REPORT

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Human-environment interaction systems between regional and continental scales in mid-latitude Eurasia during 6000–3000 years ago

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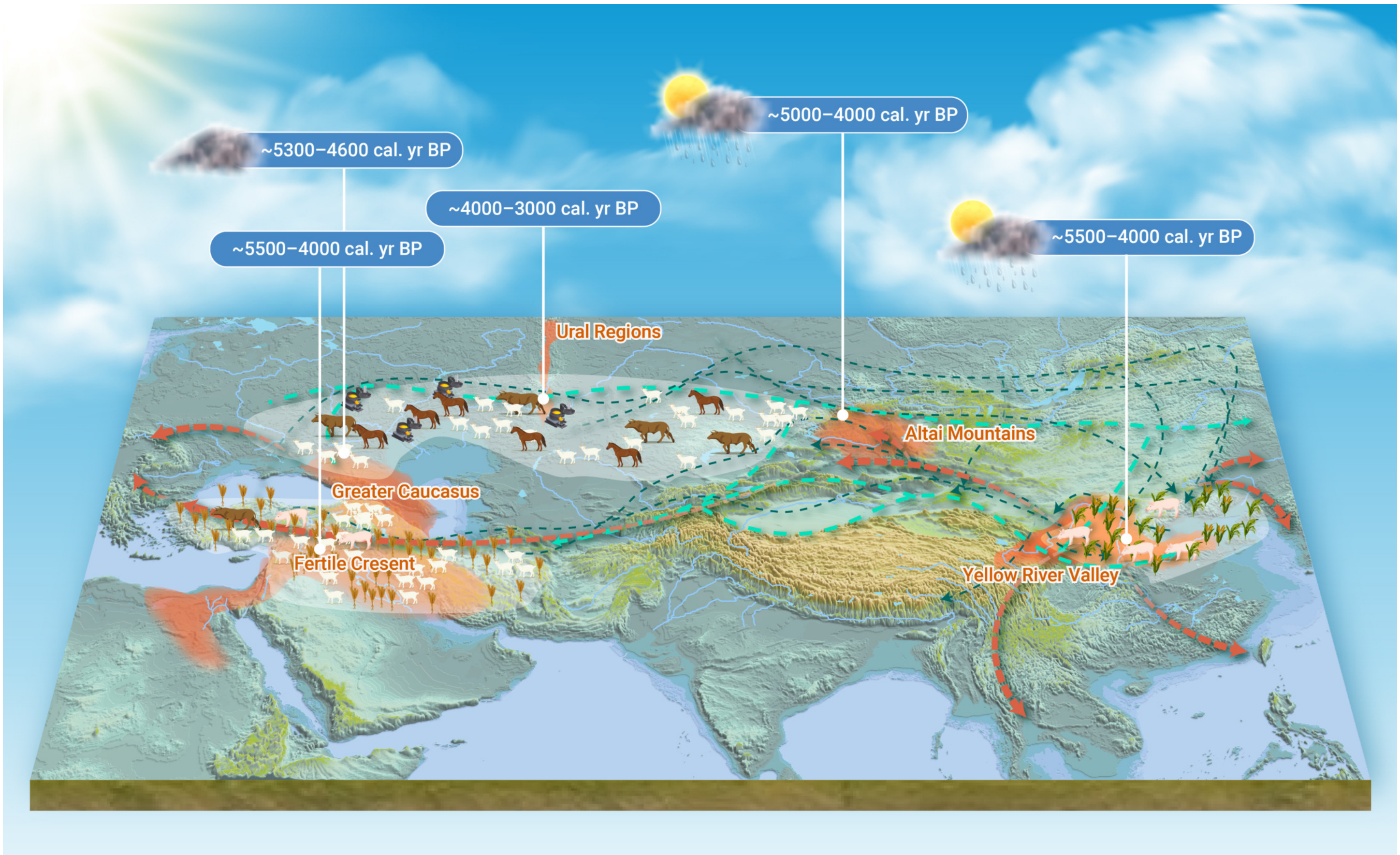
GRAPHICAL ABSTRACT



PUBLIC SUMMARY

- Centuries of archaeological studies reveal the ebb and flow of settlement centers across Eurasia.
- The primary drivers encompass new technologies, human migration, and climate change.
- Their concatenation progressively redefines the human-environment relation on various scales.
- Multi-cycle interaction between local and continental networks integrates Eurasia as a whole.

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The Late Neolithic and Bronze Ages witnessed the extensive expansion of human settlements, along with the dispersal of crops and livestock originating from West and East Asia. These events profoundly reshaped the human-environment relationship in mid-latitude Eurasia and the underlying trans-Eurasian exchange. While the processes and factors that underpin the interaction between human societies and ever-changing environments have been a heated debate in various regions of Eurasia, there is still a lack of synergistic discussion regarding human-environment interactions at regional and continental scales. To this end, we provide a comprehensive review and synthesis of updated radiocarbon dates and archaeobotanical and zooarchaeological data from sites dated between 6000 and 3000 cal. yr BP in mid-latitude Eurasia, coupled with associated archaeological and palaeoclimatic records. The results reveal the emergence and expansion of a number of regional settlement centers along the prehistoric Silk Roads and Eurasian Steppes during the 6th–4th millennium cal. yr BP. The prime drivers include the spread of new technologies, human migration, and climate change. As a result of successful food production and increasing social complexity, many areas have experienced rapid population growth, creating a foundation for subsequent widespread expansion of farming and herding communities across Eurasia. Under this overarching picture, many regional patterns arose due to specific natural and social conditions, weaving into broad spatiotemporal variations across Eurasia. A new conceptual model is proposed to depict this feedback loop of the interaction between human-environment systems at and between regional and continental scales.

INTRODUCTION

The interaction between social and natural systems during late prehistory, particularly during the 6th–4th millennium cal. yr BP has attracted enormous research interest from various disciplines, ranging from archaeology to geosciences. During this period, the Late Neolithic and Bronze Age groups were widely spread across Eurasia, often echoing the emergence of some of the earliest civilizations documented in the literature.[1-5] At the regional scale, climate change has been proposed as an important but also complex factor for social evolution. On the one hand, climate deterioration very likely triggered the collapse of ancient civilizations.[6-9] On the other, it may well have facilitated technological innovations and changes to new livelihoods[10-14] and further promoted the development and expansion of farming and pastoral groups.[15-18] High precipitation has often been favourable for social development in most regions,[19-20] though it could result in catastrophes, such as flooding.[21-22] Regional culture evolution during the Late Neolithic and Bronze Age was also affected by the transformation of social systems, including the innovations in production and social organization.[23-25] At the continental scale, this benefited from the emergence and intensification of trans-Eurasian exchange,[26-27] the spatiotemporal pattern of human societies during 6000–3000 cal. yr BP was primarily transformed by the dispersal of new lifestyles, involving crop cultivation, livestock herding, metallurgical production, and social complexity.[28-29] Nevertheless, the mechanism that links human-environment systems between the regional and continental scales has yet to be systematically reconstructed.

The majority of sites dated to 6000–3000 cal. yr BP in Eurasia were distributed in mid-latitude regions, where the Silk Roads and Eurasian Steppes provide crucial passages for both short- and long-distance human migration and dispersal of crops, livestock, technologies, and beliefs originating from different areas of Eurasia.[25,30-32] In this period, mid-latitude Eurasia witnessed the rise of many important ancient civilizations, including Sumer, Elam, and China, as well as notable spatio-temporal variations of cultural landscapes over the vast geography.[33-35] A comparative study of human-environment relationships provides a greater understanding of the mechanisms underlying the interaction between human societies and their natural environments on various geographical scales. Here, we reviewed radiocarbon dates and archaeobotanical and zooarchaeological data from Late Neolithic and Bronze Age sites in mid-latitude Eurasia to reveal the spatiotemporal patterns of human settlement and subsistence strategies in the area during 6000–3000 cal. yr BP. These data are also interpreted alongside the most recent archaeological and palaeoclimatic studies, aiming for a new conceptual model to explore the interconnection of human-environment systems evolution on both regional and continental scales.

METHODS

A comprehensive database was synthesized containing the geographical location, chronology, and types of archaeological cultures of 2172 archaeological sites from 6000 to 3000 cal. yr BP and covers 53 modern countries and regions. The data were mainly obtained from the works of Dani and Masson,[36] Wittke et al.,[37] and Dong et al.,[5] as well as from other published papers and monographs. All the data were grouped into a series of 1000-year time slots (500-year time slots in the supplementary files). Those that fell on the boundary were replicated in both adjacent groups. Kernel density analysis of the archaeological sites was applied to the spatial distribution of these sites using ArcGIS 10.2. Current kernel density analysis follows the most widely employed model and agreed parameters.[38-40] The underlying rationale assumes that each site should be represented by a three-dimensional smooth curve with a hypothetical radius that can be artificially set up. These curves can be accumulated mathematically using the kernel density function. The radius of the curve is normally set to 1° to better capture major variations in the kernel distribution at various geographic levels. More archaeological sites in one region result in a higher kernel density and, therefore, a darker colour for the local region. Finally, a standardized colour spectrum (0 ~ >3) was applied to the overall datasets attributed to the same period to facilitate visual comparison. A total of 288 sites with complete reports on the proportions of different species of charred seeds and 151 sites with NISP (the Number of Identified Specimens) for different animal species were collected to illustrate the temporal-spatial patterns of subsistence across Eurasia from the Neolithic to the Bronze Age.[41]

RESULTS AND DISCUSSION

The timing of intensive human occupation and population growth in different regions of mid-latitude Eurasia during the Neolithic and Bronze Ages (~10500–3000 cal. yr BP) presents remarkable variation, mainly driven by the emergence and diffusion of early farming.[42] During 10500–6000 cal. yr BP, intensive agriculture practices, based on the cultivation of wheat and barley and herding of sheep, goats, and cattle, were widely developed in West Asia, the Iranian Plateau, and Europe,[43-45] whereas rain-fed agriculture based on

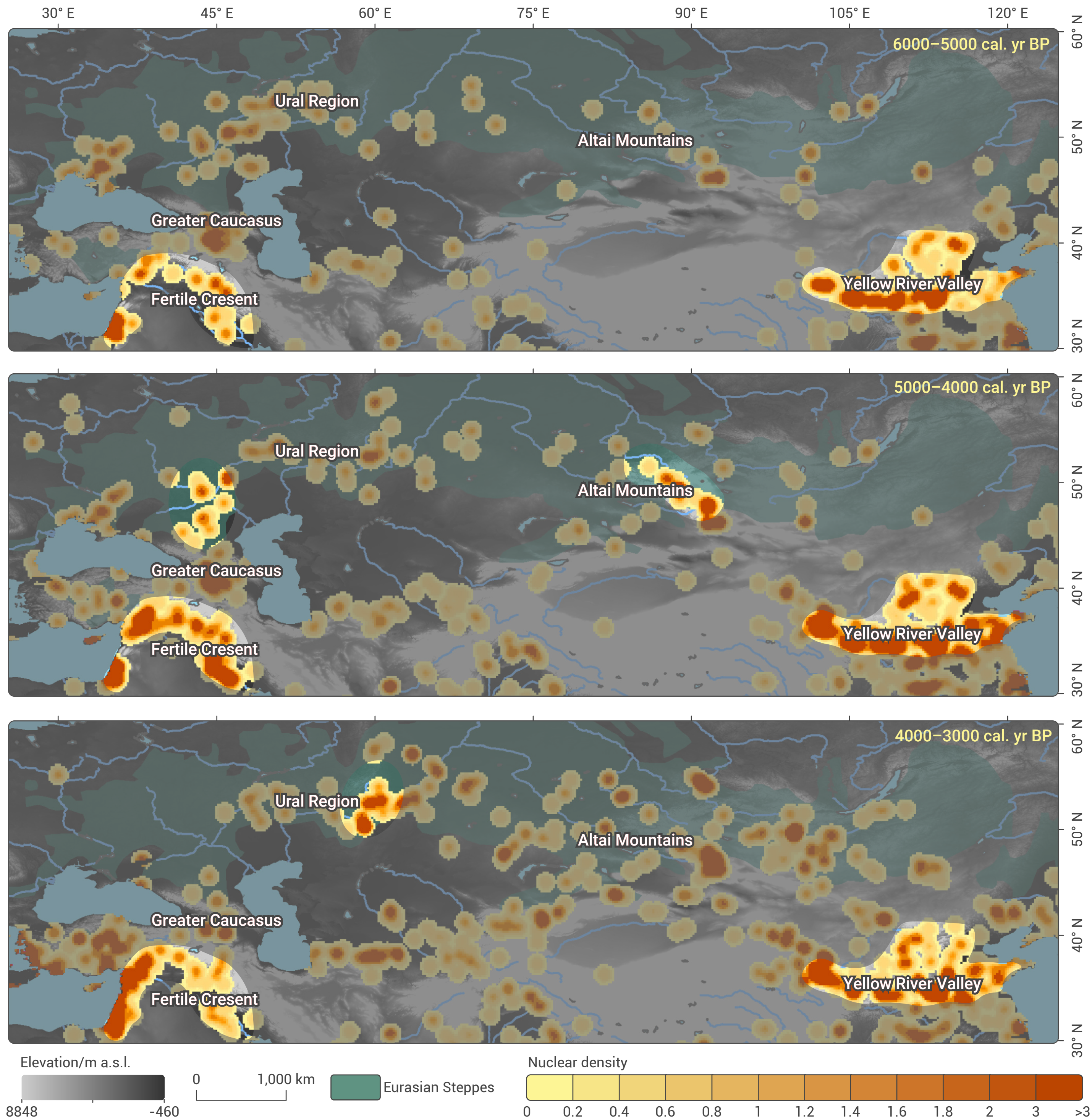

Figure 1. Kernel density of mid-latitude Eurasia archaeological site distribution between 6000 and 3000 cal. yr BP The higher kernel density suggests more archaeological sites.

millet cultivation became the most important subsistence in northern China.[46] In sharp contrast, the central and eastern parts of the Eurasian Steppes, as well as the Tibetan Plateau, were primarily dominated by hunting/fishing-gathering.[47-48] The diversified subsistence strategies fostered drastically different population growth and settlement patterns in the subsequent millennia.

The grandiose scheme after 6000 cal. yr BP in the old world was to 'occupy the north'. The spatial-temporal pattern of human settlements in mid-latitude Eurasia shows substantial changes, probably as a result of the further expansion of farming and herding groups equipped with draft animals (horses, cattle, and camels), carts, and chariots.[49-50] This expansion not only facilitated long-distance exchange but also enhanced human adaptability to diverse natural environments over the following millennia.[25,51-52]

Kernel density analysis illustrates the increasing intensity and scope of human occupation areas across mid-latitude Eurasia during the Late Neolithic and Bronze Ages (6000–3000 cal. yr BP), especially in the Eurasian Steppes and Central Asia (Figure 1). Human habitats displayed a broadly scattered distribution in the western and eastern parts of mid-latitude Eurasia between 6000 and 5500 cal. yr BP, with several distinctive clusters in the Near East, Middle Yellow River Valley, and Lower Yangtze Delta. Major clusters flourished in the middle Yellow River Valley of China and the Caucasus from 5500 to 5000 cal. yr BP. The core areas of human settlements in the

Figure 2. Temporal and spatial changes in plant resources between 6000 and 3000 cal. yr BP across the steppe (A) and oasis (B) routes of prehistoric Silk Roads show the trans-continental exchange of crop systems between East and West Asia, as demonstrated by the pie charts with both light/dark blue (wheat and barley from the West) and yellow/orange (foxtail/broomcorn millet from the East).

Yellow River Valley expanded further during the 5th millennium cal. yr BP. During the same period, another cradle of ancient civilization was formed in Mesopotamia. During this period, intensive occupation began to be detected in the central Eurasian Steppes, as exemplified by the Minusinsk Basin. In these millennia, a prominent center can be observed in the Levant area of West Asia, which links Egypt, Mesopotamia, and Anatolia, and is one of the earliest centers for metallurgy and urbanization.[53-54] The scope of human settlements in mid-latitude Eurasia continued to extend during 4000–3000 cal. yr BP. Regions such as the Tianshan Mountains in Xinjiang and high-altitude areas in the northeastern Tibetan Plateau have experienced unprecedented settlement density. Meanwhile, a new settlement center emerged in the Urals region during 4000–3500 cal. yr BP. Intriguingly, the human settlement cluster in the Yellow River Valley, which lasted for millennia, disintegrated into a few smaller settlement centers during 3500–3000 cal. yr BP.

The emergence, expansion, and disintegration of human settlement clusters during 6000–3000 cal. yr BP in mid-latitude Eurasia were driven by multiple factors, such as rapid climate change, agricultural intensification, transregional exchange, and the improvement of social systems.[17,20,25,55-56] These factors were convoluted in different natural and social settings, giving rise to regional discrepancies. At continental scales, the spatiotemporal variation in settlement across Late Neolithic and Bronze Age Eurasia was unlikely to occur without large-scale human migration, which inevitably promoted the dispersal of crops, livestock, and metallurgical technology.[42]

The interaction between human and environment systems at different scales can be detected in the Caucasus and Eurasian Steppes during the Late Neolithic period. Livelihoods characterized by a wider spectrum of subsistence strategies, including herding sheep, goats, and cattle, cultivation of wheat and barley, pig husbandry, hunting, fishing, and gathering, were established in the Caucasus during 6000–5000 cal. yr BP.[57-59] This economic pattern likely enabled diverse local landscapes to be more effectively explored and created a firmer economic basis for the local population to engage with other groups, such as the Yamnaya culture (~5600–4200 cal. yr BP) across the Eurasian Steppes,[60-61] which further contributed to social development in both Europe and the central-eastern Eurasian Steppes.[12,62] The migration of the Yamnaya groups to the central Eurasian Steppes resulted in the emergence of the Afanasievo culture (~5500–4500 cal. yr BP) in the Altai Region and probably preluded the shift of primary subsistence from hunting/fishing-gathering to herding herbivorous livestock supplemented by barley and wheat cultivation.[4,25,63]

The domestication of horses started to revolutionize transportation, allowing early humans to traverse vast distances on an annual or seasonal basis during the Neolithic and Eneolithic Ages in the Eurasian Steppes.[64-66] This opened more pastures for sheep, goats, and cattle, which became the dominant livestock at around 4500–4000 cal. yr BP (Figure 3A). The high proportion of weeds in the plant remains (Figure 2A) suggests that the cultivation of barley and wheat offered an auxiliary subsistence strategy. These new livelihoods probably facilitated humans to sufficiently utilize grassland, valleys, and mountainous areas and promoted a rapid population increase in the Altai Region and the Minusinsk Basin, as reflected by the increasing settlement density during 4500–4000 cal. yr BP (Figure 1). During ~4000–3000 cal. yr BP, the Eurasian Steppes continued to be dominated by herbivorous livestock. Broadly speaking, cattle and sheep/goats were utilized as the most important subsistence in the north and south of the central steppes, respectively (Figure 3A and 3B),[42,67-68] potentially due to their different physiological characteristics, such as water requirement and disease resistance.[67] Furthermore, the development of metallurgical production across Eurasia has provided more effective materials for craft production, transportation, and ritual systems, thereby significantly enhancing human capabilities of natural resource utilization and carrying out large-scale production. Large and complex systems, such as the Eurasian Metallurgical Province, vividly exemplify the rapidly increasing scales of bronze production and connectivity across different regions (~4000–3500 cal. yr BP),[69-71] in which case metal-rich deposits, such as the Ural Mountains, became major attractions.[72]

In the eastern Silk Roads, the development of rain-fed agriculture facilitated the rise and expansion of the Yangshao culture (~7000–5000 cal. yr BP) along the Yellow River Valley and intensive settlements in the middle reaches of the Yellow River before 5500 cal. yr BP (Figure 1). It continued to expand westward and southward from ~5500–4000 cal. yr BP (Figure 1), which was probably driven by the development of rain-fed agriculture. Isotopic evidence from the Dadiwan site suggests the establishment of intensive rain-fed agriculture in the western Loess Plateau at approximately 5900 cal. yr BP.[73] Recent archaeobotanical studies have revealed that broomcorn millet was widely cultivated in this area from ~6100–5600 cal. yr BP. However, a climate deterioration event occurred at approximately 5500 cal. yr BP shifted the primary cultivated crops to foxtail millet.[11,74] The latter had almost twice the yield of broomcorn millet.[75] This transformation, which was also synchronous with the obvious intensification of millet-pig agriculture,[76] promoted rapid population growth, and the subsequent westward expansion of millet farmers along the upper Yellow River Valley, as well as southward expansion along the eastern margin of the Tibetan Plateau during ~5300–4000 cal. yr BP.[77-78]

Wheat, barley, sheep/goats, and cattle were introduced into the eastern Silk Roads at around 4000 cal. yr BP,[79-80] but their localization varied in accordance with different regions. Wheat, barley, sheep/goats, and cattle have been utilized as major subsistence sources in the Hexi Corridor since ~3700

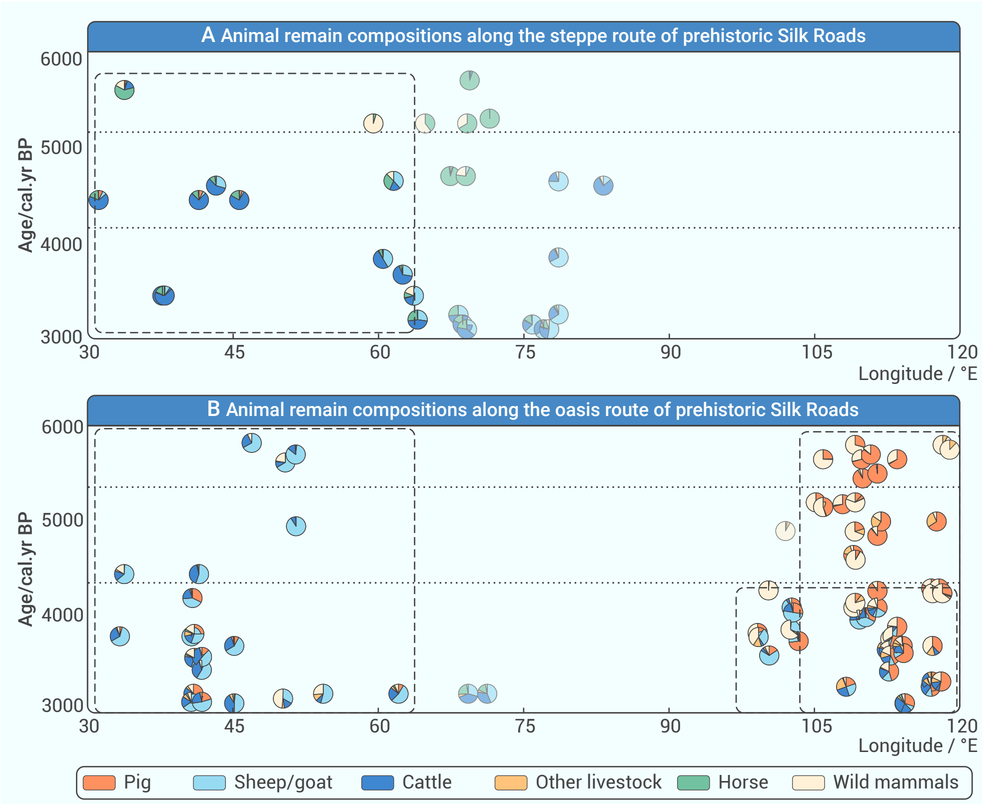

Figure 3. Temporal and spatial changes in animal resources between 6000 and 3000 cal. yr BP across the steppe (A) and oasis (B) routes of prehistoric Silk Roads indicate the dispersal of pastoralism based on ruminant livestock in Central and East Asia, as demonstrated by the replacement of other colours by light/dark blue (sheep/goat and cattle) in the pie charts, especially post 5000 cal. yr BP.

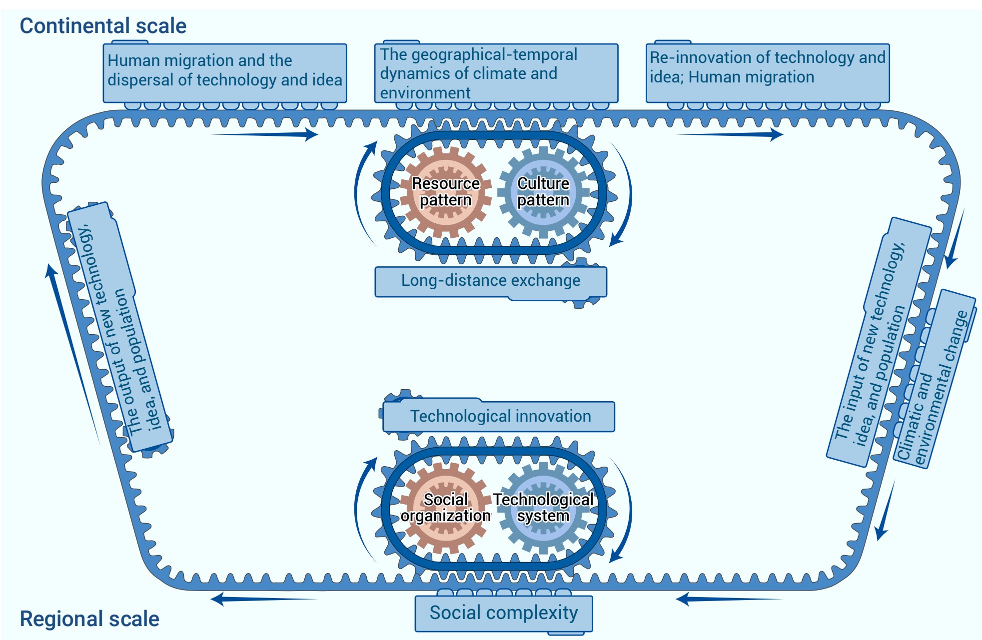

Figure 4. Gear model of the dynamic feedback-loop for human-environment systems incorporating the regional and continental scales.

cal. yr BP,[81] whereas barley and sheep became the primary food sources in areas above 2500 masl in the northeastern Tibetan Plateau after ~3600 cal. yr BP.[51] Indigenously developed millet remained the dominant crop in the mid-lower reaches of the Yellow River from 4000 to 3000 cal. yr BP,[42] with significant spatial differences in subsistence in northern China during 4000–3000 cal. yr BP (Figure 2B and 3B), which were probably triggered by a substantial decline in temperature and precipitation.[82-85] The diversification of livelihoods in Bronze Age northern China may have induced the expansion of human settlements and the emergence of new settlement centers (Figure 1). New habitats, including the highlands of the Tibetan Plateau,[51] and the Tianshan Mountains in Xinjiang, started to see intensive settlements.[86]

The gear model of a dynamic feedback-loop is illustrated to summarize the human-environment interaction at regional and continental scales (Figure 4). It emphasizes that interaction at every scale of communication is always in motion, powered by different combinations of factors at different times and spaces, encompassing climatic changes, technological innovations, human migration, and cultural communications. At the regional scale, interactions between social organizations and subsistence strategies may lead to technological innovations and social complexity. In return, it provides more natural resources and higher production efficiency, and ultimately increase the regional population, which supports more labour, technological transfer, and migration. New technologies, lifestyles, rites, and people are spread through direct migration, communication, trade, exchange, or warfare. Coupled with other externally important factors, particularly climate and environmental changes, these new cultural packages have the potential to exert a much wider impact on social evolution in other regions through a variety of newly occupied geographic channels, such as the Silk Road and Eurasian Steppes. As a result, the spatiotemporal patterns of cultural landscapes have been constantly transformed at the continental scale. New technologies and population growth encourage the exploration of new lands, particularly those with specific natural resources such as metal deposits in the Altai Region, and the Ural Mountains. The successful localization of new technologies, species and economic patterns in wider regions led to the extraction of more natural resources and social energy, which backfilled the social complexity of the local region(s) that came up with technological invention. Nevertheless, all sorts of localization must be context-specific, and it is likely that in these processes, new technologies, economic patterns, social organization, and identities were again reinvented, diffused, and gradually converged into continental-scale phenomena. Underlying this is the ever-increasing number of settlements established in old and new lands, which naturally turn Eurasia into a well-connected network (Figure 4).

CONCLUSIONS

Reconstruction of the dynamic settlement distribution in mid-latitude Eurasia at 6000–3000 cal. yr BP illustrated long-term human-environment interactions and highlighted key examples on both regional and continental scales, which assisted in disentangling the hidden drivers behind these broad archaeological narratives. The successful occupation of the northern Eurasian Steppe bridged the crucial geographical gap in East-West communication and permitted trans-regional/continental exchange with new people, technologies, species, and ideas across the entire Eurasian region, imposing a global web of communication that interconnected cultural groups at various times and spaces. The regional scale is primarily concerned with the basic parameters of social organizations and technological systems and often involves technological invention. Facilitated by migration, cultural exchange, and potential climatic and environmental changes, a variety of local inventions, such as new species of animals and metallurgy, wove into the overall network and increased production efficiency as well as population size on a continental scale, which provided feedback to the local levels. Multiple cycles drove the evolution of the human-environment interaction system in Late Neolithic and Bronze Age Eurasia.

REFERENCES

1. Spengler, R., Frachetti, M., Doumani, P., et al. (2014). Early agriculture and crop transmission among Bronze Age mobile pastoralists of Central Eurasia. Proc. R. Soc. Lond. B, *281*, 20133382.
2. Sharifi, A., Pourmand, A., Canuel, E.A., et al. (2015). Abrupt climate variability since the last deglaciation based on a high-resolution, multi-proxy peat record from NW Iran: The hand that rocked the cradle of civilization. Quat. Sci. Rev. *123*, 215–230.
3. Dixit, Y., Hodell, D.A., Giesche, A., et al. (2018). Intensified summer monsoon and the urbanization of Indus Civilization in northwest India. Sci. Rep. *8*, 4225.
4. Zhou, X.Y., Yu, J.J., Spengler, R.N., et al. (2020). 5,200-year-old cereal grains from the eastern Altai Mountains redate the trans-Eurasian crop exchange. Nat. Plants *6*, 78–87.
5. Dong, G.H., Lu, Y.X., Zhang, S.J., et al. (2022). Spatiotemporal variation in human settlements and their interaction with living environments in Neolithic and Bronze Age China. Prog. Phys. Geog. *46*, 949–967.
6. Staubwasser, M., Sirocko, F., Grootes, P.M., et al. (2003). Climate change at the 4.2 ka BP termination of the Indus valley civilization and Holocene south Asian monsoon variability. Geophys. Res. Lett. *30*, 1425–1432.
7. Kuper, R., and Kröpelin, S. (2006). Climate-controlled Holocene occupation in the Sahara: Motor of Africa's evolution. Science *313*, 803–807.
8. Weiss, H. (2017). Megadrought and Collapse: From Early Agriculture to Angkor (Oxford University Press).
9. Hou, J.Z., Ji, K., Zhu, E.L., et al. (2023). Climate change fostered rise and fall of the Tibetan Empire during 600–800 AD. Sci. Bull. *68*, 1187–1194.
10. Lespez, L., Glais, A., Lopez-Saez, J.A., et al. (2016). Middle Holocene rapid environmental changes and human adaptation in Greece. Quat. Res. *85*, 227–244.
11. Yang, Y.S., Wang, J., Li, G., et al. (2022). Shift in subsistence crop dominance from broomcorn millet to foxtail millet around 5500 BP in the western Loess Plateau. Front. Plant Sci. *13*, 939340.
12. Scott, A., Reinhold, S., Hermes, T., et al. (2022). Emergence and intensification of dairying in the Caucasus and Eurasian steppes. Nat. Ecol. Evol. *6*, 813–822.
13. Pollard, A.M., and Gosden, C. (2023). An archaeological perspective on the history of technology. CUP Elements. Cambridge University Press.
14. Qiu, M.H., Liu, R.L., Li, X.Y., et al. (2023). Earliest systematic coal exploitation for fuel extended to ~3600 B.P.. Sci. Adv. *9*, eadh0549.
15. Pashkevych, G. (2012). Environment and economic activities of Neolithic and Bronze Age populations of the northern Pontic area. Quat. Int. *261*, 176–82.
16. Allentoft, M.E., Sikora, M., Sjögren. K., et al. (2015). Population genomics of Bronze Age Eurasia. Nature *522*, 167–172.
17. Wilkin, S., Ventresca Miller, A.R., Fernandes, R., et al. (2021). Dairying enabled early bronze age Yamnaya steppe expansions. Nature *598*, 629–633.
18. Wu, D., Ma, M.M., Lu, Y.X., et al. (2023). Out-of-phase relationship of Holocene moisture variations between the northeastern and southeastern Tibetan plateau and its societal impacts. Fundam. Res. https://doi.org/10.1016/j.fmre.2023.02.014.
19. Chen, F.H., Xu, Q.H., Chen, J.H., et al. (2015) East Asian summer monsoon precipitation variability since the last deglaciation. Sci. Rep. *5*, 11186.
20. Xiang, L.X., Huang, X.Z., Sun, M.J., et al. (2023). Prehistoric population expansion in Central Asia promoted by the Altai Holocene Climatic Optimum. Nat. Com. *14*, 3102.
21. Zhang, H.W., Cheng, H., Sinha, A., et al. (2021). Collapse of the Liangzhu and other Neolithic cultures in the lower Yangtze region in response to climate change. Sci. Adv. *7*, eabi9275.
22. Zaki, A.S., King, G.E., Haghipour, N., et al. (2021). Did increased flooding during the African Humid Period force migration of modern humans from the Nile Valley. Quat. Sci. Rev. *272*, 107200.
23. Finley, M.I. (1965). Technical innovation and economic progress in the ancient world. Econ. Hist. Rev. *18*, 29–45.
24. Diamond, J., and Bellwood, P. (2003). Farmers and their languages: The first expansions. Science *300*, 597–603.
25. Ventresca Miller, A.R., Wilkin, S., Hendy, J., et al. (2022). The spread of herds and horses into the Altai: how livestock and dairying drove social complexity in Mongolia. PLOS ONE *17*, e0265775.
26. Ventresca Miller, A.R., and Makarewicz, C.A. (2019). Intensification in pastoralist cereal use coincides with the expansion of trans-regional networks in the Eurasian Steppe. Sci. Rep. *9*, 8363.
27. Dong, G.H., Yang, Y.S., Ren, L.L., et al. (2020). The human subsistence strategy patterns and human-environment interactions in prehistoric Hexi Corridor (in Chinese). (Science Press).
28. Dong, G.H., Liu, F.W., and Chen, F.H. (2017). Environmental and technological effects on ancient social evolution at different spatial scales. Sci. China Earth Sci. *60*, 2067–2077.
29. Honeychurch, W., Rogers, L., Amartuvshin, C., et al. (2021). The earliest herders of East Asia: Examining Afanasievo entry to Central Mongolia. Archaeol. Res. Asia *26*, 100264.
30. Frachetti, M.D., Smith, C.E., Traub, C.M., et al. (2017). Nomadic ecology shaped the highland geography of Asia's Silk Roads. Nature *543* 193–198.
31. Pollard, A.M., Bray, P., Hommel, P., et al. (2018). Beyond Provenance: New Approaches to Interpreting the Chemistry of Archaeological Copper Alloys (Leuven University Press).
32. Liu, X.Y., Jones, P.J., Motuzaite-Matuzeviciute, G., et al. (2019). From ecological opportunism to multi-cropping: Mapping food globalisation in prehistory. Quat. Sci. Rev. *206*, 21–28.
33. Crawford, H. (1991). Sumer and the Sumerians (Cambridge University Press).
34. Hanks, B.K., and Linduff, K.M. (2009). Social complexity in prehistoric Eurasia: Monuments, metals, and mobility (Cambridge University Press).
35. Yan, W.M. (1996). Exploration of the origin of China civilization (in Chinese). Cult. Relics Cent. China *1*, 10–16.
36. Dani, A.H., and Masson, V.M. (2002). History of Civilizations of Central Asia·I (Chinese Edition) (in Chinese). China Translation and Publishing Corporation.
37. Wittke, A.-M., Olshausen, E., and Szydlak, R. (2012). Historischer Atlas der antiken Welt. Stuttgart.
38. Brigand, R. and Weller, O. (2018). Kernel density estimation and transition maps of Moldavian Neolithic and Eneolithic settlement. Data Brief *17*, 452–458.
39. Danese, M., Masini, N., Biscione, M., Lasaponara, R. (2014). Predictive modeling for preventive Archaeology: overview and case study. Cent. Eur. J. Geosci. *6*, 42–55.
40. Guillemot, P., Jaillet, S., Chacón, M.G., Pois, V., Moncel, M. (2023). Spatial patterning of Middle Palaeolithic lithic assemblages at the Abri du Maras, Southeast France: Combining GIS analysis and 3D palaeotopographic reconstructions. J. Archaeol. Sci. Rep. *49*, 103999.
41. McMahon, T. C. (2007). "Discerning Prehistoric Landscapes in Colorado and the Mesa Verde Region Using a Kernel Density Estimate (KDE) Method." In Digital Discovery. Exploring New Frontiers in Human Heritage, CAA 2006, edited by J. T. Clark and E. M. Hagemeister, 151–166. Budapest: Archaeolingua.
42. Dong, G.H., Du, L.Y., Yang, L., et al. (2022). Dispersal of crop-livestock and geographical-temporal variation of subsistence along the Steppe and Silk Roads across Eurasia in prehistory. Sci. China Earth Sci. *65*, 1187–1210.
43. Arbuckle, B.S. (2012). Animals and inequality in Chalcolithic central Anatolia. J. Anthropol. Archaeol. *31*, 302–313.
44. Manning, K., Downey, S.S., Colledge, S., et al. (2013). The origins and spread of stock-keeping: the role of cultural and environmental influences on early Neolithic animal exploitation in Europe. Antiquity *87*, 1046–1059.
45. Decaix, A., Mohaseb, F.A., Maziar, S., et al. (2019). Subsistence economy in kohneh Pasgah Tepesi (eastern Azerbaijan, Iran) during the late chalcolithic and the early Bronze age based on the faunal and botanical remains. In: Meyer, J.W., Vila, E., Mashkour, M., Casanova, M., Valle, R. (Eds.), The Iranian Plateau During the Bronze Age. Development Of Urbanisation, Production And Trade, MOM. Maison de l'Orient et de la M´editerran´ee, Lyon, pp. 75–88.
46. Zhao, Z.J. (2019). Introduction of the origin of agriculture in China (in Chinese). Res. Heritages Preservation *4*, 1–7.
47. Kalieva, S. and Logvin, V. (2011) On the origins of nomadism in the Asian steppes. Archaeol. Ethnol. Anthropol. Eurasia *39*, 85–93.
48. Du, L.Y., Ma, M.M., Lu, Y.W., et al. (2020). How did human activity and climate change influence animal exploitation during 7500–2000 BP in the Yellow River Valley, China. Front. Ecol. Evol. *8*, 161.
49. Anthony, D.W. (2008). The Horse, the Wheel, and Language: How Bronze-Age Riders from the Eurasian Steppes Shaped the Modern World (Princeton University Press).
50. Kirtcho, L.B. (2009). The earliest wheeled transport in Southwestern Central Asia: new

finds from Altyn-Depe. Archaeol. Ethnol. Anthropol. Eurasia *37*, 25–33.
51. Chen, F.H., Dong, G.H., Zhang, D.J., et al. (2015). Agriculture facilitated permanent human occupation of the Tibetan Plateau after 3600 BP. Science *347*, 248–250.
52. Motuzaite-Matuzeviciute, G., Ananyevskaya, E., Sakalauskaite, J., et al. (2022). The integration of millet into the diet of Central Asian populations in the third millennium BC. Antiquity *96*, 560–574.
53. Mazar, A. (1990). Chapter 4 - The emergence of cities: The early Bronze Age (ca. 3300–2300 BCE). In Archaeology of the Land of the Bible, (Doubleday), pp. 91–150.
54. Garfinkel, Y., Klimscha, F., Shalev, S., et al. (2014). The beginning of metallurgy in the Southern Levant: A late 6th millennium cal BC copper awl from Tel Tsaf, Israel. PLOS ONE *9*, e96882.
55. Tan, L.C., Dong, G.H., An, Z.S., et al. (2021). Megadrought and cultural exchange along the proto-silk road. Sci. Bull. *66*, 603–611.
56. Ma, M.M., Dong, J.J., Yang, Y.S., et al. (2023) Isotopic evidence reveals the gradual intensification of millet agriculture in Neolithic western Loess Plateau. Fundamental Research. doi:10.1016/j.fmre.2023.06.007
57. Berthon, R. (2014). Past, current and future contribution of Zooarchaeology to the knowledge of the Neolithic and chalcolithic cultures in South Caucasus. Stud. Caucasian Archaeol. *2*, 4–30.
58. Sagona, A. (2017). The Archaeology of the Caucasus: From Earliest Settlements to the Iron Age (Cambridge University Press).
59. Akashi, C., Tanno, K., Guliyev, F., et al. (2018). Neolithisation processes of the South Caucasus: As viewed from macro-botanical analyses at Hacı Elamxanlı Tepe West Azerbaijan. Paléorient *44*, 75–89.
60. Haak, W., Lazaridis, I., Patterson, N., et al. (2015). Massive migration from the steppe was a source for Indo-European languages in Europe. Nature *522*, 207–211.
61. Scorrano, G., Yediay, F.E., Pinotti, T., et al. (2021). The genetic and cultural impact of the Steppe migration into Europe. Ann. Hum. Biol. *48*, 223–233.
62. Hirose, M., Naito, Y.I., Kadowaki, S., et al. (2021). Early husbandry strategies in the southern Caucasus: intra-tooth sequential carbon and oxygen isotope analysis of Neolithic goats, sheep, and cattle from Göytepe and Hacı Elamxanlı Tepe. J. Archaeol. Sci. Rep. *36*, 102869.
63. Hermes, T.R., Tishkin, A.A., Kosintsev, P.A., et al. (2020). Mitochondrial DNA of domesticated sheep confirms pastoralist component of Afanasievo subsistence economy in the Altai Mountains (3300–2900 cal BC). Archaeol. Res. Asia *24*, 100232.
64. Chechushkov, I.V., and Epimakhov, A.V. (2018). Eurasian steppe chariots and social complexity during the Bronze Age. J. World Prehist. *31*, 435–483.
65. Librado, P., Khan, N., Fages, A., et al. (2021). The origins and spread of domestic horses from the Western Eurasian steppes. Nature *598*, 634–640.
66. Trautmann, M., Frînculeasa, A., Preda-Bălănică, B., et al. (2023). First bioanthropological evidence for Yamnaya horsemanship. Sci. Adv. *9*, eade2451.
67. Bendrey, R. (2011). Some like it hot: environmental determinism and the pastoral economies of later prehistoric Eurasian steppe. Pastoralism: Research, Policy Pract. *1*, 8.
68. Haruda, A. 2018. Regional pastoral practice in central and southeastern Kazakhstan in the Final Bronze Age (1300–900 BCE). Archaeol. Res. Asia *15*, 146–156.
69. Chernykh, E.N. (2008). Formation of the Eurasian "Steppe Belt" of stock: breeding cultures: viewed through the prism of archaeometallurgy and radiocarbon dating. Archaeol. Ethnol. Anthropol. Eurasia *35*, 36–53.
70. Grigoriev, S.A. (2017). Social processes in Ancient Eurasia and development of types of alloys in metallurgical production. Archaeoastronomy Ancient Technol. *5*, 17–44.
71. Stöllner, T., Özyarkent, H., and Gontscharov, A. (2023). Andronovo mobility revisited: New research on Bronze Age mining and metallurgical communities in Central Asia. Proc. Brit. Acad. *254*, 110–141.
72. Koryakova, L., and Epimakhov, A. (2007). The Urals and Western Siberia in the Bronze and Iron Ages (Cambridge University Press).
73. Barton, L., Newsome, S.D., Chen, F.H., et al. (2009). Agricultural origins and the isotopic identity of domestication in northern China. Proc. Natl. Acad. Sci. U.S.A. *106*, 5523–5528.
74. Tan, L.C., Li, Y.Z., Wang, X.Q., et al. (2020). Holocene monsoon change and abrupt events on the western Chinese Loess Plateau as revealed by accurately dated stalagmites. Geophys. Res. Lett. *47*, e2020GL090273.
75. Chai, Y., and Feng, B. L. (2003). Present situation and developing strategies of minor grain crops in China (in Chinese). Agric. Res. Arid Areas *3*, 145–151.
76. Yang, J.S., Zhang, D.J., Yang, X.Y., et al. (2022). Sustainable intensification of millet–pig agriculture in Neolithic North China. Nat. Sustain. *5*, 780–786.
77. Ren, L., Yang, Y., Wang, Q., et al. (2021). The transformation of cropping patterns from late Neolithic to early Iron age (5900–2100 BP) in the Gansu–Qinghai region of northwest China. Holocene *31*, 183–193.
78. Huan, X., Deng, Z., Zhou, Z., et al. (2022). The emergence of rice and millet farming in the Zang-Yi Corridor of southwest China dates back to 5000 years ago. Front. Earth Sci. *10*, 874649.
79. Dong, G.H., Yang, Y.S., Liu, X.Y., et al. (2018) Prehistoric trans-continental cultural exchange in the Hexi Corridor, northwest China. Holocene *28*, 621–628.
80. Dodson, J., Li, X.Q., Zhou, X.Y., et al. (2013). Origin and spread of wheat in China. Quat. Sci. Rev. *72*, 108–111.
81. Zhou, X.Y., Li, X.Q., Dodson, J., et al. (2016). Rapid agricultural transformation in the prehistoric Hexi corridor, China. Quat. Int. *426*, 33–41.
82. Ma, M.M., Dong, G.H., Jia, X., et al. (2016). Dietary shift after 3600 cal yr BP and its influencing factors in northwestern China: Evidence from stable isotopes. Quat. Sci. Rev. *145*, 57–70.
83. Marcott, S.A., Shakun, J.D., Clark, P.U., et al. (2013). A reconstruction of regional and global temperature for the past 11,300 years. Science *339*, 1198–1201.
84. Yang, B., Qin, C., Bräuning, A., et al. (2021). Long-term decrease in Asian monsoon rainfall and abrupt climate change events over the past 6,700 years. Proc. Natl. Acad. Sci. U.S.A. *118*, e2102007118.
85. He, K., Lu, H., Jin, G., et al. (2022). Antipodal pattern of millet and rice demography in response to 4.2 ka climate event in China. Quat. Sci. Rev. *295*, 107786.
86. Wang, W., Liu, Y., Duan, F., et al. (2020). A comprehensive investigation of Bronze Age human dietary strategies from different altitudinal environments in the Inner Asian Mountain Corridor. J. Archaeol. Sci. *121*, e105201.

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AUTHOR CONTRIBUTIONS

G.D. and R.L. designed this study and drafted the manuscript. L.D. performed the data preparation and visualization. All authors participated in discussion and manuscript revision.

DECLARATION OF INTERESTS

The authors declare no competing interests.

SUPPLEMENTAL INFORMATION

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