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Human activity and its impact on the landscape at the Xishanping site in the western Loess Plateau during 4800–4300 cal yr BP based on the fossil charcoal record

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The taxonomic identification of fossil charcoal can be a useful archaeobotanical tool, as it can reveal information about prehistoric humans' use of plant resources and other factors. In this study, we quantify the fossil charcoal in a cultural sequence from Xishanping in the western Loess Plateau of China representing 4800–4300 cal yr BP to consider aspects of humans' impact on this landscape. The fossil charcoal assemblages reveal that the relative abundances of *Picea*, *Betula*, *Acer*, *Ulmus* and *Quercus* decreased markedly after 4600 cal yr BP. This suggests a marked decline in the mixed coniferous-broadleaved forest after this time. Concurrently, an increasing abundance of Bambusoideae charcoal has been suggested to reflect the expansion of the bamboo forest. The marked changes in the vegetation after 4600 cal yr BP were not obviously influenced by climate; they may be a better reflection of the results of human activity. Furthermore, other genera that provide important resources to humans also increased after 4600 cal yr BP, including *Castanea*, *Cerasus*, *Padus* and *Diospyros*. It is nearly certain that nuts and berries were an important food resource and that fruit trees were managed by prehistoric humans in the late Neolithic. This work suggests that the scale of prehistoric human impact on the western Loess Plateau landscape during the late Neolithic was much greater than was previously believed.

1. Introduction

Agriculture is one of the most important developments in human history. It emerged in the early Holocene from the hunting and gathering society and progressed rapidly thereafter (Harlan, 1971; Bellwood et al., 2005). Agricultural activity became the main factor by which humans adapted to and impacted the environment (Cavalli-Sforza et al., 1993). Terrestrial vegetation was significantly changed by the rapid development of agriculture accompanied by alterations in land use and a sharp increase in the human population (Vitousek et al., 1997; Global Forest Watch, 1997).

Studies of human activity and its impact have recently emerged as an important issue for scientists (Ruddiman, 2003, 2008; Lu et al., 2009; Crawford, 2006; Li et al., 2009). Archaeobotanical records can be used to reconstruct human activity and its impact on the environment, which may include the identification of early agricultural activity (IGBP, 2001; Underhill, 1997; Kennett et al., 2007; Velichko et al., 2009). Plant remains from archaeological sites, especially sites of agricultural activity during the Neolithic, possess the distinct advantages of good conservation, high quantity, easy collection, and a variety of types. These plant remains have proven to be the ideal material to provide a proxy for the study of human activity.

Fossil charcoal from archaeological sites indicates the use of fire by humans. Evidence from Site Catchment Analyses indicates that the activity range of prehistoric farming groups was limited to approximately 5 km or 1 h's walking distance (Renfrew and Bahn, 1991; Qin et al., 2010). Assuming the "principle of least effort" (Zipf, 1949), it is assumed that the charcoal fossils at the archaeological site originated from nearby woody plants. Therefore, the fossil charcoal should reflect the fuel wood of the prehistoric farmer and reveal information about the woodland composition at that time on a local scale (Shackleton and Prins, 1992; Scheel-Ybert, 2000).

Fossil charcoal is the product of the incomplete combustion of wood. Therefore, the anatomic character of fossil charcoal is almost identical to that of the original wood (McGinnes et al., 1974), which

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offers improved precision in taxonomic identification, significant potential for reconstructing regional vegetation history (Shackleton and Prins, 1992; Cui et al., 2002), and a better understanding of ancient peoples' use of wood (Asouti and Austin, 2005; Dufraisse, 2006; Thiébault, 2002).

There are numerous archaeological remains at the Xishanping site, located in the Tianshui Basin, western Loess Plateau. Some scientific investigations have been conducted to obtain information on agricultural activity and the possible human influence on vegetation during the late Neolithic (Institute of Archaeology of CASS, 1999; Li et al., 2007a, 2007b). Large quantities of fossil charcoals are preserved in the cultural sediment of Xishanping. The quantitative analysis of these fossil charcoals combined with the pollen record and accelerator mass spectrometry (AMS) ^{14}C dating can help us reconstruct the woody plants, vegetation types, and ecological environment around Xishanping during the Majiayao Culture (5200–4100 cal yr BP). The fossil charcoal assemblages are also used to reveal how early farmers used plant resources and to discuss human activity and its impact on vegetation and the environment.

2. Study area

The Tianshui Basin is located in the northern Qinling Mountains, west of the Loess Plateau. This basin belongs to a warm temperate zone with a semi-humid climate. The mean annual temperature is 11.6 °C. The mean annual precipitation is 491.6 mm and is primarily concentrated in the summer months (Surface Meteorological Data of China, 1971–2000, http://cdc.cma.gov.cn/). The natural vegetation is warm-temperate mixed conifer-broadleaved forest, woodland and grasslands (Wu and Wang, 1983), although it has been greatly altered by agriculture. The few remaining natural forests are on bedrock in Longshan, Xiqinling and Guanshan, which are several kilometers from the study site (Wu and Wang, 1983).

The Xishanping site (34°33′50″N, 105°32′41″E, 1330 m a.s.l.) is located on a terrace on the southern bank of the Xihe River, approximately 50 m above the riverbed (Fig. 1). The site was first surveyed by the Gan-Qing archaeological team in 1956 and was excavated between 1986 and 1990. The site covers an area of 204,800 m^2 and contained artifacts from cultural period between 7800 and 3000 cal yr BP. However, the stoneware and pottery found there are mainly from the Majiayao and Qijia cultures of the middle-lower Neolithic (Institute of Archaeology of CASS, 1999; An et al., 2005).

Archaeobotanical studies indicate that rain-fed agriculture began to take place in the early-mid Holocene, and rice was introduced to Xishanping in the last 5000 cal yr BP (Li et al., 2007a). Fox millet, common millet, rice, wheat, oat, barley, soybean, and buckwheat have been cultivated here for 4000 years, indicating the development of a complex and broad agriculture system (Li et al., 2007a, 2007b). Based on the pollen records of the Xishanping section, Li et al. (2007b) suggested that the *Picea* forest disappeared after 4600 cal yr BP, most likely due to selective hewing by humans.

3. Methods

A 650-cm continuous and undisturbed cultural sediment profile containing fragments of pottery and stoneware, archaeobotanical remains and animal bones was selected for study. Eight accelerator mass spectrometry (AMS) radiocarbon dates, including 6 charcoal samples and 2 charred seeds, were selected for accelerator mass spectrometry (AMS) at the University of Tokyo (Table 1). The calendar ages were obtained using the Radiocarbon Calibration Program (Reimer et al., 2004). An age-depth model based on 5 AMS dates was established by Li et al. (2007a, Fig. 2), and the sample ages were linearly interpolated.

The samples were recovered from the cultural layer using the floatation method described in Tsuyuzaki (1994). Seven samples from cultural sediment of 40–450 cm depth (4800–4300 cal yr BP) with abundant charcoal were collected, and each sample comprised approximately 80 kg of sediment.

Keepax (1988) suggested that a minimum of 100 fragments per sample should be examined in temperate regions to provide a good representation of most types of charcoal. Here, two indexes are used to explain the charcoal assemblages in the Xishanping section: the "abundance ratio", or the percentage of fragments from a certain

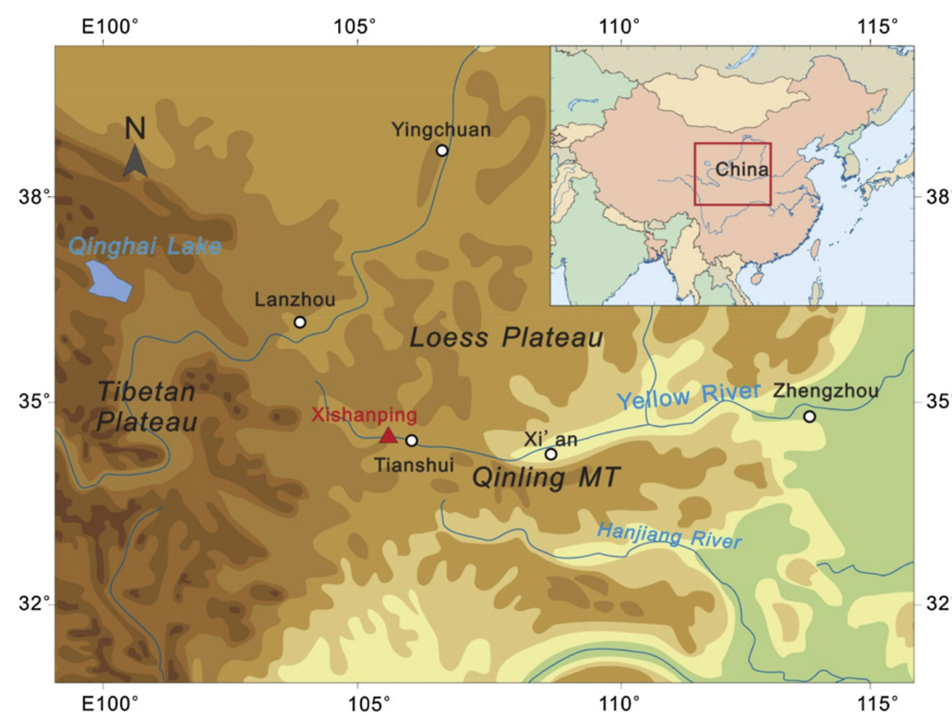

Fig. 1. Location of the Xishanping site.

Table 1
Accelerator mass spectrometry (AMS) dates from Xishanping (Li et al., 2007a).

Sample location	Depth (cm)	Lab. no.	Sample type	AMS age (yr BP)	Calibrated age (cal yr BP, 2σ)
XXP-1	60 cm	TKal3882	Charcoal	3900 ± 35	4236–4419
XXP-2	130 cm	TKal3883	Charcoal	2785 ± 30	2839–2949
XXP-3	345 cm	TKal3884	Charcoal	4430 ± 35	4870–5069
XXP-4	490 cm	TKal3885	Charcoal	4855 ± 35	5579–5655
XXP-5	560 cm	TKal3886	Charcoal	4360 ± 35	4845–4983
XXP-6	570 cm	TKal3887	Charcoal	4400 ± 35	4859–5051
XXP-7	585 cm	TKal3888	Charred seed	4430 ± 100	4833–5312
XXP-8	620 cm	TKal3889	Charred seed	4490 ± 35	5035–5295

species in the total fragments, and the "frequency", or the proportion of samples containing certain taxa.

At least 100 pieces were selected randomly from each sample. To diminish the statistical error, we attempted to select both small and large sizes of fossil charcoals, in case some of the more fragile wood taxa had only been preserved in small pieces. The identification of the fossil charcoal followed standard procedures. First, pressure-fractured charcoals were prepared with a razor blade to produce fresh, clean surfaces presenting transverse, radial and tangential sections (Leney and Casteel, 1975). These sections were examined under a stereomicroscope and categorized, and one or two samples of each type were photographed under a scanning electron microscope (SEM). The identification of the taxa was performed using a reference wood collection and wood anatomy atlases.

4. Results

A total of 808 pieces of charcoal were identified from the samples, and 20 different taxa were identified (Table 2). The most abundant taxa were *Picea*, *Castanea*, *Betula*, *Ulmus*, *Quercus*, *Carpinus*, *Toxicodendron*, *Acer*, *Liquidambar formosana* and Bambusoideae, which were present in all the samples. *Padus*, *Castanopsis*, *Pseudotsuga sinensis*, *Cerasus* and *Eucommia ulmoides* appeared in 4 samples, and *Corylus*, *Picrasma* and *Diospyros* were present in only two samples.

The abundance ratios of the charcoal types in the total charcoal fossil counts from Xishanping (Table 2) show that *Ulmus*, *Picea*, *Betula*, *Acer*, *L. formosana*, *Carpinus*, *Quercus* and *Phyllostachys glauca* make up over 70% of the charcoal fossil assemblages (Fig. 3). Therefore, they are presumed to have been the main sources of firewood of prehistoric people.

Figs. 3 and 4 show that the charcoal fossils can be divided into two main periods: 4800–4600 cal yr BP and 4600–4300 cal yr BP. During 4800–4600 cal yr BP, the abundance ratios of *Picea*, *Quercus* and *Ulmus* are high (over 20%), while the values of Bambusoideae are low, ranging from 1% to 7%. After 4600 cal yr BP, the *Picea* values decreased from a peak value of 28% to less than 5%, and *Ulmus* decreased to approximately 7%, while Bambusoideae increased significantly to a peak value of 23%.

The abundance ratios of *Carpinus*, *Betula*, *Toxicodendron* and *Acer* were relatively stable over the entire period. The abundance ratio of *Castanea* was low, but it increased gradually (from 1.5% to 4.5%) between 4800 and 4300 cal yr BP. The values of *Padus*, *Castanopsis*, *Pseudotsuga sinensis*, *E. ulmoides*, *Cerasus*, *Corylus*, *Picrasma* and *Diospyros* were low and discontinuous throughout the entire record at Xishanping.

5. Discussion

The charcoal assemblage in Xishanping includes warm-temperate taxa, such as *Picea*, *Betula*, *Acer*, *Ulmus*, *Carpinus* and *Quercus*; subtropical evergreen broadleaved taxa such as *Castanopsis*, *Phyllostachys* and *Indocalamus*; and subtropical deciduous taxa, such as *L. formosana* and *Toxicodendron*. The subtropical taxa are now distributed in the Yangtze River valley and on the southern side of the Qinling Mountains. Therefore, the fossil charcoal assemblage at Xishanping indicates that the vegetation types were evergreen broadleaved forest and mixed conifer-broadleaved forest during 4800–4300 cal yr BP. This suggests that the climate was warmer and wetter than it is currently and resembled the transition between the warm temperate and subtropical zones. Today, this transition is located at Lueyang in the south Qinling Mountains (Sun and Li, 2012).

The land use and fire activity of early farmers are much different from those of the hunting-gathering society. The vegetation and environment were affected greatly by "slash and burn" agricultural activity, rural construction, and the use of fire for pottery or in daily life. Although the main taxa present in the fossil charcoal existed at

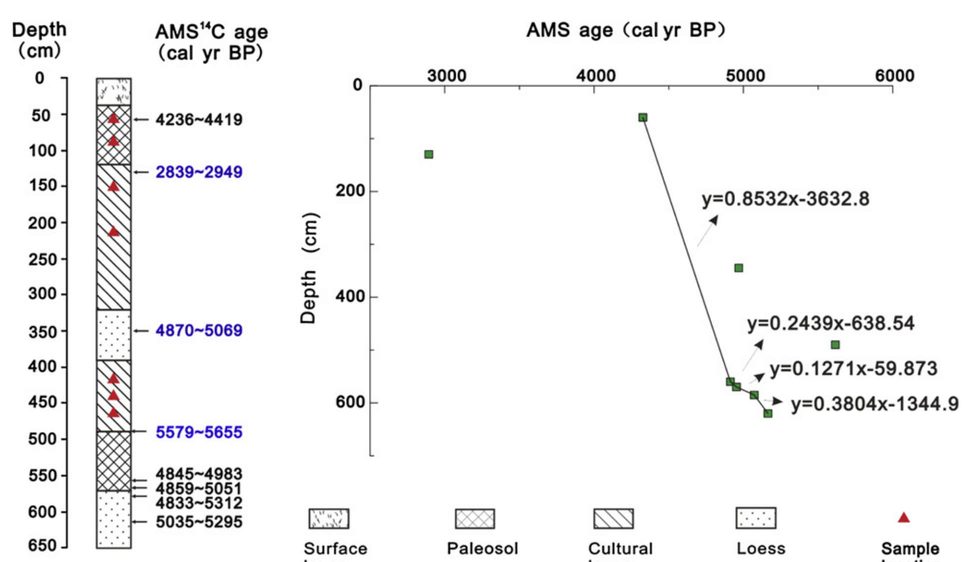

Fig. 2. Depth-age curve for AMS dates from the Xishanping section (The age-depth model was based on 5 AMS dates, excluding the blue age in the figure.). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
List of the taxa present in the charcoal assemblages and their relative abundance ratios and frequencies calculated by fragment count and ubiquity.

Taxa	Absolute fragment count	Abundance ratio (%)	Ubiquity	Frequency (%)
Picea sp.	86	10.6	7	100
Pseudotsuga sinensis	15	1.9	4	57.1
Castanea sp.	28	3.5	7	100
Quercus sp.	61	7.6	7	100
Castanopsis sp.	14	1.7	5	71.4
Toxicodendron sp.	48	5.9	7	100
Carpinus sp.	61	7.6	7	100
Betula sp.	69	8.5	7	100
Corylus sp.	5	0.6	2	28.6
Ulmus sp.	105	13.0	7	100
Prunus sp.	14	1.7	4	57.1
Padus sp.	20	2.5	6	85.7
Liquidambar formosana	63	7.8	7	100
Acer sp.	65	8.0	7	100
Picrasma sp.	3	0.4	2	28.6
Diospyros sp.	15	1.9	2	28.6
Eucommia ulmoides	7	0.9	4	57.1
Phyllostachys sp.	56	6.9	6	85.7
Phyllostachys glauca	61	7.6	6	85.7
Indocalamus sp.	12	1.5	5	71.4
Total	808	100%	7	100%

that time, the abundance ratios varied considerably between 4800 and 4300 cal yr BP at Xishanping. The trends of the abundance ratios, such as those of *Picea*, *Betula*, *Acer*, *Ulmus* and *Quercus*, decreased after 4600 cal yr BP, which is consistent with the pollen changes and indicates the decline in the mixed coniferous-broadleaved forest (Fig. 5). Correspondingly, the increasing abundance ratio of Bambusoideae indicates the expansion of the bamboo forest.

High-resolution palaeoenvironmental records depict no climatic change in the monsoon region of China between 4800 and 4300 cal yr BP (Wang et al., 2005; An et al., 2005; Xiao et al., 2009). The relative stability of some taxa in the charcoal record at Xishanping most likely reflects a relatively stable climate; this is especially apparent in taxa that prefer a warm-humid climate (e.g., *L. formosana*). It also suggests that the dramatic decrease in the abundances of some taxa in the charcoal record after 4600 cal yr BP, including *Picea*, *Betula*, *Acer*, *Ulmus*, *Carpinus* and *Quercus*, was not obviously driven by climate. The wood of *Picea*, *Betula*, *Acer*, *Ulmus*, *Carpinus* and *Quercus* has high density and weight; it also offers high heat production and is easy to burn, making it an excellent fuel wood. *Picea*, *Carpinus* and *Quercus* are good sources of timber and were used to construct houses and sacrificial sites in the Tianshui Basin during the mid-late Neolithic (Lang, 2002). Furthermore, these taxa, which were integral to the production and living conditions of prehistoric humans, have a low growth rate and a long mature period (e.g., approximately 12 years for *Picea*, 30–60 for *Betula* and more than 50 for *Ulmus*). Therefore, these taxa are difficult to restore quickly after deforestation (Gao et al., 2000).

The mature period of Bambusoideae is short, and its growth can become forest in only 2–3 years. Bambusoideae is always a pioneer species in the process of forest succession, and it is easily restored after destruction in warm temperate and subtropical zones (Li et al., 2006). Therefore, when the forest with a long mature period was destroyed, a forest gap occurred, resulting in the invasion of pioneer plants with strong competitive capacities. The taxa of *Picea*, *Ulmus*, and *Carpinus* decreased sharply, and the Bambusoideae types increased dramatically, becoming the dominant plants after 4600 cal yr BP at Xishanping (Figs. 4 and 5). This waning and waxing transformation shows that the bamboo invaded and formed the secondary vegetation after the destruction of the mixed conifer and broadleaved forest.

Bamboo forms forests quickly and has significant economic value. Ancient people at the Banpo site near Xi'an have produced bamboo goods since the early Neolithic period (Institute of Archaeology, CASS and Xi'an Banpo Museum, 1963). Over 200 bamboo products were discovered at the Qianshanyang site in Wuxing, Zhejiang Province (Zhejiang Provincial Cultural Relics Management Committee, 1960). Prehistoric humans used bamboo as a building material to construct houses at the Caoxieshan site

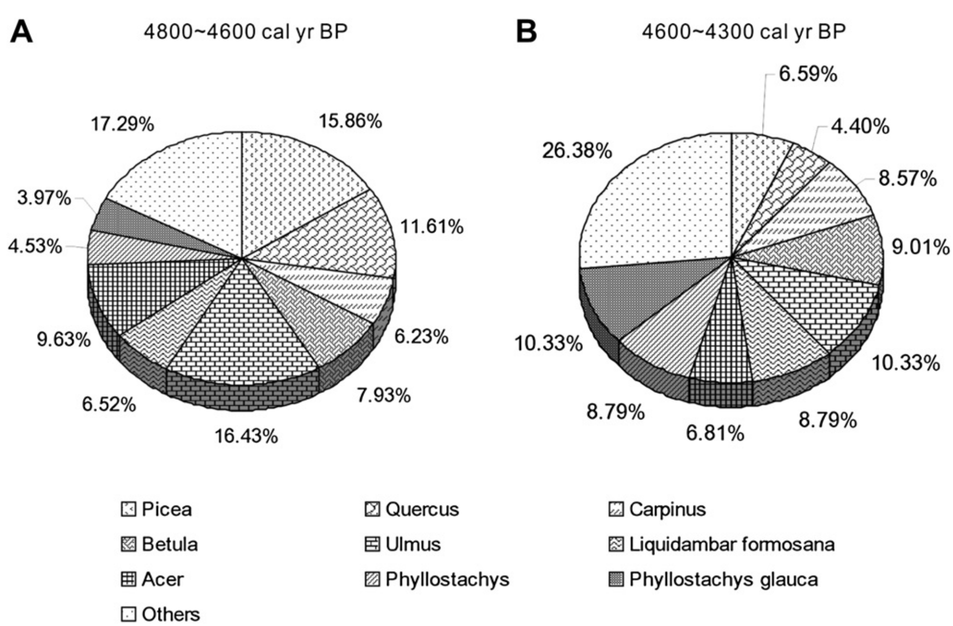

Fig. 3. Abundance ratios of primary taxa in the Xishanping charcoal assemblage. Both figures demonstrate that the fossil charcoal of *Picea*, *Quercus*, *Carpinus*, *Betula*, *Ulmus*, *Liquidambar formosana*, *Acer* and *Phyllostachys* account for approximately 80% of the total samples. The dramatic change in the primary taxa occurred at approximately 4600 cal yr BP at the Xishanping site. The fossil charcoal of *Picea*, *Quercus* and *Ulmus* decreased markedly after 4600 cal yr BP, and the evidence of Bambusoideae (*Phyllostachys*, *Phyllostachys glauca*) plants clearly increased.

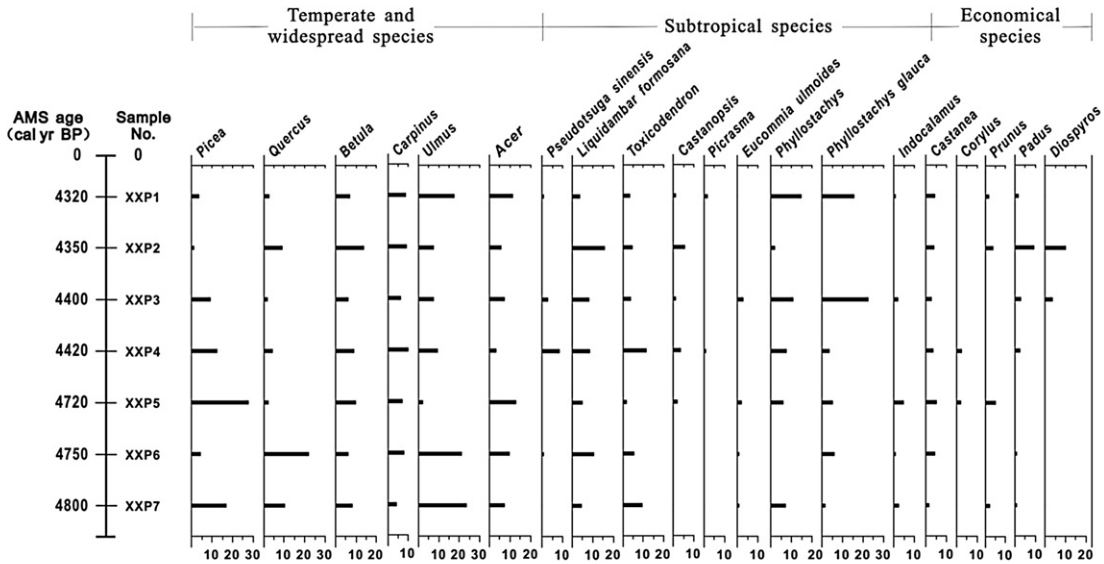

Fig. 4. Abundance ratios of fossil charcoal from the Xishanping section.

(Nanjing Museum, 1980). Bamboo shoots also served as a food, as demonstrated in some archaeological sites (Guan, 2004). Therefore, bamboo may have played an important role in the mid-late Neolithic at Xishannping.

Compared with the evidence of pollen and seeds from Xishanping (Fig. 4), the pollen of Gramineae and *Fagopyrum* increased continuously during 4800–4300 cal yr BP (Li et al., 2007a, 2007b). Meanwhile, in addition to bamboo, the economic trees *Castanea*, *Cerasus*, *Padus* and *Diospyros* also increased after 4600 cal yr BP. The common characteristics of economic trees are that they produce edible nuts or berries, which provide starches, sugars, proteins and vitamins. The fruit trees of *Castanea*, *Corylus*, *Cerasus* and *Diospyros* all originated from China and have a long history of planting, as recorded in the historical documents of the *Classic of Poetry* and *Classic of Rites*. At present, most of these fruit trees are distributed in humid valley areas. Xishanping is located on a terrace on the southern bank of the Xihe River, where the environment is suitable for fruit tree growth.

To date, it is difficult to determine whether the fruit taxa mentioned above are wild or domesticated according only to anatomic character. Generally, the domestication of fruit trees develops from their corresponding wild plants, which were an important food source of prehistoric humans, especially in the hunting-gathering stage. The fossil charcoal of fruit trees appears throughout 4800–4300 cal yr BP and increases gradually from the early to late period at the Xishanping site. It is almost certain that humans used nuts and berries as an important food resource and managed the economic fruit trees.

Evidence from archaeological investigations show that Neolithic sites were not numerous until the late Yangshao Culture (5900–5000 cal yr BP) in the western Loess Plateau (An et al., 2005), indicating a relatively low level of population and human activity. The density of archaeological sites (numbers per 100 yr) in the western Loess Plateau increased dramatically (Fig. 6; Institute of Archaeology of CASS, 1999) by approximately seven times in some areas, suggesting a rapid growth in the population (Li et al.,

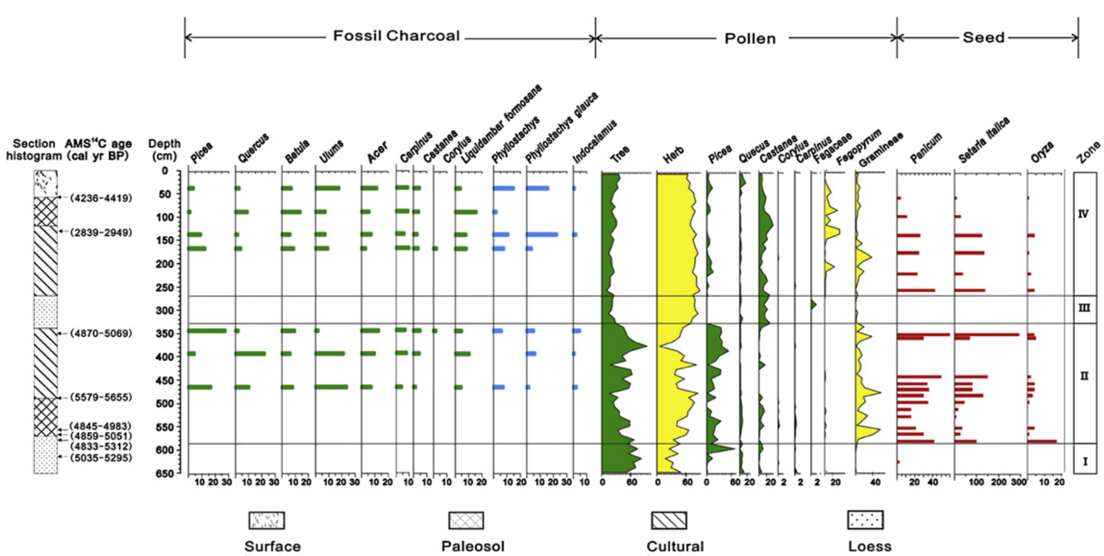

Fig. 5. The records of fossil charcoal, pollen and seeds from the Xishanping section.

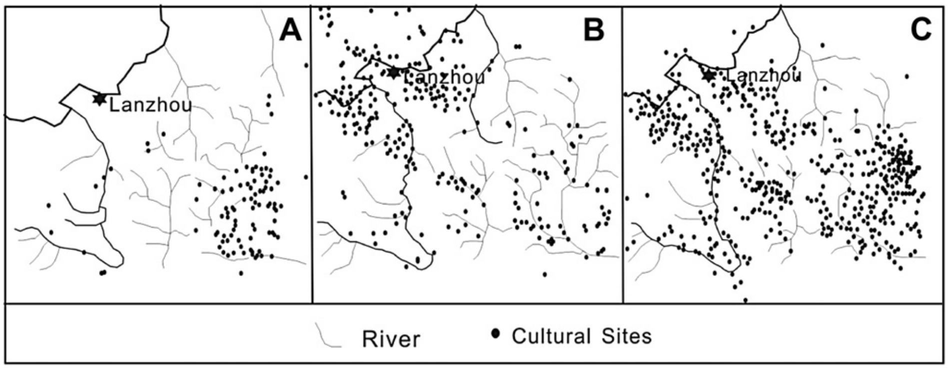

Fig. 6. Temporal distribution of excavated archaeological sites in the western part of the Chinese Loess Plateau. A. Middle-late Yangshao Culture (5900–4900 cal yr BP); B. Majiayao Culture (5300–4200 cal yr BP); C. Qijia Culture (4300–3900 cal yr BP) (cited from An et al., 2005).

2009). Prehistoric humans required cultivated land and plants to live, resulting in the clear correlation between the rapid population growth and its increasing influence on the vegetation. If the subsistence pattern at Xishanping was widespread in the Loess Plateau, it would suggest that the intensity and scale of the vegetation affected by prehistoric humans was much greater during the late Neolithic than was previously believed.

6. Conclusion

(1) The dramatic decline of the mixed coniferous-broadleaved forest and the expansion of Bamboo forest after 4600 cal yr BP were not obviously influenced by the climate but were a result of human impact.
(2) The economic fruit trees of *Castanea*, *Cerasus*, *Padus* and *Diospyros* appeared throughout 4800–4300 cal yr BP and increased gradually between the early and late periods. It is almost certain that the nuts and berries were an important food resource and that the fruit trees were managed by prehistoric humans in the late Neolithic.
(3) The intensity and scale of prehistoric humans' impact on the landscape of the west of the Loess Plateau during the late Neolithic are much greater than previously believed.

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