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Palaeovegetation of China: a pollen data-based synthesis for the mid-Holocene and last glacial maximum

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Abstract

Pollen data from China for 6000 and 18,000 ^{14}C yr BP were compiled and used to reconstruct palaeovegetation patterns, using complete taxon lists where possible and a biomization procedure that entailed the assignment of 645 pollen taxa to plant functional types. A set of 658 modern pollen samples spanning all biomes and regions provided a comprehensive test for this procedure and showed convincing agreement between reconstructed biomes and present natural vegetation types, both geographically and in terms of the elevation gradients in mountain regions of north-eastern and south-western China.

The 6000 ^{14}C yr BP map confirms earlier studies in showing that the forest biomes in eastern China were systematically shifted northwards and extended westwards during the mid-Holocene. Tropical rain forest occurred on mainland China at sites characterized today by either tropical seasonal or broadleaved evergreen/warm mixed forest. Broadleaved evergreen/warm mixed forest occurred further north than today, and at higher elevation sites within the modern latitudinal range of this biome. The northern limit of temperate deciduous forest was shifted *c.* 800 km north relative to today.

The 18,000 ^{14}C yr BP map shows that steppe and even desert vegetation extended to the modern coast of eastern China at the last glacial maximum, replacing today's temperate deciduous forest. Tropical forests were excluded from China and broadleaved evergreen/

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warm mixed forest had retreated to tropical latitudes, while taiga extended southwards to *c*. 43°N.

Keywords
Pollen data, plant functional types, biomes, vegetation changes, China, mid-Holocene, last glacial maximum.

INTRODUCTION

Several international projects are now focusing on the mid-Holocene and last glacial maximum (LGM), conventionally associated with the millennia around 6000 and 18,000 ^{14}C yr BP, as key periods at which to attempt to reconstruct natural changes in the Earth system: either using data-based reconstructions or numerical modelling, or a combination of these approaches. The BIOME 6000 project (Prentice & Webb, 1998), in particular, aims to reconstruct past vegetation patterns globally at both these times, based on the maximum available primary palaeoecological data (with appropriate quality controls) interpreted by standardized and objective methods. China represents an important region for BIOME 6000 because of its large area, its great vegetational diversity (spanning biomes from tundra and taiga to hot deserts and tropical forests; Ren *et al.*, 1979), its particular significance for understanding monsoon dynamics, and because of the large quantity of palaeoecological data that has been obtained from most regions.

Changes in the distribution of forest and non-forest biomes between the mid-Holocene and the present (e.g. Liu, 1988; Sun & Chen, 1991; Shi *et al.*, 1992; Winkler & Wang, 1993) and between the LGM and the present (e.g. An *et al.*, 1990; Winkler & Wang, 1993; Wang & Sun, 1994) have already been documented, based on parts of the available data and used to infer past climate changes. Yu *et al.* (1998) first applied the biomization technique (Prentice *et al.*, 1996), an objective technique to assign globally consistent biome labels to palaeoecological records, to a set of contemporary and 6000 ^{14}C yr BP pollen data from China. Yu *et al.* (1998) produced an initial mid-Holocene palaeovegetation map for BIOME 6000. The paper, however, had two limitations: (1) it was based entirely on digitized pollen diagrams and was confined to a restricted list of pollen types, which may cause problems especially in differentiating non-forest biomes and more generally in such a floristically diverse region as China; and (2) it was based on a restricted set of sites and contained some large geographical gaps, especially in the western part of the country. The present paper represents an attempt: (1) to make a comprehensive synthesis of available pollen data for China, including data from surface samples, for 6000 and 18,000 ^{14}C yr BP; (2) to use the surface sample data as a test of a comprehensive biomization procedure based on full taxon lists, thus allowing for the potential of some even quantitatively minor taxa to improve discrimination among biomes; and finally (3) to generate state-of-the-art palaeovegetation maps based on the individual site data for those two palaeo-time periods.

DATA AND METHODS

Pollen data for 0, 6000 and 18,000 ^{14}C yr BP

A set of 658 pollen surface samples from mainland China, the islands of Taiwan and Hainan, and the peninsula of Hongkong was compiled from published and unpublished pollen counts (Table 1). The surface samples were obtained by a variety of methods and included soil samples (430), moss polsters (59), dust trap samples (81), grab samples of surface sediments (66) and sediment core tops (22). There are multiple samples from a number of locations. All of these samples were used in the biomization to test the robustness of the method. An additional 40 samples were obtained from the digitized data set compiled by Yu *et al.* (1998) in order to fill some critical geographical gaps, particularly in the desert and tundra zones (Table 2). The final data set of 698 samples gives a reasonable spatial coverage and adequately samples the major modern vegetation types of China (Fig. 1a).

We also compiled a data set of 118 pollen records dated to 6000 ^{14}C yr BP (± 500 yr) and 37 records dated to 18,000 ^{14}C yr BP (± 2000 yr). All of the 18,000 and most of the 6000 ^{14}C yr BP records were derived from raw pollen counts, from published or unpublished sources (Table 3). A further 39 records at 6000 ^{14}C yr BP were derived from the digitized data set of Yu *et al.* (1998) (Table 2; Fig. 1b, c) in order to fill certain gaps in the coverage of available primary pollen counts. The pollen assemblage for each time period was selected on the basis of an existing age model, generally based on ^{14}C or another radiometric dating technique. The selected pollen sample represents the nearest spectrum to 6000 or 18,000 ^{14}C yr BP within the permitted windows of ± 500 yr at 6000 ^{14}C yr BP and ± 2000 yr at 18,000 ^{14}C yr BP. The quality of the dating control varies (Table 3), but >75% of the sites at 6000 ^{14}C yr BP and >35% of the sites at 18,000 ^{14}C yr BP have a dating control of 6D/3C (i.e. a single date within 2000 years or bracketing dates within 4000 years) or better according to the COHMAP dating-control terminology (Webb, 1985; Yu & Harrison, 1995).

The pollen spectra were carefully screened with respect to both site type and pollen taxa. Although the objective biomization method has been shown to be generally robust with respect to factors such as human modification of the landscape (Prentice *et al.*, 1996), initial tests on the Chinese data showed that poor results were obtained in certain types of surface pollen samples. Poor results occur with: (1) samples in which the pollen assemblage is dominated by

Table 1 Characteristics of the surface pollen sample sites from China.

Site name and code	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	No. of Samples	Modern vegetation type	References
Baiyangdian Lake	38.87	116.03	20	lake sediment	6	*Phragmites* vegetation	Xu *et al*., 1988
Hungshuihu Lake	37.77	115.70	35	lake sediment	7	*Phragmites* vegetation	QH Xu *et al*., 1996
Taihu Lake	31.20	120.33	30	lake sediment	2	*Quercus* forest	Unpublished
Wuxi	31.55	120.30	40	surface soil	1	forest	Unpublished
Yixing	31.32	119.80	50	surface soil	2	forest	Unpublished
Heishiding 1	23.37	111.42	220	surface soil	1	*Castanopsis* forest	Unpublished
Heishiding 2	23.37	111.42	280	surface soil	1	*Castanopsis* forest	Unpublished
Heishiding 3	23.37	111.42	380	surface soil	1	*Castanopsis* forest	Unpublished
Nanhai	23.33	113.13	15	deltaic sediment	1	subtropical evergreen forest‡	Unpublished
Guangzhou	23.32	113.13	10	deltaic sediment	1	subtropical evergreen forest‡	Unpublished
Jianggao	23.35	113.10	18	deltaic sediment	1	subtropical evergreen forest‡	Unpublished
Huangpu	22.93	113.15	6	deltaic sediment	1	subtropical evergreen forest‡	Unpublished
LingdingYang	22.47	113.30	−18	marine sediment	1	subtropical evergreen forest	Unpublished
Shuidong 1	21.47	111.02	−10	marine sediment	1	subtropical evergreen forest	Unpublished
Shuidong 2	21.48	111.05	−20	marine sediment	1	subtropical evergreen forest	Unpublished
Hongkong 1	22.27	113.75	−30	marine sediment	1	subtropical evergreen forest	Zheng & Wu, 1989
Hongkong 2	22.27	114.03	−30	marine sediment	1	subtropical evergreen forest	Zheng & Wu, 1989
Hongkong 3	22.25	114.30	−25	marine sediment	1	subtropical evergreen forest	Zheng & Wu, 1989
Hongkong 4	22.28	114.35	−35	marine sediment	1	subtropical evergreen forest	Zheng & Wu, 1989
Hongkong 5	22.38	114.33	−15	marine sediment	1	subtropical evergreen forest	Zheng & Wu, 1989
Hongkong 6	22.37	114.33	−20	marine sediment	1	subtropical evergreen forest	Zheng & Wu, 1989
Hongkong 7	22.38	114.32	−18	marine sediment	1	subtropical evergreen forest	Zheng & Wu, 1989
Donghai 1	31.13	122.53	−35	marine sediment	1	deciduous & evergreen mixed forest	Wang *et al*., 1983
Donghai 2	31.25	122.72	−45	marine sediment	1	deciduous & evergreen mixed forest	Wang *et al*., 1983
Donghai 3	31.17	122.75	−50	marine sediment	1	deciduous & evergreen mixed forest	Wang *et al*., 1983
Dingri County 5000	28.50	86.80	5000	surface soil	1	*Arenaria-Astragalus* forest	Unpublished
Dingri County 4500	28.30	86.40	4500	surface soil	1	*Arenaria-Astragalus* forest	Unpublished
Xiaoheigou 1	31.23	119.73	100	surface soil	1	evergreen broadleaved forest	Unpublished
Xiaoheigou 2	31.23	119.73	100	surface soil	1	evergreen broadleaved forest	Unpublished
Xiaoheigou 3	31.23	119.73	110	surface soil	1	evergreen broadleaved forest	Unpublished
Xiaoheigou 4	31.23	119.73	110	surface soil	1	evergreen broadleaved forest	Unpublished
Xiaoheigou 5	31.23	119.73	150	surface soil	1	evergreen broadleaved forest	Unpublished
Xiaoheigou 6	31.23	119.73	180	surface soil	1	evergreen broadleaved forest	Unpublished
Xiaoheigou 7	31.23	119.73	210	surface soil	1	evergreen broadleaved forest	Unpublished
Xiaoheigou 8	31.23	119.73	220	surface soil	1	evergreen broadleaved forest	Unpublished
Xiaoheigou 9	31.23	119.73	230	surface soil	1	evergreen broadleaved forest	Unpublished
Xiaoheigou 10	31.23	119.73	250	surface soil	1	evergreen broadleaved forest	Unpublished
Tianmushan Mt. 1	30.37	119.45	1500	surface soil	1	deciduous & evergreen mixed forest	Unpublished
Tianmushan Mt. 2	30.37	119.45	1300	surface soil	1	deciduous & evergreen mixed forest	Unpublished
Tianmushan Mt. 3	30.37	119.45	1200	surface soil	1	deciduous & evergreen mixed forest	Unpublished
Tianmushan Mt. 4	30.37	119.45	1000	surface soil	1	deciduous & evergreen mixed forest	Unpublished
Tianmushan Mt. 5	30.37	119.45	1000	surface soil	1	deciduous & evergreen mixed forest	Unpublished
Rongchi 1	31.22	119.68	80	surface soil	1	evergreen broadleaved forest	Unpublished
Rongchi 2	31.22	119.68	100	surface soil	1	evergreen broadleaved forest	Unpublished
Lopei Mt. 1090	24.83	121.03	1090	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1095	24.83	121.03	1095	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1170	24.83	121.03	1170	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1175	24.83	121.03	1175	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1190	24.83	121.03	1190	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1195	24.83	121.03	1195	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1200	24.83	121.03	1200	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1220	24.83	121.03	1220	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1240	24.83	121.03	1240	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1260	24.83	121.03	1260	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1280	24.83	121.03	1280	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1285	24.83	121.03	1285	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1290	24.83	121.03	1290	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1295	24.83	121.03	1295	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1300	24.83	121.03	1300	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1320	24.83	121.03	1320	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1340	24.83	121.03	1340	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1360	24.83	121.03	1360	surface soil	1	warm temperate rain forest	Unpublished

Table 1 *continued*

Site name and code	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	No. of Samples	Modern vegetation type	References
Lopei Mt. 1400	24.83	121.03	1400	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1420	24.83	121.03	1420	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1460	24.83	121.03	1460	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 1480	24.83	121.03	1480	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 540	24.83	121.03	540	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 560	24.83	121.03	560	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 580	24.83	121.03	580	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 600	24.83	121.03	600	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 700	24.83	121.03	700	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 800	24.83	121.03	800	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 850	24.83	121.03	850	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 870	24.83	121.03	870	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 872	24.83	121.03	872	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 874	24.83	121.03	874	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 876	24.83	121.03	876	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 878	24.83	121.03	878	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 880	24.83	121.03	880	surface soil	1	warm temperate rain forest	Unpublished
Lopei Mt. 615	24.83	121.03	615	surface soil	1	warm temperate rain forest	Unpublished
Daxinganling Mt. ML2	49.50	117.64	700	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. ML3	49.51	117.64	700	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. H1	49.24	118.46	590	surface soil	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. H2	49.22	118.54	580	surface soil	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. H3	49.22	118.53	570	surface soil	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. L4	49.22	118.93	540	surface soil	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. H4	49.20	118.50	550	local pond	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. H5	49.18	118.70	570	surface soil	1	shrub-steppe with sparse trees	Tong *et al*., 1996
Daxinganling Mt. H6	49.18	118.70	570	surface soil	1	shrub-steppe with sparse trees	Tong *et al*., 1996
Daxinganling Mt. L2	49.20	118.93	535	surface soil	1	shrub	Tong *et al*., 1996
Daxinganling Mt. L3	49.25	118.93	550	surface soil	1	sandy-steppe with sparse trees	Tong *et al*., 1996
Daxinganling Mt. L6	49.22	119.01	537	fluvial sediment	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. L7	49.22	118.97	537	swamp surface	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. L1	49.23	118.93	540	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. A1	49.18	119.47	600	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. A2	49.25	119.47	580	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. SL2	49.26	120.33	600	surface soil	1	shrub-steppe with sparse trees	Tong *et al*., 1996
Daxinganling Mt. SL3	49.23	120.33	600	surface soil	1	shrub-steppe with sparse trees	Tong *et al*., 1996
Daxinganling Mt. SL4	49.13	120.13	600	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. SL5	49.10	120.17	600	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. SL10	49.18	120.25	610	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. SL11	49.21	120.25	605	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. SL12	49.08	120.13	600	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. SL14	49.11	120.08	600	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. SL6	49.10	120.17	600	surface soil	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. SL7	49.13	120.17	600	surface soil	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. SL8	49.16	120.21	600	surface soil	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. SL9	49.18	120.25	620	surface soil	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. DY1	49.28	120.58	640	surface soil	1	shrub-steppe	Tong *et al*., 1996
Daxinganling Mt. SL13	49.05	120.17	600	surface soil	1	swamp	Tong *et al*., 1996
Daxinganling Mt. HL1	49.38	120.88	610	surface soil	1	meadow	Tong *et al*., 1996
Daxinganling Mt. HL2	49.38	120.88	610	surface soil	1	meadow	Tong *et al*., 1996
Daxinganling Mt. SS1	49.43	120.92	660	surface soil	1	steppe with *Salix*	Tong *et al*., 1996
Daxinganling Mt. SS2	49.40	120.92	660	surface soil	1	steppe with *Salix*	Tong *et al*., 1996
Daxinganling Mt. NC1	49.40	121.00	640	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. NC2	49.45	121.00	640	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. NC3	49.43	121.00	640	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. MY1	49.43	121.16	640	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. MY2	49.45	121.16	640	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. MY3	49.48	121.16	650	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. WS1	49.48	121.24	650	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. WRC8	49.65	121.67	700	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. WRC11	49.71	121.79	705	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. WS2	49.46	121.24	650	surface soil	1	*Salix* shrub-steppe	Tong *et al*., 1996

Table 1 *continued*

Site name and code	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	No. of Samples	Modern vegetation type	References
Daxinganling Mt. MT3	49.55	121.32	670	surface soil	1	shrub	Tong *et al*., 1996
Daxinganling Mt. MT4	49.50	121.32	670	surface soil	1	*Larix* forest margin	Tong *et al*., 1996
Daxinganling Mt. WRC4	49.65	121.63	700	surface soil	1	*Larix* forest margin	Tong *et al*., 1996
Daxinganling Mt. MT5	49.61	121.48	740	surface soil	1	*Betula* forest	Tong *et al*., 1996
Daxinganling Mt. MT6	49.55	121.48	740	surface soil	1	*Betula* forest	Tong *et al*., 1996
Daxinganling Mt. WRC10	49.68	121.79	710	surface soil	1	*Betula* forest	Tong *et al*., 1996
Daxinganling Mt. WRC1	49.65	121.56	680	surface soil	1	agriculture	Tong *et al*., 1996
Daxinganling Mt. WRC2	49.67	121.56	680	surface soil	1	agriculture	Tong *et al*., 1996
Daxinganling Mt. WRC3	49.65	121.58	700	surface soil	1	*Salix* shrub	Tong *et al*., 1996
Daxinganling Mt. WRC12	49.68	121.79	705	surface soil	1	*Salix* shrub	Tong *et al*., 1996
Daxinganling Mt. Q3	50.11	121.70	810	surface soil	1	*Salix* shrub	Tong *et al*., 1996
Daxinganling Mt. WRC5	49.66	121.58	700	surface soil	1	steppe-shrub	Tong *et al*., 1996
Daxinganling Mt. WRC7	49.63	121.67	710	surface soil	1	*Larix* forest	Tong *et al*., 1996
Daxinganling Mt. WRC9	49.65	121.79	710	surface soil	1	*Betula* forest shrub	Tong *et al*., 1996
Daxinganling Mt. Q1	50.03	121.75	860	surface soil	1	*Larix-Betula* forest	Tong *et al*., 1996
Daxinganling Mt. Q2	50.10	121.75	830	surface soil	1	steppe with sparse trees	Tong *et al*., 1996
Daxinganling Mt. Q4	50.05	121.67	805	surface soil	1	meadow	Tong *et al*., 1996
Daxinganling Mt. GH1	50.80	121.60	600	surface soil	1	riverine shrub	Tong *et al*., 1996
Daxinganling Mt. A3	50.03	121.75	580	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. GH5	50.83	121.60	650	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. GH2	50.83	121.60	670	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. GH3	50.85	121.60	700	surface soil	1	steppe	Tong *et al*., 1996
Daxinganling Mt. KLC9	50.83	121.90	1000	surface soil	1	*Larix* forest	Tong *et al*., 1996
Daxinganling Mt. KLC2	50.93	121.89	820	surface soil	1	*Larix* forest	Tong *et al*., 1996
Daxinganling Mt. WLQ1	50.20	121.60	700	surface soil	1	*Larix* forest	Tong *et al*., 1996
Daxinganling Mt. GH4	50.91	121.60	695	surface soil	1	*Larix* forest	Tong *et al*., 1996
Daxinganling Mt. WLQ2	50.26	121.60	700	surface soil	1	*Corylus* forest	Tong *et al*., 1996
Daxinganling Mt. YTL1	50.50	121.64	750	surface soil	1	*Betula-Larix* forest	Tong *et al*., 1996
Daxinganling Mt. YTL2	50.50	121.69	750	surface soil	1	*Betula-Larix* forest	Tong *et al*., 1996
Daxinganling Mt. KLC6	50.85	121.90	910	surface soil	1	*Betula-Larix* forest	Tong *et al*., 1996
Daxinganling Mt. KLC3	50.93	121.90	830	surface soil	1	*Betula-Larix* forest	Tong *et al*., 1996
Daxinganling Mt. XA	50.04	121.70	720	surface soil	1	*Betula-Larix* forest	Tong *et al*., 1996
Daxinganling Mt. KLC1	50.95	121.90	800	surface soil	1	*Larix* forest with *Corylus*	Tong *et al*., 1996
Daxinganling Mt. KLC13	50.96	122.00	990	surface soil	1	*Larix-Pinus* forest	Tong *et al*., 1996
Daxinganling Mt. KLC12	50.93	122.00	970	surface soil	1	*Larix-Pinus* forest	Tong *et al*., 1996
Daxinganling Mt. KLC11	50.90	122.00	950	surface soil	1	*Larix-Pinus* forest	Tong *et al*., 1996
Daxinganling Mt. KLC10	50.95	122.00	900	surface soil	1	*Larix-Pinus* forest	Tong *et al*., 1996
Daxinganling Mt. KLC7	50.88	121.90	950	surface soil	1	*Larix-Pinus* forest	Tong *et al*., 1996
Daxinganling Mt. KLC4	50.88	121.90	880	surface soil	1	*Larix-Pinus* forest	Tong *et al*., 1996
Daxinganling Mt. KLC5	50.91	121.90	900	surface soil	1	*Betula-Larix-Pinus* forest	Tong *et al*., 1996
Daxinganling Mt. KLC8	50.93	121.90	820	surface soil	1	shrub	Tong *et al*., 1996
Daxinganling Mt. CY1	50.05	124.35	347	surface soil	1	*Betula-Quercus* forest	Tong *et al*., 1996
Daxinganling Mt. CY2	50.10	124.43	351	surface soil	1	*Betula-Quercus* forest	Tong *et al*., 1996
Daxinganling Mt. CY3	50.05	124.39	351	surface soil	1	*Betula-Quercus* forest	Tong *et al*., 1996
Daxinganling Mt. CY4	50.05	124.39	340	surface soil	1	*Betula-Quercus* forest	Tong *et al*., 1996
Yulin, Hainandao	18.20	109.70	10	surface soil	1	tropical forest‡	Unpublished
Sanya 1, Hainandao	18.30	109.60	0	marine sediment	1	tropical forest	Yu & Han, 1992
Sanya 2, Hainandao	18.30	109.60	0	marine sediment	1	mangrove	Yu & Han, 1992
Sanya 3, Hainandao†	18.20	109.50	–1	marine sediment	1	mangrove	Yu & Han, 1992
Sanya 4, Hainandao	18.20	109.50	–1	marine sediment	1	mangrove	Yu & Han, 1992
Yalongwan, Hainandao	18.30	109.80	4	marine sediment	1	mangrove	Yu & Han, 1992
Tongzha, Hainandao	18.90	110.00	800	surface	1	montane rain forest	Unpublished
Nanbanjiang, Hainandao	19.40	109.70	35	forest soil	1	tropical forest	Unpublished
Qinglan, Hainandao	19.50	110.80	4	forest soil	1	tropical forest	Unpublished
Paipu, Hainandao	19.60	109.00	2	surface	1	tropical coastal shrub	Unpublished
Wenchang, Hainandao	19.60	110.70	45	forest soil	1	tropical seasonal forest	Unpublished
Yangpu 1, Hainandao	19.80	109.20	1	forest soil	1	tropical seasonal forest‡	Yu & Han, 1992
Yangpu 2, Hainandao	19.80	109.20	2	marine sediment	1	tropical seasonal forest	Yu & Han, 1992
Yangpu 3, Hainandao	19.70	109.10	0	marine sediment	1	tropical seasonal forest	Yu & Han, 1992
Yangpu 4, Hainandao	19.70	109.10	–1	coastal mud	1	tropical dry shrub	Yu & Han, 1992
Yangpu 5, Hainandao	19.80	109.20	–1	coastal mud	1	tropical dry shrub	Yu & Han, 1992
Sandu, Hainandao	19.90	109.40	34	coastal mud	1	tropical dry shrub	Yu & Han, 1992

Table 1 *continued*

Site name and code	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	No. of Samples	Modern vegetation type	References
Lingao, Hainandao	19.90	109.60	2	surface soil	1	tropical dry shrub	Unpublished
Dongshui, Hainandao†	20.00	109.70	10	surface soil	1	tropical dry shrub	Unpublished
Hongyuan County	32.67	102.50	3400–3600	surface soil	10	alpine meadow forest	FB Wang *et al.*, 1996
Nanjing a, ... g	32.05	119.32	5–35	lake core top	7	deciduous & evergreen mixed forest	Unpublished
Baxi 1, ... 7	33.53–33.57	102.78–103.18	3440–3520	surface soil	7	alpine meadow forest	Unpublished
Urumqui T-21	43.10	86.75	3680	surface soil	1	alpine cushion vegetation	Yan *et al.*, 1996
Urumqui T-27	43.10	86.75	3880	surface soil	1	alpine cushion vegetation	Yan *et al.*, 1996
Urumqui T-29	43.10	86.75	3850	surface soil	1	alpine cushion vegetation	Yan *et al.*, 1996
Urumqui T-32	43.10	86.75	3760	surface soil	1	alpine cushion vegetation	Yan *et al.*, 1996
Urumqui T-33	43.10	86.75	3760	surface soil	1	alpine cushion vegetation	Yan *et al.*, 1996
Urumqui T-19	43.10	86.75	3740	surface soil	1	alpine cushion vegetation	Yan *et al.*, 1996
Urumqui T-36	43.10	86.75	3570	surface soil	1	alpine meadow	Yan *et al.*, 1996
Urumqui T-34	43.10	86.75	3700	surface soil	1	alpine meadow	Yan *et al.*, 1996
Urumqui T-35	43.10	86.75	3600	surface soil	1	alpine meadow	Yan *et al.*, 1996
Urumqui T-38	43.10	86.75	3520	surface soil	1	alpine meadow	Yan *et al.*, 1996
Kunlun Mt. 1200	39.60	75.80	1200	dust flux	1	desert-steppe	Unpublished
Kunlun Mt. 3400	38.80	74.90	3400	dust flux	1	desert-steppe	Unpublished
Kunlun Mt. 4070	38.30	74.90	4070	dust flux	1	desert-steppe	Unpublished
Kunlun Mt. 1500	37.70	77.40	1500	dust flux	1	desert-steppe	Unpublished
Kunlun Mt. 2500	37.20	77.10	2500	dust flux	1	desert-steppe	Unpublished
Kunlun Mt. 3850	36.40	77.80	3850	dust flux	1	desert-steppe	Unpublished
Kunlun Mt. 3750	36.30	78.20	3750	dust flux	1	desert-steppe	Unpublished
Kunlun Mt. 4050	36.20	78.70	4050	dust flux	1	desert-steppe	Unpublished
Kunlun Mt. 5100	35.80	78.30	5100	dust flux	1	desert-steppe	Unpublished
Kunlun Mt. 4890	35.60	79.40	4890	dust flux	1	desert-steppe	Unpublished
Ejinaqi	42.00	101.00	1000	desert surface	1	desert	Kong & Du, 1981
Chaiwobao	43.55	87.80	1100	desert surface	1	desert	Yan & Xu, 1989
Zhejiang 1§	29.92	122.33	20	surface soil	1	*Castanopsis-Schima* forest	Unpublished
Zhejiang 2§	29.67	121.25	50	surface soil	1	*Castanopsis-Schima* forest	Unpublished
Zhejiang 3	29.67	121.25	100	surface soil	1	*Castanopsis-Schima* forest	Unpublished
Zhejiang 4	29.67	121.33	50	surface soil	1	*Castanopsis-Schima* forest	Unpublished
Fujian 400	27.75	118.10	400	surface soil	1	*Pinus* forest	Unpublished
Fujian 2158	27.83	117.75	2158	surface soil	1	grassland	Unpublished
Yunnan 1	21.83	100.67	560	surface soil	1	tropical seasonal forest	Tang, 1992
Yunnan 2	21.83	100.67	560	surface soil	1	tropical seasonal forest	Tang, 1992
Yunnan 3	21.67	100.59	400	surface soil	1	tropical seasonal forest	Tang, 1992
Guizhou-1	26.45	106.75	1070	surface soil	1	shrub	Unpublished
Guizhou-2	26.25	105.91	1300	surface soil	1	shrub	Unpublished
Guizhou-3	25.97	105.75	1350	surface soil	1	shrub	Unpublished
Guizhou-4	25.97	105.75	1350	surface soil	1	shrub	Unpublished
Guizhou-5	25.97	105.75	1350	surface soil	1	shrub	Unpublished
Lanzhou-1 [7]	35.91	104.10	2800	surface soil	1	*Cyperaceae* meadow	Unpublished
Lanzhou-2 [7]	35.91	104.10	3100	surface soil	1	*Cyperaceae* meadow	Unpublished
Lanzhou-3 [7]	35.91	104.10	3600	surface soil	1	*Cyperaceae* meadow	Unpublished
S-Tibet1	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
S-Tibet2 [1]	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
S-Tibet3	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
S-Tibet4 [1]*	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
S-Tibet5	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
S-Tibet6 [1]	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
S-Tibet7	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
S-Tibet8 [1]*	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
S-Tibet9 [1]*	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
S-Tibet10	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
S-Tibet11 [1]*	28.83	85.33	4590	surface soil	1	shrub-steppe	Unpublished
Qinghai ql1, ... ql11	34.02	107.35	2200	surface soil	11	forest	Unpublished
Jiangsu	33.45	119.92	100	surface soil	1	grassland‡	Tang *et al.*, 1991
Inner Mongolia	43.00	117.00	1200	surface soil	18	*Picea* forest, steppe	Li, 1991a
Dajiuh	31.30	110.20	1700	surface soil	1	deciduous & evergreen mixed forest	Zhou & Li, 1993
Tianshan Mt 1	43.00	87.00	2000	surface soil	1	*Picea* forest, steppe	Li, 1991a
Tianshan Mt 2	43.00	87.00	1740	surface soil	1	*Picea* forest, steppe	Li, 1991a

Table 1 *continued*

Site name and code	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	No. of Samples	Modern vegetation type	References
Tianshan Mt 3	43.00	87.00	2500	surface soil	1	*Picea* forest, steppe	Li, 1991a
Tianshan Mt 5	43.00	87.00	3015	surface soil	1	*Picea* forest, steppe	Li, 1991a
Tianshan Mt 6	43.00	87.00	1740	surface soil	1	*Picea* forest, steppe	Li, 1991a
Tianshan Mt 7	43.00	87.00	1740	surface soil	1	*Picea* forest, steppe	Li, 1991a
Tianshan Mt 4 (2)	43.00	87.00	1740	surface soil	1	*Picea* forest, steppe	Li, 1991a
Lushan	29.35	116.00	1474	surface soil	6	*Pinus* forest, shrub	Li, 1985
Miaoershan	25.20	110.20	1800	surface soil	1	*Tsuga* forest	Li, 1993a
Shennongjia	31.30	110.20	1700	surface soil	1	*Abies* forest	Li, 1991b
Qinghai-1	34.90	102.83	3140	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-2	34.75	102.60	3100	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-3	34.70	102.50	3397	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-4	34.68	102.50	3170	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-5	34.32	102.33	3602	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-6	34.20	102.50	3470	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-7	34.05	102.72	3181	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-27	33.20	101.47	3496	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-9	33.68	102.97	3485	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-10	33.95	102.62	3480	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-11	33.90	102.55	3396	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-12	33.82	102.75	3330	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-13	33.72	102.50	3355	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-14	33.28	102.52	3495	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-15	32.72	102.38	3489	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-16	33.28	102.52	3495	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-17	32.48	102.37	3509	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-18	32.72	102.38	3489	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-19	32.72	102.13	3718	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-20	32.72	102.15	3718	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-21	32.73	102.10	3750	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-22	32.73	102.10	3780	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-23	32.73	102.10	3750	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-24	32.73	102.10	3780	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-25	32.75	102.08	3550	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-26	32.83	102.03	3440	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-8	33.93	102.87	3414	surface mud	1	subalpine steppe or meadow	Unpublished
Qinghai-28	33.37	101.33	4192	surface moss	1	alpine meadow	Unpublished
Qinghai-29	33.43	101.07	4159	surface moss	1	alpine meadow	Unpublished
Qinghai-30	33.30	100.45	4137	surface moss	1	alpine meadow	Unpublished
Qinghai-31	33.93	99.75	4344	surface moss	1	alpine meadow	Unpublished
Qinghai-32	34.67	100.63	3285	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-33	34.67	100.63	3360	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-34	34.67	100.63	3370	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-35	34.62	100.57	3370	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-36	34.53	100.42	3771	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-39	34.58	99.88	3734	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-40	34.52	99.97	3760	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-41	34.52	99.97	3760	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-42	34.52	99.97	3730	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-43	34.37	100.25	3765	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-37	34.47	100.40	4140	surface moss	1	alpine meadow	Unpublished
Qinghai-38	34.58	99.85	4140	surface moss	1	alpine meadow	Unpublished
Qinghai-44	34.55	99.57	4298	surface moss	1	alpine meadow	Unpublished
Qinghai-45	34.58	99.45	4782	surface moss	1	alpine meadow	Unpublished
Qinghai-46	34.55	99.33	4519	surface moss	1	alpine meadow	Unpublished
Qinghai-47	34.72	99.08	4529	surface moss	1	alpine meadow	Unpublished
Qinghai-48	34.72	99.08	4529	surface moss	1	alpine meadow	Unpublished
Qinghai-49	34.72	99.08	4529	surface mud	1	alpine meadow	Unpublished
Qinghai-50	35.10	98.80	4350	surface mud	1	alpine meadow	Unpublished
Qinghai-57	34.93	98.13	4263	surface mud	1	alpine meadow	Unpublished
Qinghai-58	34.78	98.12	4280	surface moss	1	alpine meadow	Unpublished
Qinghai-59	35.52	99.52	4358	surface moss	1	alpine meadow	Unpublished
Qinghai-51	35.03	98.63	4443	surface moss	1	alpine meadow	Unpublished

Table 1 *continued*

Site name and code	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	No. of Samples	Modern vegetation type	References
Qinghai-52	34.97	98.55	4233	surface soil	1	desert-shrub	Unpublished
Qinghai-53	34.90	98.20	4282	surface soil	1	desert-shrub	Unpublished
Qinghai-54	35.05	97.70	4282	surface soil	1	desert-shrub	Unpublished
Qinghai-55	35.03	97.67	4314	surface soil	1	desert-shrub	Unpublished
Qinghai-56	34.95	98.12	4251	surface soil	1	desert-shrub	Unpublished
Qinghai-60	35.68	99.57	3752	surface soil	1	desert-shrub	Unpublished
Qinghai-61	35.82	99.90	3890	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-62	35.82	99.90	3890	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-63	35.97	100.17	3230	surface moss	1	subalpine steppe or meadow	Unpublished
Qinghai-64	36.08	100.37	2925	surface soil	1	subalpine steppe, desert shrub	Unpublished
Qinghai-65	36.50	100.77	3105	surface soil	1	subalpine steppe, desert shrub	Unpublished
Qinghai-66	36.73	99.58	3670	surface soil	1	subalpine steppe, desert shrub	Unpublished
Qinghai-67	36.72	99.25	3065	surface soil	1	subalpine steppe, desert shrub	Unpublished
Qinghai-68	36.78	98.97	3063	surface soil	1	subalpine steppe, desert shrub	Unpublished
Qinghai-69	36.50	100.77	3105	surface soil	1	subalpine steppe, desert shrub	Unpublished
Qinghai-70	36.00	97.63	3099	surface soil	1	subalpine steppe, desert shrub	Unpublished
Qinghai-71	36.12	97.35	2900	mud	1	meadow	Unpublished
Qinghai-72	36.38	96.30	2865	mud	1	meadow	Unpublished
Qinghai-73	35.78	94.33	4075	surface moss	1	alpine meadow	Unpublished
Qinghai-74	35.88	94.42	3680	surface soil	1	desert shrub	Unpublished
Qinghai-75	35.92	94.70	3460	surface soil	1	desert shrub	Unpublished
Qinghai-76	36.07	94.68	3304	surface soil	1	desert shrub	Unpublished
Qinghai-77	36.63	95.03	3010	surface soil	1	desert shrub	Unpublished
Qinghai-78	37.73	95.35	2997	surface soil	1	desert shrub	Unpublished
Qinghai-79	37.73	95.35	2997	surface soil	1	desert shrub	Unpublished
Qinghai-80	37.73	95.35	2997	surface soil	1	desert shrub	Unpublished
Qinghai-81	39.57	94.28	1860	surface soil	1	desert shrub	Unpublished
Qinghai-82	40.28	95.35	1735	surface soil	1	desert shrub	Unpublished
Qinghai-83	35.73	103.97	3700	surface moss	1	subalpine steppe	Unpublished
Qinghai-84	35.77	103.95	3342	surface moss	1	subalpine steppe	Unpublished
Qinghai-85	35.77	103.95	3195	surface moss	1	subalpine steppe	Unpublished
Qinghai-86	35.80	104.07	2391	surface moss	1	subalpine steppe	Unpublished
Qinghai-87	35.80	104.07	2391	surface moss	1	subalpine steppe	Unpublished
Dunde	38.10	96.40	5325	ice core top	1	ice cap	Unpublished
Qidong	31.90	121.70	10	fluvial core top	1	deciduous & evergreen mixed forest	Unpublished
Kenli	37.54	118.56	100–150	fluvial sediment	3	grassland	QH Xu *et al*., 1996
Qinghai	36.32	99.36	3196	surface soil	6	desert-shrub	Kong *et al*., 1992
Tibet 1	37.90	77.40	2400	dust flux	1	desert-shrub	Huang, 1993
Tibet 2 (1)	37.50	77.20	2400	dust flux	1	desert-shrub	Huang, 1993
Tibet 3	37.20	77.10	2400	dust flux	1	desert-shrub	Huang, 1993
Tibet 4	37.10	76.90	2400	dust flux	1	desert-shrub	Huang, 1993
Tibet 5	37.00	76.90	2400	dust flux	1	desert-shrub	Huang, 1993
Tibet 6 (1)	37.00	77.00	3600	dust flux	1	subalpine steppe	Huang, 1993
Tibet 7	36.90	77.00	3600	dust flux	1	subalpine steppe	Huang, 1993
Tibet 8	36.80	77.00	3600	dust flux	1	subalpine steppe	Huang, 1993
Tibet 9	36.80	77.00	3600	dust flux	1	subalpine steppe	Huang, 1993
Tibet 10 (1)	36.80	77.10	3600	dust flux	1	subalpine steppe	Huang, 1993
Tibet 11	36.70	77.00	3600	dust flux	1	subalpine steppe	Huang, 1993
Tibet 12	36.70	77.10	3600	dust flux	1	subalpine steppe	Huang, 1993
Tibet 13	36.20	78.40	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 14	34.60	80.40	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 15	34.70	80.40	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 16	33.70	80.00	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 17	33.20	79.80	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 18	32.50	80.00	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 19	33.10	80.20	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 20	34.00	81.10	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 21	34.20	81.00	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 22	34.30	80.90	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 23	34.50	80.90	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 24	35.00	80.40	4300	dust flux	1	alpine meadow	Huang, 1993
Tibet 25	35.40	79.60	4300	dust flux	1	alpine meadow	Huang, 1993

Table 1 *continued*

Site name and code	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	No. of Samples	Modern vegetation type	References
Tibet 26	36.00	79.70	4500	dust flux	1	alpine meadow	Huang, 1993
Tibet 27	36.20	79.20	4500	dust flux	1	alpine meadow	Huang, 1993
Tibet 28	36.30	78.20	4500	dust flux	1	alpine meadow	Huang, 1993
Tibet 29	36.60	77.10	4500	dust flux	1	alpine meadow	Huang, 1993
Tibet 30	37.40	77.30	4500	dust flux	1	alpine meadow	Huang, 1993
Tibet 31	39.50	76.00	4500	dust flux	1	alpine meadow	Huang, 1993
Tibet 32	37.30	77.20	4500	dust flux	1	alpine meadow	Huang, 1993
Flux-1	39.50	116.30	50	dust flux	1	forest	Unpublished
Flux-2	39.50	116.30	20	dust flux	1	forest	Unpublished
Flux-3	38.80	116.10	20	dust flux	1	forest	Unpublished
Fluxb-1¶	33.40	116.20	20	dust flux	1	forest	Unpublished
Fluxb-3¶	32.50	115.50	20	dust flux	1	forest	Unpublished
Fluxb-5¶	31.50	114.00	20	dust flux	1	forest	Unpublished
Fluxc-1¶	37.20	114.60	20	dust flux	1	forest	Unpublished
Fluxc-2¶	37.50	114.20	750	dust flux	1	forest	Unpublished
Fluxc-3¶	37.50	114.20	600	dust flux	1	forest	Unpublished
Fula_s1	28.30	116.20	20	dust flux	1	forest	Unpublished
Fula_s3	37.50	116.30	20	dust flux	1	forest	Unpublished
Fula_s5¶	37.20	116.70	20	dust flux	1	forest	Unpublished
Fulxa_s1¶	36.30	116.90	300	dust flux	1	forest	Unpublished
Fulxa_s2¶	35.30	117.00	20	dust flux	1	forest	Unpublished
Fulxa_s3¶	34.20	117.00	200	dust flux	1	forest	Unpublished
Hbwm1¶	30.50	112.30	20	dust flux	1	forest	Unpublished
Hbwm2¶	29.70	111.60	50	dust flux	1	forest	Unpublished
Hbwm3¶	29.30	111.60	20	dust flux	1	forest	Unpublished
Sjz1¶	37.80	114.50	50	dust flux	1	forest	Unpublished
Sjz2	29.80	112.10	20	dust flux	1	forest	Unpublished
Sjz3¶	31.00	113.90	20	dust flux	1	forest	Unpublished
Wulungu Lake	47.10	87.30	650	lake sediment	1	desert-shrub	Yang & Wang, 1996
Maili 1	42.87	122.88	155	peat core top	1	open deciduous forest-steppe	Ren & Zhang, 1997
Maili 2	42.60	122.95	155	peat	1	open deciduous forest-steppe	Ren & Zhang, 1997
Maili 3	42.55	122.90	155	surface soil	1	open deciduous forest-steppe	Ren & Zhang, 1997
Baikeyao	42.92	122.20	155	lake sediment	1	open deciduous forest-steppe	Ren & Zhang, 1997
Nanshan	40.80	111.70	1063	surface soil	1	steppe	Kong & Du, 1981
Xishan 1	25.30	102.45	2000	forest soil	1	*Keteleeria-Castanopsis* forest	Sun & Wu, 1987
Xishan 2	25.25	102.51	2000	forest soil	1	*Keteleeria* forest	Sun & Wu, 1987
Xishan 3	25.21	102.50	2200	forest soil	1	*Pinus* forest	Sun & Wu, 1987
Xishan 4	25.22	102.52	1900	forest soil	1	shrub	Sun & Wu, 1987
Xishan 5	25.20	102.53	1900	forest soil	1	evergreen broadleaved forest	Sun & Wu, 1987
Changbaishan 1	42.33	126.83	860	forest soil	1	*Pinus*, broadleaved mixed forest	Sun *et al.*, 1991
Changbaishan 2	42.33	126.89	920	forest soil	1	*Pinus*, broadleaved mixed forest	Sun *et al.*, 1991
Changbaishan 3	42.33	126.92	1000	forest soil	1	*Pinus*, broadleaved mixed forest	Sun *et al.*, 1991
Changbaishan 4	42.33	127.00	1080	forest soil	1	*Pinus*, broadleaved mixed forest	Sun *et al.*, 1991
Changbaishan 5	42.30	126.85	1117	forest soil	1	*Pinus*, broadleaved mixed forest	Sun *et al.*, 1991
Changbaishan 6	42.31	126.86	775	forest soil	1	*Larix* forest	Sun *et al.*, 1991
Changbaishan 7	42.30	126.88	775	forest soil	1	*Larix* forest	Sun *et al.*, 1991
Changbaishan 8	42.33	126.38	775	forest soil	1	*Larix* forest	Sun *et al.*, 1991
Changbaishan 9	42.33	126.40	700	peat surface	1	swamp	Sun *et al.*, 1991
Changbaishan 10	42.33	126.44	700	peat surface	1	swamp	Sun *et al.*, 1991
Changbaishan 11	42.33	126.46	700	peat surface	1	swamp	Sun *et al.*, 1991
Changbaishan 12	42.33	126.50	700	peat surface	1	swamp	Sun *et al.*, 1991
Changbaishan 13	42.33	126.00	700	peat surface	1	swamp	Sun *et al.*, 1991
Changbaishan 14	42.00	126.00	2600	forest soil	1	*Betula* forest	Sun *et al.*, 1991
Changbaishan 15	42.33	128.00	1950	forest soil	1	*Betula* forest	Sun *et al.*, 1991
Changbaishan 16	42.50	127.83	1620	forest soil	1	*Picea-Abies* forest	Sun *et al.*, 1991
Changbaishan 17	42.50	127.83	1270	forest soil	1	*Picea-Abies* forest	Sun *et al.*, 1991
Changbaishan 18	42.50	127.83	1270	forest soil	1	*Picea-Abies* forest	Sun *et al.*, 1991
Qingshuigou	27.50	102.40	3660	forest soil	25	conifer & evergreen broadlvd forest	Li, 1986
Zijinshan	32.30	118.60	200	forest soil	1	*Quercus-Liquidambar* forest	Yu & Han, 1995
Hanjiang 1	23.55	116.63	5	deltaic core top	1	subtropical broadleaved forest	Unpublished
Hanjiang 3	23.34	116.58	5	deltaic core top	1	subtropical broadleaved forest	Unpublished
Inner Mongolia C1	41.64	111.60	1000–1500	surface soil	1	steppe	FY Wang *et al.*, 1996

Table 1 *continued*

Site name and code	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	No. of Samples	Modern vegetation type	References
Inner Mongolia C2	42.20	112.30	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C3	42.30	112.40	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C4	42.66	112.60	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C5	42.84	112.61	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C6	43.72	113.40	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C7	43.86	113.90	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C8	43.92	115.20	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C9	43.87	116.20	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C10	43.84	116.44	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C11	43.66	116.60	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C12	43.67	116.61	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C13	43.30	116.01	1000–1500	surface soil	1	steppe	FY Wang *et al*., 1996
Inner Mongolia C14	43.18	116.00	1000–1500	surface soil	1	forest-steppe	FY Wang *et al*., 1996
Inner Mongolia C15	43.44	115.70	1000–1500	surface soil	1	forest-steppe	FY Wang *et al*., 1996
Loess Plateau 2	35.47	109.78	1200	surface soil	1	alpine meadow	Unpublished
Loess Plateau 3	35.47	109.78	1200	surface soil	1	alpine meadow	Unpublished
Loess Plateau 8	35.97	109.75	1160	surface soil	1	woodland	Unpublished
Loess Plateau 9	35.97	109.75	1200	surface soil	1	woodland	Unpublished
Loess Plateau 11	35.97	109.75	1250	surface soil	1	woodland	Unpublished
Loess Plateau 34	35.97	109.75	1250	surface soil	1	woodland	Unpublished
Loess Plateau 13	35.97	109.75	1150	surface soil	1	woodland	Unpublished
Loess Plateau 15	35.87	108.67	1400	surface soil	1	meadow	Unpublished
Loess Plateau 15 (1)	35.87	108.67	1400	surface soil	1	meadow	Unpublished
Loess Plateau 16	35.87	108.67	1400	surface soil	1	meadow	Unpublished
Loess Plateau 18	35.72	106.47	2650	surface soil	1	shrub meadow	Unpublished
Loess Plateau 18 (1)	35.72	106.47	2650	surface soil	1	shrub meadow	Unpublished
Loess Plateau 22	35.58	106.08	2070	surface soil	1	steppe	Unpublished
Loess Plateau 29	36.37	106.33	2050	surface soil	1	steppe	Unpublished
Loess Plateau 30	36.37	106.33	2050	surface soil	1	steppe	Unpublished
Loess Plateau 31	36.37	106.33	2050	surface soil	1	steppe	Unpublished
Loess Plateau 36	36.40	106.22	1700	surface soil	1	desert-steppe	Unpublished
Loess Plateau 37	36.40	106.22	2050	surface soil	1	desert-steppe	Unpublished
Loess Plateau 38	37.27	106.28	2610	surface soil	1	forest	Unpublished
Loess Plateau 41	37.25	106.28	2500	surface soil	1	needle & broadleaved mixed forest	Unpublished
Loess Plateau 44	37.23	106.27	2400	surface soil	1	needle & broadleaved mixed forest	Unpublished
Loess Plateau 45	37.23	106.27	2400	surface soil	1	needle & broadleaved mixed forest	Unpublished
Loess Plateau 46	37.22	106.23	2000	surface soil	1	*Artemisia* steppe	Unpublished
Loess Plateau 47	37.22	106.23	2000	surface soil	1	desert-steppe	Unpublished
Loess Plateau 52	37.53	105.37	1400	surface soil	1	dry steppe	Unpublished
Loess Plateau 54	37.53	105.37	1400	surface soil	1	dry steppe	Unpublished
Loess Plateau 56	37.13	105.63	2250	surface soil	1	meadow-steppe	Unpublished
Loess Plateau 57	37.30	105.63	2510	surface soil	1	alpine shrub meadow	Unpublished
Loess Plateau 58	36.45	105.63	2600	surface soil	1	meadow	Unpublished
Loess Plateau 60	36.27	105.62	2100	surface soil	1	meadow	Unpublished
Tianshi lac	43.67	88.17	2000	lake core top	1	desert-steppe	Unpublished
V. de Payango	43.75	87.50	1500	surface soil	1	desert-steppe	Unpublished
V. de Gangou	43.75	87.50	1300	surface soil	1	desert-steppe	Unpublished
Glacier boue	43.00	87.00	3800	surface soil	1	alpine meadow	Unpublished
Glacier mousse	43.00	87.00	3800	surface soil	1	alpine meadow	Unpublished
Tibet-F1	39.90	77.20	1200	dust flux	1	desert	Van Campo *et al*., 1996
Tibet-F2	39.50	74.50	1500	dust flux	1	desert	Van Campo *et al*., 1996
Tibet-F3	38.80	74.90	3400	dust flux	1	subalpine steppe	Van Campo *et al*., 1996
Tibet-F4	38.60	74.90	3360	dust flux	1	subalpine steppe	Van Campo *et al*., 1996
Tibet-F5	38.30	74.90	4070	dust flux	1	alpine meadow	Van Campo *et al*., 1996
Tibet-F6	37.90	75.10	3150	dust flux	1	subalpine steppe	Van Campo *et al*., 1996
Tibet-F7	37.00	75.40	3680	dust flux	1	subalpine steppe	Van Campo *et al*., 1996
Tibet-F8	37.40	75.20	3600	dust flux	1	subalpine steppe	Van Campo *et al*., 1996
Tibet-F9	37.60	75.30	3300	dust flux	1	subalpine steppe	Van Campo *et al*., 1996
Tibet-F10	38.40	76.80	1340	dust flux	1	desert	Van Campo *et al*., 1996
Tibet-F11	36.40	77.10	3800	dust flux	1	alpine meadow	Van Campo *et al*., 1996
Tibet-F12	36.40	77.80	3850	dust flux	1	alpine meadow	Van Campo *et al*., 1996

Table 1 *continued*

Site name and code	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	No. of Samples	Modern vegetation type	References
Tibet-F13	35.60	79.40	4880	dust flux	1	desert	Van Campo *et al*., 1996
Tibet-F14	35.80	79.30	5100	dust flux	1	desert	Van Campo *et al*., 1996
Tibet-F15	36.30	78.20	3750	dust flux	1	alpine meadow	Van Campo *et al*., 1996
Tibet-F16	36.20	78.70	4050	dust flux	1	alpine meadow	Van Campo *et al*., 1996
Tibet-F17	37.20	77.10	2500	dust flux	1	desert	Van Campo *et al*., 1996
Tibet-F18	37.70	77.40	1500	dust flux	1	desert	Van Campo *et al*., 1996
Reshuitang 1–2	43.75	117.65	1200	surface soil	1	steppe	Jiang, 1992
Qinghai-Tibet N6	29.89	92.54	4180	surface soil	1	alpine forest-steppe, alpine meadow	Unpublished
Qinghai-Tibet N38	31.59	91.56	4590	surface soil	1	alpine forest-steppe, alpine meadow	Unpublished
Qinghai-Tibet N61	29.26	90.61	3710	surface soil	1	alpine forest-steppe, alpine meadow	Unpublished
Qinghai-Tibet N7	30.15	101.86	3810	surface soil	1	alpine forest-steppe, alpine meadow	Unpublished
Qinghai-Tibet N42	30.25	97.27	4140	surface soil	1	alpine forest-steppe, alpine meadow	Unpublished
Jiuxian Mt.	25.75	118.13	1360	core top	1	alpine forest-steppe, alpine meadow	Unpublished
Sang Jiang	47.58	133.52	55	surface soil	6	marsh	Unpublished
Sang Jiang	47.58	133.52	56	surface soil	6	*Quercus-Corylus-Betula* forest	Unpublished
Bao Qing 1	45.95	132.07	272	surface soil	1	deciduous broadleaved forest	Unpublished
Bao Qing 2	45.95	132.07	272	surface soil	1	deciduous broadleaved forest	Unpublished
Bao Qing 3	45.95	132.07	272	surface soil	1	mixed conifer & broadleaved forest	Unpublished
Bao Qing 4 (7)	45.95	132.07	272	surface soil	1	mixed conifer & broadleaved forest	Unpublished
Bao Qing 5 (7)	45.58	131.73	388	surface soil	1	mixed conifer & broadleaved forest	Unpublished
Bao Qing 6 (7)	45.58	131.73	388	surface soil	1	mixed conifer & broadleaved forest	Unpublished
Bao Qing 7	46.68	132.08	190	surface soil	1	*Quercus-Corylus-Betula* forest	Unpublished
Bao Qing 8	46.68	132.08	190	surface soil	1	*Quercus-Corylus-Betula* forest	Unpublished
Hu Mao 1	52.27	123.92	680	surface soil	1	*Pinus* forest	Unpublished
Hu Mao 2	52.27	123.92	680	surface soil	1	*Pinus* forest	Unpublished
Hu Mao 3†	52.27	123.92	680	surface soil	1	*Pinus* forest	Unpublished
Hu Mao 4	52.27	123.92	680	surface soil	1	*Pinus* forest	Unpublished
Hu Mao 5†	52.30	123.90	700	surface soil	1	*Larix* forest	Unpublished
Hu Mao 6	52.30	123.90	700	surface soil	1	*Larix* forest	Unpublished
Hu Mao 7	52.30	123.90	700	surface soil	1	*Larix* forest	Unpublished
Hu Mao 8	52.30	123.90	700	surface soil	1	*Larix* forest	Unpublished
Hu Mao 9	52.28	123.97	680	surface soil	1	*Larix* forest with *Betula*	Unpublished
Hu Mao 10 [7]	52.28	123.97	680	surface soil	1	*Larix* forest with *Betula*	Unpublished
Hu Mao 11 [7]	52.28	123.97	680	surface soil	1	*Larix* forest with *Betula*	Unpublished
Hu Mao 12 [7]	52.28	123.97	680	surface soil	1	*Larix* forest with *Betula*	Unpublished
Hu Mao 13 [7]	52.25	123.98	720	surface soil	1	coniferous forest	Unpublished
Hu Mao 14 [7]	52.25	123.98	720	surface soil	1	coniferous forest	Unpublished
Hu Mao 15 [7]	52.25	123.98	720	surface soil	1	coniferous forest	Unpublished
Hu Mao 16	52.25	123.98	720	surface soil	1	coniferous forest	Unpublished
Chanling	44.75	124.17	140	surface soil	2	grassland	Unpublished
Hal Dal 1	49.22	119.75	670	surface soil	1	shrub-steppe	Unpublished
Hal Dal 2	49.22	119.75	670	surface soil	1	shrub-steppe	Unpublished
Hal Dal 3	49.22	119.75	550	surface soil	1	shrub-steppe	Unpublished
Hal Dal 4	49.22	119.75	550	surface soil	1	shrub-steppe	Unpublished
Hal Dal 5 [7]	49.43	117.90	550	surface soil	1	grassland	Unpublished
Hal Dal 6 [7]	49.43	117.90	550	surface soil	1	grassland	Unpublished
Hal Dal 7 [7]	48.78	119.20	655	surface soil	1	grassland	Unpublished
Hal Dal 8 [7]	48.78	119.20	655	surface soil	1	grassland	Unpublished
Daluoba	48.00	88.00	2020	lake core top	1	desert-steppe	Yan, 1991
Guhu Core 28	27.67	100.83	2780	peat core top	1	conifer & evergreen broadlvd forest	Wang & Sun, 1986
Maohebei	39.50	119.17	50	profile top	1	deciduous forest	Li & Liang, 1985
Napahai Core 34	27.80	99.60	3260	peat core top	1	conifer & evergreen broadlvd forest	Wang & Sun, 1986
Xiaoxinanling	48.37	129.70	486	core top	1	conifer & broadleaved forest	Xia, 1996
Yangerzhuang	38.20	117.30	5	core top	1	deciduous forest	Xu *et al*., 1993
Luojishan	27.50	102.40	3800	core top	1	conifer & evergreen broadlvd forest	Li & Liu, 1988
Wuqia	43.20	83.50	1320	profile top	1	desert-shrub	XJIETRE, 1994

* Long-distance transport contamination.
† Very low pollen counts.
‡ Anthropogenically altered.
§ Unsuitable for biomization because biomised spectrum consists of single species.
¶ Dust flux samples, with (heavy) anthropogenic contamination.

Table 2 Characteristics of the surface sample and fossil pollen sites derived from the digitized data set of Yu *et al*. (1998).

Site name	Lat. (°N)	Long. (°E)	Elev. (m)	Time interval (^{14}C yr BP)
Aibi	45.00	82.80	194	0
Balikun Lake	43.70	92.80	2027	0, 6000
Beikan	32.30	121.10	22	0, 6000
Beisu Lake	45.50	120.70	322	0
Caerhan	36.50	96.30	2680	0, 6000
Chagannuoer	42.90	113.10	1302	0, 6000
Changxingdao	39.60	121.20	40	0
Chaoli	36.10	120.10	10	0, 6000
Chasuqi	40.67	111.10	1200	0
Chitsai Lake	23.73	121.23	2890	0
Cuiluan	47.40	128.70	250	0, 6000
Daishan	30.80	120.20	4	6000
Dianchi	25.00	102.67	1893	0, 6000
Dingshan	31.40	119.30	93	6000
Donglingshan	40.00	115.43	1030	0
Fengqiao	32.10	118.70	15	6000
Fuzhou	26.10	119.30	85	0, 6000
Gaobiantou	24.40	117.80	79	6000
Gaojiawuzi	36.30	120.00	10	6000
Gonggouyan	40.50	112.45	1255	0, 6000
Hani	42.90	130.00	910	0, 6000
Heqiao	31.50	119.90	51	0, 6000
Hongshen	46.40	123.40	149	0, 6000
Huishui	26.60	106.50	1071	6000
Huma	51.80	126.20	250	0, 6000
Jiajihe	48.70	128.10	380	0, 6000
Jiangchun	34.40	109.50	879	0
Junshan	29.30	112.80	31	0
Kaitong	44.80	123.10	148	0
Ledeli	48.10	133.20	93	6000
Lianyungang	34.80	119.40	0	0, 6000
Liushuwan	37.80	108.83	1448	0, 6000
Longquan Lake	31.00	112.10	100	0
Luoqu	33.10	102.10	3593	6000
Luxun Lake	30.00	112.20	58	0
Manasi Lake	45.97	84.83	257	0
Miaoershan	25.33	110.33	1850	0
Muhuaheke	40.60	112.80	1232	0, 6000
Nanchuan	37.00	95.90	4050	6000
Nangong	37.80	115.50	40	0, 6000
Nanshan	40.80	111.70	1063	0
Nanyang	31.80	121.80	−3	6000
Nariyong Co	28.30	91.90	4750	6000
Poyang Lake	29.70	116.30	8	0
Punandian	39.40	122.00	32	0
Qianjing	48.30	128.40	500	6000
Qianshang	35.80	119.90	62	6000
Selin Co	31.67	88.42	4530	0
Tanghongling	48.40	129.10	465	0, 6000
Tongguanshan	31.70	119.50	400	0
Wumaqu	30.40	91.10	4737	0, 6000
Xiachai	24.50	117.50	439	6000
Xingou	29.80	112.80	44	6000
Xiyaohu	28.60	115.90	50	0, 6000
Yinjiahe	39.80	116.60	15	6000
Yuntaishan	34.80	119.20	150	0
Zhenjiang	32.30	119.50	25	6000
Zhenpiyan	27.10	117.10	513	6000

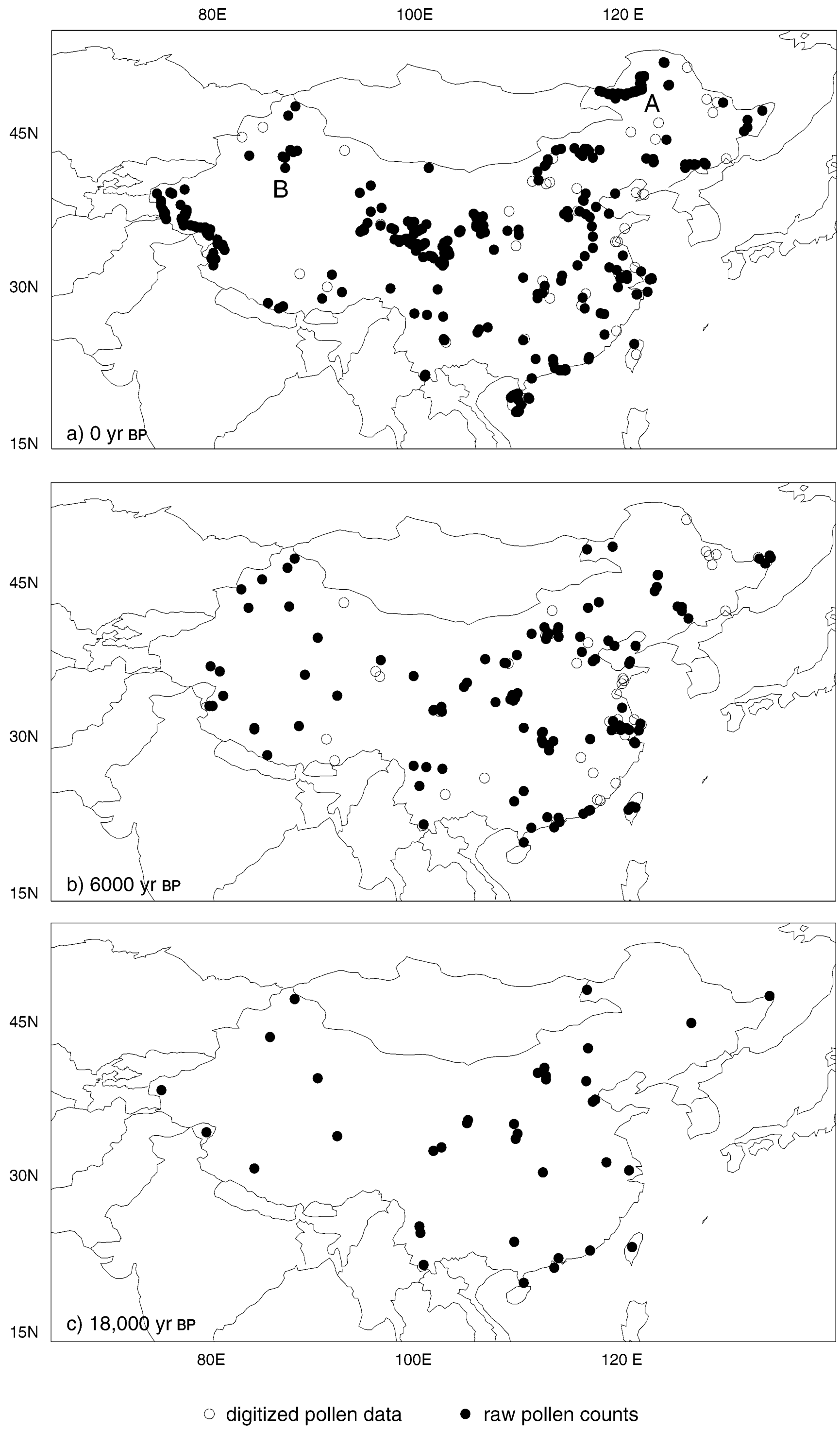

Figure 1 Site maps for (a) modern, (b) 6000 ^{14}C yr BP and (c) 18,000 ^{14}C yr BP. Closed circles represent sites for which raw pollen counts were available; open circles represent sites for which digitized pollen data (from Yu *et al*., 1998) were used. A = Daxinganling Mountains; B = Tianshan Mountains.

Table 3 Characteristics of the fossil pollen sites. Dating control (DC) codes are based on the COHMAP dating control scheme (Webb, 1985; Yu & Harrison 1995). For sites with continuous sedimentation (indicated by a C after the numeric code), the dating control is based on bracketing dates where 1 indicates that both dates are within 2000 years of the selected interval, 2 indicates one date within 2000 years and the other within 4000 years, 3 indicates both within 4000 years, 4 indicates one date within 4000 years and the other within 6000 years, 5 indicates both dates within 6000 years, 6 indicates one date within 6000 years and the other within 8000 years, and 7 indicates bracketing dates more than 8000 years from the selected interval. For sites with discontinuous sedimentation (indicated by a D after the numeric code), 1 indicates a date within 250 years of the selected interval, 2 a date within 500 years, 3 a date within 750 years, 4 a date within 1000 years, 5 a date within 1500 years, 6 a date within 2000 years, and 7 a date more than 2000 years from the selected interval. Sites where additional dating control is provided by pollen correlation with a nearby radiocarbon-dated site are indicated by *.

Site name	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	Record length (kyr)	No. of ^{14}C dates	DC at 6000 ^{14}C yr BP	DC at 18,000 ^{14}C yr BP	References
Aibi Lake	45.00	82.80	194	lake core	0–12	2 (+ 3TL)	2C		XJIETRE, 1994; Weng & Qiao, 1992
Angulitun	41.30	113.70	1400	lake core	0–>10	2	7		Li *et al.*, 1990
Bailiangdong1	24.33	109.40	97	cave profile	0–30	1	7		Kong *et al.*, 1994
Bailiangdong2	24.33	109.40	97	cave profile	0–30	2		7	Kong *et al.*, 1994
Baisu Lake	41.30	112.35	2000	lake profile	0–8	5	1C		Kong & Du, 1992
Baiyangdian	38.90	116.00	7	lake core	0–12	3	2C†		Xu *et al.*, 1988
Bangong Co1	33.63	79.68	4800	lake core	0–10	10	1C		Van Campo *et al.*, 1996
Bangong Co2	33.63	80.00	4860	lake core	0–17	5	2C		Huang *et al.*, 1996
Banpo	34.27	109.03	395	loess profile	2–10	2	1C		Ke & Sun, 1990
Baohuashan	32.13	119.03	5	peat profile	0–7	1	3D		Kong *et al.*, 1991
Bataigou	40.92	113.63	1357	peat profile	3–11	4	1C		Liu & Li, 1992
Beijing	40.00	116.42	100	lake core	0–18	1		4D	Kong & Du, 1991
Beikekule	36.67	89.00	4680	fluvial profile	0–10	1	2D		Huang *et al.*, 1996
Beilahong	48.08	134.42	60	peat profile	0–6	3	5D		Xia, 1988
Beiwangxu	37.75	120.61	6	fluvial core	0–10	2	1C		Zhao & Qiu, 1992
Beiyuan	36.20	104.90	1200	loess profile	0–100	2		7	Chen & Zhang, 1993
Beizhuangcun–2	34.37	109.54	490	loess profile	10–32	5		1C	Ke & Sun, 1991
Cangumiao	39.97	118.60	70	fluvial core	0–10	2	1D		Unpublished
Chaiwobao2	43.33	87.47	1114	peat profile	1.6–10.6	8	1C		WY Li *et al.*, 1990
Changbaishan	42.16	126.39	775	peat core	0–10	3	2C		Sun *et al.*, 1991
Changxin	39.50	121.23	6	fluvial core	0–6	2	1D		Xia, 1996
Changzhou (Changzou)	31.72	119.68	5	archaeological site	0–7	1	1D		Han, 1991
Chasuqi	40.67	111.10	1200	peat profile	0–10	4	3C		Unpublished
Chitsai Lake	23.73	121.23	2890	lake core	0–6	4	5D		Liew & Huang, 1994
Chuangye	48.30	134.30	50	peat profile	0–18	3	3C	7	Xia, 1988
Da-3	40.58	112.70	1200	lake core	0–6	1*	7		Shen & Tang, 1991
Da-5	40.58	112.70	1200	lake core	0–6	1	7		Shen & Tang, 1991
Da-7	40.52	112.62	1200	lake core	0–6	2	3D		Shen & Tang, 1991
Dahewan	40.87	113.57	1298	fluvial profile	5–9	3	2C		Liu & Li, 1992
Dajahu	31.50	110.33	1700	peat core	0–10	3	2C		Zhou & Li, 1993
Dalainuoer	43.20	116.60	1290	lake core	0–150	2	7†	2C	RQ Li *et al.*, 1990
Daluoba	48.00	88.00	2020	lake core	0–50	2 (1TL)	2C	7	Yan, 1991
Dazeyin	39.50	119.17	50	peat core	6–9.8	2	7		Li & Liang, 1985
Diaojiaohaizi	41.30	112.35	2000	lake core	0–10	4	2C		Song & Wang, 1995
Dingxi	35.50	104.50	2200	loess profile	0–100	1	5D		Chen & Zhang, 1993
Dishaogou	37.83	108.45	1200	loess profile	0–50	5	2C		Ke & Sun, 1992
Dunde	38.10	96.40	5325	ice core	0–11	0	7†		Unpublished
East Taihu Lake1	31.30	120.60	3	lake core	0–15	8	1C		XM Xu *et al.*, 1996
East Taihu Lake2	31.50	120.30	3	lake core	0–15	8	1C		XM Xu *et al.*, 1996
Erhai (Z18)	25.83	100.16	1984	lake core	10–35	2	7	3D	Zhu, 1989
Erhai (Z27)	25.20	100.26	1700	lake core	2–30	2		4D	Zhu, 1989
Fuping BK13	34.70	109.25	422	fluvial core	0–12	1	2D		Ke & Sun, 1991
Fuxian	35.82	109.38	917	loess profile	10–128	1		7	Ke & Sun, 1993
Guanzhou	30.40	116.80	125	archaeological site	4.6–6	7	4D		Huang & Liang, 1981
Guchenghu	31.27	118.90	6	lake core	3–14	4	6D		Wang *et al.*, 1996
Guhu Core 28	27.67	100.83	2780	peat core	0–12	1	7		Wang & Sun, 1986
Haerbin	45.67	126.67	150	fluvial profile	0–20	1		1D†	Liu *et al.*, 1985
Hahai-1	40.17	112.50	1200	peat profile	0–18	2	5D	7	Shen & Tang, 1991
Hailaer	49.17	119.00	760	peat profile	2.4–10	3	2C		Xia, 1996
Hanjiang-CH2	23.48	116.80	5	fluvial core	3–50	5	2C	7	Zheng, 1991

Table 3 *continued*

Site name	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	Record length (kyr)	No. of ^{14}C dates	DC at 6000 ^{14}C yr BP	DC at 18,000 ^{14}C yr BP	References
Hanjiang-SH5	23.12	116.14	8	fluvial core	0–10	4	2C		Zheng, 1990
Hanjiang-SH6	23.42	116.68	3	fluvial core	0–10	2	4C		Zheng, 1991
Heitutang	40.38	113.74	1060	peat profile	0–7	1	1D		Kong *et al*., 1992
Hemudu1	30.10	121.10	50	archaeological site	4–7	0	7		Sun *et al*., 1981
Hemudu2	30.00	121.20	50	archaeological site	4–7	2	1C		Sun *et al*., 1981
Hetian	37.50	79.80	1330	fluvial profile	0–15	3	4C		XJIETRE, 1994
HF (Peiku Co)	28.83	85.33	4660	lake core	0–13	3	2D§		Tang & Shen, 1996
Hongyuan	33.25	101.57	3492	peat profile	0–12	9	1C		Wang *et al*., 1996
Hulun Lake	48.90	116.50	650	lake core	0–20	7	1C	4C	Yang *et al*., 1995
Jianghan Core	30.20	113.21	35	lake core	0–10	4	1C		Unpublished
Jianghan Plain	31.10	112.20	50	fluvial core	0–22	6	1C	7	Liu, 1991
Jianli	29.80	112.80	44	lake core	0–10	0	7		Yu, 1985
Jinbian	37.80	108.60	1400	peat core	0–12.5	4	4C		Li, 1991
Jiuzhoutai	35.90	104.80	2136	loess profile	0–70	Magnetics	7	7	Chen & Zhang, 1993
Junshan	29.30	112.80	31	lake core	0–10	0	7		Yu, 1985
Kansu	39.12	75.01	1470	loess profile	15–70	3 (+ 1 TL)		7	XJIETRE, 1994
Kekexili	34.63	92.15	4690	lake core	0–20	3	7	2C	Shan *et al*., 1995
Lantian	34.16	109.32	540	fluvial profile	1–9	4	1C		Ke & Sun, 1991
Leizhou Core TY1	20.33	110.33	90	fluvial core	6–90	6	7	2C	Zheng & Lei, 1992
Liuhe	42.90	125.75	910	peat profile	0–8	1	7		Wang & Xia, 1990
Lop Nur K1	40.28	90.25	780	lake core	6–80	2	7	7	Yan *et al*., 1983; Yan *et al*., 1998
Luojishan	27.50	102.40	3660	lake core	0–12.5	3	1C		Li & Liu, 1988
Luxlun Lake	30.00	112.20	58	lake core	0–10	1	4D		Yu, 1985
Madagou	37.00	80.70	1370	fluvial profile	0–16	6	2C		XJIETRE, 1994
Manasi	45.97	84.83	257	lake core	0–14	7	2C		Sun *et al*., 1994
Manxi (Core M)	22.08	100.57	1202	lake core	0–28	7	4C	5C	Tang, 1992
Maohebei	39.50	119.17	50	fluvial profile	0–11	4	2C		Li & Liang, 1985
Mengcun	38.00	117.06	7	fluvial core	0–25	2	5D	7	Xu *et al*., 1993
Mengjiawan	38.60	109.67	1190	fluvial profile	0–7	0*	1C		Ke & Sun, 1991
Miaoershan	25.33	110.33	1850	peat core	1–10	6	1C		Li, 1993b
Nanjing City	32.15	119.05	10	fluvial profile	0–6	1	2D		Unpublished
Nanshan	40.80	111.70	1063	archaeological site	18–20	0*		7	Kong & Du, 1981
Napahai Core 34 (Nabahai)	27.80	99.60	3260	peat core	0–10	1	2D		Wang & Sun, 1986
Niuquanzi	44.30	85.60	1420	loess profile	15–50	1		7†	XJIETRE, 1994
Nuoergai	33.54	102.31	3396	peat core	0–20	3	1C	7	Liu *et al*., 1995
Puzhen	32.08	118.39	15	peat core	14–18	2		7	Unpublished
Qianhuzhuang	40.00	118.58	80	peat profile	0–10	1	6D		Unpublished
Qidong	31.90	121.70	10	fluvial core	0–12	6	1C		KB Liu *et al*., 1992
Qingdeli	48.00	133.30	52	peat profile	0–12	5	1C		Xia, 1988
Qingfeng	33.45	119.92	2	fluvial profile	0–10	9	1C		Tang *et al*., 1993
Qinghai Lake	36.55	99.60	3196	lake core	0–18	5	2C		Du *et al*., 1989; Kong *et al*., 1990
QL-1	34.00	107.58	2200	lake core	0–16	3	7		Tang *et al*., 1990
Reshuitang	43.75	117.65	1200	palaeosol	3–8	2	1C		Jiang, 1992
RM-F	33.08	102.35	3400	peat core	0–7	4	2C		Tang & Shen, 1996
Selin Co	31.67	88.42	4530	lake core	0–11	5	1C		Sun *et al*., 1993
Shanghai City	31.25	121.55	5	fluvial core	0–10	1	1D		Unpublished
Shashi	30.30	112.10	58	lake core	0–10	0*	4D		Yu, 1985
Sheli	45.23	123.31	150	peat profile	1–7	1	4D		Qiu *et al*., 1992
Shengli	47.53	133.87	52	peat profile	0–7	3	2D		Xia, 1988
Shuangyang	43.27	125.75	215	peat profile	0–7	4	1C		Unpublished
Shuidong Core A1	21.75	111.07	−9	fluvial core	0–7	2	2C		Unpublished
Shuidonggou	38.20	106.57	1200	fluvial profile	0–11	2	5D		Ke & Sun, 1988
Sumxi Co 1	34.62	81.03	5058	lake core	0–13	14	1C		Van Campo & Gasse, 1993
Sun-Moon Lake	23.51	120.54	726	lake core	0–18	4	2C		Lu, 1996
Suzhou	31.30	120.60	2	lake core	0–18	2	7	7	Cao *et al*., 1993
Tailai	46.40	123.43	146	palaeosol	0–7	2	5D		Qiu *et al*., 1992
Tianshuigou	34.87	109.73	360	loess profile	6–400	0 (3 TL)	7	2C	Ke & Sun, 1991
Tianshuihai	35.01	79.40	4570	lake core	17–230	8		1D	Unpublished
Tongtu	45.23	123.30	150	palaeosol	2–7	1	7		Qiu *et al*., 1992
Tongyu	44.83	123.10	148	palaeosol	1–8	1	5D		Qiu *et al*., 1992
Toushe Lake	23.82	120.90	650	lake core	1.8–20	17	1C	2C	Kuo, 1994

Table 3 *continued*

Site name	Lat. (°N)	Long. (°E)	Elev. (m)	Sample type	Record length (kyr)	No. of ^{14}C dates	DC at 6000 ^{14}C yr BP	DC at 18,000 ^{14}C yr BP	References
Wajianggou	40.50	112.50	1476	lake terrace profile	0–70	3		7	RQ Li *et al.*, 1990
Wangguangtun	40.37	113.73	1063	peat profile	0–7	2	2C		Kong *et al.*, 1992
Wankou	31.00	112.10	75	lake core	0–10	0*	4D		Yu, 1985
Wasong	33.20	101.52	3490	peat profile	0–30	9	1C	6C	Wang *et al.*, 1996
Weinan	41.3	112.35	650	loess profile	0–100	6	5D	1C	Sun *et al.*, 1996
West Taihu Lake	31.30	119.80	1	lake core	0–11	8	1C		XM Xu *et al.*, 1996
Wulungu Lake	47.10	87.30	650	lake core	0–10	2	6D		Yang & Wang, 1996
Wuqia	43.20	83.50	1320	fluvial profile	0–11	1	7		XJIETRE, 1994
Xiaonan	43.33	125.33	209	peat profile	0–9	2	1C		Xia, 1996
Xichang	40.37	115.83	1450	fluvial core	0–14	7	1C		Cui & Kong, 1992
Yangerzhuang	38.20	117.30	5	fluvial core	0–25	3	7	6C	Xu *et al.*, 1993
Yaocun	34.70	109.22	405	fluvial profile	0–10	2	2C		Ke & Sun, 1991
Yueyawan	37.98	120.71	5	fluvial core	0–10	4	1C		Zhao & Qiu, 1992
Yutubao	40.75	112.67	1254	peat profile	5–12	1	7		Liu & Li ,1992
Zhabuye	31.48	84.07	4421	lake core	0–30	3	1D	7	Wu & Xiao, 1996
Zhabuyechaka	31.48	84.07	4300	fluvial core	0–10	2	4D		Unpublished
Zhujiang delta Core L2	22.33	113.83	−3	delta core	2.5–41	3	7		Unpublished
Zhujiang delta K5	22.78	112.63	12	delta core	0–30	2	1D		Huang *et al.*, 1982
Zhujiang delta PK16	22.73	113.72	15	delta core	0–19	4	7	1C	Huang *et al.*, 1982
Zhujiang delta PK19	21.80	113.30	6	delta core	0–30	3	7	7	Li *et al.*, 1987

† Size of sample too small to biomise.
§ Probable contamination by long-distance transported pollen.

agricultural crops and/or weeds, and swamp or saltmarsh taxa; (2) samples in which only small numbers of pollen were counted and which are dominated by a small number of ubiquitous taxa; (3) samples from sites at extremely high elevations (> 4000 m) and apparently dominated or strongly influenced by long-distance pollen transport from lowland regions; and (4) dust trap samples representing abnormal phenological or meteorological events rather than the regional vegetation. Contamination of the pollen assemblages of high elevation sites by extra-regional components, through long-distance transport of pollen grains, can be readily identified by the presence of pollen grains of obligate tropical species. Similarly, dust flux samples representing abnormal phenological or meteorological events can be readily identified because they are typically overwhelmingly dominated by one or a few taxa that are not particularly abundant plants at a regional scale. The exclusion of aberrant surface samples in these categories is reasonable because they do not represent conditions normally found in fossil pollen assemblages. Long-distance transport could potentially pose problems for the biomization of fossil samples. However, the presence of obviously extra-local taxa was noted in only one fossil sample (HF at 6000 ^{14}C yr BP; Table 3). Difficulties inherent in applying the biomization procedures to small samples with low diversity and dominated by ubiquitous taxa also obliged us to exclude a few fossil samples. Using these guidelines, altogether 25 surface samples, 4 6000 ^{14}C yr BP samples and 2 18,000 ^{14}C yr BP samples were excluded from the maps showing the results of the biomization procedure. Excluded sites and the cause of their exclusion are indicated in Tables 1 and 3.

There has been no attempt to standardize the pollen taxonomy for China, and such a task is beyond the scope of the work described here. Nevertheless, we have corrected the data sets to deal with some of the more obvious taxonomic equivalencies (e.g. *Zanthoxyllum*/*Fagara*; *Justicia*/*Rostellularia*; Fabaceae/Papilionaceae, etc.). We have also deleted things that are not pollen (e.g. moss, *Cocentricystes*), a few specifically agricultural pollen taxa (e.g. *Oryza*), redeposited pollen and spores of pre-Quaternary plants (e.g. *Tricolporopollenites*) and species that are known to be recent human introductions (e.g. *Opuntia, Eucalyptus*) from the data set. Obligate aquatics (e.g. *Sparganium*, *Potamogeton*), mangroves (e.g. *Rhizophora*), succulents (e.g. Cactaceae) and climatically ubiquitous ferns (e.g. *Equisitum*, *Polypodium*, *Pteridium*) are not used in the biomization procedure and, for ease of computation, were also excluded from the data set.

Biomization procedure

The biomization method was first developed by Prentice *et al.* (1996) and is described there and in Prentice & Webb (1998). The basis of the method is: (1) the assignment of individual pollen taxa to plant functional types (PFTs); and (2) specification of the set of PFTs that can occur in specific biomes; so that (3) a quantitative index of affinity can be constructed between every pollen assemblage and every biome. The affinity index takes into account the diversity as well as the abundance of taxa belonging to each PFT.

Initial assignments of 68 pollen taxa to one or more PFTs are given in Yu *et al.* (1998). The very numerous taxa not represented in this earlier work were classified using information on the biology and distribution of the plants derived from the available biogeographical and taxonomic literature (Editorial Committee of Chinese Vegetation, 1980; Academy of China, 1988; Wu, 1991; Institute of Botany of Chinese Academy of Science, 1994). Some finer PFT distinctions were made, reflecting physiological differences that are expressed in bioclimatic ranges. The PFT assignments were checked by plotting the maps of the distribution of individual taxa from the surface pollen samples (Fig. 2) to see if they gave reasonable geographical distribution patterns. Some adjustments of the PFT assignments were made in a few ambiguous cases. This procedure was also applied to the original set of pollen taxa used by Yu *et al.* (1998) and led to some re-assignments. Altogether 10 new PFTs (arctic/alpine forb: af; arctic/alpine fern or fern ally: ax; tree fern: tx; tropical/subtropical evergreen forb: Tef; temperate forb: tf; southern warm-temperate summergreen conifer: tsc3; aquatic: aq; mangrove: man; succulent: suc; and undifferentiated fern or fern ally: x) are recognized, in addition to those used in Yu *et al.* (1998). Some of these PFTs represent very specific, local vegetation (e.g. aquatics and mangrove), while others are too widely distributed to have diagnostic value (e.g. undifferentiated fern or fern ally, temperate forb and tropical/subtropical evergreen forb). These five PFTs were excluded from the biomization procedure. Pollen from obligate succulents is highly susceptible to degradation and is rarely found in fossil samples; this PFT was therefore not used in the biomization procedure. Other new PFTs, however, proved to have useful diagnostic value for biomes, for example arctic/alpine forb (af) as an indicator of tundra, southern warm-temperate summergreen conifer (tsc3) as an indicator of broadleaved evergreen/warm mixed forest, and tree fern (tx) as a primarily tropical evergreen forest plant.

The modern distributions of some taxa representing particular PFTs, based on the modern surface sample data set, are shown in Fig. 2 for illustration. Table 4 shows the assignments of pollen taxa to the PFTs used in the biomization procedure and Table 5 shows the defined composition of each biome in terms of PFTs. Biomes were identified in the order they appear in Table 5.

RESULTS

Predicted vs. observed modern biomes

Comparison of the modern biome distribution reconstructed from the surface pollen samples (Fig. 3a) with the actual modern biomes at the same sites (Fig. 3b) shows good agreement, with 72% of the sampling sites being correctly assigned. The level of agreement is greatest in the broad latitudinal forest zones of eastern China. Seven sites (2 from Hainan Island, 3 from Taiwan and 2 from the coastal lowlands of southern mainland China) are shown as tropical seasonal forest. This distribution is in good agreement with the very restricted zone of true tropical forests in China (Fig. 3b). Altogether 152 sites from southern China are reconstructed as broadleaved evergreen/warm mixed forest, with a northern boundary at *c.* 31–33°N. This pattern is in clear agreement with the range limits of the subtropical (according to standard Chinese vegetation nomenclature) evergreen and mixed deciduous forests of southern China (Academy of China, 1988). The apparent intermingling of broadleaved evergreen/warm mixed and temperate deciduous forests in the northern part of this range reflects elevational gradients, with temperate deciduous forest occurring at elevations between 400 and 1500 m a.s.l. Temperate deciduous forest is reconstructed at 60 sites in the lowlands between 32°N and 42°N. Temperate deciduous forest is also correctly reconstructed in north-eastern China, in the region of the Daxinganling Mountains. The Daxinganling Mountains run approximately north–south and reach maximum elevations of 1530 m a.s.l. The mountains block the passage of moisture-bearing winds from the Pacific (Ren *et al.*, 1979) and there are therefore strong gradients in plant-available moisture within this region. These moisture-availability gradients are reflected in the vegetation. Modern pollen surface samples from sites on the western (i.e. rain shadow) slope of the Daxinganling Mountains (Fig. 4a) show cold mixed and cold deciduous forests at the highest elevations. Temperate deciduous forest replaces cool mixed forest in the zone where moisture availability becomes limiting for species such as *Abies* and *Picea*. The temperate deciduous forest is itself replaced by steppe, and ultimately desert, vegetation at lower elevations. Thus, the Daxinganling Mountains determine the location, which is suprisingly far eastward, of the boundary between forests and steppe in northern China.

Forest biomes (cool mixed, cold mixed and cold decidous forests and taiga) occur in the extreme north-east of China. The distribution of each type is in good agreement with the ranges of comparable vegetation types in the vegetation map of China (Editorial Committee of Chinese Vegetation, 1980; Academy of China, 1988). The same four biomes are reconstructed at high elevation in the Loess Plateau and the Mongolian Plateau of central China, the eastern margin of the Tibetan Plateau, and the Tianshan Mountains of western China, again in good agreement with the actual distribution of these biomes. The procedure appears to be able to capture elevational gradients within these mountain regions reasonably well. The Tianshan Mountains, for example, run broadly west–east and reach elevations of >4000 m a.s.l. The main source of moisture on the north slope of the Tianshan is the Arctic Ocean (Ren *et al.*, 1979; Academy of China, 1988). Our biomization of surface samples from the northern slope shows tundra above *c.* 3000 m a.s.l., cool mixed forest above *c.* 2000 m a.s.l., with steppe and then desert below *c.* 1700 m a.s.l. (Fig. 4b). The reconstructed vegetation zonation is in good agreement with observations (Academy of China, 1988).

The treeless biomes (steppe, desert and tundra) are reasonably well reconstructed. Most of the 79 samples assigned to tundra are located in eastern and central Tibet, in agreement with the fact that the modern vegetation in this

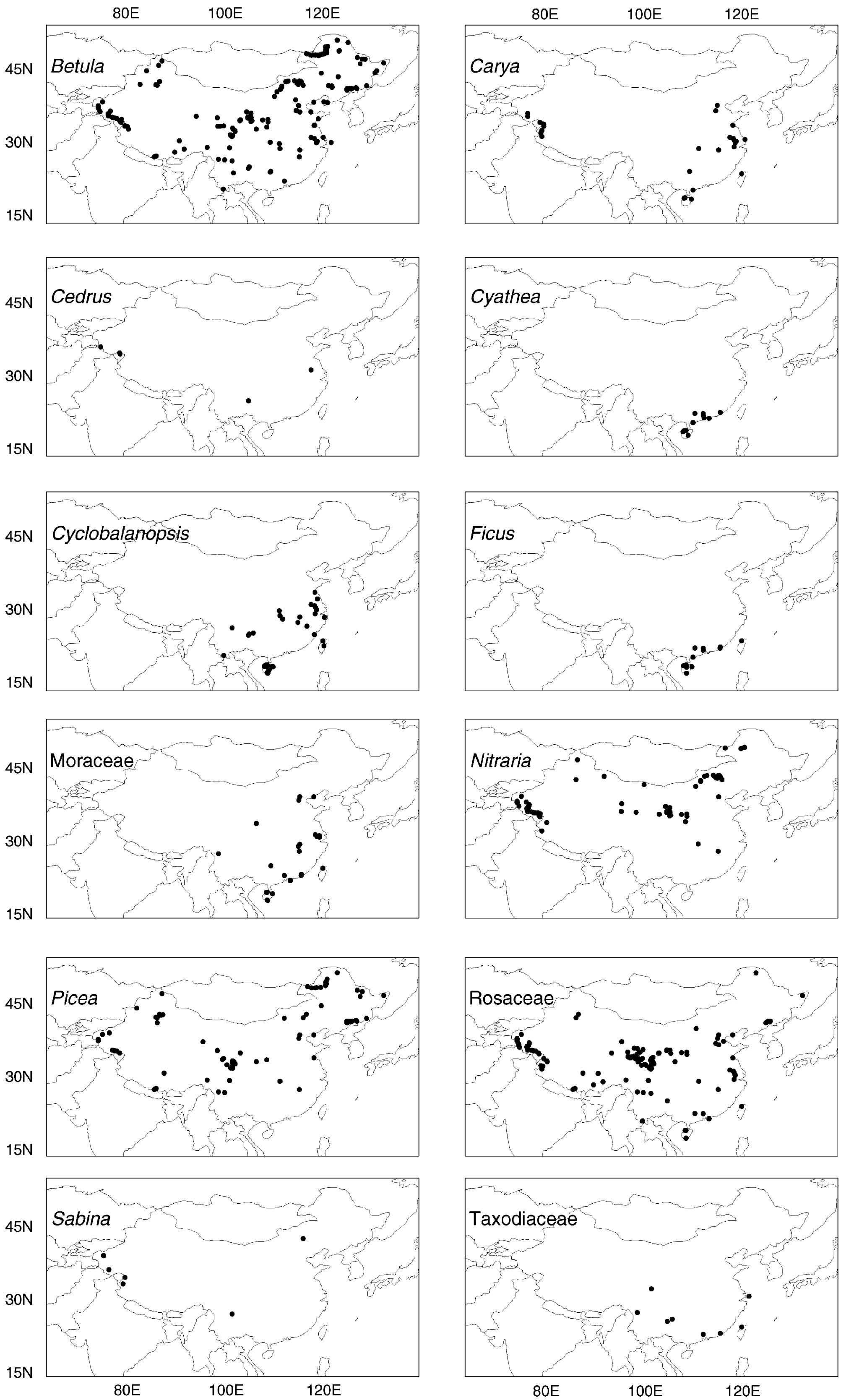

Figure 2 Distribution maps based on surface pollen sample data for specific taxa, chosen as characteristic of key plant functional types.

Table 4 Assignments of pollen taxa from China to the plant functional types (PFTs) used in the biomization procedure.

Abbr.	Plant functional type	Pollen taxa
aa	arctic/alpine shrub	*Betula*, *Betula*-type, Betulaceae, *Hippophae, Sabina, Salix*
af	arctic/alpine forb	*Androsace, Arenaria*, Campanulaceae, *Caragana*, Caryophyllaceae, *Centaurea, Christolea*, Compositae, Cruciferae, *Dianthus, Gentiana*, Gentianaceae, Leguminosae, Liguliflorae, *Onobrychis, Orostachys*, Papilionaceae, *Pedicularis*, Polygonaceae, *Polygonum, Potentilla, Primula*, Primulaceae, *Rhodiola, Saussurea, Saxifraga*, Saxifragaceae, *Sedum, Sibbaldia, Stelleria, Thalictrum*, Tubuliflorae, *Viburnum*
ax	arctic/alpine fern or fern ally	*Botrychium, Woodsia*
bec	boreal evergreen conifer	*Abies, Picea, Pinus* (Haploxylon)
bs	boreal summergreen	*Alnus, Betula*, *Betula*-type, Betulaceae, *Maackia, Populus, Salix*
bsc	boreal summergreen conifer	*Larix*
ctc	cool-temperate conifer	*Abies*, Taxaceae, *Taxus, Tsuga*
df	desert forb/shrub	*Alhagi, Anabasis, Atriplex, Brachyactis, Calligonum, Caragana*, Caryophyllaceae, *Centaurea, Ceratoides*, Chenopodiaceae, *Christolea*, Compositae, Cruciferae, Elaeagnaceae, *Elaeagnus, Ephedra, Hippophae*, Leguminosae, Liguliflorae, Liliaceae, *Lilium, Myricaria, Nanophyton, Nitraria, Onobrychis, Orostachys*, Papilionaceae, *Polemonium*, Polemoniaceae, Polygonaceae, Polygonum, Polypodiaceae, *Potentilla*, *Reaumuria*, *Sedum*, *Solidago*, *Suaeda*, *Tamarix*, Tubuliflorae, *Zygophyllum*
ec	eurythermic conifer	Cupressaceae, *Juniperus*, Pinaceae, *Pinus* (Diploxylon)
g	grass	Gramineae, *Hierochloe*, Poaceae
h	heath	*Empetrum*, Ericaceae, *Ledum, Vaccinium*
s	sedge	*Carex*, Cyperaceae, *Dichostylis, Eriophorum, Eriophostylis*
sf	steppe forb/shrub	*Atractylodes*, *Ajania*, *Ambrosia*, *Artemisia*, *Aster*, *Astragalus*, *Atractylis*, *Atriplex*, *Bidens*, *Brachyactis*, Campanulaceae, Caryophyllaceae, *Centaurea, Ceratoides*, Compositae, Cruciferae, *Daphne, Dianthus*, Elaeagnaceae, *Elaeagnus, Filifolium, Gentiana*, Gentianaceae, *Gerbera, Hemerocallis, Hypecoum*, Iridaceae, *Iris*, Leguminosae, Liguliflorae, Liliaceae, Linaceae, *Macleaya, Medicago, Onobrychis*, Papilionaceae, *Paraphlomis, Patrinia, Polemonium*, Polemoniaceae, Polygonaceae, *Polygonum, Portulaca, Potentilla, Primula*, Primulaceae, *Rheum*, Rosaceae, *Rumex*, Rutaceae, *Saussurea, Saxifraga*, Saxifragaceae, *Solidago, Thalictrum, Tribulus*, Tubuliflorae, *Verbascum, Veronica, Viola*, Violaceae, *Xanthium, Zanthoxylum*
Te	tropical evergreen	*Aglaia, Altingia*, Altingiaceae, Anacardiaceae, Annonaceae, Apocynaceae, Araliaceae, *Artocarpus, Averrhoa, Bowringia, Calamus, Canarium, Cassia*, Combretaceae, *Cycas, Decaspermum, Elaeocarpus, Ficus*, Flacourtiaceae, *Fortunella*, Guttiferae, *Helicia, Homalium, Koelreuteria, Lannea*, Lardizabalaceae, Lauraceae, Leguminosae, *Macaranga, Malania, Mappianthus, Melanolepis*, Melastomataceae, Meliaceae, *Mimosa*, Mimosaceae, Moraceae, Myristicaceae, Myrtaceae, *Neolitsea, Nothopanax*, Oleaceae, Palmae, Papilionaceae, *Phoenix, Piper*, Piperaceae, Proteaceae, *Psidium, Pterolobium, Randia, Saururus, Trachycarpus, Trema*, Ulmaceae
Tr	tropical raingreen	*Acacia, Aeschynanthus, Albizia, Allomorphia, Alnus, Anodendron, Aphanamixis*, Bombacaceae, *Bombax, Caesalpinia, Chingiacanthus, Chukrasia*, Combretaceae, *Dalbergia, Decaspermum, Elytranthe*, Euphorbiaceae, Fagraea, *Ficus, Flacourtia*, Flacourtiaceae, *Hainania, Helicteres, Homalium*, Icacinaceae, *Kleinhovia*, Leguminosae, *Lithocarpus, Mappianthus, Melanolepis, Microtropis, Mimosa*, Mimosaceae, *Myrsinaceae, Nyssa*, Olacaceae, *Olax, Pachygone*, Papilionaceae, *Pistacia, Platea*, Proteaceae, *Prunus, Pterolobium*, Sabiaceae, *Sapium*, Sapotaceae, *Syzygium, Terminalia*, Tiliaceae, Ulmaceae, *Ulmus, Wendlandia*
ts	temperate summergreen	*Acalypha, Acanthopanax, Acer*, Aceraceae, Anacardiaceae, *Aphanamixis, Aquilegia, Aralia*, Araliaceae, *Betula*, *Betula*-type, Betulaceae, Celastraceae, *Celastrus, Chingiacanthus, Clematis, Cotoneaster*, Cornaceae, *Cornus, Crataegus, Elytranthe*, Euphorbiaceae, *Evodia, Flacourtia, Glochidion, Hydrangea, Hypericum, Jasminum, Kalopanax*, Leguminosae, *Lespedeza*, Myrsinaceae, Oleaceae, *Osmanthus*, Papilionaceae, *Phellodendron, Philadelphus, Platanus, Populus, Quercus (*deciduous*)*, Rhamnaceae, *Rhamnus, Rosa*, Rosaceae, Rubiaceae, Rutaceae, *Salix, Sambucus, Spiraea, Syringa, Tilia*, Tiliaceae, *Toxicodendron, Vaccinium, Viburnum, Vitex, Ziziphus*
ts1	cool-temperate summergreen	*Alnus, Carpinus, Cladrastis, Corylus*, Euphorbiaceae, *Fraxinus*, Lonicera, *Ostryopsis, Pyrus, Sorbus*, Ulmaceae, *Ulmus*

Table 4 *continued*

Abbr.	Plant functional type	Pollen taxa
ts2	intermediate-temperate summergreen	*Acacia, Aesculus, Ailanthus, Alnus, Albizia, Broussonetia,* Caprifoliaceae, *Carpinus, Carya, Castanea, Castanea*-type, *Celtis, Cladrastis,* Commelinaceae, *Corylus, Cyclocarya, Diospyros,* Ebenaceae, Elaeagnaceae, *Elaeagnus, Fagus, Forsythia, Ginkgo,* Hamamelidaceae, Juglandaceae, *Juglans, Koelreuteria, Lagerstroemia, Liriodendron, Liquidambar, Lonicera, Melia,* Meliaceae, *Microtropis, Mimosa,* Mimosaceae, Moraceae, *Morus, Myrica, Myrsine, Nyssa, Ostrya, Pistacia, Platycarya, Pterocarya, Pyrus, Schisandra, Sorbus,* Thymelaeaceae, Ulmaceae, *Ulmus,* Urticaceae, *Vitis,* Vitaceae
ts3	warm-temperate summergreen	*Albizia, Berberis, Corylopsis,* Ebenaceae, *Euonymus, Fontanesia, Helwingia, Liriodendron, Rhus, Sapium, Wikstroemia, Zelkova*
tsc3	southern warm-temperate summergreen conifer	*Pseudolarix,* Taxodiaceae, *Taxodium*
tx	tree fern	*Cyathea,* Cyatheaceae, Davalliaceae
wtc	warm-temperate conifer	*Cedrus, Cryptomeria, Cunninghamia, Dacrydium, Glyptostrobus, Keteleeria, Podocarpus,* Taxaceae, *Taxus, Tsuga*
wte	warm-temperate broadleaved evergreen	*Acacia, Alchornea, Acalypha,* Acanthaceae, *Actinidia, Adinandra, Alangium, Aleurites, Allophylus, Alyxia,* Anacardiaceae, *Aralia,* Araliaceae, *Ardisia,* Bignoniaceae, *Bredia, Camellia,* Capparidaceae, *Capparis, Castanopsis, Casuarina,* Celastraceae, *Clethra, Clerodendrum, Cocculus, Cotoneaster, Cyclobalanopsis, Dalbergia, Daphne, Dendropanax, Distylium, Dodonaea, Elaeocarpus, Engelhardtia, Erycibe, Eucalyptus,* Euphorbiaceae, *Eurya, Excoecaria, Ficus,* Flacourtiaceae, *Fortunella, Glochidion,* Hamamelidaceae, *Hamamelis, Heritiera, Idesia, Justicia, Koelreuteria,* Lauraceae, *Lithocarpus,* Loranthaceae, *Macaranga, Magnolia,* Magnoliaceae, *Mallotus, Manglietia,* Meliaceae, *Meliosma,* Menispermaceae, *Michelia,* Moraceae, Myrsinaceae, Myrtaceae, *Neolitsea, Nerium, Nothocarpus,* Nyctaginaceae, *Olea,* Oleaceae, *Phoebe,* Pittosporaceae, *Quercus (*evergreen*), Reevesia,* Rhamnaceae, *Rhamnus,* Rubiaceae, Rutaceae, Sabiaceae, Sapindaceae, *Sapindus, Schefflera, Schima, Styrax, Sycopsis,* Symplocaceae, *Symplocos,* Theaceae, *Tricalysia, Trochodendron, Wendlandia*
wte1	cool-temperate broadleaved evergreen	*Hedera, Ilex, Ligustrum,* Loranthaceae, *Rhododendron*

Table 5 Assignments of plant functional types (PFTs) to biomes in China.

Biome	Code	Plant functional types
tropical rain forest	TRFO	Te, tx, wtc, wte
tropical seasonal forest	TSFO	Te, Tr, tx, wtc, wte
tropical dry forest/savanna	TDFO	g, Tr
cold deciduous forest	CLDE	bs, bsc, ec, h
taiga	TAIG	bec, bs, bsc, ec, h
cold mixed forest	CLMX	bs, bsc, ctc, ec, h, ts1
cool conifer forest	COCO	bec, bs, ctc, ec, h
temperate deciduous forest	TEDE	bs, ctc, ec, h, ts, ts1, ts2, wte1
cool mixed forest	COMX	bec, bs, ctc, ec, h, ts, ts1
broadleaved evergreen/warm mixed forest	WAMF	ec, h, ts, ts2, ts3, tsc3, tx, wtc, wte, wte1
xerophytic woods/scrub	XERO	ec, wte
tundra	TUND	aa, af, ax, g, h, s
steppe	STEP	g, sf
desert	DESE	g, df

region is alpine dwarf-shrub tundra and alpine meadows (Academy of China, 1988). The tundra biome is also correctly reconstructed at the highest elevations of, e.g. the Tianshan Mountains (Fig. 4b). The desert biome was assigned at 117 sites and the steppe biome at 98 sites. Surface samples assigned to desert were mainly located in northern Tibet and in north-western and western China including Xinjiang and Inner Mongolia, following the modern distribution of 'dry desert' vegetation. Samples assigned to steppe are located mostly in central and north-eastern China covering the Loess Plateau and the eastern part of the Mongolian Plateau, consistent with the narrow zone of steppe orientated north-east–south-west and shown on vegetation maps (Editorial Committee of Chinese Vegetation, 1980; Academy of China, 1988).

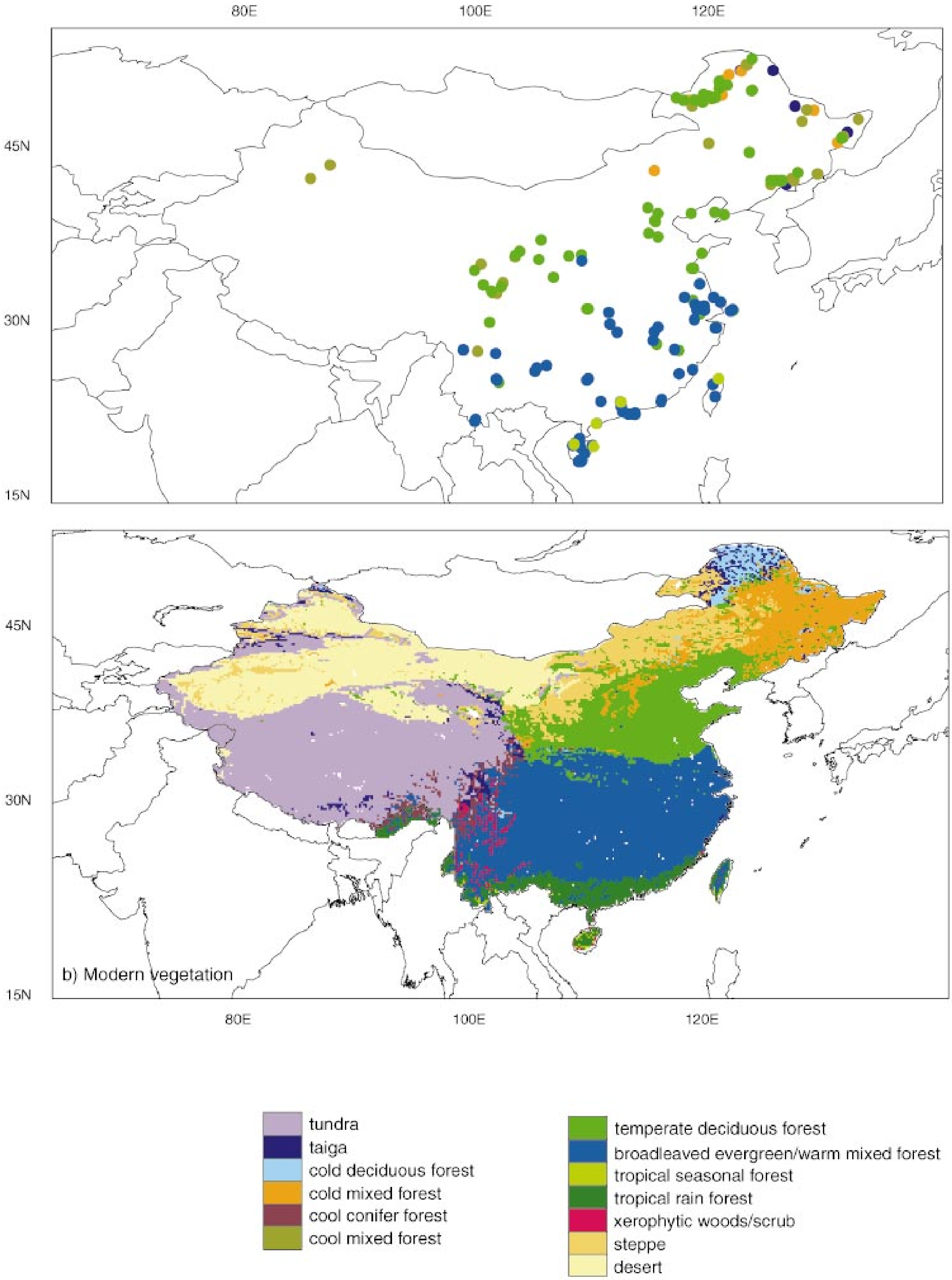

Figure 3 Modern biomes (a) reconstructed from surface pollen data compared with (b) modern vegetation divisions of China (from Ni *et al*., in press).

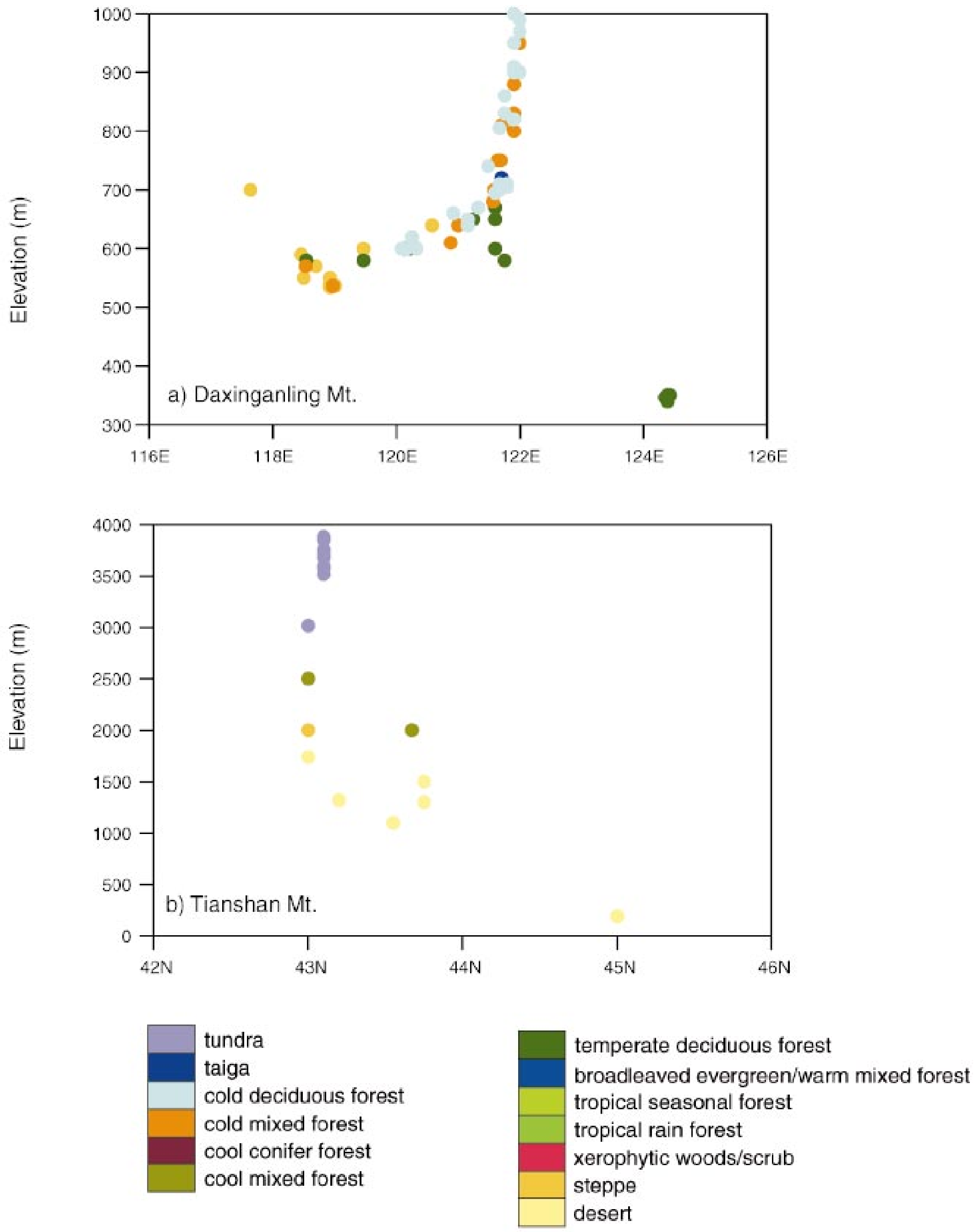

Figure 4 Surface pollen-based biomes along elevation gradients in the (a) Daxinganling and (b) Tianshan mountain ranges.

In the transition region where the pollen data indicate a mingling of steppe and desert samples, the vegetation maps indicate a mosaic of steppe and desert. A similar mosaic of steppe and desert is correctly reconstructed in western Tibet.

Mid-Holocene biomes

The reconstruction at 6000 ^{14}C yr BP (Fig. 5a) shows that the forest biomes in eastern China were systematically shifted northwards and extended westwards compared to the present. Tropical rain forest occurred at sites on mainland China are occupied today either by tropical seasonal or broadleaved evergreen/warm mixed forest. There are 2 sites (Bailiangdong and Hanjiang) where tropical forest occurs *c.* 100 km beyond the modern limit of tropical forest biomes. Broadleaved evergreen/warm mixed forest was more extensive than today. A shift of the northern boundary of this zone is only registered at a single site (Lianyungang) on

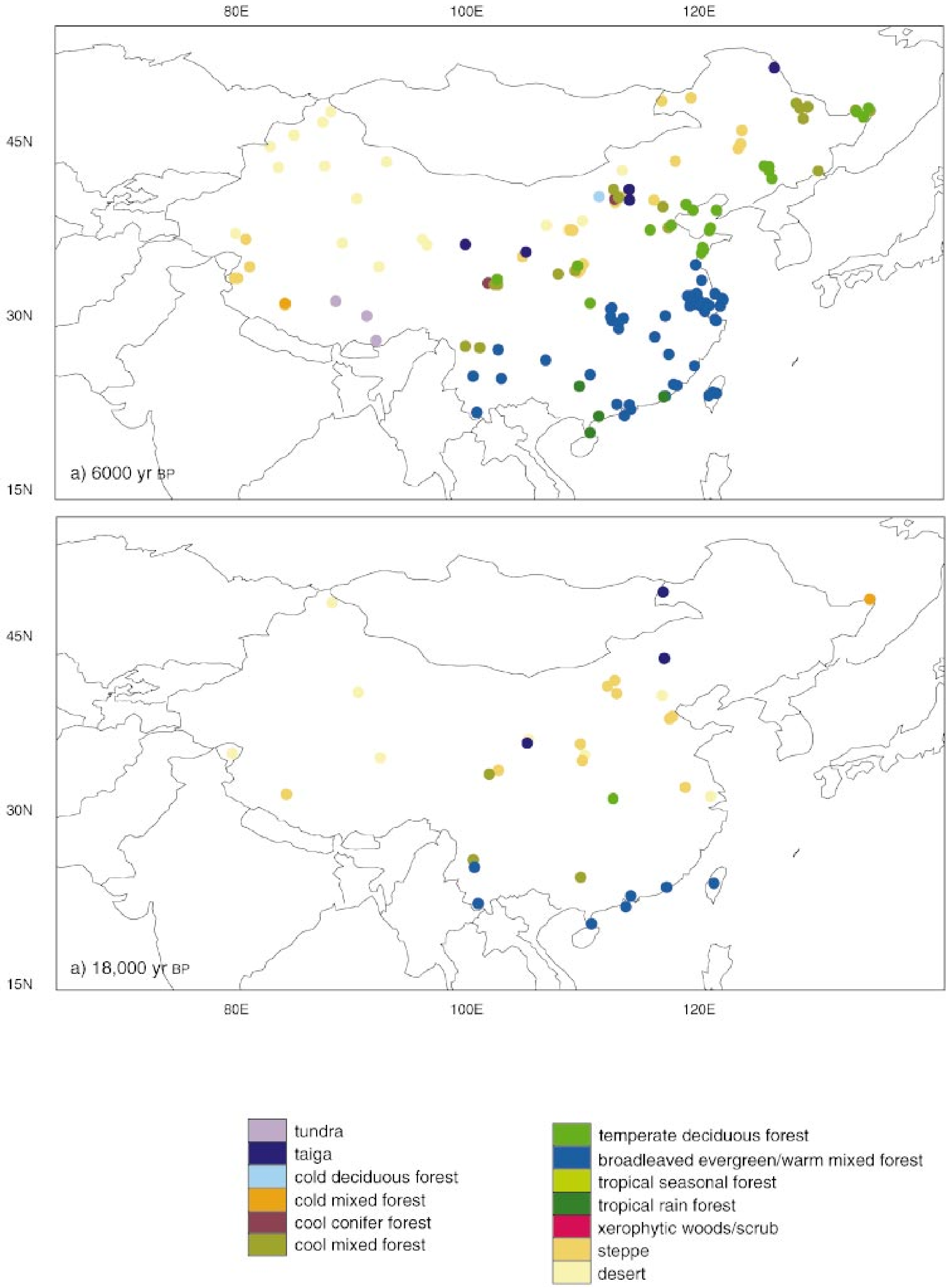

Figure 5 Biomes reconstructed from fossil pollen data at (a) 6000 ^{14}C yr BP and (b) 18,000 ^{14}C yr BP.

the east coast, which is nevertheless *c.* 200 km north of the modern limit. However, broadleaved evergreen/warm mixed forest also expanded into higher elevation sites, occupied today by temperate deciduous forest, at the northern end of the modern range of this biome (i.e. between 26°N and 34°N). The temperate deciduous forest occurred as far north as *c.* 48°N, i.e. *c.* 800 km north of its present limit. Correspondingly, taiga retreated to north of 50°N.

Changes in the elevational ranges of forest types, in addition to the example of broadleaved evergreen/warm mixed forest discussed above, can also be inferred from the 6000 ^{14}C yr BP results. On the eastern margin of the Tibetan Plateau, forest was present at higher elevations than today, and the tundra in the eastern plateau region may have been somewhat reduced in area. For example, site RM-F at *c.* 3400 m is classified as cool mixed forest at 6000 ^{14}C yr BP; alpine meadow and steppe are found at this elevation today and the conifer forest belt occurs between 2000 and 2900 m a.s.l. (Academy of China, 1988), indicating that the treeline was *c.* 500 m higher than today in the mid-Holocene.

In central China, the eastern boundary of steppe vegetation was shifted westwards due to a greater extension (*c.* 300–500 km) of forest biomes: predominantly temperate deciduous forest and cool mixed forest, but with some sites also assigned to cool conifer or cold mixed forest biomes. There is no indication that the desert areas of western China were reduced compared to today: the reconstructed steppe desert boundary occurs at about the same place in the 0 and 6000 ^{14}C yr BP maps.

Last glacial maximum biomes

The biome map for 18,000 ^{14}C yr BP (Fig. 5b) shows a notable eastward expansion of both steppe and desert vegetation, reaching the present-day coastline in the latitude band between 32°N and 40°N. The temperate deciduous forests characteristic of this latitude band today are not present in the 18,000 ^{14}C yr BP map. A single site on the Jianghan Plain (31.10°N, 112.20°E), with an assemblage including *Abies*, *Betula, Crataegus, Pinus* and *Quercus* (deciduous) is classified as temperate deciduous forest. It is possible that the temperate deciduous forest occurred further south than today, but we have no sites from eastern China between 25°N and 30°N to test this hypothesis.

To the south, tropical forests were apparently banished, and broadleaved evergreen/warm mixed forests were forced to retreat southward in the lowlands as far as 24°N, a shift of *c.* 1000 km relative to today. Cool mixed forest occurred on the northern margin of the broadleaved evergreen/warm mixed forest zone. Cool mixed forest is found today at high elevations in the eastern Tibetan mountains, and its eastward expansion into the lowlands to *c.* 109°E implies a shift of *c.* 1000 km. To the north of the steppe/desert zone there was a strong southward expansion of taiga. One taiga site (Dalainuoer) occurs as far south as 43.2°N in a region where temperate deciduous forest occurs today.

On the Tibetan Plateau, a single site is characterized as tundra at 18,000 ^{14}C yr BP, rather than the desert vegetation that is characteristic of that region today. However, the data from Tibet are insufficient to determine whether there was a substantial expansion of tundra at the expense of desert. Other 18,000 ^{14}C yr BP sites from Tibet record desert or steppe, just as they do today, and the western interior of China was occupied by desert, again as it is today.

DISCUSSION AND CONCLUSIONS

The biomization method

Comparison of the modern and 6000 ^{14}C yr BP pollen-based biome maps in this paper with biome reconstructions based on a more limited set of digitized data (Yu *et al.*, 1998) shows that the initial reconstructions made by Yu *et al.* (1998) have proved robust: the major biome changes seen on comparison of modern and 6000 ^{14}C yr BP maps appear similar in the two analyses. Although the present analysis allows greater geographical resolution due to the much greater site density, the position of the forest zone boundaries (except the tropical forests) in eastern China are not affected by the use of pollen counts rather than digitized data. This reflects the fact that the taxa diagnostic of e.g. boreal or temperate forests are tree species which are nearly always included in the standard type of pollen diagrams from which digitized data sets are produced. However, the differences between the two analyses in the positioning of specific biome boundaries becomes larger in more species-rich forests (e.g. tropical forests) or in regions characterized by non-forest biomes.

A more precise distinction between steppe and desert biomes is achieved in the present study because the full set of identified pollen taxa was available for the great majority of modern and 6000 ^{14}C yr BP sites used. For example, we classified the following taxa as typical steppe forb/shrub (sf): *Ajania*, *Ambrosia*, *Artemisia*, *Aster*, *Astragalus*, *Bidens*, *Filifolium*, *Gerbera*, *Hemerocallis*, Iridaceae, *Iris*, Linaceae, *Patrinia*, *Portulaca*, *Rumex*, *Tribulus*, *Veronica*, *Viola*, *Xanthium* and *Zanthoxylum*; and as typical desert forb/shrub (df): *Alhagi*, *Anabasis*, *Calligonum*, Chenopodiaceae, *Ephedra*, *Myricaria*, *Nanophyton*, *Nitraria*, *Reaumuria*, *Suaeda*, *Tamarix* and *Zygophyllum*. Each of these taxa was assigned to a single PFT, df or sf, except for Chenopodiaceae which was considered as either df or temperate forb/shrub (tf) because of the existence of temperate weedy species; this difference does not affect the outcome of the biomization because the tf category was not used in biome assignments. Thus, a large set of taxa was available to differentiate desert and steppe.

Note that *Artemisia* and Chenopodiaceae might alternatively be assigned to both sf and df, as done by Tarasov *et al.* (1998) for the Central Asian republics. Tarasov *et al.* (1998) found that this alternative worked well, provided that the full list of identified taxa was used. Yu *et al.* (1998) discuss the rationale for treating these two taxa as sf and df, respectively, which is based on a systematic pattern in their abundances (and correspondingly in their pollen percentages) in the steppes and deserts of China. We have retained the convention of Yu *et al.* (1998) here because it gives excellent results for the modern pollen spectra from China, although a reasonably accurate reconstruction of the present distributions of steppe and desert could now be generated following the alternative convention of Tarasov *et al.* (1998).

Comparison of our maps with those in Yu *et al.* (1998) shows that the use of digitized data produces reliable results in the temperate and boreal forest zones. This conclusion is consistent with the good prediction of forest biomes in Europe (Prentice *et al.*, 1996). However, digitized data are less able to differentiate non-woody biomes (e.g. steppe, desert and tundra). These conclusions underline the importance of continued public support for archiving primary pollen data in regional data bases, such as the Chinese Pollen Data Base.

Vegetation and climate of China at 6000 ^{14}C yr BP

The northward shifts of the tropical, broadleaved evergreen/warm mixed and cool mixed forest zones in eastern China must imply warmer *winters* than present since the poleward boundaries of the affected biomes in China today are associated with winter-temperature isotherms that in turn reflect the typical tolerance limits of tropical, subtropical (broadleaved evergreen) and temperate broadleaved deciduous woody plants. The northern boundary of temperate deciduous forest, which showed the greatest northward shift of all, is also controlled by winter temperatures, occurring where the winter temperatures become cold enough to satisfy the chilling requirements of boreal needle-leaved evergreen trees.

Warm winters at 6000 ^{14}C yr BP are contrary to what would be expected in terms of direct (radiative) effects of orbital changes during the Holocene, because mid-Holocene winter insolation in the northern mid-latitudes was less than today (Berger, 1978). An over-riding explanation is therefore needed, perhaps involving a weakening or deflection of the East Asian winter monsoon (Yu *et al.*, 1998). Takahara *et al.* (2000) suggest the vegetation distributions in Japan at 6000 ^{14}C yr BP are similar to those of today, and that there was therefore no significant change in winter climate. This suggested difference in the behaviour of winter temperature anomalies between the Japanese islands and the Chinese continent, suggests the involvement of an indirect climatic response acting through a change in the atmospheric and/or oceanic circulation. The possible nature of this circulation change is an unresolved issue at present since climate model simulations have not produced warmer winters at 6000 ^{14}C yr BP in China (Harrison *et al.*, 1998). However, there are persistent discrepancies between the observed pattern of the East Asian winter monsoon and simulations using current climate models (Li *et al.*, 1994; Giorgi *et al.*, 1998) and furthermore, the response of the East Asian monsoon to orbital forcing in coupled atmosphere–ocean model simulations needs further analysis.

The mid-Holocene expansion of forests in Inner Mongolia into regions that are currently occupied by warm steppe and warm desert vegetation must reflect increased annual moisture availability. This can be explained as a result of direct radiative effects (i.e. high summer insolation), producing a stronger-than-present summer monsoon (e.g. Winkler & Wang, 1993). The expansion of forests in eastern Tibet into high elevations where alpine plant communities occur today is also easily explained due to greater growing-season warmth at 6000 ^{14}C yr BP. The absence of any discernible change in the area of deserts may imply no climate change in the interior, or that a balance was reached between increased penetration of monsoonal precipitation and increased evaporation due to increased summer insolation and direct heating at 6000 ^{14}C yr BP.

Vegetation and climate of China at the LGM

Our reconstruction of 18,000 ^{14}C yr BP biomes is broadly consistent with previous studies based on partial syntheses of pollen data (An *et al.*, 1990; Winkler & Wang, 1993; Wang & Sun, 1994). A remarkable feature of the 18,000 ^{14}C yr BP biome reconstructions for China is the mid-latitude (30–40°N) extension of steppe and desert biomes to the modern eastern coast. Terrestrial deposits of glacial maximum age from the northern part of the Yellow Sea between 33°N and 40°N suggest that this region of the continental shelf was occupied by desert and steppe vegetation (Xu, 1982; Han & Meng, 1986; Meng & Wang, 1987). The presence of a single site with temperate deciduous forest at *c.* 31°N suggests that temperate forests could have been displaced southwards, as suggested by Winkler & Wang (1993) and Wang & Sun (1994). However, the absence of data in the 25–30°N range makes it difficult to test this hypothesis.

The shift from temperate forests to steppe and desert implies conditions very much drier than present in eastern China. This conclusion is fully consistent with other palaeodata, including the huge thickness of last-glacial loess deposits in central China (Liu *et al.*, 1986; An *et al.*, 1991) and the drying-up of numerous lakes in eastern China (Fang, 1991; Wang & Wang, 1992). Dry conditions might be explained by a strong winter monsoon (e.g. Xiao *et al.*, 1995) and/or a weak summer monsoon (e.g. An *et al.*, 1991), both of which are plausible for the glacial maximum. In addition, relative sea level along the East China Sea coast was as low as –140 m (Zhu & Zeng, 1979, 1981; An *et al.*, 1990) and the coastline was located at the far edge of the continental shelf at 125–127°E (Zhu & Zeng, 1979, 1981; Zhao & Li, 1990). These palaeogeographic changes may further have contributed to producing a more continental mid-latitude climate.

The northern boundary of broadleaved evergreen/warm mixed forest at 18,000 ^{14}C yr BP has previously been reconstructed at 23°N (Winkler & Wang, 1993) or 21–22°N (Wang & Sun, 1994), in broad agreement with our results. We show that this boundary was displaced southward by *c.* 1000 km. Together with the extension of cool mixed forests *c.* 1000 km eastward into the lowlands, this displacement indicates a very strong depression of winter temperatures in southern China at the LGM and contrasts with the rather slight change observed in this region since the mid-Holocene. The equatorward shifts of the northern forest biomes also imply large reductions in winter and/or growing-season temperature over the whole of north-eastern China.

One site from the Tibetan Plateau showed tundra at 18,000 ^{14}C yr BP in the far western region where today there is steppe or desert. This finding could be taken to imply conditions that were wetter than at present, consistent with high LGM water levels reconstructed from inland lakes such as Chaiwobao Lake (Shi *et al.*, 1993) and Balikun Lake (Han & Dong, 1990; Han & Yuan, 1990; Han *et al.*, 1993) in north-western China, and Tianshui Lake (Wang *et al.*, 1990; Li *et al.*, 1991) on the Tibetan Plateau. However, there is no evidence for wetter conditions at lower elevations (extensive deserts were still present in western China). The high-elevation shift to tundra and the lake-level changes could simply be due to a large year-round temperature depression, leading to a low growing degree-day total, and incidently reducing evaporation from both vegetation and water surfaces and prolonging ice cover on lakes. The reconstruction of year-round conditions much colder than today right across China is consistent with biome reconstructions from adjacent regions including Japan (Takahara *et al.*, 2000) and western Beringia (Edwards *et al.*, 2000) at the LGM, and testifies to the global scale of the climatic impacts of glacial boundary conditions on climate and vegetation.

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BIOSKETCH

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