



Plant diversity of the Tianshui Basin in the western Loess Plateau during the mid-Holocene – Charcoal records from archaeological sites



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ABSTRACT

Assessing the potential impact of increased temperature needs examination of robust palaeorecords that contain analogues. The fossil charcoal (anthracological) records from the mid-Holocene archaeological sites can provide palaeo-analogues on the impacts of climate change. The Xishanping and Dadiwan sites were continuously developed during the Neolithic Culture in the Tianshui Basin, western Loess Plateau. A total of 24 samples of fossil charcoal were recovered using a floatation method. At least 100 fragments were examined from each sample, and these fragments were identified following standard procedures, and the results were used to reconstruct the vegetation and plant diversity between 5200 and 4300 cal BP, which was a warm period for the region. The charcoal evidence from the Xishanping and Dadiwan sites confirm that woody plants were widely available, including temperate taxa such as *Betula*, *Ulmus*, *Quercus*, *Carpinus*, *Acer*, *Corylus* and *Padus*, and typical subtropical taxa such as *Bambusoideae*, *Liquidambar formosana*, *Castanopsis*, *Pseudotsuga sinensis*, and *Eucommia ulmoides*. The assemblages of fossil charcoal show that mixed forests of north-subtropical evergreen and deciduous broadleaved trees existed. This is a broader range of woody plants than at present in the Tianshui Basin. This leads to the conclusion that the warmer and increasing monsoon precipitation resulted in a northward shift in the southern vegetation zones. And that the natural botanical diversity between 5200 and 4300 cal BP was also greater than at present in the Tianshui Basin, western Loess Plateau.

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1. Introduction

The IPCC's fourth assessment report (2007) concluded that global mean temperature rises resulting from anthropogenic induced green-house gas emissions will produce the risk that global mean temperatures will rise 2–3 °C when the CO₂ concentration reaches about 2 times today's levels (Caldeira et al., 2003; Hegerl et al., 2006). This may lead to sea-level rise, species extinction, biodiversity decreases, more frequent extreme events in climate, spread of tropical infectious diseases into temperate zones, food shortages and possible regional conflicts. Therefore, climate change and its abatement are key issues for governments and scientists (IPCC, 2007; Ding et al., 2009).

One way of assessing the potential impact of increased temperature is to examine robust palaeorecords which provide the

possible palaeo-analogue when the predicted conditions were represented. In this way, the responses of interactions of climate–human–ecosystems can provide system wide insights into the impacts of climate change.

The Holocene witnessed significant periods in societal developments, and palaeoenvironmental data recorded in loess, ice-core, marine and coral records indicate that the environment has undergone several climate changes in the period. These varied from place to place, but there was a warm period during 8000–3000 cal BP, called the Holocene Megathermal (Shi and Kong, 1992), or Holocene climatic optimum (An et al., 2000), and this was widespread. In China, the temperature between 5000 and 3000 cal BP was 2 °C higher than today, and January temperature was 3–5 °C higher (Zhu, 1973). Lu et al. (1996) concluded that the mean annual temperature was 14–16 °C, and the mean annual precipitation was 700–800 mm at Baoji in the southern Loess Plateau during the Holocene Megathermal, indicating that the temperature was 1–3 °C higher than today. Therefore, the mid-Holocene is a potential analogue of future climatic conditions.

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Pollen records from northern China during the Holocene Megathermal show that forest biomes expanded in the area and generally shifted northwards (Yu et al., 1998, 2000; Sun et al., 1999; Ni et al., 2010; Prentice et al., 2000). In the Chinese monsoon regions, the productivity of terrestrial ecosystems increased, and the frequency and extent of large magnitude climatic events decreased (Shi and Kong, 1992; Lu et al., 1999). The archaeological evidence also indicates a rapid development and expansion of human culture and civilization during the warm period (Zhu, 1973; Hsü, 1996; Xu, 1998).

Previous studies on regional vegetation histories are mainly based on the ratio and concentration of pollen records. However, their precision is limited due to pollen production rates, dispersal range, and identification precision. In general, there is limited evidence confirming vegetation types, plant community attributes and hence, plant diversity and representing local or extra-local occurrences of the source plants (Gaillard et al., 2008a,b).

Fossil charcoal results from incomplete burning, and retains the anatomic character of the original wood (Carcaillet, 2007). This raises the possibility of much greater precision in the level of taxonomic identification, and thus can overcome some of the limitations of plant microfossils (Cui et al., 2002). Anthracology has distinct advantages and has the significant potential for reconstructing terrestrial vegetation types and estimating plant diversity at a local scale due to the relatively limited dispersal of charcoal from source trees.

Some studies on macro-fossils of seeds and fossil charcoal have been used in studies on early agriculture and vegetation history in China (Li et al., 2007a,b; Zhao, 2010), but they are seldom used as a proxy for systematical reconstruction of Holocene vegetation and environment. This paper attempts to reconstruct the vegetation characteristics and plant diversity between 5200 and 4300 cal BP in

the Tianshui Basin, through fossil charcoal analyses from sediment at the Xishanping and Dadiwan archaeological sites, which have been dated by AMS radiocarbon techniques.

2. Regional setting

The Tianshui Basin is located in the northern Qinling Mountains, China, west of the Loess Plateau (Fig. 1). The mean annual temperature is 11.6 °C, and the mean annual precipitation is 491.6 mm, mainly concentrated in the summer months. The natural vegetation is warm-temperate mixed conifer-broad leaved forest, woodland and grasslands (Wu and Wang, 1983). It has, however, been greatly altered by agriculture. The few remaining natural forests are found on bedrock in Longshan, Xiqinling and Guanshan (Wu and Wang, 1983). The common natural woody plants today are members of the Fagaceae, Betulaceae, Pinaceae, Salicaceae, Ulmaceae, Aceraceae, Rosaceae and Tiliaceae, and the main herbaceous plants are species of Gramineae, Compositae, Leguminosae, and Ranunculaceae.

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, and is about 50 m above the river bed (Fig. 1). The site covers an area of 204,800 m². Archaeologically there were eight cultural periods between 7800 and 3000 cal BP, although the stoneware and pottery were mainly from the Majiayao (5300–4050 cal BP) and Qijia (4300–3700 cal BP) cultures of the late Neolithic (Institute of Archaeology, Chinese Academy of Social Sciences, 1999; An et al., 2005). Archaeobotanical evidence from the Xishanping indicates the broadening of early agriculture for the last 4300 cal BP (Li et al., 2007a,b).

The Dadiwan site (35°0'29.40"N, 105°54'40.70"E, 1500 m a.s.l.) is located in Shaodian village, northeast of Qin'an, on the I and II

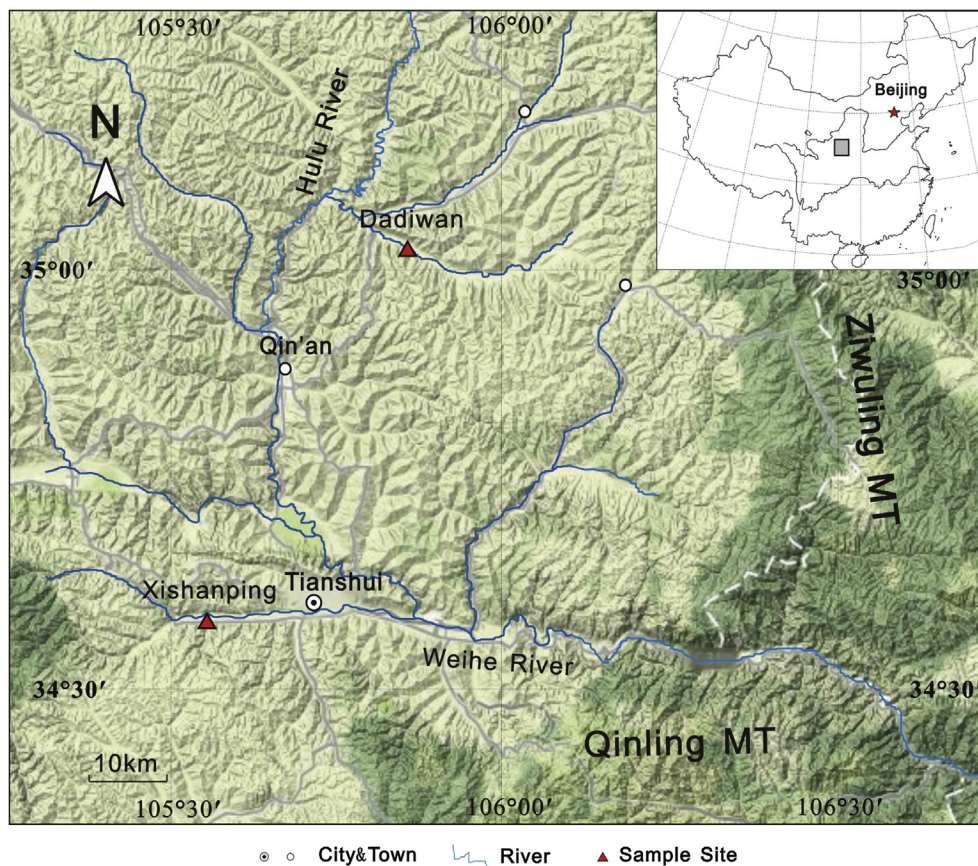


Fig. 1. The modern vegetation distribution of the Loess Plateau and location of the Xishanping and Dadiwan sites, NW China.

terraces and the gentle slope zone of the south bank of the Qingshuihe River (Fig. 1). Extensive archaeological excavation work has been done at the Dadiwan site (Gansu Provincial Institute of Archaeology, 2006), and the culture of this site is supposed to be the most developed and continuous, including the Pre-Yangshao (8000–7000 cal BP), the Yangshao (7000–5000 cal BP), the Majiayao (5000–4100 cal BP) and early phase of the Changshan culture (4100–3800 cal BP).

3. Materials and methods

3.1. Sample selection

A 650 cm continuous and undisturbed cultural sediment profile on the northern side of the Xishanping site was selected as the Xishanping section, with 40 cm of modern cultivation layers on the top of the stratigraphy. Previous research based on pollen, phytolith and seeds have been published (Li et al., 2007a,b). Eight accelerator mass spectrometry (AMS) radiocarbon dates including 6 charcoal samples (branches or twigs of wood) and 2 charred seeds were conducted at the University of Tokyo. The calendar ages were calculated using the Reimer et al. (2009) Radiocarbon Calibration Program (Table 1). The sediment above 40 cm had been disturbed by modern agriculture, and fossil charcoals below 450 cm depth are rare, and because of their small size (below 4 mm) are difficult to identify. Therefore, seven samples from the cultural sediment at 40–450 cm depth with abundant charcoal, were collected.

Table 1
Accelerator mass spectrometry (AMS) radiocarbon dates from the Xishanping (XXP) and Dadiwan (DDW) sites.

Sample location	Depth (cm)	Lab. no	Sample type	$\delta^{13}\text{C}$	AMS age (BP)	Calibrated age (cal BP, 2 σ)
XXP1	60 cm	TKal3882	Charcoal	-20.3	3900 ± 35	4235–4424
XXP2	130 cm	TKal3883	Charcoal	-26.9	2785 ± 30	2837–2956
XXP3	345 cm	TKal3884	Charcoal	-26.2	4430 ± 35	4873–5071
XXP4	490 cm	TKal3885	Charcoal	-29.4	4855 ± 35	5580–5655
XXP5	560 cm	TKal3886	Charcoal	-27.8	4360 ± 35	4850–4980
XXP6	570 cm	TKal3887	Charcoal	-23.7	4400 ± 35	4859–5054
XXP7	585 cm	TKal3888	Charred seed	-22.7	4430 ± 100	4840–5314
XXP8	620 cm	TKal3889	Charred seed	-10.4	4490 ± 35	5038–5297
DDW3	420 cm	OZK647	Charcoal	-23.7	4470 ± 60	4958–5303
DDW4	500 cm	OZK648	Charcoal	-25.1	4485 ± 50	4969–5307
DDW5	640 cm	OZK649	Charcoal	-22.8	4370 ± 50	4839–5056
DDW6	760 cm	OZK650	Charcoal	-24.1	4445 ± 50	4876–5090
DDW7	810 cm	OZK651	Charcoal	-24.8	4555 ± 50	5048–5445

The Dadiwan profile is located on the second terrace of the south Qingshuihe River. The total thickness is 820 cm, and the Neolithic culture layer occurs between 400 and 820 cm. Five charcoal AMS radiocarbon dates were conducted at the Australian Nuclear Science and Technology Organisation (ANSTO), and the calendar ages estimated (c.f. Reimer et al., 2009) (Table 1).

Charcoal samples are abundant in the cultural layers. They were recovered using the floatation method described in Tsuyuzaki (1994). Sufficient charcoal samples were recovered from the sediment in order to analyze them quantitatively.

3.2. Statistical analyses

The number of taxa present in a sample rises sharply as the first few charcoal specimens are examined (Keepax, 1988; Smart and Hoffman, 1988). Keepax (1988) suggested that a minimum of 100 fragments per sample should be examined in temperate regions, which would normally provide good representation of most types of charcoal. A similar analysis was carried in the Dadiwan site, and the saturation curve shows that there were almost no more new taxa recognized after examination of more than 100 fragments (Fig. 2). Therefore, examination of about 100 pieces of fossil charcoal from each sample examined is considered suitable in the study area.

At least 100 pieces were selected randomly, and identified, following standard procedures: first, pressure fractured charcoal fragments were prepared with a razor blade, in order to produce fresh clean surfaces to show transverse, radial and tangential sections (Leney and Casteel, 1975). These were examined under a stereo microscope, categorized, and one or two samples from each type were photographed under a scanning electron microscope (SEM). Identification of the taxa was carried out using wood anatomy atlases (Cheng et al., 1985; Yao, 1988; Schweingruber, 1990; Yao et al., 2002).

In order to describe the taphonomic characteristics of the fossil charcoal quantitatively, the index of diversity was used through three common formulas as follows (using Bio-Dap software; Magurran, 1988):

- (1) Simpson index: $D = 1 - \sum_{i=1}^S n_i(n_i - 1)/N(N - 1)$
- (2) Shannon–Wiener index: $H' = 3.3219(\lg N - 1/N \sum_{i=1}^S n_i \lg n_i)$
- (3) Pielou evenness index: $E = H'/H'_{\max}$ (with $H'_{\max} = \lg S$)

where n_i is the number of individuals of species i , N is the total number of all individuals counted, S is the total number of species in the community.

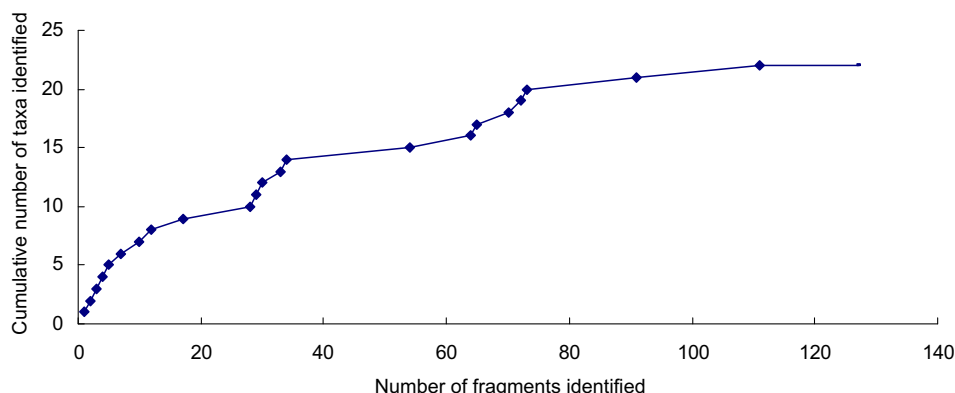


Fig. 2. Identification saturation curve of fossil charcoal from the Dadiwan site, China.

Diversity indices serve the purpose of distinguishing between “generalized” and “specialized” plant assemblages (Popper, 1988). The cultural layers accumulated over a relatively long time and contained scattered charcoal, and thus probably reflect the “generalized” local plant assemblage. Short-lived contexts such as hearths are likely to represent isolated burning situations, especially the last phase of fire prior to abandonment of the hearth, and therefore only give “specialized” information.

4. Results

A good chronological framework of Xishanping section was established by Li et al. (2007a) and will also be quoted in this study (Fig. 3). The seven samples from the depth of 40–450 cm cover the period of 4800–4300 cal BP (Fig. 3). A total of 808 pieces of charcoal were identified and 20 different taxa were identified from the samples in the Xishanping section (Table 2). The most abundant taxa were *Picea*, *Acer*, *Betula*, *Castanea*, *Carpinus*, *Liquidambar formosana*, *Quercus*, *Ulmus*, *Toxicodendron* and *Bambusoideae*, which were present in all samples. *Padus*, *Castanopsis*, *Pseudotsuga sinensis*, *Cerasus* and *Eucommia ulmoides* appeared in 4 samples, and *Corylus*, *Picrasma* and *Diospyros* were only present in two samples.

Table 2

Taxa of fossil charcoal and their relative frequencies and abundance ratio from the Xishanping site, China.

Taxa	Absolute fragment count	Abundance ratio (%)	Ubiquity	Frequency (%)
<i>Acer</i> sp.	65	8.04	7	100
<i>Betula</i> sp.	69	8.54	7	100
<i>Carpinus</i> sp.	61	7.55	7	100
<i>Castanea</i> sp.	28	3.47	7	100
<i>Castanopsis</i> sp.	14	1.73	5	71.43
<i>Cerasus</i> sp.	14	1.73	4	57.14
<i>Corylus</i> sp.	5	0.62	2	28.57
<i>Diospyros</i> sp.	15	1.86	2	28.57
<i>Eucommia ulmoides</i>	7	0.87	4	57.14
<i>Indocalamus</i> sp.	12	1.49	5	71.42
<i>Liquidambar formosana</i>	63	7.80	7	100
<i>Padus</i> sp.	20	2.48	6	85.71
<i>Phyllostachys</i> sp.	56	6.93	6	85.71
<i>Phyllostachys glauca</i>	61	7.55	6	85.71
<i>Picea</i> sp.	86	10.64	7	100
<i>Picrasma</i> sp.	3	0.37	2	28.57
<i>Pseudotsuga sinensis</i>	15	1.86	4	57.14
<i>Quercus</i> sp.	61	7.55	7	100
<i>Toxicodendron</i> sp.	48	5.94	7	100
<i>Ulmus</i> sp.	105	13.00	7	100
Total	808	100	7	100

The abundance of charcoal types in the whole fossil charcoal counts from the Xishanping section (Table 2) show that *Ulmus*, *Picea*, *Betula*, *Acer*, *L. formosana*, *Carpinus*, *Quercus* and *Phyllostachys glauca*, make up over 70% of the fossil charcoal assemblages, and are presumed to be the main sources of firewood for prehistoric people.

Fig. 3 shows that the abundance of *Picea*, *Quercus* and *Ulmus* are high (over 20%), while the values of *Bambusoideae* are low, with a range from 1% to 7% during 4800–4600 cal BP. After 4600 cal BP, *Picea* values decreased from a peak value of 28% to below 5%, *Ulmus* decreased to about 7%, while *Bambusoideae* increased significantly to a peak value of 23%. The abundance of *Carpinus*, *Betula*, *Toxicodendron* and *Acer* were relatively stable. The abundance of *Castanea* was low, but increased gradually (from 1.5% to 4.5%) The

values of *Padus*, *Castanopsis*, *P. sinensis*, *E. ulmoides*, *Cerasus*, *Corylus*, *Picrasma* and *Diospyros* were low and discontinuous through the whole record at Xishanping.

At Dadiwan (Fig. 4) and according to the AMS ¹⁴C dating, the depth of 400–820 cm is cultural sediment from 5300 to 4900 cal BP, and belongs to the Late Yangshao and the early Changshan cultures. A total of 2307 charcoal fragments from 34 different taxa were identified from the 17 samples in the Dadiwan (Table 3). *Betula*, *Corylus*, *Ulmus*, *Quercus mongolica* and *Acer* were present in all 17 samples, while *Picea brachytyla*, *Abies*, *Ostrya*, *Quercus aliena*, *Xylosma racemosum*, *Toxicodendron* and *L. formosana* were present in 16 samples. *Alnus*, *Sorbus pohnuashanensis*, *Juglans*, *Gymnocladus chinensis*, *E. ulmoides*, *Ehretia* and *Fargesia* appeared in more than 10 samples.

Table 3

Taxa of fossil charcoal and their relative frequencies and abundance ratio from the Dadiwan site, China.

Taxa	Absolute fragment count	Abundance ratio (%)	Ubiquity	Frequency (%)
<i>Abies</i> sp.	46	1.99	16	94.12
<i>Acer</i> sp.	246	10.66	17	100.00
<i>Alangium</i> sp.	15	0.65	7	41.18
<i>Alnus</i> sp.	78	3.38	14	82.35
<i>Betula</i> sp.	166	7.20	17	100.00
<i>Castanea</i> sp.	22	0.95	9	52.94
<i>Cercidiphyllum japonicum</i>	55	2.38	15	88.24
<i>Corylus</i> sp.	65	2.82	17	100.00
<i>Cyclobalanopsis</i> sp.	90	3.90	15	88.24
<i>Ehretia</i> sp.	48	2.08	10	58.82
<i>Eucommia ulmoides</i>	74	3.21	12	70.59
<i>Fagus</i> sp.	5	0.22	2	11.76
<i>Fargesia</i> sp.	34	1.47	11	64.71
<i>Firmiana</i> sp.	4	0.17	4	23.53
<i>Gymnocladus chinensis</i>	84	3.64	14	82.35
<i>Indocalamus</i> sp.	6	0.26	5	29.41
<i>Juglans</i> sp.	53	2.30	12	70.59
<i>Liquidambar formosana</i>	103	4.46	16	94.12
<i>Lonicera</i> sp.	10	0.43	4	23.53
<i>Osmanthus fragrans</i>	12	0.52	6	35.29
<i>Ostrya</i> sp.	118	5.11	16	94.12
<i>Phyllostachys</i> sp.	97	4.20	15	88.24
<i>Picea brachytyla</i> sp.	33	1.43	16	94.12
<i>Picrasma</i> sp.	7	0.30	5	29.41
<i>Prunus</i> sp.	2	0.09	1	5.88
<i>Prunus armeniaca</i>	3	0.13	3	17.65
<i>Quercus aliena</i>	190	8.24	16	94.12
<i>Quercus mongolica</i>	138	5.98	17	100.00
<i>Sorbus pohnuashanensis</i>	52	2.25	15	88.24
<i>Tilia</i> sp.	42	1.82	8	47.06
<i>Toxicodendron</i> sp.	102	4.42	16	94.12
<i>Ulmus</i> sp.	200	8.67	17	100.00
<i>Vaccinium</i> sp.	20	0.87	6	35.29
<i>Xylosma racemosum</i>	87	3.77	16	94.12
Total	2307	100	17	100

At Dadiwan, the abundance of *Acer* (10.7%), *Ulmus* (8.7%), *Q. aliena* (8.2%), *Betula* (7.2%), *Q. mongolica* (6%), *Ostrya* (5.1%) and *Bambusoideae* (the total abundance of *Phyllostachys*, *Fargesia* and *Indocalamus* is 5.93%) are high, and their frequency of occurrence is above 80%. These are assumed to be the main sources for firewood.

Fig. 4 shows that the abundance of *Ostrya* (peak value of 11.7%), *Alnus* (peak value of 17.3%), *G. chinensis* (peak value of 13.8%), *Toxicodendron* (peak value of 12.1%), *Tilia* (peak value of 11.3%), and *Bambusoideae* (peak value of 14.1%) were high between 5200 and 5100 cal BP, and after 5100 cal BP the abundance of these taxa reduced generally. The abundances of *Picea* and *Abies* were relatively low before 5100 cal BP, and increased after 5100 cal BP.

To assess variation within the charcoal assemblages, the values of diversity from the individual samples were compared with the average values (mean, median and standard deviation) in all samples. All 24 samples from Xishanping (Table 4) and Dadiwan (Table 5) sites have high and almost even diversity values with low standard deviation, which exclude the possible effects such as trampling, reheating and weathering, and thus breakdown of fossil charcoal. This almost even distribution of diversity values suggest that the fossil charcoals are the results of the long term burning history and thus reflects a generalized plant assemblage.

Table 4
Diversity index of fossil charcoal from the Xishanping site, China.

Sample no.	No. of taxa	No. of individuals	Simpson index	Shannon–Wiener index	Pielou index
XXP1	17	115	0.809	2.44	0.86
XXP2	14	109	0.913	2.46	0.93
XXP3	17	111	0.906	2.54	0.9
XXP4	16	120	0.925	2.6	0.94
XXP5	16	101	0.883	2.41	0.87
XXP6	14	115	0.876	2.25	0.85
XXP7	15	137	0.882	2.32	0.86
Mean			0.885	2.431	0.887
Median			0.883	2.44	0.87
Standard deviation			0.025	0.109	0.045

Table 5
Diversity index of fossil charcoal from the Dadiwan site, China.

Sample no.	No. of taxa	No. of individuals	Simpson index	Shannon–Wiener index	Pielou index
DDW1	14	35	0.919	2.4	0.91
DDW2	27	116	0.947	2.99	0.91
DDW3	23	99	0.942	2.89	0.92
DDW4	25	137	0.928	2.83	0.88
DDW5	27	167	0.946	3.01	0.91
DDW6	25	157	0.939	2.9	0.9
DDW7	26	171	0.937	2.88	0.89
DDW8	26	172	0.925	2.8	0.86
DDW9	26	147	0.949	3.02	0.93
DDW10	21	144	0.916	2.73	0.9
DDW11	24	194	0.935	2.86	0.9
DDW12	23	161	0.941	2.88	0.92
DDW13	24	165	0.935	2.88	0.91
DDW14	24	159	0.935	2.84	0.89
DDW15	19	123	0.911	2.59	0.88
DDW16	15	33	0.917	2.46	0.91
DDW17	21	127	0.922	2.71	0.89
Mean			0.932	2.804	0.901
Median			0.935	2.86	0.9
Standard deviation			0.011	0.178	0.017

5. Discussion and conclusion

The anatomic character of fossil charcoal, which is almost the same as in original wood (McGinnes et al., 1974), raises the possibility of more precision in taxonomic identification. Evidence from Site Catchment Analysis indicates that the activity range of pre-historic farming groups was limited to around 5 km or 1 h's walking distance (Renfrew and Bahn, 1991; Qin et al., 2010). Here, it is considered that the fossil charcoal in the archaeological site originated from nearby woody plants. Unavoidably, subjective criteria linked to cultural contingencies, simple preferences or taboos will always be difficult to perceive. It can be assumed that the distortions of anthracological spectra are constant through time and do not hide real environmental variations, so that palaeoecological

interpretations can then be put forward (Théry-Parisot et al., 2010). Therefore, the charcoal presence should reflect site-related information and reveal information on woodland composition on a local scale (Shackleton and Prins, 1992; Scheel-Ybert, 2000).

Charcoal in archaeological sites has been used widely to make inferences regarding use of wood by people, and on forest composition in recent years (e.g. Thiébaud, 2002; Asouti and Austin, 2005; Dufraisse, 2006). However, composition would be influenced by human selection; and usually the “selection” is thought to be happened when people search for “good fuel”. The concept of “good fuel” is a very recent principle which refers to domestic heating wood. Although the combustible properties of wood depend on the species, caliber of the wood, humidity, and the physiological state of the wood, the calorific value varies little from one species to another (Théry-Parisot, 2001). Therefore, the “selection” of fuel wood mostly depend on the wood's abundance, the ease of collecting, and the ability to transport the wood (Théry-Parisot, 2001). Models from the field of human behavioral ecology also suggest that humans used wood types for fuel in proportion to their local availability (Marston, 2009). Hence, the fossil charcoal from the archaeological site should reflect the local wood community.

There were possible effects of post-depositional breakage on charcoal fragments, but the fragmentation of charcoal in an archaeological sample is the same for all species (Chabal, 1992), charcoal quantification of all the species have an average similar behavior concerning fire and post-deposition process (Théry-Parisot et al., 2010). It therefore follows that the proportions of taxa in the archaeological charcoal assemblages can be used to interpret differences resulting from climate setting (e.g. Newton, 2005) and/or human activity (e.g., Willcox, 1974, 1999, 2002; Miller, 1985; Sun et al., 2010). The ancient people in the Tianshui Basin settled as a farming group between 5200 and 4300 cal BP and the range of agricultural activities was broad (Li et al., 2007a,b). The abundance of fossil charcoal from the Xishanping and Dadiwan sites were thus closely related to fire activities managed by humans.

The charcoal evidence from the Xishanping and Dadiwan sites confirm that the woody plants were widely available, including temperate taxa such as *Betula*, *Ulmus*, *Quercus*, *Carpinus*, *Acer*, *Corylus* and *Padus*, and also typical subtropical taxa such as *Bambusoideae*, *L. formosana*, *Castanopsis*, *P. sinensis*, and *E. ulmoides*. Some plant identifications are possible to species level, and help the reconstruction of vegetation types and their characteristics more precisely. The fossil charcoal records reveal that more woody types were present compared to today.

Fossil charcoal analysis has limitations, as it represents a record of the remains of woody plants (trees and shrubs, not herbs), and thus it is hard to assess the plant diversity directly. The charcoal assemblages, however, can provide an indication of the vegetation community, and different communities would contain different kinds of trees, shrubs and herbs. In the Asian monsoonal area especially, the vegetation belt can always be recognized from the characteristic woody species (Song, 1999).

The Qinling Mountains provide a natural boundary between north and south China. A majority of areas in the southern side of the Qinling Mountains supported subtropical evergreen broadleaved forest and mixed north-subtropical evergreen and deciduous broadleaved forests, with vegetation types including temperate deciduous broadleaved forest and shrub, subtropical coniferous forest, temperate grasses, weedy meadows, as well as subtropical evergreen and deciduous broadleaved mixed forest, subtropical evergreen and deciduous broadleaved shrub, and bamboo forest. The main vegetation to the north of the Qinling Mountains is temperate and warm-temperate vegetation including temperate deciduous forest and shrub, temperate and subtropical coniferous

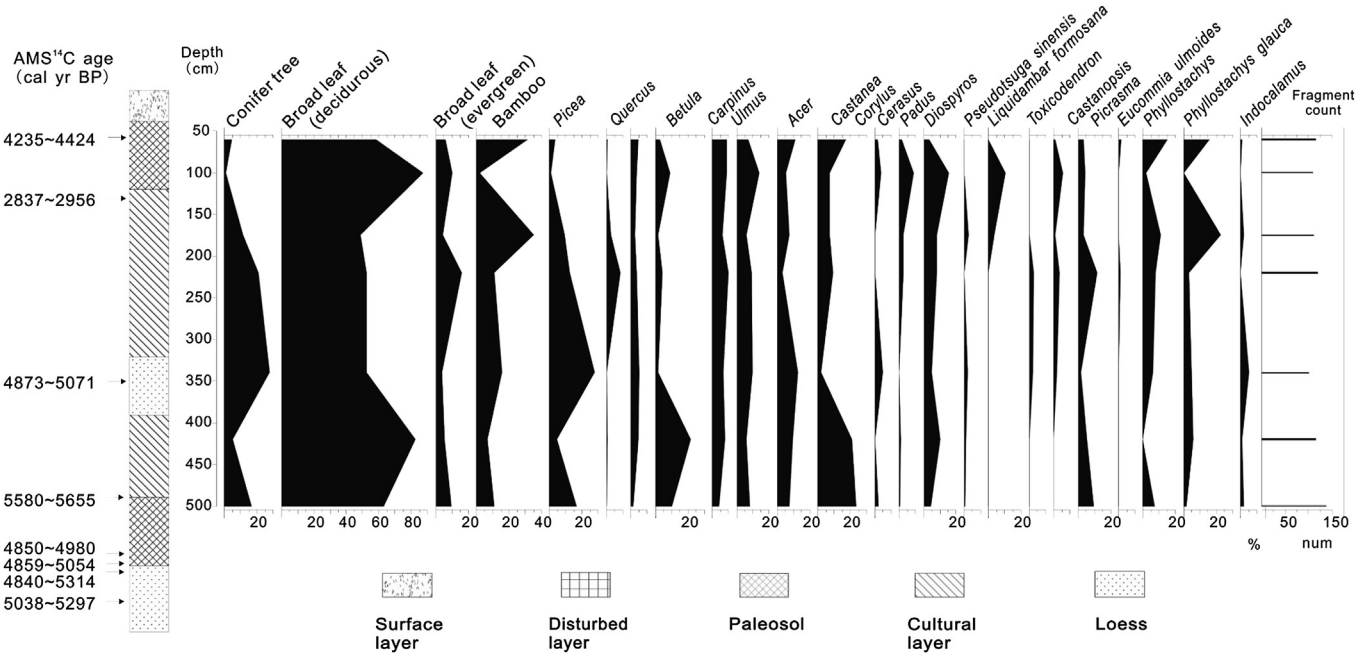


Fig. 3. The percentage of fossil charcoal from the Xishanping section, China.

forest, temperate grasses, and meadows. Thus, the distribution of main taxa in China (*Flora Reipublicae Popularis Sinicae*) (Fig. 5) shows that most of the subtropical taxa are distributed south of the Qinling Mountains (Fig. 5A, B), while temperate and some eur-choric taxa grow well in the north, and all over China.

Chinese vegetation mapping (Editorial Committee of Chinese Vegetation, 1980; Editorial Board of the Vegetation Map of China, CAS, 2001) categorized the Tianshui Basin on the north side of the Qinling Mountains in the temperate deciduous broadleaved area of the south *Quercus* forest zone. Well developed forests of *Quercus liaotungensis*, *Q. aliena* var. *acuteserrata*, *Quercus variabilis*, *Quercus acutissima*, *Populus davidiana*, *Betula platyphylla*, *Betula albo-sinensis*,

Picea, *Abies*, *Pinus armandii*, and *Pinus bungeana* occur. The woody taxa from the assemblages of fossil charcoal in the Xishanping and Dadiwan sites show the presence of subtropical plant taxa. Some typical subtropical animals such as *Macaca* and *Rhizomys* (Institute of Archaeology, Chinese Academy of Social Sciences, 1999) were also found in the Xishanping site between 4800 and 4300 cal BP. The vegetation type represented can be defined as a mixed forest of north-subtropical evergreen and deciduous broadleaved. The climate can be described as a transition zone of warm temperate and subtropical zones. Both are similar to the modern vegetation and climate in southern Shaanxi and northern Sichuan provinces south of the Qinling Mountains (Fig. 5D).

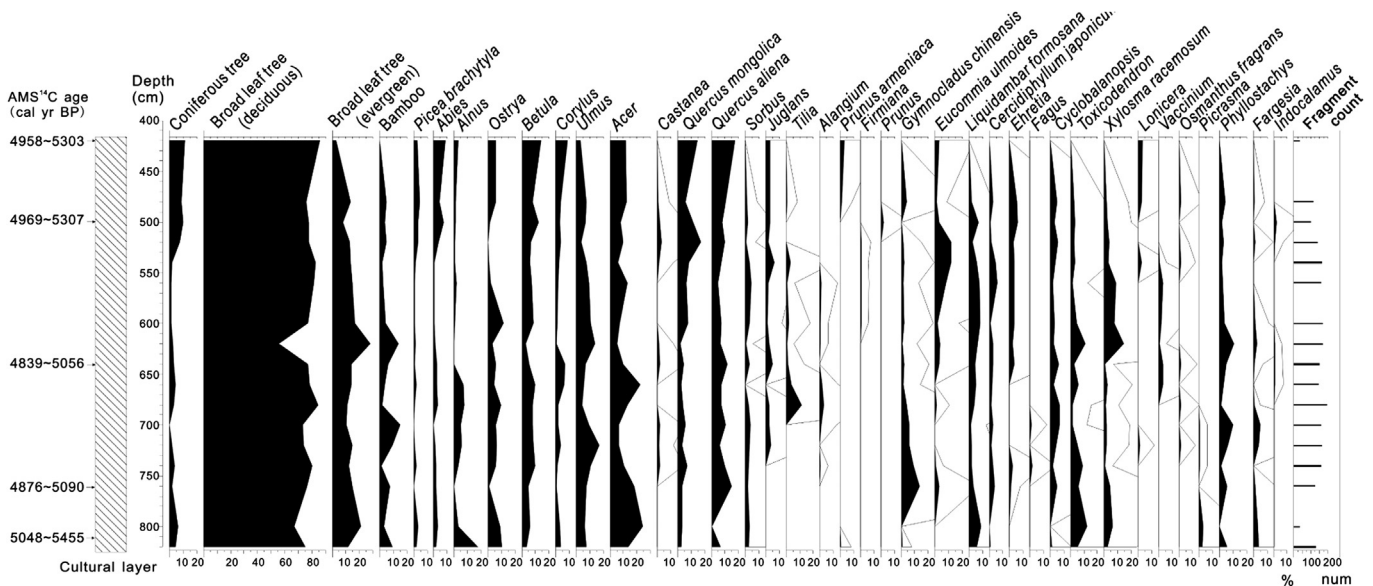


Fig. 4. The percentage of fossil charcoal from the Dadiwan section, China.

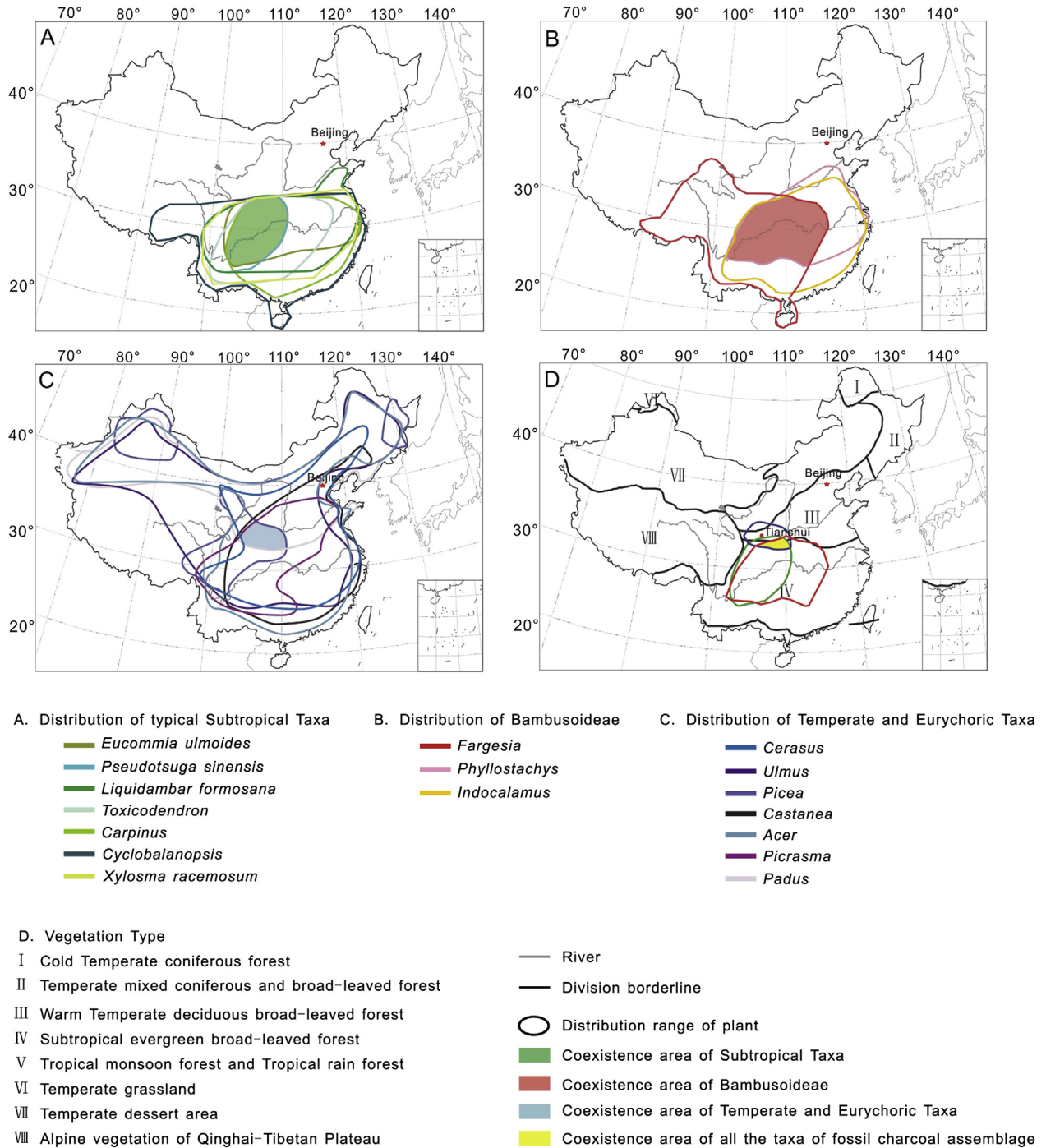


Fig. 5. The distribution of modern species of 17 typical taxa found at the prehistorical Xishanping and Dadiwan sites, China (*Flora Reipublicae Popularis Sinicae*).

The species diversity of subtropical vegetation is greater than for temperate vegetation in eastern China (Wu and Wang, 1983). The subtropical area on the southern side of the Qinling Mountains covers 51.2% of the land area, and contains representatives of 235 families, 1203 genera, and more than 4000 species. The temperate area on the northern side such as the Tianshui Basin contains 169 plant families, 750 genera, and about 1479 species. Therefore, it seems that a warmer mid-Holocene resulted in the vegetation zones shifting northwards. Thus the subtropical vegetation developed in the northern side of the Qinling Mountains during the 5200–4300 cal BP period and the mixed forest of evergreen and

deciduous broadleaved species appeared, more to the north of the Qinling Mountains than at present.

The effect of climate change on biodiversity is currently a contentious issue. Some scientists argue that climate change may cause species extinction and biodiversity loss in tropical zones (Lovejoy and Hannah, 2005), resulting in the loss of diversity in tropical forests in Australia (Steffen et al., 2009). New evidence shows that tropical forest diversity was high during the Palaeocene-Eocene Thermal Maximum, and this was a warmer period than today (Jaramillo et al., 2010). The new results suggest that the growing seasons were extended, timberlines were

elevated, forest invaded into tundra, and that shrub invasions into meadows accompanied the period of warmer climate. Meanwhile, vegetation cover and forest area increased for almost all regions of China (Fang et al., 2003). Pollen data shows that during the warm period forests shifted northwards and westwards, and that these forests were much wider in distribution than today (Sun et al., 1999).

Climate is an essential factor to the distribution of forest vegetation and in species abundance (e.g. Huntley and Birks, 1983; Bartlein et al., 1986; Fang et al., 2001). Regional differences in warming result in uneven distribution of its effects, and in different levels of response of plant taxa. In eastern Asia, warming temperatures are always accompanied by increasing intensity of the summer monsoon and thus increasing precipitation. Usually the precipitation is the main-control factor to forest on the Loess Plateau during the Holocene (Shang and Li, 2010; Zhou and Li, 2012). This will result in species modifying their distribution patterns (Willis et al., 2007), and hence the vegetation zone may shift.

Between 5000 and 3000 cal BP, climate of the Loess Plateau was wetter and warmer than today (Shi and Kong, 1992), with temperatures 2 °C higher (Zhu, 1973) and an increasing intensity of monsoon precipitation (An et al., 2000). The fossil charcoal records from the Tianshui Basin suggest that subtropical forest developed there, and the botanical diversity was increased between 5200 and 4300 cal BP. Therefore, if vegetation growth is not disturbed, it is theoretically possible that future warming will likely bring more precipitation and result in the southern vegetation zones shifting northwards, resulting in natural botanical diversity increases in the Tianshui Basin, and western Loess Plateau.

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References

- An, C.B., Tang, L.Y., Barton, L., Chen, F.H., 2005. Climate change and cultural response around 4000 cal BP in the western part of Chinese Loess Plateau. *Quaternary Research* 63, 347–352.
- An, Z.S., Wang, S.M., Liu, X.D., Li, X.Q., Zhou, W.J., 2000. Asynchronous Holocene optimum of the East Asian monsoon. *Quaternary Science Reviews* 19, 743–762.
- Asouti, E., Austin, P., 2005. Reconstructing woodland vegetation and its exploitation by past societies, based on the analysis and interpretation of archaeological wood charcoal macro-fossils. *Environmental Archaeology* 10, 1–18.
- Bartlein, P., Prentice, I., Webb III, T., 1986. Climatic response surfaces from pollen data for some eastern North American taxa. *Journal of Biogeography* 13, 35–57.
- Caldeira, K., Jain, A.K., Hoffert, M.I., 2003. Climate sensitivity uncertainty and the need for energy without CO₂ emission. *Science* 299, 2052–2054.
- Carcaillat, C., 2007. Charred particles analyses. In: Elias, S.A. (Ed.), *Encyclopedia of Quaternary Science*. Elsevier, Amsterdam, pp. 1582–1593.
- Chabal, L., 1992. La représentativité paléocécologique des charbons de bois archéologiques issus du bois de feu. In: Vernet, J.L. (Ed.), *Les charbons de bois les anciens écosystèmes et le rôle de l'Homme*, Bulletin de la Société Botanique de France, Paris, vol. 139, pp. 213–236.
- Cheng, J.Q., Yang, J.J., Liu, P., 1985. Chinese Timber Chorography. China Forestry Publishing House, Beijing.
- Cui, H.T., Li, Y.Y., Hu, J.M., Yao, X.S., Li, Y., 2002. Vegetation reconstruction of Bronze Age by using microscopic structure of charcoals. *Chinese Science Bulletin* 47, 2014–2017.
- Ding, Z.L., Duan, X.N., Ge, Q.S., Zhang, Z.Q., 2009. Control of atmospheric CO₂ concentrations by 2050: a calculation on the emission rights of different countries. *Science in China (Series D)* 52, 1447–1469.
- Dufraisse, A., 2006. Charcoal anatomy potential, wood diameter and radial growth. Charcoal analysis. In: Dufraisse (Ed.), *Charcoal Analysis: A New Analytical Tools and Methods for Archaeology (Papers from the Table-Ronde Held in Basel 2004)*. Archaeopress, Oxford, pp. 47–60.
- Editorial Board of the Vegetation Map of China, CAS, 2001. *The Vegetation Atlas of China 1:1000000*. Science Press, Beijing (in Chinese).
- Editorial Committee of Chinese Vegetation, 1980. *Chinese Vegetation*. Science Press, Beijing (in Chinese).
- Fang, J.Y., Chen, A.P., Peng, C.H., Zhao, S.Q., Ci, L.J., 2001. Changes in forest biomass carbon storage in China between 1949 and 1998. *Science* 291, 2320–2322.
- Fang, J.Y., Piao, S.L., He, J.S., Ma, W.H., 2003. Increasing terrestrial vegetation activity in China, 1982–1999. *Science in China (Series C)* 47, 229–240.
- Flora Reipublicae Popularis Sinicae (electronic version). <http://frps.plantphoto.cn/pdf.asp>. (in Chinese).
- Gaillard, M.J., Sugita, S., Bunting, J., Dearing, J., Bittmann, F., 2008b. Human impact on terrestrial ecosystems, pollen calibration and quantitative reconstruction of past land-cover. *Vegetation History and Archaeobotany* 17, 415–418.
- Gaillard, M.J., Sugita, S., Bunting, M.J., Middleton, R., Broström, A., Caseldine, C., Giesecke, T., Hellman, S.E.V., Hicks, S., Hjelte, K., Langdon, C., Nielsen, A.B., Poska, A., Stedingk, H.V., Veski, S., Members, P., 2008a. The use of modeling and simulation approach in reconstructing past landscapes from fossil pollen data: a review and results from the POLLANDCAL network. *Vegetation History and Archaeobotany* 17, 419–443.
- Gansu Provincial Institute of Archaeology, 2006. *Excavation Report of Qin'an Dadiwan Site*. Cultural Relics Publishing House, Beijing.
- Hegerl, G., Crowley, T.J., Hyde, W.T., Frame, D.J., 2006. Climate sensitivity constrained by temperature reconstructions over the past seven centuries. *Nature* 440, 1029–1032.
- Hsü, J.K., 1996. Could global warming be a blessing for mankind? *Terrestrial, Atmospheric and Oceanic Science* 7, 375–392.
- Huntley, B., Birks, H.J.B., 1983. *An Atlas of Past and Present Pollen Maps for Europe: 0–13000 Years Ago*. Cambridge University Press, New York.
- Institute of Archaeology of Chinese Academy of Social Sciences, 1999. *Shizhaocun and Xishanping*. Chinese Encyclopaedia Press, Beijing (in Chinese).
- IPCC, 2007. *Summary for Policymakers of Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.
- Jaramillo, C., Ochoa, D., Contreras, L., Pagani, M., Carvajal-Ortiz, H., Pratt, L.M., Krishnan, S., Cardona, A., Romero, M., Quiroz, L., Rodriguez, G., Rueda, M.J., Parra, F., Morón, S., Green, W., Bayona, G., Montes, C., Quintero, O., Ramirez, R., Mora, G., Schouten, S., Bermudez, H., Navarrete, R., Parra, F., Alvarán, M., Osorno, J., Crowley, J.L., Valencia, V., Vervoort, J., 2010. Effects of rapid global warming at the Palaeocene–Eocene boundary on neotropical vegetation. *Science* 330, 957–959.
- Keepax, C.A., 1988. *Charcoal Analysis with Particular Reference to Archaeological Sites in Britain*. PhD thesis. University of London.
- Loney, L., Casteel, R.W., 1975. Simplified procedure for examining charcoal specimens for identification. *Journal of Archaeological Science* 2, 153–159.
- Li, X.Q., Dodson, J., Zhou, X.Y., Zhang, H.B., Masutomo, R., 2007a. Early cultivated wheat and broadening of agriculture in Neolithic China. *The Holocene* 17, 555–560.
- Li, X.Q., Zhou, X.Y., Zhou, J., Dodson, J., Zhang, H.B., Shang, X., 2007b. The earliest archaeological evidence of the broadening agriculture in China recorded at Xishanping site in Gansu province. *Science in China (Series D)* 50, 1707–1714.
- Lovejoy, T.E., Hannah, L., 2005. *Climate Change and Biodiversity*. Yale University Press, New Haven.
- Lu, H.Y., Liu, T.S., Wu, N.Q., Han, J.M., 1999. Phytolith record of vegetation succession in the southern Loess Plateau since Late Pleistocene. *Quaternary Sciences* 4, 336–349.
- Lu, H.Y., Wu, N., Liu, T.S., Han, J.M., Qin, X.G., 1996. Seasonal changes on phytolith assemblage in loess in Baoji since 150 ka. *Science in China (Series D)* 26, 131–136.
- Magurran, A.E., 1988. *Ecological Diversity and Its Measurement*. Princeton University Press, Princeton.
- Marston, J.M., 2009. Modeling wood acquisition strategies from archaeological charcoal remains. *Journal of Archaeological Science* 36, 2192–2200.
- McGinnes, E.A., Szopa, P.S., Phelps, J.E., 1974. Use of scanning electron microscopy in studies of wood charcoal formation. *Scanning Electron Microscopy* 1974, 469–476.
- Miller, N.F., 1985. Palaeoethnobotanical evidence for deforestation in ancient Iran: a case study of urban Malyan. *Journal of Ethnobiology* 5, 1–21.
- Newton, C., 2005. Upper Egypt: vegetation at the beginning of the third millennium BC inferred from charcoal analysis at Adaima and Elkab. *Journal of Archaeological Science* 32, 355–367.
- Ni, J., Yu, G., Harrison, S.P., Prentice, I.C., 2010. Palaeovegetation in China during the late Quaternary: biome reconstructions based on a global scheme of plant functional types. *Palaeogeography, Palaeoclimatology, Palaeoecology* 289, 4–61.
- Popper, V.S., 1988. Selecting quantitative measurements in palaeoethnobotany. In: Hastorf, C.A., Popper, V.S. (Eds.), *Current Palaeoethnobotany*. University of Chicago Press, Chicago and London, pp. 53–71.
- Prentice, I.C., Jolly, D., BIOME 6000 Members, 2000. Mid-Holocene and glacial maximum vegetation geography of the northern continents and Africa. *Journal of Biogeography* 27, 507–519.
- Qin, L., Fuller, D.Q., Zhang, H., 2010. Modelling wild food resource catchments amongst early farmers: case studies from the lower Yangtze and central China. *Quaternary Sciences* 30, 245–261.
- Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Burr, G.S., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F.,

- Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., Talamo, S., Turney, C.S.M., van der Plicht, J., Weyhenmeyer, C.E., 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal BP. *Radiocarbon* 31, 1111–1150.
- Renfrew, C., Bahn, P., 1991. *Archaeology Theories, Methods and Practice*. Thames and Hudson Ltd, London.
- Scheel-Ybert, R., 2000. Vegetation stability in the Southeastern Brazilian coastal area from 5500 to 1400 ¹⁴C BP deduced from charcoal analysis. *Review of Palaeobotany and Palynology* 110, 111–138.
- Schweingruber, F.H., 1990. *Anatomy of European Woods*. Verlag Paul Haupt, Stuttgart Publishers, Stuttgart.
- Shackleton, C.M., Prins, F., 1992. Charcoal analysis and the principle of least effort – a conceptual model. *Journal of Archaeological Science* 19, 631–637.
- Shang, X., Li, X.Q., 2010. Holocene vegetation characteristics of the southern Loess Plateau in the Weihe River valley in China. *Review of Palaeobotany and Palynology* 160, 46–52.
- Shi, Y.F., Kong, Z.C., 1992. *The Climates and Environments of Holocene Megathermal in China*. China Ocean Press, Beijing.
- Smart, T.L., Hoffman, E.S., 1988. Environmental interpretation of archaeological charcoal. In: Hastorf, C.A., Popper, V.S. (Eds.), *Current Palaeoethnobotany*. University of Chicago Press, Chicago and London, pp. 165–205.
- Song, Y.C., 1999. Perspective of the vegetation zonation of forest region in eastern China. *Acta Botanica Sinica* 41, 541–552.
- Steffen, W., Burbidge, A.A., Hughes, L., Kitching, R., Lindenmayer, D., Musgrave, W., Stafford, S.M., Werner, P., 2009. *Australia's Biodiversity and Climate Change: A Strategic Assessment of the Vulnerability of Australia's Biodiversity to Climate Change*. A report to the Natural Resource Management Ministerial Council commissioned by the Australian government. CSIRO Publishing, Canberra.
- Sun, N., Li, X.Q., Zhou, X.Y., Zhao, K.L., Yang, Q., 2010. Early smelting recorded by fossil charcoal in Hexi corridor, Gansu province – a environmental influence factor. *Quaternary Sciences* 30, 310–316.
- Sun, X.J., Song, C.Q., Chen, X.D., 1999. "China Quaternary Pollen Database" (CPD) and "BIOME 6000" project. *Advance in Earth Sciences* 14, 407–411.
- Thiébaud, S., 2002. Charcoal analysis: methodological approaches, palaeoecological results and wood uses. In: *Proceedings of the Second International Meeting of Anthracology*, Paris, September 2000. Archaeopress, Oxford.
- Théry-Parisot, I., 2001. Économie du combustible au Paléolithique. *Anthracologie, Expérimentation, Taphonomie*. In: *Dossier de Documentation Archéologique*, 20. C.N.R.S., Paris.
- Théry-Parisot, I., Chabal, L., Chravzev, J., 2010. Anthracology and taphonomy, from wood gathering to charcoal analysis. A review of the taphonomic process modifying charcoal assemblages, in archaeological contexts. *Palaeogeography, Palaeoclimatology, Palaeoecology* 291, 142–153.
- Tsuyuzaki, S., 1994. Rapid seed extraction from soils by a flotation method. *Weed Research* 34, 433–436.
- Willcox, G., 1974. A history of deforestation as indicated by charcoal analysis of four sites in eastern Anatolia. *Anatolian Studies* 24, 117–133.
- Willcox, G., 1999. Charcoal analysis and Holocene vegetation history in southern Syria. *Quaternary Science Reviews* 18, 711–716.
- Willcox, G., 2002. Evidence for ancient forest cover and deforestation from charcoal analysis of ten archaeological sites on the Euphrates. In: Thiébaud, S. (Ed.), *Charcoal Analysis: Methodological Approaches, Palaeoecological Results and Wood Uses*, Proceedings of the Second International Meeting of Anthracology, Paris, September 2000. Archaeopress, Oxford, pp. 141–145.
- Willis, K.J., Kłeczkowski, A., New, M., Whittaker, R.J., 2007. Testing the impact of climate variability on European plant diversity, 320 000 years of water–energy dynamics and its long-term influence on plant taxonomic richness. *Ecology Letters* 10, 673–679.
- Wu, Z.Y., Wang, H.S., 1983. *Botanical Geography*. Science Press, Beijing.
- Xu, J.H., 1998. Sun, climate, famine and folk nation transfer. *Science in China (Series D)* 28, 366–384.
- Yao, X.S., 1988. *Structure of Main Chinese Woods*. China Forestry Publishing House, Beijing.
- Yao, X.S., Yi, T.M., Ma, N.X., Wang, Y.F., Li, Y., 2002. *Bamboo Culm Anatomy of China*. Science Press, Beijing.
- Yu, G., Chen, X., Ni, J., Cheddadi, R., Guiot, J., Han, H., Harrison, S.P., Huang, C., Ke, M., Kong, Z., Li, S., Li, W., Liew, P., Liu, G., Liu, J., Liu, K.-B., Prentice, I.C., Qui, W., Ren, G., Song, C., Sugita, S., Sun, X., Tang, L., Van Campo, E., Xia, Y., Xu, Q., Yan, S., Yang, X., Zhao, J., Zheng, Z., 2000. Palaeovegetation of China: a pollen data-based synthesis for the mid-Holocene and last glacial maximum. *Journal of Biogeography* 27, 635–664.
- Yu, G., Prentice, I.C., Harrison, S.P., Sun, X., 1998. Pollen-based biome reconstruction for China at 0 and 6000 years. *Journal of Biogeography* 25, 1055–1069.
- Zhao, Z.J., 2010. *Archaeobotany: Theory and Practice*. Science Press, Beijing.
- Zhou, X.Y., Li, X.Q., 2012. Variations in spruce (*Picea* sp.) distribution in the Chinese Loess Plateau and surrounding areas during the Holocene. *The Holocene* 22, 687–696.
- Zhu, K.Z., 1973. Primary research on Chinese climate changes over 5000 years. *Science in China (Series A)* 16, 168–189.