

The settlement patterns of the Beixin Culture and its influencing factors in the Xue River Basin, Southwest Shandong

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Abstract

The Xue River Basin (XRB), a key sub-basin of the Wen-Si River Basin in south-central Shandong, contains one of the densest concentrations of Beixin Culture settlements (7.3–6.1 ka BP) and offers a case for examining Middle Neolithic settlement formation in northern China. Yet intra-Beixin settlement evolution remains poorly resolved. Here, we integrate newly available systematic survey records with GIS-based spatial analysis to reconstruct Beixin settlement patterns in the XRB. Settlements were preferentially located on higher, well-drained fluvial terraces, suggesting that stable secondary terraces, reliable water and soil resources, and a warm, humid mid-Holocene climate supported early occupation and agricultural development. From the early to middle Beixin phase, settlements became increasingly clustered, although regional settlement organization remained at an early developmental stage. These results reveal localized trajectories of settlement aggregation and provide insight into the emergence of social complexity in the Haidai region.

Introduction

Settlements provide a direct spatial record of prehistoric human activity, reflecting patterns of resource use, environmental adaptation, and social organization^{1–5}. Their distribution and evolution are shaped by both environmental conditions, such as climate, hydrology, topography, and social processes, including demographic growth, economic development, interaction networks, and changing forms of organization^{6–16}. Understanding how these factors operated at regional and local scales is therefore essential for reconstructing prehistoric human-environment interactions and early social development. With the increasing application of quantitative approaches in settlement archaeology, geographic information system (GIS)-based spatial analysis has become an important tool for examining settlement location, aggregation, and relationships with environmental variables^{2,5,13}. However, existing studies have often focused on broad settlement distributions or general environmental factors, whereas detailed changes within a single archaeological culture, including intra-cultural settlement clustering, spatial heterogeneity, and changing human-environment relationships, remain less well understood.

The Beixin Culture (7.3–6.1 ka BP) represents a major middle Neolithic culture in the Haidai region, with nearly 100 sites documented through archaeological investigations and previous regional studies¹⁷. Centered on the Wen-Si River Basin in south-central Shandong, it also extended into surrounding areas and developed several regional variants, including those in northern Shandong, northern Jiangsu, and the Jiaodong Peninsula¹⁸(Fig. 1a). Chronologically, the Beixin Culture can be divided into early, middle, and late phases¹⁸. Culturally, it developed from the Houli culture, interacted with neighboring cultural traditions such as the Peiligang Culture from the Central Plains and the Shuangdun Culture from the Huai River Basin¹⁹, and later contributed to the formation of the Dawenkou Culture in the Haidai region¹⁷. The Beixin Culture featured a diverse subsistence economy that included crop cultivation, livestock rearing, hunting, and gathering^{20–22}. In some areas, archaeobotanical evidence also suggests the coexistence of millet and rice farming^{23,24}. This relatively stable subsistence economy provided important conditions

for settlements, sedentism, and regional social development^{25,26}. Previous studies of the Beixin Culture have mainly addressed cultural characteristics, chronological sequence, subsistence economy, and regional interaction^{20,23,27}. However, its settlement organization remains poorly understood at the intra-cultural and micro-regional scale. In particular, it is still unclear how Beixin settlements were arranged within individual phases, whether local settlement aggregation had begun to emerge, and how these spatial patterns were related to river terraces, drainage conditions, and other local environmental settings. This gap limits our understanding of how early sedentary communities in the Haidai region organized space and adapted to local landscapes.

Within this context, the Xue River Basin (XRB), which contains abundant Beixin Culture remains and preserves a relatively continuous prehistoric cultural sequence in the western Haidai region, provides a suitable small-watershed case for examining how local settlement organization developed within the Beixin Culture. Compared with single-site analysis, a basin-scale approach allows relationships among settlements, patterns of aggregation, and site-location choices to be evaluated in relation to landforms, river systems, and drainage conditions. Here, we use newly available archaeological survey data with GIS-based spatial analysis to reconstruct Beixin Culture settlement patterns in the XRB. By focusing on settlement variations within a small watershed, this study provides a micro-regional perspective on early settlement organization and human-environment interactions in the Haidai region.

Methods

Study area

The Xue River Basin is located on the southern margin of the Wen-Si River Basin, and the Xue River originates from Chai Mountain and eventually flows southward into Weishan Lake, with a total length of approximately 89.6 km²⁷. The basin covers an area of about 960 km² and lies in the southern part of the North China Plain, bordered by the Nishan Hills to the northeast (Fig. 1b). The XRB contains diverse geomorphological settings. Its upper reaches are characterized by low-mountains and hills, with elevations ranging from 200 to 500 m. The middle reaches consist mainly of piedmont denudation plains, generally between 100 and 150 m in elevation. The lower reaches are dominated by lacustrine depressions and transitional lowlands, with elevations of 30 to 40 m²⁸. These geomorphological differences provide varied environmental settings for prehistoric settlement location and land use.

Since the 1960s, several Beixin Culture sites have been identified in the XRB, including Beixin, Minzhuangxinan (MZNXN), Xikangliu (XKL), and Guanqiaocun (GQCUN)^{18,29–32}. A systematic regional archaeological survey conducted jointly by the National Museum of China and Shandong University from 2010 to 2012 further recorded prehistoric sites and artifact collection points across the basin, providing the main spatial dataset for the present study³³. Together with published excavation reports and previous regional studies, these materials form the basis for reconstructing Beixin Culture settlement units and analyzing their spatial distribution in relation to local landforms and river systems.

Archaeological data and GIS database

Using GPS positioning and GIS analysis, the survey redefined site boundaries and systematically analyzed the macro-morphology and diachronic evolution of settlements from a settlement archaeology perspective. The survey identified a total of 77 prehistoric sites, including eight belonging to the Beixin Culture. These results not only enriched the distribution data of known sites but also provided a more systematic and solid archaeological foundation for further research on the formation, development, and social organization of Beixin settlements.

The archeological data in this study were obtained from were compiled from the Chinese Cultural Relic Atlas, published excavation reports³³, previous regional studies, and the systematic archaeological survey report of the Xue River Basin. The dataset includes 72 Beixin Culture artifact collection points recorded during regional survey, and 10 settlement sites previously reported. These data were standardized and integrated in ArcGIS Pro to construct a GIS database containing coordinates, cultural attribution, chronological phase, pottery types and quantities, settlement attribution, landform category, elevation, and hydrological context.

All spatial data were transformed into a projected coordinate system suitable for distance-based analysis in the study area (CGCS2000 / 3-degree Gauss-Kruger CM 117E, EPSG:4548). Elevation data were derived from a 15-arcsecond DEM sourced from the General Bathymetric Chart of the Oceans (GEBCO). Because this DEM resolution is insufficient for independently identifying small-scale terrace morphology, landform and terrace assignments were based primarily on the systematic archaeological survey report, published geomorphological descriptions, and regional archaeological records. River courses and the XRB boundary were digitized and modified according to the systematic archaeological survey report of the Xue River Basin and checked against the DEM and modern hydrological data.

Settlements identification

To reconstruct settlements units from artifact distributions, density-based spatial clustering of applications with noise (DBSCAN) was applied to the 72 Beixin Culture artifact collection points gathered from the regional systematic survey. DBSCAN was selected because it can identify spatially dense artifact clusters while distinguishing low-density scatters as noise results. The neighborhood distance threshold (Eps) was determined using incremental spatial autocorrelation analysis, which progressively evaluates spatial autocorrelation intensity across increasing distance intervals and identifies the scale at which artifact clustering is most pronounced^{34,35}. The strongest spatial association occurred at 300 m; therefore, Eps was set to 300 m. The minimum number of points required to form a cluster was set to 3.

The DBSCAN results were further evaluated using published excavation reports, previous survey records, and known site information. Low-density artifact scatters located within 300 m of an identified cluster and sharing the same Beixin Culture attribution were assigned to the corresponding settlement unit.

Scattered points outside existing clusters were generally retained as noise. However, when scattered points were spatially isolated from known settlements and unlikely to represent artifact drift from nearby clusters, they were considered as tentative independent settlement units after comparison with archaeological records. Through this procedure, the artifact collection points were converted into settlement units for subsequent spatial analysis.

The chronological attribution of each settlement was based mainly on diagnostic pottery assemblages, together with published excavation records and existing chronological studies of the Beixin Culture. Settlements were assigned to the early, middle, or late Beixin phases where phase-specific pottery evidence was available. Sites that could only be attributed broadly to the Beixin Culture were treated as undetermined in the phase-specific analysis.

Environmental setting and site-location analysis

The environmental setting of each reconstructed settlement was evaluated using landform category, elevation, slope, aspect, and distance to rivers. Landform categories were assessed descriptively because they represent categorical geomorphological units. Elevation, slope, aspect, and distance to the nearest river channel were extracted from the GIS database for each artifact collection point and settlement unit. River distance was calculated as Euclidean distance to the nearest major river or tributary.

To explore spatially varying relationships between artifact distribution and environmental variables, multiscale geographically weighted regression (MGWR) was applied to the artifact-point dataset. The dependent variable was pottery sherd count recorded at each artifact collection point, and the explanatory variables included elevation, slope, aspect, and distance to the nearest river. All explanatory variables were standardized before modelling. MGWR was used as an exploratory tool because it allows different environmental variables to operate at different spatial scales^{36,37}. Local regression coefficients and their statistical significance were mapped to evaluate whether the effects of environmental variables were spatially consistent or heterogeneous across the XRB.

Settlement aggregation and spatial structure analysis

Settlement aggregation and spatial relationships were examined using kernel density estimation (KDE), Ripley's K-function, Thiessen polygons, and site catchment analysis (SCA). KDE was applied to the artifact collection points to visualize spatial variation in artifact concentration and to identify areas of higher settlement intensity. The bandwidth was set to 3.8 km.

Ripley's K-function was calculated using the centroids of reconstructed settlement units to test whether Beixin settlements were clustered, randomly distributed, or dispersed at different spatial scales. Confidence envelopes were generated using 99 Monte Carlo simulations under complete spatial

randomness. The transformed L(d) curve was used to compare the observed settlement distribution with the expected random pattern across increasing distance ranges.

Thiessen polygons were generated from settlement centroids to approximate nearest-neighbor spatial relationships among settlements. These polygons were used only as theoretical zones of spatial proximity rather than direct evidence for territorial control. SCA was used to estimate potential catchment areas around settlements based on a maximum catchment radius determined by nearest-neighbor distances. The distance was set to 2592 m. Catchment overlap was interpreted cautiously as an exploratory indicator of possible spatial interaction or shared resource zones, rather than as direct evidence of resource competition or political territoriality.

Results

Spatial and temporal distribution of settlements

According to DBSCAN results, there are seven Beixin Culture settlements in XRB: Beixin (BX), Qiantainan (QTN), Fancundongnan (FCDN), Huloubai (HLB), Qianbaqiao (QBQX), XKL and MZXN (Fig. 2). There are four additional areas with scattered, low-density artifact distributions. To mitigate the inherent detection bias of the current regional survey, we calibrated the DBSCAN outputs using past excavation and survey materials. This added three sites to our inventory: Mengzhuangdongbei (MZDB) from a previous survey³² and GQCN from later excavations³⁰, both missed during the current survey. Near Wuxiaozhuangnan (WXZN), two adjacent artifact noises are quite distant from other Beixin Culture sites. Given the low likelihood of artifact drift from those distant locations, this area can tentatively be considered an independent site. Consequently, XRB contains 10 Beixin Culture settlements.

In terms of chronological scope, by integrating mainstream scholarly research on the phasing and chronology of the Beixin Culture and conducting detailed analysis of diagnostic artifacts from each settlement—with pottery assemblages serving as the core dating material—the developmental sequence of Beixin Culture settlements in the study area can be divided into Early, Middle and Late phases. Although the available archaeological materials are limited and numerous undiscovered settlements dating to this culture likely remain unexcavated, the existing data still reveals general and phase-specific spatiotemporal characteristics of settlement distribution. A spatiotemporal analysis of the settlements reveals that they were predominantly concentrated in the central and eastern regions of the study area, yet their quantity and spatial extent display certain variations. In the early stage, the BX and XKL were located near the Guanqiao paleochannel in the upper section of the lower Xue River, flanking this segment to the east and west. In the middle stage, settlements proliferated to 6. Expanding towards the southwest and northeast, new settlements emerged in both the upper section of the middle Xue River and the lower section of the lower Xue River. In the late stage, the number of settlements stood at four. While previously prosperous sites such as XKL and GQCN saw no continuation, the overall spatial distribution broadened further. New settlements such as the MZXN and the QBQX had appeared in the upper and lower reaches of the middle and lower reaches of the Xue River. WXZN settlement in the lower

section of the middle Xue River can be preliminarily dated to the Beixin Culture period, though its specific phase is yet to be determined.

Settlement selection strategy

Beixin Culture settlements in XRB were distributed across diverse geomorphic settings. QTN, MZXN, and FCDN were located on the piedmont alluvial fan; MZDB and WXZN on the fluvio-alluvial plain in the middle Xue River; BX, XKL and GQCN on the lower alluvial-fan plain; and HLB and QBQX on the lower alluvial-proluvial plain.

In terms of elevation distribution, 10 settlements were concentrated between 30 and 100 m in elevation, none occurred below 30 m or above 100 m. In terms of distance from rivers, settlements were highly dependent on the mainstream and major tributaries of the Xue River, with their distribution closely aligning with the water system. FCDN lay approximately 1.7 km southeast of the Xue River, and GQCN was distributed at approximately 500 m from south of the current Xiaowei River. Other settlements were mostly located between 100 and 200 m from the main channel of the Xue River.

MGWR results indicated that the influence of elevation on pottery shard distribution exhibited spatial heterogeneity (Fig. 3a). In the central part of the study area observed significant effects, while the eastern and western areas showed predominantly nonsignificant effects. The regression coefficients were predominantly positive, pointing to a positive correlation between shard quantity and elevation within a specific range. Spatially, the settlements located within these statistically significant zones mainly included BX, XKL, HLB, and WXZN. In contrast, the effects of river distribution, slope, and aspect were generally nonsignificant across the study area (Fig. 3b-3d). Although their regression coefficients fluctuated between positive and negative values, the majority failed to demonstrate statistical significance.

Settlement hierarchy and aggregation patterns

KDE results (Fig. 4a) revealed a high-density zone at BX in the central study area, exactly where the Guanqiao paleochannel meets the Dasha River. This area has the highest kernel density values and the largest clustered area. The medium-density zones are mainly found around the outside of this main center, forming two clear secondary clusters. One is located to the west in the Xiaowei River basin, and the other is to the northeast in the upper reaches of the Xue River. The low-density zones are found in places like the Xiaosu River basin and south of the Dasha River. In these areas, scattered, smaller settlements form isolated patches that cover a small area and have low density.

The Thiessen polygon results (Fig. 4a) showed that the central study area contained smaller polygons with complex boundaries, whereas the western and southeastern regions featured relatively larger polygons. Additionally, there was overlap between the resource catchments of settlements in the central and northeastern regions. The seven settlements from the middle stage generated a relatively balanced

distribution of polygons and resource catchments, and most settlements maintained independent theoretical resource ranges. However, the resource catchments of XKL and GQCN, QTN and MZXN, as well as MZXN and MZDB exhibited a high degree of overlap.

According to the Beixin DBSCAN results (Fig. 4b), the core artifact distribution zone spanned 93 m, and the general distribution zone covered about 240 m. The analysis identified six general distribution zones, the clusters to the west, east and north of the core area are closer to the center, showing tighter spatial connections. In contrast, the clusters in the northwest and south are further away from the core, displaying a more scattered pattern.

Ripley's K-function (SI Appendix, Fig. S1) demonstrated the observed $L(d)$ curve drops below the expected value, falling under the lower confidence interval. This means the settlements did not form significant spatial clusters at the basin-wide scale. At a scale of about 4,200 to 7,000 m, the curve rises and touches the upper confidence interval. Within this specific larger range, the settlements show a slight tendency to cluster.

Discussion

The fluvial terraces and foundations of Beixin Culture settlement distribution

Our analysis shows that Beixin Culture settlements in XRB were mainly distributed along fluvial terraces and increased inter-settlement connectivity within specific river reaches. To understand the process of development from scattered settlement to local settlement clusters, we further discuss the results of settlement distribution in the comprehensive context of secondary terraces environment, resource acquisition strategies and early social development.

Although XRB currently lacks local high-resolution paleoenvironmental records, existing regional environmental data^{38–40} can provide a reference for understanding settlement selection. During the Beixin Culture period, XRB experienced the warm and humid climate typical of the mid-Holocene (Fig. 5). The East Asian summer monsoon was strong and stable³³, while rising sea surface temperatures in the nearby Yellow Sea indicated that the East Asian winter monsoon remained weak³⁹. In the early Beixin period, after an initial phase of incision, the Xue River channel gradually stabilized and secondary fluvial terraces formed³³, providing a stable topographical foundation for settlements. Driven by intensified summer monsoon precipitation, surface weathering and fluvial transport processes were likely enhanced^{41–43}. During seasonal flooding events, the Xue River would have continuously delivered fine-grained materials, such as silt and clay, to the valley margins and the alluvial-proluvial plain, resulting in the gradual thickening of the sedimentary layers^{44,45}. Optimal hydrothermal conditions may increase vegetation coverage and fostered extensive deciduous broadleaf forests and deciduous-evergreen broadleaf forests dominated with subtropical species^{46–48}. The plant litter and root residues from the

lush vegetation provide an abundant potential carbon source, enabling the continuous accumulation of surface organic matter and thereby improving soil fertility^{49–51}.

Influenced by these environmental factors, most settlements of the Beixin Period in XRB were located on relatively high, flat areas or on secondary fluvial terraces. Archaeological evidence from the middle and lower Yangtze River regions clearly show that the locations of prehistoric settlements were heavily influenced by changing river levels^{52–54}. Rivers do more than provide a reliable water supply and food sources, they also serve as vital corridors for transportation, resource exchange, and cultural communication^{55,56}. Although the archaeological records of XRB never directly explain the river's function, the pattern of settlements in the basin exhibits a ribbon-like and beaded pattern along the river, resembling the macro-scale pattern of Neolithic settlements in the Yangtze River basin. This pattern is a common feature of Neolithic settlements in eastern China. It serves as direct evidence that early agricultural societies were highly dependent on water resources. The Xue River and its tributaries not only supported subsistence and settlement activities but also likely functioned as important corridors for movement and exchange.

These climatic, topographical, and soil conditions constituted an ecological setting in XRB during the Beixin period, which was highly suitable for stable settlement and early agricultural development. Specifically, the warm, rainy climate and abundant river networks provided a rich resource base, enabling the Beixin Culture people to integrate hunting, fishing, foraging, and animal husbandry^{21,22}. This environmentally supported diversification acted as a natural buffer, granting the settlement the resilience to withstand extreme weather, floods, and crop failures, thereby allowing the community to adapt and thrive across generations.

From the perspective of settlement location selection, the Beixin Culture settlements in XRB were not confined to a single type of terrain, instead ranging from mountain foothills to the floodplains in the middle and lower parts of the river. This revealed that the Beixin people were highly flexible in adapting their living spaces to different natural environments. In terms of exact positions, most settlements revealed a remarkably consistent preference for specific local terrain. They were primarily built on elevated fluvial terraces or relatively high, flat ground, while always remaining close to the main Xue River, its tributary gully, or natural gully. This indicates that Beixin Culture settlements did not merely prioritize being close to water, but rather balanced access to water, terrain safety, and suitable conditions for farming and daily activities when selecting settlement locations. The results from the MGWR analysis pointed to the exact same conclusion. Elevation demonstrated comparatively strong explanatory power for pottery sherd distribution, while the effects of river distribution, slope, and aspect were generally nonsignificant. This did not imply that water sources did not matter. Settlements in XRB were typically built near rivers, water sources served as a standard background condition. The factors that truly determined the exact locations of these settlements were likely relative elevation, drainage conditions, and local terrain stability. In other words, the site selection for Beixin Culture settlements in the XRB can be summed up as being close to water broadly but seeking higher ground locally. Findings from the FCXN also indicated that the location of Beixin Culture settlements were not determined strictly by their

distance from the river. Despite this settlement being relatively far from the Xue River, it lay in a transition zone between the piedmont alluvial fan and alluvial-proluvial plain, where mountain floods carved several natural gullies, likely providing a sufficient water supply. Additionally, the settlement was backed by several isolated bedrock hills, which likely made it easy to gather wild plants and animals, stone, and other piedmont resources. This suggested that the site selection for Beixin Culture settlements carefully weighed water sources, terrain, drainage conditions, access to resources, and production activities.

Ultimately, the fluvial terrace environment provided an important environmental basis for the emergence and development of Beixin Culture settlements in XRB. The stable secondary terraces provided a relatively safe living space for the settlement, while the river and its tributary gullies offered water, natural passageways, and a variety of resources. Under these environmental conditions, Beixin Culture settlements expanded along the main course of the Xue River and its adjacent terraces, serving as the spatial basis for the subsequent development of localized settlement clusters.

The emergence of local settlement clusters and their resource connections

In the XRB, the emergence of settlement clusters shows unique regional differences. The upper, middle, and lower reaches of the Xue River each show distinct clustering patterns. The Guanqiao paleochannel in the middle reaches maintained a high settlement density from early on. In contrast, the upper and lower reaches only began to show clustering in later periods.

Ripley's K analysis also demonstrates this conclusion. The Beixin Culture settlements in XRB had not yet developed into a mature and densely integrated settlement system across the entire basin. It also wouldn't be accurate to simply view them as a regional network with a clear center-periphery structure. It also did not provide sufficient evidence to interpret the region as a settlement system with a clear center-periphery structure.

These findings indicated that while Beixin Culture settlements in XRB were still widely scattered overall, they had started to form local clusters along suitable river sections. These settlement clusters were not mature, hierarchical systems, but simply groups of nearby settlements that likely interacted daily and shared resources. In short, these indicated that early signs of local settlement clusters had likely emerged in XRB during the Beixin Culture period, but their internal organization, inter-settlement relationships, and social complexity still required further archaeological evidence for verification.

The presence of low-density artifact areas around the BX also provided clues about how local settlement clusters were formed. These low-density artifact zones are located 100–500 m from the Beixin settlement, with collection densities significantly lower than those of larger sites. Based on BDSCAN results in the BX, these areas were better understood as outlying activity spots or small-scale activity loci linked to the BX, rather than independent settlements. If further excavations found well-stratified and well-dated deposits, it would suggest that a local activity network connecting the main settlement and several outlying activity spots might have existed within about 1 km of BX.

SCA further revealed that local settlement clusters might have shared access to the same resources. Thiessen polygons and SCA showed that settlements in the central area were clustered with overlapping resource catchments, whereas those in the outer areas were scattered with little overlap. This spatial pattern suggested that local settlement clusters might have had more frequent resource sharing, movement of people, or daily contact, while the outer settlements likely had relatively independent areas for obtaining resources. However, the Thiessen polygons and resource catchments of the seven settlements during the middle Beixin Culture were relatively balanced. This indicated that the settlements at that time did not yet show any clear signs of one controlling or being subordinate to another. Most settlements maintained relatively independent theoretical resource catchments with a primary activity radius of about 2.6 km, a distance that generally fell within a practical walking range for prehistoric people's daily farming, foraging, and short round excursions^{36,57}. Evidence from excavated settlements like BX, XKL, and GQCN showed that the subsistence resources available within the resource catchments were relatively abundant, included wild plants and animals associated with gathering and hunting activities, land suitable for early agricultural production, and raw materials such as clay, stone, and construction materials used in craft production and daily life^{29–31}. This diverse range of resources laid the foundation for the settlements' stable growth and their interactions with one another.

Notably, their resource catchments overlapped didn't automatically mean they were competing for resources, sharing them, or politically controlling one another. The XKL and GQCN sat very close to each other, and their resource catchments heavily overlapped. This suggested they likely had a tight connection and interaction. Seeing that foraging played a major role in the survival strategy at the GQCN, we offered a cautious explanation. This site might have functionally complemented surrounding long-term settlements, taking on specific roles like resource gathering and seasonal activities. Yet, we couldn't prove that GQCN was strictly subordinated to XKL or any other settlement.

Further analysis of the mean center and central feature revealed that both were concentrated around the BX, which was not only located near the geometric center of the Beixin Culture settlements in XRB, but also likely a convenient hub for connecting with neighboring settlements. The BX was noticeably larger than other sites and was situated along a river with superior resources and transportation. Benefited from a prime location, it likely held a central position within the local settlement network. However, we proposed that this centrality was rooted more in practical advantages such as its physical location, resources, and long-term continuity, rather than in forced political control.

Therefore, we concluded that the Beixin Culture settlements in XRB showed an early trend of were moving from scattered living to forming small local groups. Several factors caused this trend, stable living spaces provided by river terraces, the need for diverse resources, and the daily interactions and shared resource use among these settlements. However, these groups were still in their early stages. They acted more like loose groups of settlements brought together by physical closeness and shared resources, rather than a fully developed regional settlement system.

Developmental stages and limits of early settled societies

Differences in settlement size are a key indicator for studying prehistoric social organization and how complex these early societies were^{58,59}. It is generally understood that settlement area can reflect its population aggregation, residential stability, and the complexity of its function⁶⁰. The survey results show that BX covers 58,000 m², settlements like XKL, GQCN, and QTN are about 15,000 to 20,000 m² in size^{18,33}. As for the remaining settlements, it is hard to figure out their exact size right now because there aren't many clues left on the surface, such as scattered pottery fragments or exposed soil layers. Still, most of them are likely smaller than the BX.

The Beixin Culture settlements in XRB had already begun to display noticeable differences in size. Among them, the BX had a long and stable presence. But it's important to emphasize that we cannot judge a settlement hierarchy by size alone. We must consider a wide range of evidence, including the types of remains, artifact collections, burial data, craft production, public facilities, and the spatial layout between settlements^{61,62}. Given the data we currently have, the differences among the Beixin Culture settlements in XRB are better understood simply as variations in size, or as the early signs of a central hub. It would be a stretch to directly view this as a fully developed social hierarchy. With the current data, the differences among the Beixin Culture settlements in XRB are better understood simply as variations in size or the early signs of a central hub, not a fully developed social hierarchy.

Based on published archaeological records^{18,20,29–31}, we knew that cultural deposits like BX, XKL are roughly 0.8 to 2 m thick. XKL also contains dwelling foundations. BX, XKL and GQCN all contain ash pits, and other occupations remain. This indicates that people had already formed relatively stable communities at that time. Specifically, the discovery of clear semi-subterranean dwellings, ash pits, and other occupation remains at XKL points to a highly settled way of life. While the GQCN also discovered Beixin Culture remains, the evidence there highlighted a stronger focus on a gathering economy. This may reflect differences in subsistence strategies among settlements.

Beixin Culture society in XRB was still at a stage of development dominated by small, stable settlements. The dwelling foundations tended to be small and contained several daily living utensils and production tools²⁹. At present, the excavated materials had not revealed any communal architecture, ritual and ceremonial structures or specialized craft production area that were distinctly different from ordinary dwelling foundations. Based on the general features of the Beixin Culture in the Haidai region, the dwelling foundations were generally quite small and typically featured just one hearth inside^{63,64}. These indicated that single families or small groups remained the core units of everyday life and production, and the degree of functional differentiation within settlement was still relatively limited.

Burial records in XRB were extremely limited, only two urn burials were discovered in BX⁶⁵. It was difficult to directly reveal the local social structure in XRB. Therefore, the general profile of Beixin Culture provides a basis for our inferences. Most burials were small vertical earthen pits without any funerary objects⁶⁴. Even in the burials containing funerary objects, the quantity was highly limited, and funerary assemblage was generally quite simple^{23,64}. Most were just everyday items like pottery and stone tools,

no high-status objects with marked disparities in quantity or prestige items used as status symbols were observed. It was highly likely that wealth accumulation and power gaps were still minimal during this period, allowing settlement members to maintain a balanced economic and social status. From these patterns, we can infer that the Beixin Culture in XRB was likely in an egalitarian phase.

However, social equality did not mean that social structure was entirely simple. Beixin Culture settlements in XRB already showed certain signs of increasing organizational complexity. On the one hand, the number of settlements increased during the middle phase, and settlements in some river sections were located relatively close to one another, leading to the formation of local settlement clusters. On the other hand, the resource catchments of different settlements overlapped to some extent, suggesting interaction in resource use, population movement, and productive cooperation. Larger settlements such as Beixin settlement may have played a more important role within local interaction networks. These phenomena pointed out that Beixin Culture society in XRB was no longer composed of completely isolated villages, it may have begun to develop a regional interaction network based on several stable settlements.

The social nature of this interaction network should be interpreted with caution. The increase in settlement numbers during the middle Beixin Culture period may have been related to population growth, increasing pressure on land resources, and settlement fission. As the population of parent settlements continued to grow, nearby farmland, wild resources, and other necessities may gradually have become insufficient to support all residents. Some groups may therefore have established new settlements in suitable nearby locations^{66,67}. Although spatial distance increased between the old and new settlements, they may have remained connected through shared pottery traditions, similar artifact assemblages, daily interactions, and kinship or geographical proximity. Nevertheless, spatial proximity and cultural similarity alone are insufficient to demonstrate that these settlement clusters were organized as clearly defined clan and tribal structures.

Therefore, the social developmental stage of the Beixin Culture in XRB can be understood as a period in which settled village society expanded and local settlement connections became stronger, while social hierarchy and regional integration remained limited. The formation of local settlement clusters was more likely the result of shared use of fluvial terrace environments, resource acquisition, and everyday interaction than of centralized political authority or clear hierarchical control.

In summary, the spatial pattern of Beixin Culture settlements in XRB was not simply the result of adaptation to the natural environment. Rather, it reflected the combined effects of environmental selection, resource allocation, and social cooperation. Fluvial terrace environments provided the basis for stable settlement. Diverse resource acquisition strategies encouraged interaction among settlements. Increasing sedentism and a growing number of settlements promoted the gradual formation of local settlement clusters. Beixin Culture settlements in XRB had begun to show an initial trend from scattered settlement toward local settlement clusters, although this process was still at an early stage. Its social organization was more like an early regional settled village society and linked by

shared resources and daily interactions, rather than a mature hierarchical society or a regional political center. This pattern provides an important regional case for understanding the development of early sedentary societies and the later expansion of settlement systems in the Haidai region.

Declarations

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CRedit authorship contribution statement

Z.F. conducted data analysis, wrote the manuscript, and edited manuscript. L.D. participated in writing the manuscript. Q.C. and H.W. provided overall guidance and detailed revisions throughout the manuscript and were responsible for determining the research content and methodology. All authors reviewed the manuscript.

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Figures

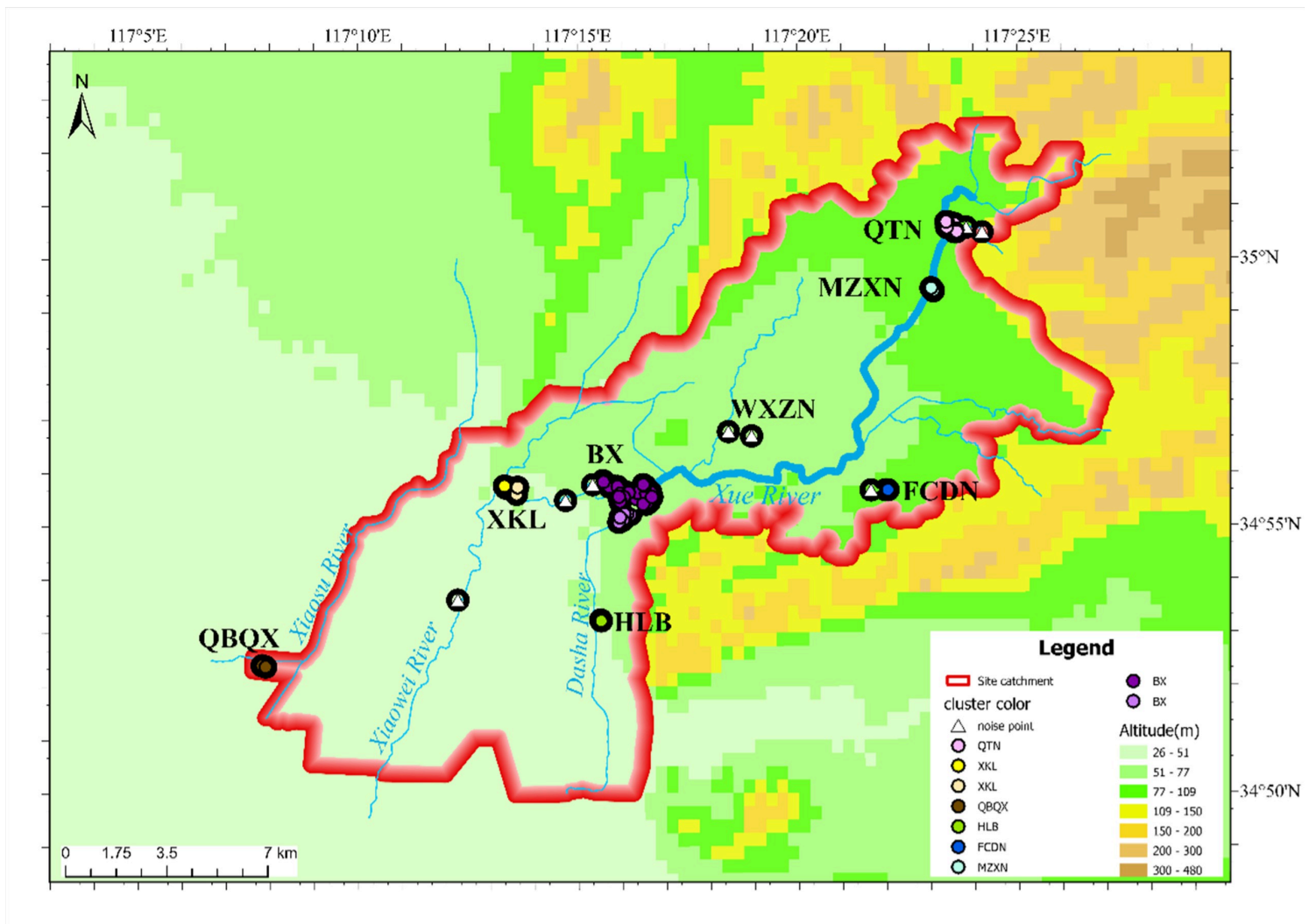


Figure 2

DBSCAN of artifact collection points from the Beixin Culture period in XRB. Triangles represent noise points, circles represent remains collection points, and the black areas indicate a 300 m buffer zone, approximating the activity range.

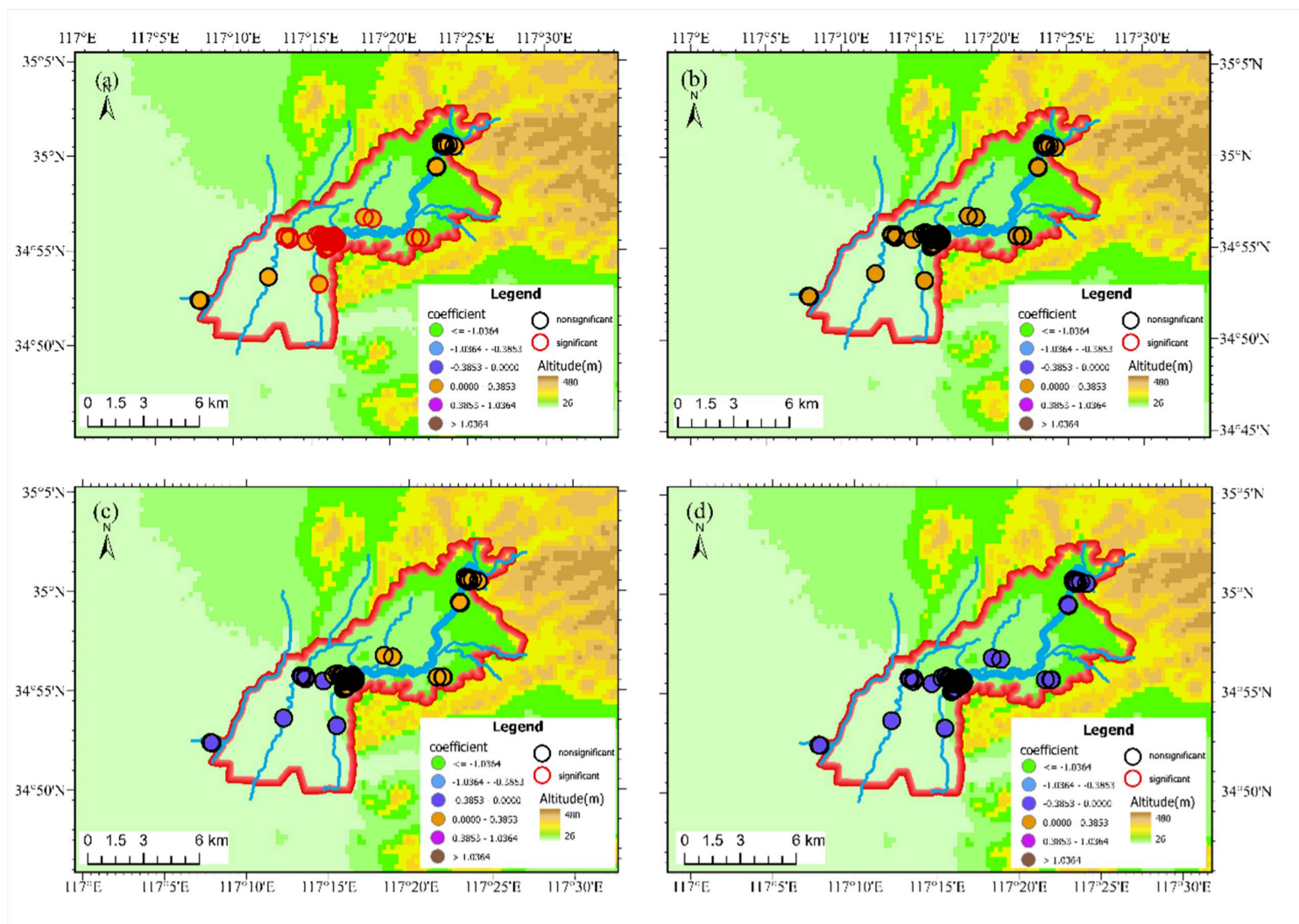


Figure 3

MGWR result of artifact collection points from the Beixin Culture period in XRB. (a) Effect of elevation on settlements, (b) effect of slope on settlements, (c) effect of aspect on settlements, (d) effect of river distribution on settlements.

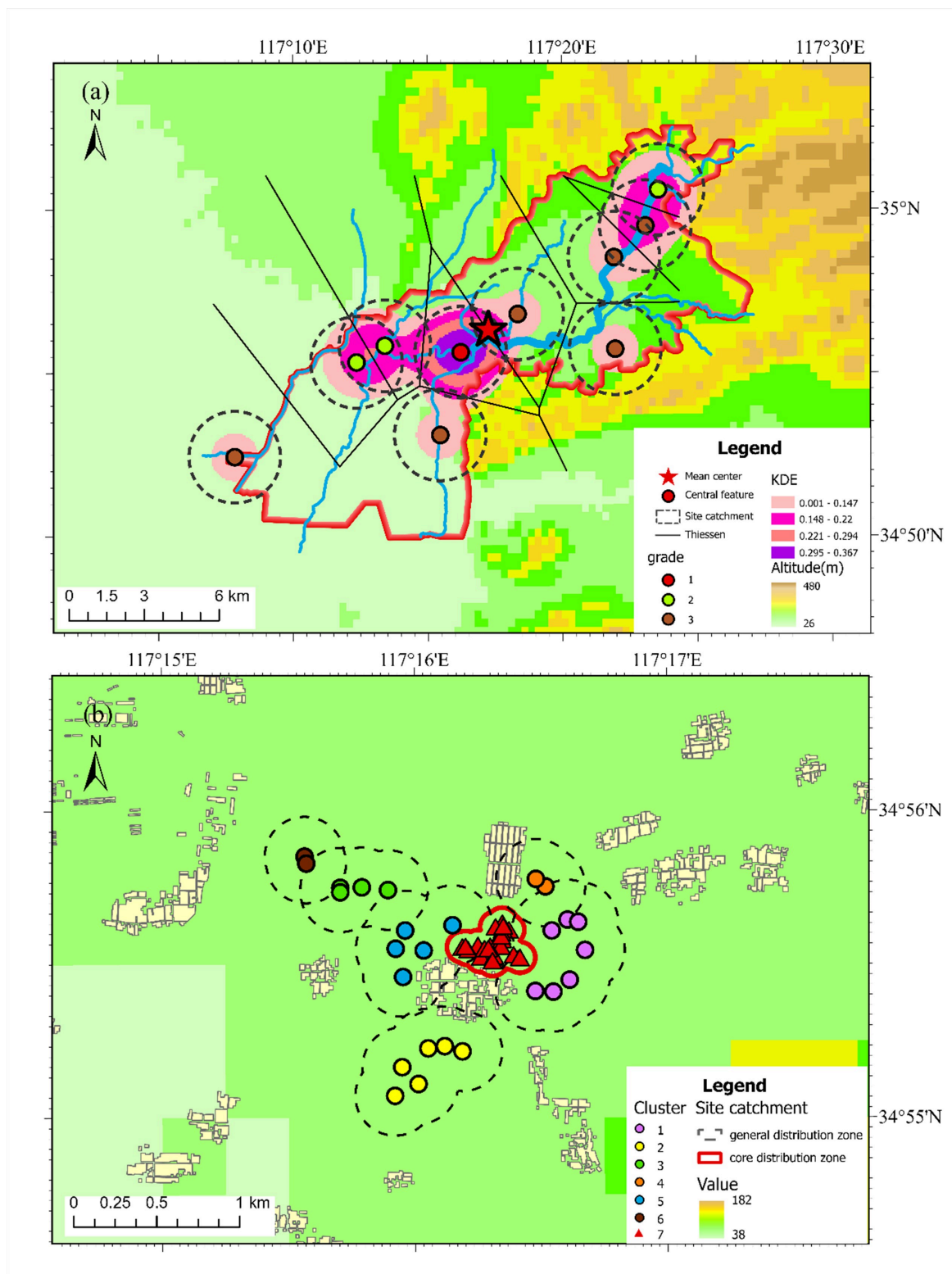


Figure 4

Spatial structure map of the Beixin Culture in in XRB. (a) Results of KDE, Thiessen polygons, and SCA. Black lines represent Thiessen polygons, black circles represent resource catchments, white triangles represent unknown period, purple dots represent late period settlements, green dots represent middle-late period settlements, blue dots represent middle period settlements, red dots represent early-middle-late period settlements and the mean center, yellow dots represent early-middle period settlements,

white five-pointed stars represent central features. (b) Distribution of Beixin settlement and its surrounding areas. Dots and triangles represent artifact collection points, red indicates the core area, the black dashed line indicates the general distribution area.

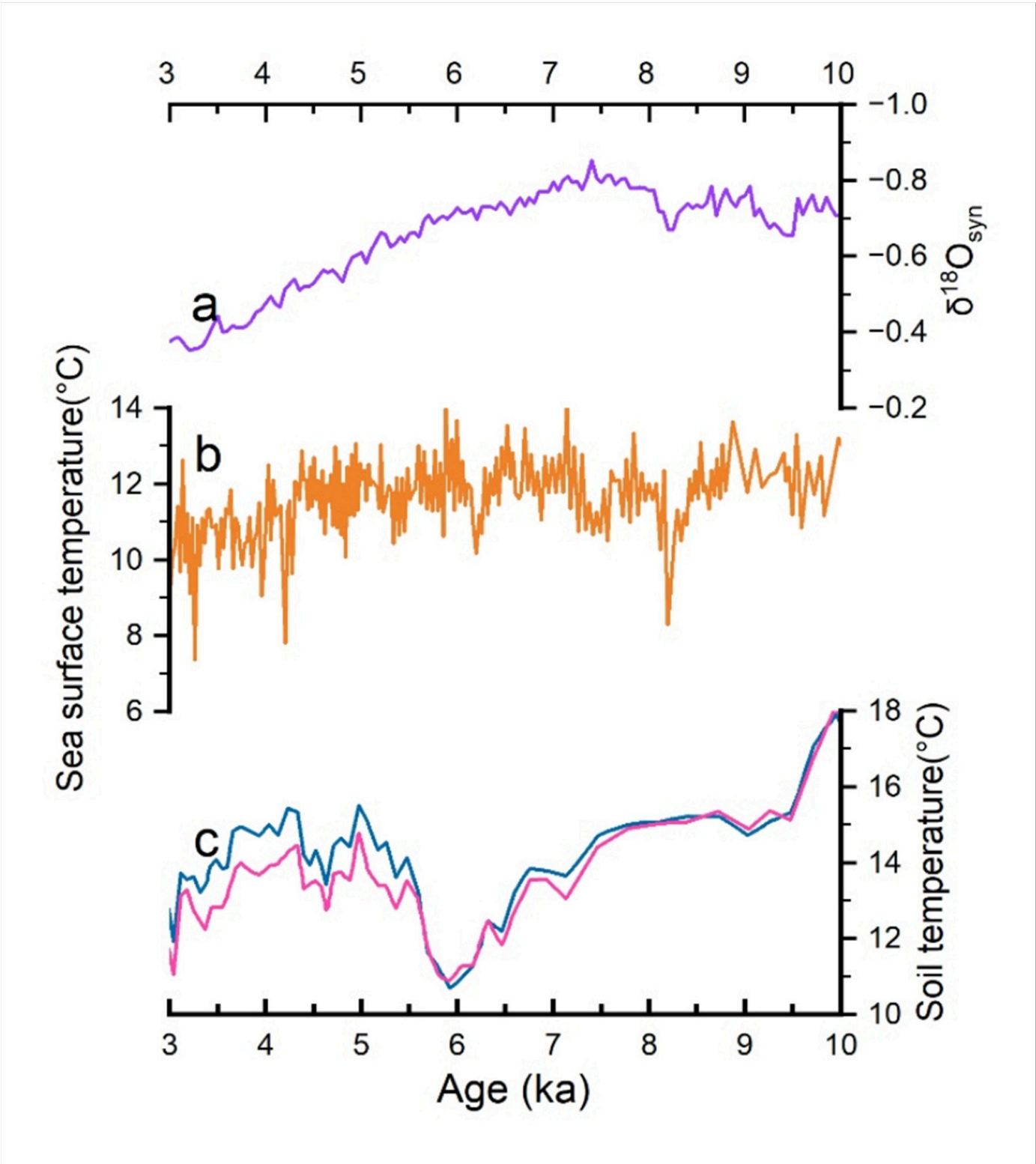


Figure 5

Hydrological climate and soil temperature during the Beixin Culture period. (a) Normalized stalagmite oxygen isotope³⁸, (b) sea surface temperature in the Yellow Sea region³⁹, (c) soil temperature in the Loess Plateau region⁴⁰, the blue curve is based on global soil calibration, and the pink line is the regional calibration based on Chinese soils.

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