau. *Science*, 246(4929): 474–477.
- Thompson L G, Thompson E M, Davis M E *et al.*, 1990. Glacial stage ice core records from the subtropical Dunde Ice Cap, China. *Annals of Glaciology*, (14): 288–297.
- Wagner M, Tarasov P, Hosner D *et al.*, 2013. Mapping of the spatial and temporal distribution of archaeological sites of northern China during the Neolithic and Bronze Age. *Quaternary International*, 290: 344–357.
- Wang H Y, Liu H Y, Zhu J L *et al.*, 2010. Holocene environmental changes as recorded by mineral magnetism of sediments from Anguli-nuur Lake, southeastern Inner Mongolia Plateau, China. *Palaeogeography Palaeoclimatology Palaeoecology*, 285(1/2): 30–49.
- Wang L, Wu H, Jia X, 2016. Study on the temporal-spatial evolution of prehistoric settlements and its correlation with subsistence strategy and climate history in the Western Liao River area. *Advances in Earth Science*, 31(11): 1159–1171. (in Chinese)
- Wen R L, Xiao J L, Chang Z G *et al.*, 2010. Holocene precipitation and temperature variations in the East Asian monsoonal margin from pollen data from Hulun Lake in northeastern Inner Mongolia, China. *Boreas*, 39(2): 262–272.
- Wu L, Wang X Y, Zhou K S *et al.*, 2010. Transmutation of ancient settlements and environmental changes between 6000–2000 a BP in the Chaohu Lake Basin, East China. *Journal of Geographical Sciences*, 20(5): 687–700.
- Xia Z K, Deng H, Wu H L, 2000. Geomorphologic background of the prehistoric cultural evolution in the Xar

- Moron River Basin, Inner Mongolia. *Acta Geographica Sinica*, 55(3): 329–336. (in Chinese)
- Xiao J L, Si B, Zhai D Y *et al.*, 2008. Hydrology of Dali Lake in central-eastern Inner Mongolia and Holocene East Asian monsoon variability. *Journal of Paleolimnology*, 40(1): 519–528.
- Xiao J L, Wu J T, Si B *et al.*, 2006. Holocene climate changes in the monsoon/arid transition reflected by carbon concentration in Daihai Lake of Inner Mongolia. *Holocene*, 16(4):551–560.
- Xu J J, Jia Y L, Ma C M *et al.*, 2016. Geographic distribution of archaeological sites and their response to climate and environmental change between 10.0–2.8 ka BP in the Poyang Lake Basin, China. *Journal of Geographical Sciences*, 26(5): 603–618.
- Yancheva G, Nowaczyk N R, Mingram J *et al.*, 2007. Influence of the intertropical convergence zone on the East Asian monsoon. *Nature*, 445(7123): 74–77.
- Yang H, Liu G X, Shao G T, 2000. Research of the Xinglonggou Site in Aohanqi Banner in the Inner Mongolia Autonomous Region. *Archaeology*, (9): 30–48. (in Chinese)
- Yang X Y, Ma Z K, Li J *et al.*, 2015. Comparing subsistence strategies in different landscapes of North China 10,000 years ago. *Holocene*, 25(12): 1957–1964.
- Zhang H, Bevan A, Fuller D *et al.*, 2010. Archaeobotanical and GIS-based approaches to prehistoric agriculture in the upper Ying valley, Henan, China. *Journal of Archaeological Science*, 37(7): 1480–1489.
- Zhang H Q, Zhao W M, Liu B, 2007. Mathematical modelling of the relationship between Neolithic sites and the rivers in Xi'an (Shaanxi Province, China). *Archaeometry*, 49(4): 765–773.
- Zhang J F, Wang X Q, Qiu W L *et al.*, 2011. The paleolithic site of Longwangchan in the middle Yellow River, China: Chronology, paleoenvironment and implications. *Journal of Archaeological Science*, 38(7): 1537–1550.
- Zhao Z J, 2004. To study the origin of primitive agriculture from the flotation results of Xinglonggou Site. In: the Department of Cultural Relics and Museology of Nanjing Normal University (ed.). *Antiquities of Eastern Asia* (Volume A). Beijing: Cultural Relics Press, 188–199. (in Chinese)