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Mapping Holocene pollen data and vegetation of China

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Abstract

Holocene pollen maps of China north of the Yangtze River are presented for six time slices at 2000 year intervals and for ten taxa or taxon combinations on the basis of a data set of pollen diagrams of 142 sites. In spite of the problems with the differentiated data quality, a general correspondence of modern pollen maps with actual vegetation distribution justifies the feasibility of using the pollen maps to illustrate the past temporal and spatial patterns of vegetation change and to tentatively reconstruct palaeo-biomes for the specific time slices. The pollen maps reveal large changes in Holocene vegetation. In the southeastern half of the study area, arboreal taxa generally expanded in the early Holocene times, reaching their maximum at 6 or 4 ka BP, and then shrank during the late Holocene. An exception was found for eastern and northern Northeast China where the maximum development of arboreal taxa occurred during the last 4000 or 2000 years. The evident drop in AP percentages, and therefore the decline of forests, occurred after 6 ka BP in the most southeastern regions, especially in the middle and lower reaches of the Yellow River, and may have been caused by the expansion of farming since the Yangshao Culture period. The reconstructed biomes enable the visual expression of palaeo-vegetation change. A relatively open forest with *Pinus* as its dominant component developed in the southeastern Loess Plateau and western North China Plain from 8 to 6 ka BP, but it came to an end at about 4 ka BP. On the other hand, cold temperate conifer forest, and temperate mixed conifer and deciduous forest in Northeast China did not yet exist between 10 and 6 ka BP. They appeared at 4 ka BP and then continued to develop through time. Warm temperate deciduous forest experienced a remarkable reduction during the last 6000 years. Alpine valley *Picea*/*Abies* forest in the eastern Qinghai-Tibet Plateau developed in the early and mid Holocene, but started to decline at 4 ka BP, and has almost disappeared today.

1. Introduction

Mapping of pollen data is one means of palaeo-data syntheses, which is essential for understanding the temporal and spatial structure, and furthermore the dynamics, of palaeo-vegetation and palaeo-environment on sub-continental or larger scales (Firbas, 1949; Bernabo and Webb, 1977; Huntley and Birks, 1983; Webb, 1988; Prentice et al., 1996; Ren and Zhang, 1998). Pollen map series of the last 12,000 years have been produced for North America (Bernabo and Webb, 1977; Anderson and Brubaker, 1994) and Europe (Huntley and Birks, 1983; Huntley, 1990a, b). These contribute greatly to the understanding of the tempo-spatial pattern and mechanism of palaeo-environmental changes (Huntley and Webb, 1988; COHMAP Members, 1988; Wright et al., 1992).

China represents a huge geographical unit, and pollen data synthesis for the Holocene or the more remote past is lacking. A few syntheses have been attempted to obtain the general trends of the changes in pollen and palaeo-vegetation on the basis of site data (Liu, 1988; An et al., 1990; Sun and Chen, 1991; Winkler and Wang, 1993; Liu and Qiu, 1994). An international cooperative project aimed to map the global palaeo-biomes of 6 and 18 ka BP is underway (Guiot et al., 1996; Prentice et al., 1996; Prentice and Webb, 1998), and a compilation of data for China for 18, 6 and 0 ka BP has been completed (Yu et al., 1998, 2000). These attempts are important in the light of the role they play in increasing the understanding of the traditionally data-scarce region. However, they suffer from the limited number of data sites used and time slices specified. Currently they are not comparable to the pollen mapping work conducted in North America and Europe.

Ren et al. published a preliminary mapped summary of the Holocene pollen data for Northeast China (Ren,

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1994; Ren and Zhang, 1998). The tempo-spatial pattern of past vegetation change that appears from the mapping study indicates the importance of this type of work for investigating possible causes of Holocene environmental changes. The study area of that work, however, is confined to Northeast China which only accounts for less than one fifth of the country's territory. Here we report the reconstructed vegetation based on the pollen maps of China north of 30°N. Following a brief description of data and methods, these newly produced maps and the main features of changes in pollen percentages will be represented. A reconstruction of the Holocene vegetation history in the light of taxa change, forest cover change, and biome evolution will be attempted.

2. Physical environment and human history

The area under study is mainland China north of 30°N, or approximately north of the Yangtze River, excluding a small part north of 52°N and the regions west of the longitude of 85°E. This area has diverse topography, climate conditions, terrestrial biomes, and human made landscapes. The basic environmental features are described here. For more details, refer to Wu (1980), Chang (1981), CAS (1982), Zhao (1986), Zhao and Xie (1988), Zheng and Li (1990), Winkler and Wang (1993), Ding (1993), Zhao (1994), Meyer (1994), and Loewe and Shaughnessy (1999).

2.1. Topography

The study area can be divided into three large landform units (Fig. 1): (1) the eastern lowlands, mainly consisting of the Northeast China Plain (called NE China Plain hereafter), the North China Plain, and the plain of the lower reaches of the Yangtze River (called Yangtze River Plain hereafter). Average altitude of this area is less than 500 m a.s.l.; (2) the middle lower

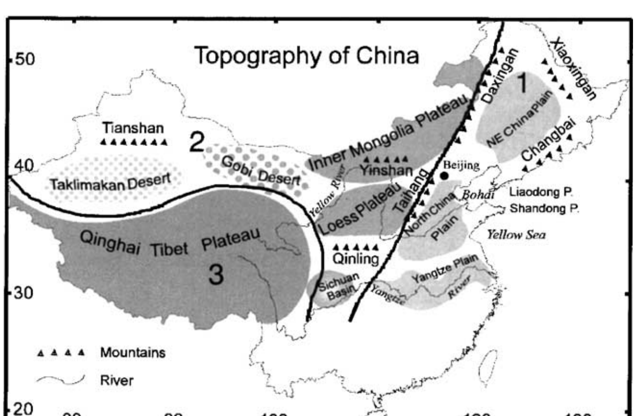

Fig. 1. Main topographical units mentioned in the text.

plateaus and basins including the Inner Mongolian Plateau, the Loess Plateau, and the Sichuan Basin with an average altitude of 1000–2000 m a.s.l.; (3) the western higher plateau and deserts including the Qinghai-Tibet Plateau, the Taklimakan Desert, and the Gobi Desert. The average altitude of the Qinghai-Tibet Plateau reaches more than 4000 m a.s.l.

There exist some mountains and hills within each of the large landform units. In the two eastern landform units, the mountains and hills are usually lower in terms of both absolute and relative elevation, and they therefore do not impose much influence on vegetation distribution. In spite of this, those in arid regions could be very important in the vertical redistribution of energy and water, and possess a potential to affect the vegetation. The Yellow River and the Yangtze River both flow eastward from the Qinghai-Tibet Plateau to the seas through the three landform units. In this paper, the middle and lower reaches of the two rivers refer to the associated drainage areas located in the two eastern landform units. The Middle and Lower Reaches of the Yellow River (thereafter MLRYR) therefore include the Loess Plateau, most of the North China Plain, and a small part of the southern Inner Mongolia Plateau.

2.2. Climate

The climate of the area can also be roughly divided into three large groups: the east monsoon climate, the northwest arid climate, and the alpine climate of the Qinghai-Tibet Plateau. The boundary between the monsoon climate and the arid climate goes approximately along the Daxingan Mts., the Yinshan Mts., and the northwestern rim of the Loess Plateau, and corresponds to the 350 mm isohyet of the total annual precipitation (Fig. 2A). In the east monsoon area, large variation in temperature and precipitation occurs from southeast to northwest (Fig. 2A–C). The Yangtze River basin possesses a relatively warm and moist climate characterized by a mean January temperature of 4°C, a mean July temperature of 28°C, and an annual precipitation of more than 1100 mm, while the northernmost part of Northeast China is usually classified as a cold temperate climate with a mean January temperature well below −28°C, a mean July temperature less than 20°C, and an annual precipitation of about 400 mm (Fig. 2). The largest contrast in precipitation, or wetness, occurs from southeast to northwest, with the southern Inner Mongolia Plateau and the northwestern Loess Plateau actually being reduced to a semiarid zone.

Compared with other regions of the world at the same latitude, precipitation in China's monsoon area is characterized by the largest variability (Ding, 1994). Seasonal variation, for example, is very evident, and the rainfall of the three summer months (JJA) usually accounts for 80% or more of the total annual

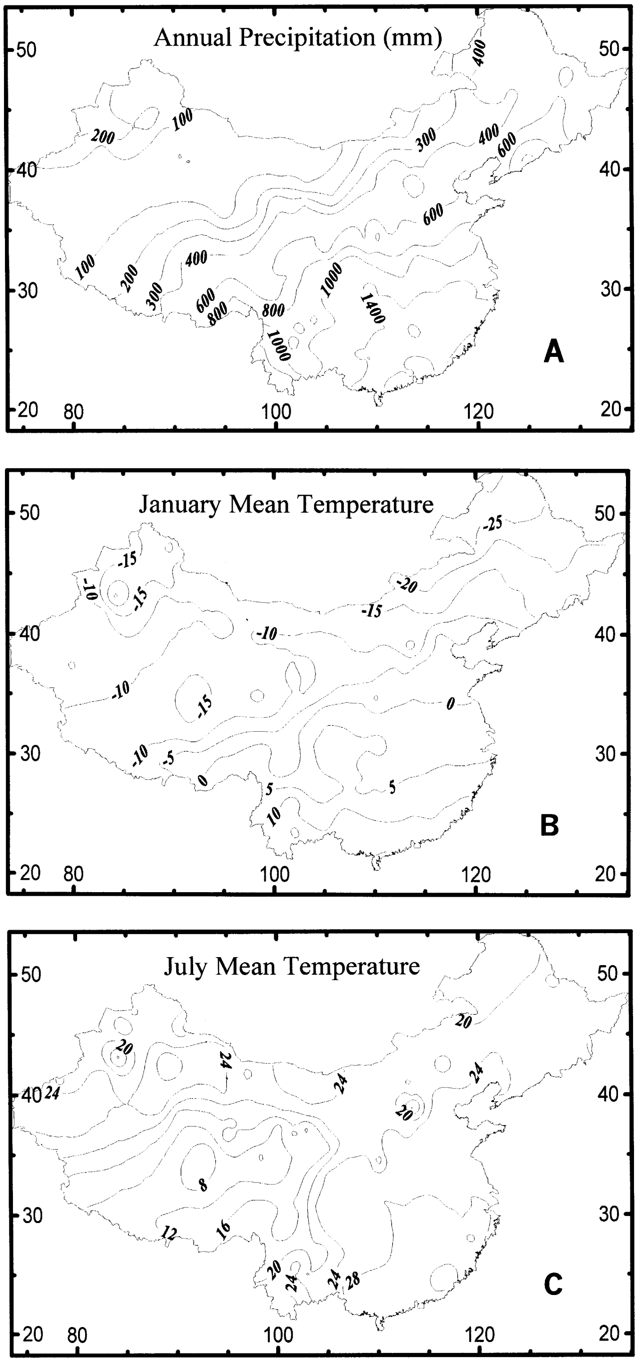

Fig. 2. Modern climate features of mainland China (1961–1990). (A) Total annual precipitation; (B) mean January temperature; (C) mean July temperature.

precipitation in the Northeast and in North China, leaving winter and spring extremely dry (Ren, 1988). Even in the rainy summer, much of the rain falls in a few rainstorms, leading to a relatively low effectiveness of the rainwater for plant growth. The notorious annual variations are illustrated by the frequent presence of severe droughts and floods in the history of the MLRYR and Yangtze River Plain.

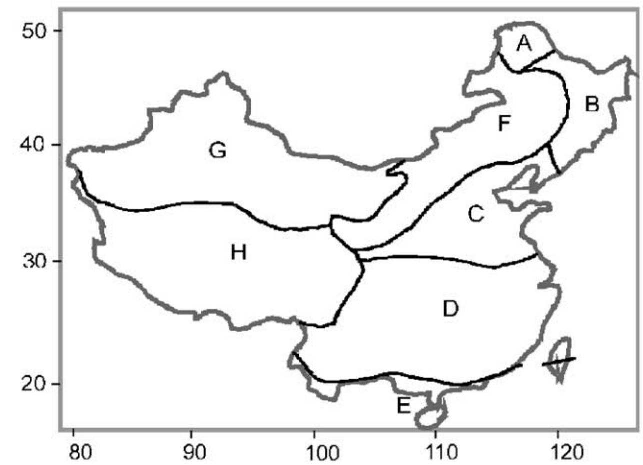

Fig. 3. Modern vegetation regions. A: Cold temperate conifer forest; B: temperate mixed conifer and deciduous forest; C: warm temperate deciduous forest; D: mixed subtropical evergreen and deciduous forest; E: tropical evergreen monsoon rainforest; F: temperate steppe; G: temperate desert; H: alpine steppe and desert. From Wu (1980).

2.3. Vegetation

Eight vegetation types (Fig. 3) were recognized (Wu, 1980). Cold temperate conifer forest (A on Fig. 3) appears in the northernmost part of the Daxingan Mts. and the northern Xiaoxingan Range, with *Larix dahurica* as its dominating species. Other tree species are *Betula platyphylla, B. dahurica, B. ermanii, Picea koraiensis,* and *Quercus mongolica*. Temperate mixed conifer and deciduous forest (B on Fig. 3) develops in the Changbai Mts., the Xiaoxingan Range, and the western pediment belts facing the NE China Plain, in which *Pinus koraiensis* is the dominant species. Other important components include *Abies holophylla, Carpinus cordata, Acer mono, Quercus mongolica, Ulmus propinqua, Fraxinus mandshurica, Juglans mandshurica, Tilia amurensis*, and *Betula platyphylla*. Warm temperate deciduous forest (C on Fig. 3) grows in the southern Northeast China, the Shandong Peninsular, the Taihang Mts., and the southeastern Loess Plateau. Varied species of *Quercus* are common in this biome, and species of *Ulmus, Juglans, Tilia, Carpinus, Acer, Corylus, Populus, Pinus*, and *Betula* are also important components of that forest type.

The southern slope of the Qinling Mts. and the Yangtze River Plain are covered by a subtropical mixed evergreen and deciduous forest (D on Fig. 3). Among the deciduous trees, species of *Quercus* are dominant, such as *Q. acutissima*, *Q. variabilis*, *Q. fabri*, *Q. glandulifera*, *Q. aliena*, and *Q. chienii*. The most common evergreen trees are *Castanopsis sclerophylla* and *Cyclobalanopsis glauca* in this biome, and there are also *Cyclobalanopsis gracilis*, *C. myrisinaefolia*, *Pinus massoniania*, and a few species of evergreen

Quercus. *Pinus armandii, Abies*, and *Betula* can be found in the mountains. The Sichuan Basin and its surrounding regions are mainly covered by an evergreen forest.

A typical temperate steppe occurs in the western NE China Plain, the Inner Mongolian Plateau, and the northwestern Loess Plateau (F on Fig. 3). Its floristic components mainly include the families of Compositae, Gramineae, Chenopodiaceae, and Cyperaceae. A genus commonly found in the steppe is *Artemisia*. Between steppe and forest to the southeast, there is a forest-steppe belt forming a transitional biome. The best-developed forest-steppe appears on the eastern fringe of the NE China Plain, where trees and herbs grow alternately in the different topographical units. Beyond the steppe, a temperate desert is met, which only supports such herbaceous plants as Compositae, Gramineae, Fabaceae, Brassicaceae, and Chenopodiaceae (G on Fig. 3). Species of Chenopodiaceae achieve a maximum development in this biome. *Artemisia* abundance is also high. Within the Taklimakan Desert and the Gobi Desert, even herbaceous plants are rarely found. Another distinctive vegetation region in western China is the Qinghai-Tibet Plateau which is mainly covered by alpine steppe and alpine desert, with various herbaceous taxa as the dominant components (H on Fig. 3). In eastern and southeastern parts of the plateau, however, arboreal taxa achieve unexpected development in mountainous valleys. Most frequently found trees are *Picea* and *Abies* in the alpine valley forest. Other important trees are species of the genera *Pinus*, *Larix*, *Betula*, and *Quercus*.

2.4. Human activity history

China has a long history of agriculture and civilization. Recent archaeological excavation reveals a Neolithic agriculture phase at Jiahu in mid-Henan Province (in the MLRYR) dated to 7700–9000 cal yr BP (Zhang et al., 1999). The Yangshao Culture, which was widely distributed in the MLRYR (more than a thousand archaeological sites have been found so far) during 4500–6500 cal yr BP, was a typical agricultural community (Tan, 1982; An, 1991; Meyer, 1994; Loewe and Shaughnessy, 1999). Since 2000 BC, the ancient political and economic center of China had long been in the MLRYR. From there, population spread, and technology diffused outward the surrounding regions for much of the historical time. The last migration wave started about 500 years ago, leading to the settlement of such regions as northern Xinjiang and the central and northern Northeast China. At present, the rain-fed agriculture spreads wherever it can be practiced in the country.

3. Data and methods

3.1. Data sources and sites

Data and methods for drawing pollen maps are basically consistent with those used by Ren and Zhang (1998). We expanded the Holocene pollen database to include additional profiles in the regions outside Northeast China, but data published after April 1998 was not available at the beginning of this work (e.g. Tang et al., 1998). Pollen percentage values were mostly digitized from the published pollen diagrams, with a few from master or doctoral dissertations. In choosing the pollen sites and values, we took into consideration the problems with the sediment type, the relative elevation of the profile, the sampling interval or time resolution, and the radiocarbon dating control.

Principally we preferred to use data obtained from lake sediment or peat samples. Data from other sediment layers, if necessary, were chosen on an exceptional basis. Pollen mapping demands that there should not be much altitude difference among nearby situated sites. Therefore, we decided usually not to choose pollen profiles with large altitude differences between the nearby sites. Even so, we still found that data from the two profiles on the eastern Yinshan Mts. may result in some deviation behavior of isopolls. A few sites from the relatively higher mountains surrounding the Sichuan Basin were adopted due to the general lack of pollen data, but once more, they may lead to the same problems.

In order to ensure better precision and at the same time to include pollen sites sufficient for the preliminary study, we set the lowest time resolution criteria of about 600 radiocarbon years for the average sampling interval. In a few cases where poor data coverage was met, sites were included with a time resolution of up to 1000 years. All of those data without radiocarbon dates on profiles in situ were omitted (Ren, 1994; Ren and Zhang, 1998). In addition, it was found that radiocarbon dates obtained from lacustrine sediments of the Inner Mongolia Plateau and Qinghai-Tibet Plateau are generally 1000–2000 years older than expected probably due to a residuum effect (Ren, 1998). Further research is needed to verify that effect and to provide correcting methods, and so far we are not able to take this problem into account. Dates used here are given in un-calibrated ^{14}C years if not specified.

Finally but by no means less important, the sample processing and pollen counting procedures in a few laboratories might not be meeting the standards set in most of the palynological laboratories worldwide. Systematic correlation analysis has not been carried out up to now. A preliminary comparison shows, however, that the error is significant for some taxa, and pollen grains of a few taxa that exist in the sample sediments have not been found using the sub-standard procedures (Shi, personal communication). It seems that some taxa, obviously *Ulmus* and Gramineae, have been underestimated in pollen counting, and taxa such as *Pinus* and *Artemisia* have been overestimated, though the proportion of arboreal and herbaceous pollen types remains approximately unchanged.

A data set of 142 pollen sites was developed (Table 1). The data sites for each of the fixed time slices are less than the total sites chosen because data values for some time levels may not be used any more due to the quality problems. Figs. 4 and 5 give distributions of all data sites used and of each of the selected time slices. Regions with better data coverage include eastern Northeast China, the North China Plain, the southeastern Loess Plateau, the Yangtze River Plain, and the easternmost Qinghai-Tibet Plateau. Much of the Qinghai-Tibet Plateau and Inner Mongolia Plateau, the entire northwestern deserts, the eastern Loess Plateau, and the Sichuan Basin are poorly represented.

3.2. Methods

Ten taxa were selected for mapping. They are *Picea/Abies*, *Betula*, *Pinus*, *Quercus*, *Ulmus*, total arboreal pollen (AP), *Artemisia*, Chenopodiaceae, Gramineae and Compositae (the latter two not presented here) respectively. These taxa represent the most common families or genera in the study area, and they are usually indicative of main biomes or biogeographical units. *Picea* and *Abies* are combined because they are usually not given separately in the originally published reports prior to 1990 (Ren and Zhang, 1998). This is regrettable because their Holocene history and spreading peculiarities cannot be assumed to be identical at all. Data values digitized from the original diagrams were recalculated using a common sum, which is defined as the total sum of pollen grains from terrestrial plants excluding Cyperaceae. This process is necessary because different sums were used for calculating pollen percentages in the published diagrams. Six mapping time-slices are 10, 8, 6, 4, 2 and 0 ka BP, respectively. The time slices were chosen in 2000-year rather than in a finer interval partly due to the generally lower time resolution in the pollen profiles available. For more general description about mapping methods, see Bernabo and Webb (1977), Huntley and Birks (1983), Webb (1988), Huntley (1990a, b), Anderson and Brubaker (1994), and Ren and Zhang (1998).

We use the software of Surfer Version 5.01 for Windows to automatically generate the pollen maps. Intervals of isopolls were defined as 5% for all the taxa except for arboreal, for which the interval is 10%. Medium smoothing was performed for contours, and the grid size chosen is 160 rows by 300 columns. Problems may exist, of course, when using the computer software to automatically produce isopolls in case of inefficient data coverage. A major problem is that it often assigns higher-biased values to the data-scarce regions. An example is from the biased isopolls of *Picea/Abies* at 8 ka BP in the central Qinghai-Tibet Plateau and eastern Taklimakan Desert. Incorrect percentage values, ranging from 0 to 5, are shown for the regions actually without any *Picea/Abies* trees. The same problem can be found in the nearby plains or plateaus around the mountains in the arid and semi-arid zones. The computer cannot identify the region where zero is not given just because the data is not available. It is evident, however, that such a problem appears mainly due to the scarce of the data sites rather than the software used and the methods designed. If the data sites are sufficient enough, the error could be much less significant. This condition will surely happen in the future. Of course, caution has to be drawn when explaining the mapping outcomes in such regions as the central Qinghai-Tibet Plateau and eastern Taklimakan Desert.

A total series of 70 pollen maps were produced, of which 60 are isopoll maps, and 10 are isochrone maps (not shown here). To save space, the isopoll maps were compressed in size and were incorporated to 10 figures (Fig. 7–14) according to taxa.

4. Pollen maps and vegetation of modern time

The ability of isopolls to reflect modern plant taxa distribution has been examined. This examination indicates the extent to which we have confidence in the pollen maps and the vegetation reconstruction based on them.

Modern pollen data comes totally from the core top samples. This procedure can guarantee the consistency of the analysis methods and the sampling locations, and enable a comparison between the modern pollen and vegetation more relevant to the reconstruction of the past vegetation. Strictly speaking, however, core top values are not of modern data. What we called the modern data here are actually pollen values occurring at any time from 0.3 ka BP to 0 ka. In addition, the number of modern data sites is the second least in all the time slices selected (Fig. 5). This condition occurs because lacustrine sedimentation and peat growth usually stopped as lakes and bogs disappeared during the late Holocene, especially in the North China Plain. In spite of these, a good correspondence between the modern isopolls and plant distribution can be found. As examples, *Quercus* and *Picea/Abies* are illustrated as follows.

Fig. 6 gives the distribution of modern *Picea/Abies* and *Quercus*. Growth of *Picea/Abies* is largely concentrated in two regions: the eastern part of the

Table 1
Pollen data sites used for mapping in China north of the Yangtze River[a]

No.	Site	Province	Longi.	Lati.	Dates	Times used	Authors Pub. time
1	Qianjin	Heilongjia.	128.41	48.25	1	0–4	Yin (1984)
2	Tangbei	Heilongjia.	129.67	48.35	3	0–4	Xia (1996)
3	Tuqiang	Heilongjia.	122.8	52.23	2	0–2	Xia (1996)
4	Jiajihe	Heilongjia.	128.07	48.7	2	0–2	Yin (1984)
5	Tanghongling	Heilongjia.	129.22	48.5	3	0–6	Yin (1984)
6	Farm853	Heilongjia.	132.83	46.7	1	4,6	Ye et al. (1983)
7	Bielahonghe	Heilongjia.	134	47.5	3	1–6	Xia (1988)
8	Qindeli	Heilongjia.	133.25	48	5	0–10	Xia (1988)
9	Chuangye	Heilongjia.	134.25	48.17	3	0–10	Xia (1988)
10	Qinghe	Heilongjia.	132.83	46.33	1	0–2	Xia (1988)
11	Yangmuxiang	Heilongjia.	132.33	45.67	1	0–2	Xia (1988)
12	Shenjiadian	Heilongjia.	130.67	46.67	3	0–2	Xia (1988)
13	Laodaomiao	Heilongjia.	129.58	45	1	2,4	Xiao and Sun (1987)
14	Hailangxiang	Heilongjia.	129.2	44.33	1	0–4	Xiao and Sun (1987)
15	Harbin	Heilongjia.	126.67	45.83	2	2	Liu et al. (1985)
16	Hongsheng	Heilongjia.	123.67	46.5	2	0, 4–6	Qiu et al. (1992)
17	Wenggenshan	Heilongjia.	123.75	46.33	4	0,4	Ye et al. (1991)
18	Bolehu	Jilin	124.75	44.83	5	2–6	Xia et al. (1993)
19	Xiaonan	Jilin	125.33	43.77	1	6	Wang and Xia (1988)
20	Sanxianpu	Jilin	123.83	44.3	2	2–4	Wang and Xia (1988)
21	Zhoujia1	Jilin	126.58	44.75	1	4–10	Wang and Xia (1988)
22	Zhoujia2	Jilin	126.58	44.75	4	6	Sun et al. (1980)
23	Kaitong	Jilin	123	44.8	1	0,8	Qiu et al. (1992)
24	Sheling	Jilin	125.5	43.7	1	0	Qiu et al. (1981)
25	Liangshuixiang	Jilin	126.1	42.2	2	0,8	Wang and Xia (1990)
26	Sandaomiao	Jilin	126.38	42.15	?	0–10	Yuan and Sun (1990)
27	Gushantun	Jilin	126	42.23	4	0–10	Liu (1989)
28	Dadianzi	Jilin	126.37	42.33	4	0–10	Sun and Yuan (1990)
29	Harbaling	Jilin	128.67	43.28	1	0–2	Peat Group (1983)
30	Qianwatun	Liaoning	122.83	39.8	2	2–6	Chen et al. (1977)
31	Dagushan	Liaoning	123.63	39.85	3	4–8	Chen et al. (1977)
32	Qianyang	Liaoning	124.2	39.96	2	2–8	Chen et al. (1977)
33	Pulandian	Liaoning	121.97	39.43	4	4–10	Chen et al. (1977)
34	Bachagou	Liaoning	121.25	39.55	1	2	Chen et al. (1977)
35	Lianhuashan	Liaoning	121.5	39.42	9	6–10	Zhao (1989)
36	Paoya	Liaoning	121.68	39.67	11	2–10	Zhao (1989)
37	Xinbarhudong	Inner Mon.	118.28	48.22	2	2–4	Xia (1993)
38	Ewenkeqi	Inner Mon.	119.83	49	1	0,2	Xia (1993)
39	Hailar	Inner Mon.	119.5	49.25	3	4	Xia (1993)
40	Zhalanor	Inner Mon.	117.6	49.42	6	4–10	Yang et al. (1995)
41	Wulunguqi	Xinjiang	87.33	47	2	2–6	Yang et al. (1995)
42	Gonghelai	Inner Mon.	123.13	42.9	3	2–6	Xia et al. (1993)
43	Maili	Inner Mon.	122.88	42.87	7	0–4	Ren (1994)
44	Jiaolaihe	Inner Mon.	120.75	42.92	6	0,2,10,12	Han (1992)
45	Hetun	Inner Mon.	120.67	42.67	1	8–10	Wang (1990)
46	Wulanaodu	Inner Mon.	119.22	42.93	2	8	Wu and Zheng (1992)
47	Shaolanghe	Inner Mon.	119	42.97	1	2	Wu and Zheng (1992)
48	Wudan	Inner Mon.	119	42.97	1	2	Jiang (1992)
49	Dadianzi	Inner Mon.	119.5	42.5	2	4	Kong et al. (1991)
50	Reshuitang	Inner Mon.	119.18	42.17	2	6	Jiang (1992)
51	Dalainor	Inner Mon.	116.63	43.25	4	2–10	Li et al. (1990)
52	Dishaogou	Inner Mon.	108.78	38.18	5	6,10	Sun et al. (1991)
53	Liangcheng	Inner Mon.	112.75	40.53	1	10	Shi (1991)
54	Daihai	Inner Mon.	112.58	40.52	2	6–10	Wang and Feng (1991)
55	Bataigou	Inner Mon.	113.5	40.83	2	4–8	Jiang (1992)
56	Huangqihai	Inner Mon.	113.5	40.83	4	6–8	Liu and Li (1992)
57	Gonggouyan	Inner Mon.	112.52	40.45	2	6–8	Zhou et al. (1982)
58	Luweichang	Inner Mon.	112.5	40.6	1	2	Liu and Li (1992)
59	Dahewan	Inner Mon.	113.28	40.8	1	8	Jiang (1992)
60	Bojianghaizi	Inner Mon.	109.83	39.83	1	0	Shi (1991)
61	baisuhaizi	Inner Mon.	112.52	41.12	8	2–10	Song (1992)
62	Diaojiaohaizi	Inner Mon.	112.35	41.3	4	2–10	Song et al. (1996)

Table 1 (*continued*)

No.	Site	Province	Longi.	Lati.	Dates	Times used	Authors Pub. time
63	Huitengliang	Inner Mon.	112.52	41.12	5	2–6	Cui et al. (1993)
64	Pingdingcun	Hebei	114.33	40.14	4	6–8	Jiang (1988)
65	Nanzhuangtou	Hebei	115.5	39.2	7	10	Yuan et al. (1991)
66	Daziying	Hebei	119	39.2	2	8–10	Li and Liang (1985)
67	Maohebei	Hebei	119.2	39.51	4	4–10	Li and Liang (1985)
68	Mengcun	Hebei	117.17	38.08	2	6–8	Xu et al. (1993)
69	Yangerzhuang	Hebei	117.5	38.33	3	2–10	Xu et al. (1993)
70	Baiyangdian	Hebei	116	38.6	3	2–10	Xu et al. (1988)
71	Xinlitun	Beijing	116.22	40	1	2	Zhou (1984)
72	Gaolizhang	Beijing	116.67	40.04	2	8–10	Zhang et al. (1981)
73	Kunminghu	Beijing	116.27	39.95	4	2	Zhou et al. (1993)
74	Kunminghu2	Beijing	116.27	39.95	3	0–4	Huang (1996)
75	Taoshan	Beijing	116.67	40.47	2	4–6	Zhang et al. (1981)
76	Dawangzhuang	Beijing	116	40.5	3	6–8	Kong et al. (1982)
77	Xiwuliying	Beijing	116	40.53	3	2–6	Kong et al. (1982)
78	Fenzhuang	Beijing	116	39.66	5	10	Zhang et al. (1981)
79	Donggaocun	Beijing	117.1	40.23	1	2	Wang (1991)
80	Yueyawuan	Shandong	120.7	37.98	4	4–6	Zhao (1992)
81	Xiaohai	Shandong	122.4	37.37	3	0–4	Zhao (1992)
82	Beiwangxu	Shandong	120.6	37.72	2	2–6	Zhao (1992)
83	Laizhouwan	Shandong	119.83	37.18	3	2–6	Lu (1989)
84	Huanghe1	Shandong	115.6	36.3	2	2–6	Xu et al. (1991)
85	Huanghe2	Shandong	116.67	37.04	3	6–8	Xu et al. (1991)
86	Dingziwan	Shandong	120.84	36.61	2	2–10	Han and Meng (1986)
87	Huanghe3	Shandong	117.75	37.5	4	2–4,10	Xu et al. (1991)
88	Jiaozhouwan	Shandong	120.2	36.2	6	6,8	Wang and Li (1983)
89	Gaojiawuzi	Shandong	120.18	36.25	1	0	Han and Meng (1986)
90	Jiaozhou2	Shandong	120.3	36.07	2	10	Wang (1987)
91	Wangguantun	Shanxi	113.7	40.22	2	2–6	Kong and Du (1992)
92	Dahecun	Henan	113.75	34.84	2	2–10	Yan et al. (1986)
93	Gaojiacun	Shannxi	110.14	39.07	6	6–8	Chen et al. (1993)
94	Yaocun	Shannxi	109.18	34.75	2	2–10	Sun et al. (1991)
95	Huangcun	Shannxi	109.13	34.84	1	6	Sun et al. (1991)
96	Macun	Shannxi	109.09	34.68	2	8–10	Sun et al. (1991)
97	Xian	Shannxi	109.07	34.34	2	4–8	Sun et al. (1991)
98	Dongcheng	Shannxi	109.42	34.09	4	4–8	Sun et al. (1991)
99	Beiwangcun	Shannxi	109.53	34.37	13	8–10	Sun et al. (1991)
100	Yangguo	Shannxi	109.5	34.4	6	8–10	Sun et al. (1993)
101	Shuidonggou	Ningxia	106.35	38.07	2	6–8	Sun et al. (1991)
102	Maxianshan	Gansu	104	35.75	4	0–8	Wang et al. (1991)
103	Lanzhou	Gansu	103.82	36.13	6	2–8	Wang et al. (1991)
104	Zairjiapugai	Gansu	102.38	34.5	1	6–8	Yin (1991)
105	Manasihu	Xinjiang	86	45.77	7	2–10	Sun et al. (1994)
106	Aibihu	Xinjiang	83	45.1	4	2–10	Wen and Zheng (1988)
107	Hetian	Xinjiang	79.97	37.18	1	6–8	Wen and Qiao (1990)
108	Qinghaihu	Qinghai	100.33	36.83	5	0–10	Du et al. (1989)
109	Maduo	Qinghai	98.52	34.92	2	0–10	Zhang et al. (1996)
110	Hongyuan	Sichuan	102.62	32.83	5	0–10	Wang (1987)
111	Waqie	Sichuan	102.6	33.2	2	0–8	Yin et al. (1991)
112	Wasong	Sichuan	103.09	33.2	9	6–10	Wang et al. (1996)
113	Sumxi Co	Xizang	80.3	34.53	6	4–10	Campo and Gasse (1993a,b)
114	Dajiuhu	Hubei	110.09	31.56	3	0–10	Chou and Li (1993)
115	Nanping	Hubei	108.74	30.4	5	4–10	Gao (1988)
116	Longquanhu	Hubei	112.47	30.95	7	0–10	Liu (1991)
117	Yujiatan	Anhui	117.35	32.94	3	2–8	Li and Chao (1996)
118	Xujiagang	Anhui	117.32	33	2	6–10	Jin (1990)
119	Huangkou	Anhui	116.75	34.33	2	6	Tang et al. (1991)
120	Qingfeng	Jiangsu	119.91	33.48	6	2–10	Tang and Shen (1992)
121	Qingfeng2	Jiangsu	119.92	33.48	4	4–10	Wu et al. (1990)
122	Jinhu	Jiangsu	119.67	33.5	2	0,6	Wu et al. (1996)
123	Sanchakou	Jiangsu	119.8	33.5	2	0–10	Wu et al. (1996)
124	Qingdun	Jiangsu	120.33	32.61	?	4–6	Huang and Liang (1984)
125	Wanbei	Jiangsu	118.8	34.18	1	6	Tang and Shen (1992)

Table 1 (*continued*)

No.	Site	Province	Longi.	Lati.	Dates	Times used	Authors Pub. time
126	Dunde	Qinghai	96.4	38.1	Ice core	0–10	Liu et al. (1998)
127	Guchenghu	Jiangsu	118.9	31.27	6	6–10	Yang et al. (1996)
128	Zhenjiang	Jiangsu	119.43	32.2	3	10	Liu and Chang (1996)
129	Zhenjiang2	Jiangsu	119.43	32.18	4	8–10	Yang and Chen (1988)
130	Nongjixueyuan	Jiangsu	119.5	32.13	4	6–10	Xu et al. (1987)
131	Changshan	Jiangsu	120.26	31.92	3	2–8	Xu et al. (1987)
132	Xitaihu	Jiangsu	120.5	31.5	5	0–10	Xu et al. (1996)
133	Dongtaihu	Jiangsu	120.6	31.5	7	0–6	Xu et al. (1996)
134	Dongmenzhen	Jiangsu	118.95	32.08	4	8–10	Xu et al. (1987)
135	Qidong	Jiangsu	121.65	31.87	8	2–10	Liu et al. (1992)
136	Kakitu	Qinghai	96.47	38.4	2	8,10	Beug (1987)
137	Hongyuan	Sichuan	102.48	32.7	7	2–10	Thelaus (1992)
138	Ximencuo	Xizang	101.1	33.4	2	0–6	Schluetz (1999)
139	Kekehe	Xizang	101.01	33.13	2	0–4	Schluetz (1999)
140	Becken	Xizang	101.4	33.27	2	2–4	Schluetz (1999)
141	Lerzha	Xizang	101.03	33.35	3	0–10	Schluetz (1999)
142	Bangong	Xizang	79	33.67	?	0–8	Van Campo et al. (1996)

[a]Note: Longi.: Longitude; Lati.: Latitude; Pub. time: publishing time; Heilongjia.: Heilongjiang; Inner Mon.: Inner Mongolia.

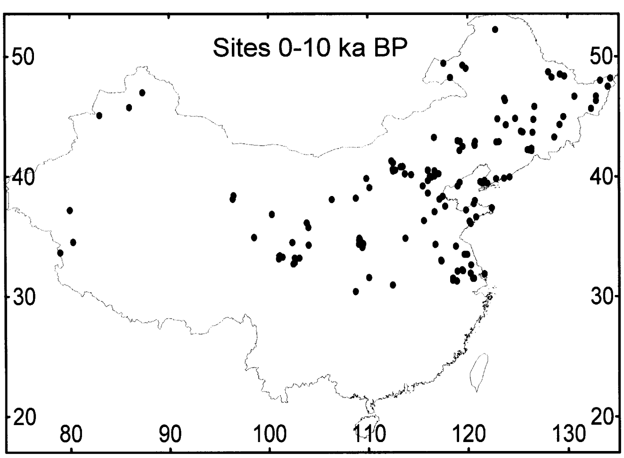

Fig. 4. Distribution of all pollen data sites used in the study.

Qinghai-Tibet Plateau and the Northeast China mountains (Fig. 6A). *A. nephrolepis*, *P. koraiensis*, and *P. jezoensis* grows in the Xiaoxingan Range, the Daxingan Mts., and the Changbai Mts. of Northeast China, and *A. faxoniana*, *A. ernestii*, *A. squamata*, *A. fabri*, *A. georgi*, *A. delavay*, *P. likiangensis*, *P. complanata*, and *P. purpurea* develop in the eastern part of the Qinghai-Tibet Plateau. In the other regions, such as the Tianshan Mts., the Qinling Mts. and the Taihang Mts., *Picea/Abies* appears fragmentarily only at high elevations.

Evident correspondence is found between the modern *Picea/Abies* distribution regions (Fig. 6A) and the high value centers of *Picea/Abies* percentages (Fig. 7). Centers with percentages above 5% are located in the eastern Qinghai-Tibet Plateau, the Daxingan Mts.—Xiaoxingan Range, and the Changbai Mts. These regions, in particular the first two, are just the actual distribution centers of *Picea/Abies*. The good correspondence shows that the pollen maps well reflect modern vegetation, and they could be confidently used to reconstruct past vegetation changes.

In case of *Quercus*, the northwestern limit of its distribution is roughly consistent with the isohyet of 400 mm annual precipitation, but it generally concentrates in more moist regions like the eastern Northeast China and the Yangtze River Plain. In the Liaodong and Shandong Peninsulas, for example, various species of *Quercus* dominate the temperate deciduous forests which are at present shrinking in size. Species most frequently found are *Q. mongolica, Q. aliena*, *Q. variabilis*, *Q. liaotungensis*, and *Q. dentata*. The Yangtze River Plain, on the other hand, possesses both deciduous and evergreen species of *Quercus*, with deciduous oak species being more common.

Zero isopleth of *Quercus* is approximately in line with the distribution limit of modern *Quercus* east of the 100th meridian (Figs. 6B and 10). In the west, the lack of modern data does not encourage such a comparison. Areas with *Quercus* pollen above 10%, which mostly are in the Changbai Mts. and in the Yangtze River Plain, could be thought of as the concentrated distribution regions. However, another concentrated distribution region of the Liaodong and Shandong Peninsulas is not reflected in the modern pollen map. The most probable cause for that difference is the large impact of human activities which inhibit *Quercus* to naturally grow. In fact, mature *Quercus* trees can hardly be seen nowadays on the peninsulas, and they often grow as bushes on the hills. The mismatch, therefore, are not due to the problem of the pollen maps. Rather, they may have been caused by the modern vegetation map, which give the potential, rather than actual vegetation distribution.

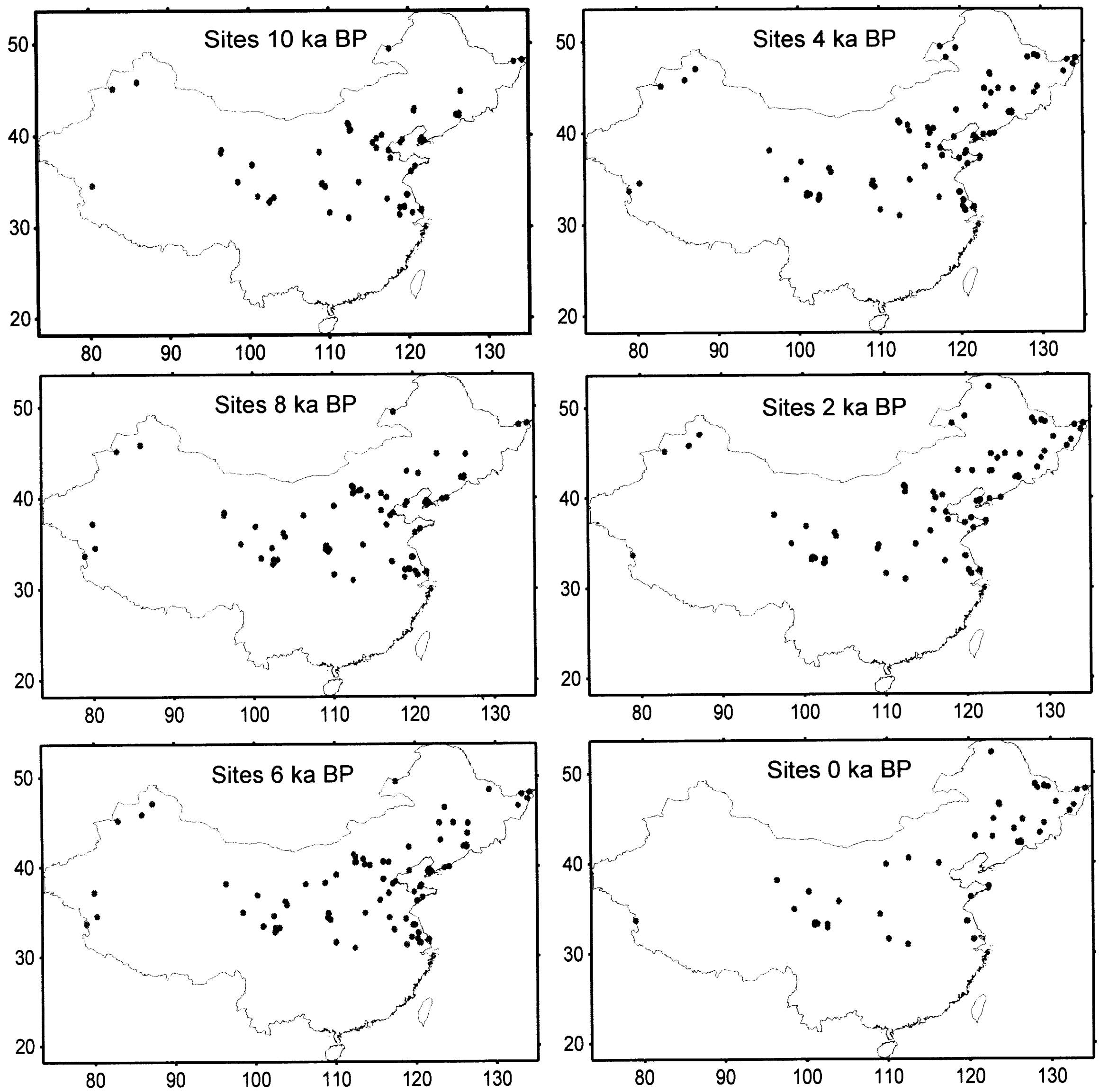

Fig. 5. Distribution of pollen data sites for each of the selected mapping time slices (10, 8, 6, 4, 2 and 0 ka BP respectively)

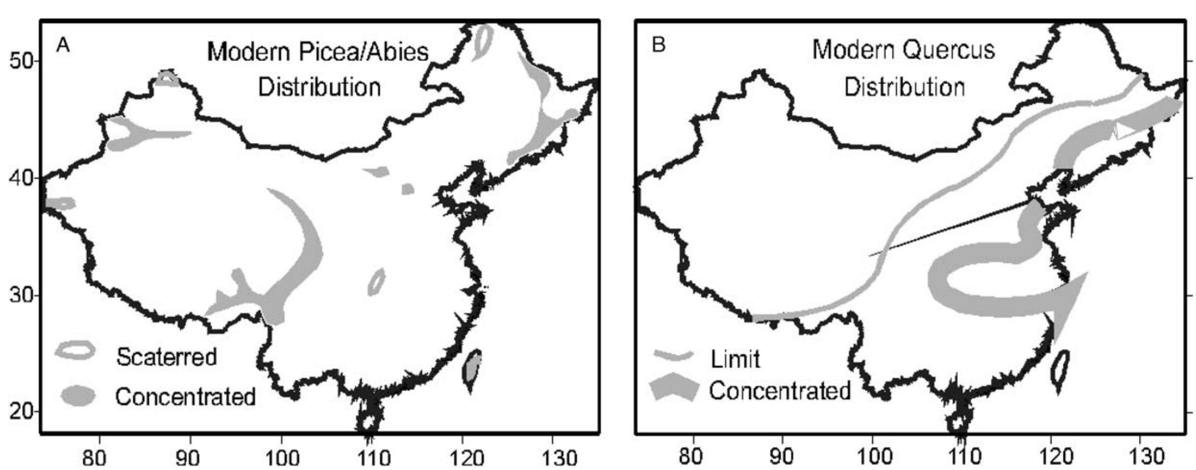

Fig. 6. Modern distribution of *Picea/Abies* (A) and *Quercus* (B) in the study area. (A) modified from Shi (1994), and (B) modified from Wu (1980).

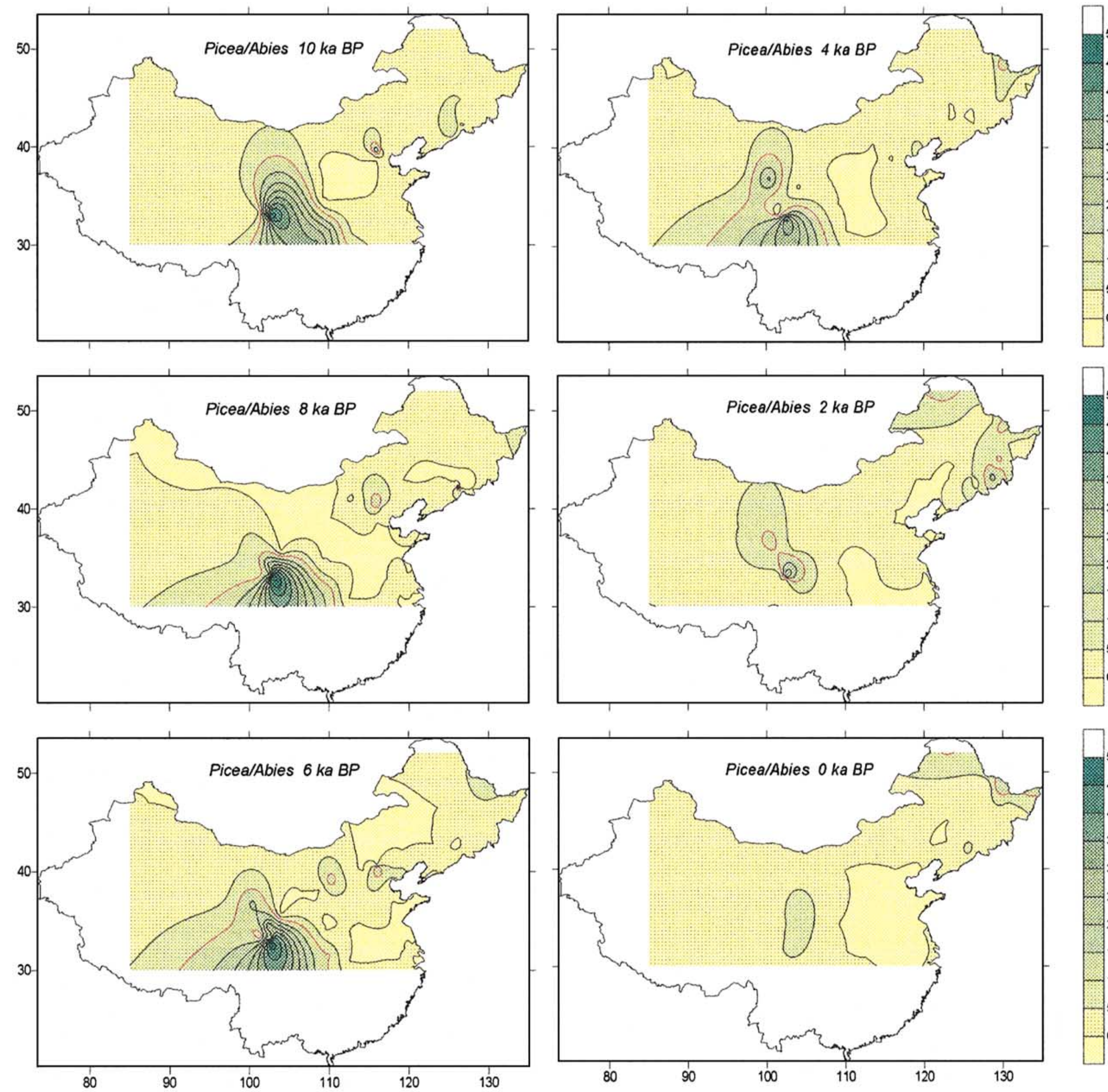

Fig. 7. Isopoll maps of *Picea/Abies* for 10, 8, 6, 4, 2 and 0 ka BP in China north of the 30th parallel. Interval of isopolls is 5 percentages. Pink lines on maps indicate 10% isopoll.

5. Pollen maps of the Holocene

5.1. *Picea/Abies*

The largest pollen deposition center had long been located around the eastern rim of the Qinghai-Tibet Plateau until 4 ka BP, though it seems to have moved slightly to the west during the early stages (10–6 ka BP) and then to the north (6–4 ka BP) (Fig. 7). For 10 ka BP, values of 0–5% are indicated for most arid areas, which is due to long distance transport, if not to the drawback of the computer software when working with data scarce regions. A vast area displays percentages above 10%, and a maximum could be more than 40% from 10 to 6 ka BP. A tremendous drop in the percentages has occurred since 4 ka BP. Now it has become the secondary center of distribution after the northern mountains of Northeast China, and nowhere does the pollen percentages exceed 10%.

The second area with a remarkable change is in Northeast China. In the early Holocene, very low pollen deposition was recorded, with tiny centers respectively in the Changbai Mts. (8 ka BP) and Xiaoxingan Range (6 ka BP). From 4 ka BP to 2 ka BP, however, the percentages evidently increased, leading to regions in the Changbai Mts., Xiaoxingan Range, and the Daxingan Mts. surrounded by 10% isopoll for the first time. After 2 ka BP, pollen values in the Xiaoxingan Range and the Daxingan Mts. have remained more or less stable, but the center of the Changbai Mts. has disappeared. It also seems notable that the pollen maximum centers migrated from south to north, and they anchored in the northern mountains at 0 ka BP.

In the period 10–6 ka BP, there were a few centers of less importance in the mountains of northern China, a most marked one in the northern Taihang Mts., which lasted for at least 6000 years. All of them disappeared from 4 to 0 ka BP.

5.2. *Pinus*

At 10 ka BP, high percentages were centered in the North China Plain and Yinshan Mts. (Fig. 8). *Pinus* seems to experience a slight drop from 10 to 8 ka BP everywhere except for the eastern Qinghai-Tibet Plateau and the delta of the Yangtze River, where two tiny high value centers came out with the highest values of more than 25%. The center previously situated in the Yinshan Mts. almost disappeared by 8 ka BP, and the extent of the area with percentages of less than 5% maximized at 8 ka BP, stretching from the northwestern deserts throughout the Loess Plateau to the NE China Plain.

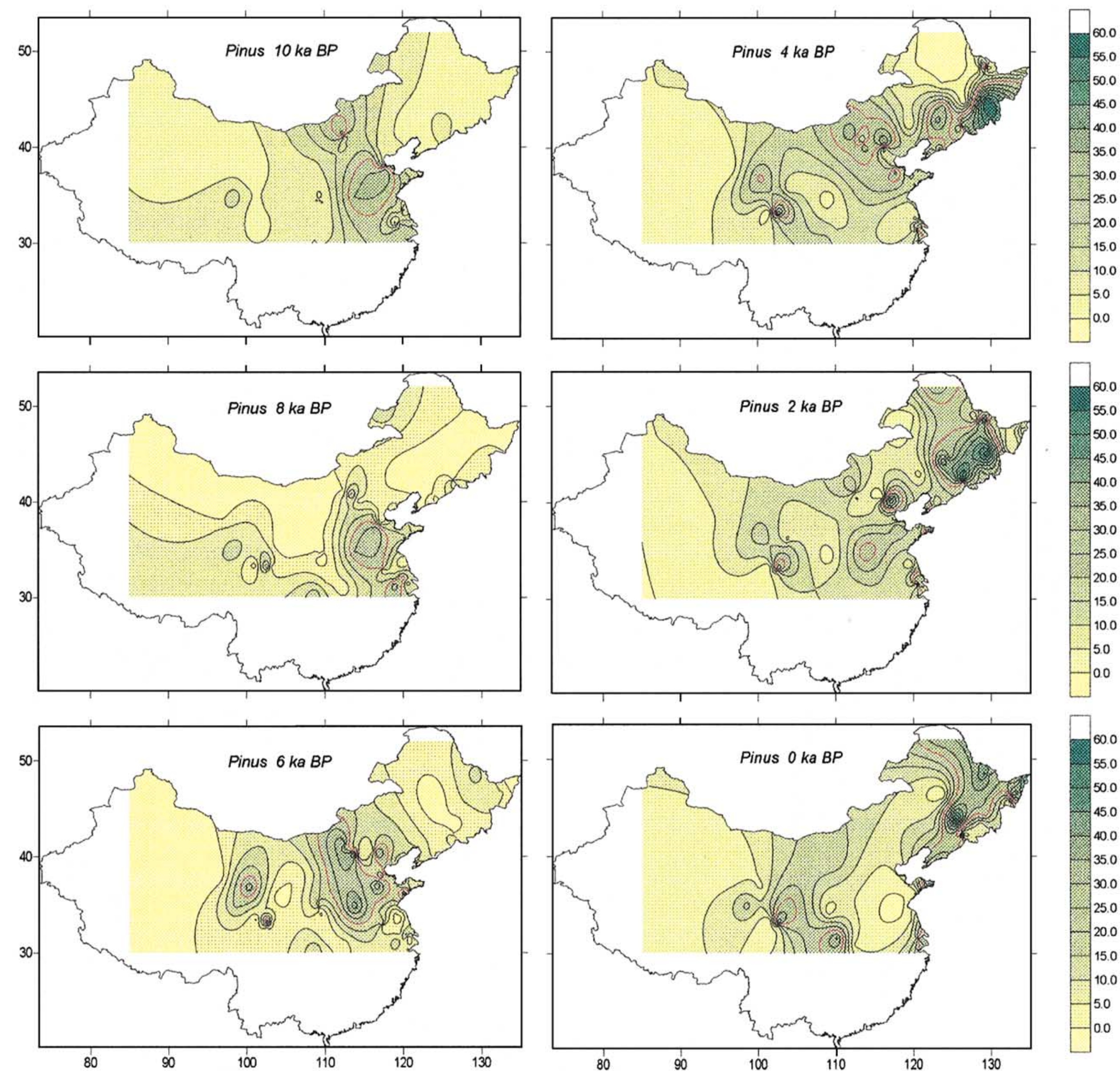

Fig. 8. Isopoll maps of *Pinus* for 10, 8, 6, 4, 2 and 0 ka BP in China north of the 30th parallel. Interval of isopolls is 5 percentages. Pink lines indicate 25% isopoll.

For Northeast China, the earliest two time slices record a Holocene minimum.

Some major changes happened afterward. Firstly, the isopoll of 25% in the North China Plain, and therefore the extent of the high value center, expanded toward the north and west to include parts of the southern Inner Mongolia Plateau and eastern Loess Plateau from 8 to 6 ka BP. This enlarged center then began to split and shrink. At 4 ka BP, the decrease in *Pinus* first occurred in the North China Plain and in the Loess Plateau, followed by the southern Inner Mongolia Plateau at 2 ka BP. Today, nowhere in the three regions are the values higher than 15%, and a large area from the southern North China Plain to the northern Yangtze River Plain has percentages below 5%.

Second notable change after 8 ka BP was in the eastern Qinghai-Tibet Plateau. The tiny maximum center that appeared at 8 ka BP remained stable or increased during the following periods, and the percentages in the northeastern part of the plateau rose at 6 ka BP though they dropped after that and returned to the level of early Holocene. The eastern Qinghai-Tibet Plateau as a whole displays the highest values in *Pinus* percentages at 4 ka BP.

Finally, Northeast China experienced radical changes during the Holocene. Percentages had been very low until 4 ka BP when a swift rise occurred in the eastern regions, most evidently in the Liaodong Peninsula and Changbai Mts. Since then, Northeast China has maintained the largest center, though there has been a slight drop in a few regions. Values over 40% occurred in the northeastern Changbai Mts. at 4 ka BP, and they appeared in the Changbai Mts., eastern NE China Plain, and Xiaoxingan Range after that. It is also evident that the increase in the northern part seems to lag behind that in central and southern regions.

5.3. *Betula*

Most evident changes occurred between 10 and 8 ka BP and between 8 and 6 ka BP in Northeast China (Fig. 9). At 10 ka BP, significantly higher percentages were recorded for almost all sites, and a maximum of more than 30% occurred in the southeastern Changbai Mts. However, the time slice of 8 ka BP witnesses the lowest values in the Holocene, and the isopoll of 10% merely appears in the southeastern part. *Betula* increased once again at 6 and 4 ka BP, and the maximum center became more restricted to the north. A distinct maximum center developed in the Xiaoxingan Range at 4 ka BP, with values well above 30%. During the last 2000 years, however, the center was somewhat weaker.

Outside Northeast China higher percentages can be seen in the Yinshan Mts., the eastern Qinghai-Tibet Plateau, mountainous region between the Qinling Mts., the Sichuan Basin, the Yangtze River Plain, and the Shandong Peninsula. These secondary centers began to be obvious at 8 ka BP, more so for 8 and 6 ka BP, and then gradually weakened. The most marked decrease has been found for the Yinshan Mts. and the Shandong Peninsula where the high centers came to an end. It is interesting to note that, in the early Holocene, when the percentages at 8 ka BP were at the minimum of the Holocene in Northeast China, the high value centers elsewhere were being formed.

5.4. *Quercus*

Quercus pollen is largely distributed in the Yangtze River Plain, the eastern Northeast China, and the coastal regions during the Holocene (Fig. 10). At 10 ka BP, three regions with percentages above 10% were found for the Changbai Mts., the Shandong Peninsula, and the Yangtze River Plain. Western Liaodong Peninsula, northern North China Plain, and northern Taihang Mts. also had higher percentages in the early Holocene.

The high center in the Changbai Mts. expanded to the south and north so that it included the Liaodong Peninsula and the northeastern most part of Northeast China from 10 to 8 ka BP. At the same time, percentages in eastern Yangtze River Plain obviously increased. Across the study area, highest values occur at 8 and 6 ka BP, and a continuous high percentage belt along the coastal zone had been formed. The belt still existed at 4 ka BP, but a decline within the belt is evident. It is also worth noting that percentages rose at 4 ka BP in the Xiaoxingan Range.

During the last 2000 years, the decrease in percentages within the coastal *Quercus* belt continued, leading to a break up at first, and then to disappearance. The most evident decrease happened in regions around the Bohai Sea, including the Liaodong and Shandong Peninsulas where *Quercus* dropped from more than 20% at 4 ka BP to less than 5% at present. A significant decrease can also be found for the North China Plain and the Yangtze River Plain. Percentages today have dropped to the lowest level of the whole Holocene period for most regions.

5.5. *Ulmus*

Higher values as marked by the isopoll of 5% were found mainly for the eastern Northeast China at 10 ka BP (Fig. 11). A general rise was evident in most regions from 10 to 8 ka BP, and different from *Quercus*, the highest Holocene *Ulmus* percentages were reached at 8 ka BP for most sites. The decrease for the area of the Gobi Desert is most probably due to the lack of data sites and the biased response of the computer software in such cases. At 6 ka BP, a decrease clearly occurred in the northeastern most Northeast China and the western

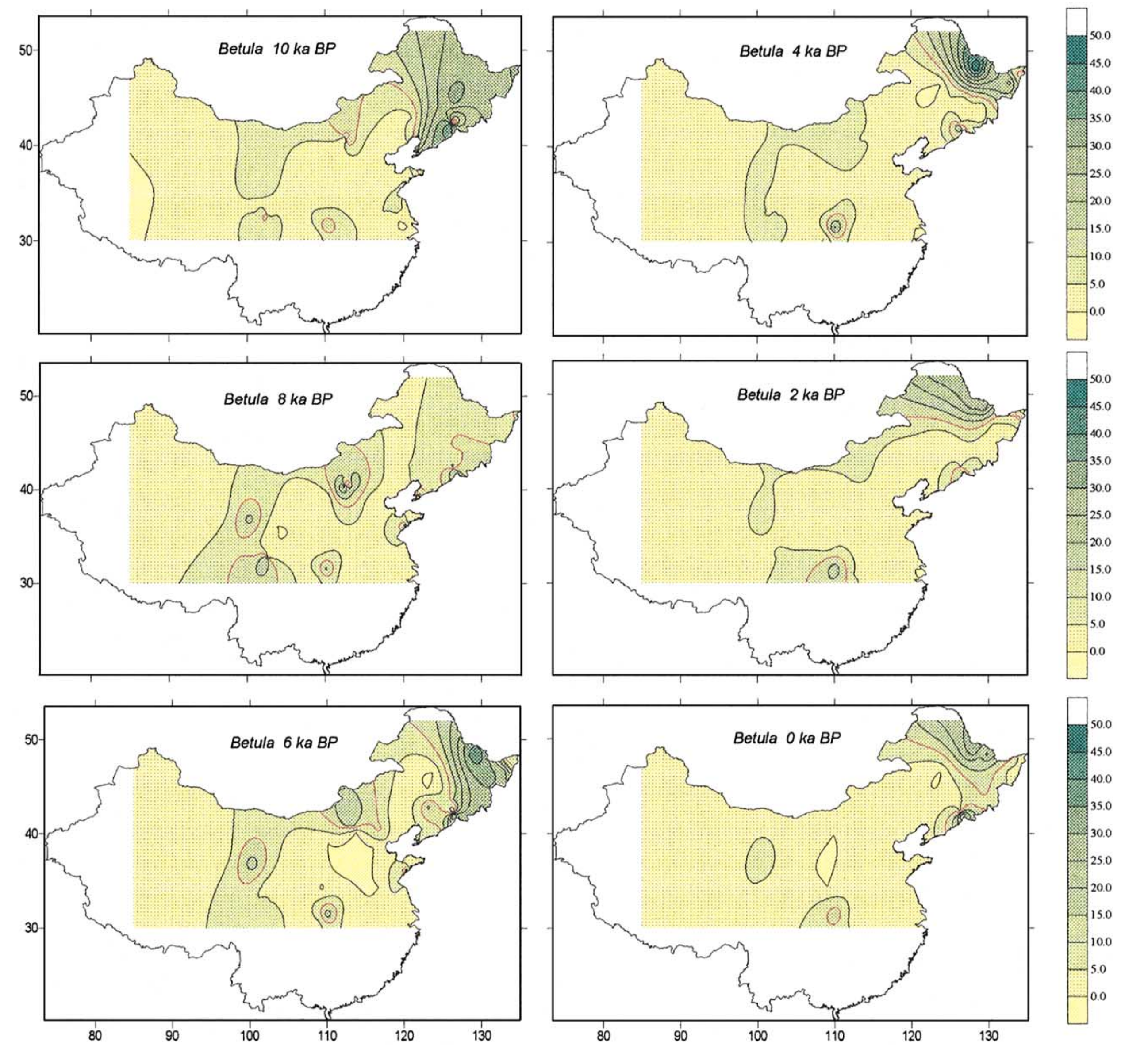

Fig. 9. Isopoll maps of *Betula* for 10, 8, 6, 4, 2 and 0 ka BP in China north of the 30th parallel. Interval of isopolls is 5 percentages. Pink lines indicate 10% isopoll.

Yangtze River Plain. The decrease generally continued during later periods, and percentages in the other regions started to drop at 4 ka BP. Except for a few sites, the present percentages, just as *Quercus*, have all reached the lowest of the Holocene.

5.6. Trees

A remarkable change in total AP percentages has been found throughout the Holocene, especially after 6 ka BP (Fig. 12). This change was frequently pointed out by researchers on the basis of profile analyses, but never before does it become evident in a tempo-spatial pattern so clearly and dynamically.

AP percentages were generally lower at 10 ka BP as compared to the average level at the following time slices. They do not exceed 80% in most of the area mapped. Highest values occur on the delta of the Yangtze River and Changbai Mts. It is interesting to note, however, that no site recorded an AP percentage below 10% as seen at later times. The gradient of AP percentages, therefore, is not so steep as during the last 8 ka. The more western position of the isopoll of 40% AP needs further investigation as few data sites in northern and western Northeast China available for the early Holocene. Of course, it may have been caused partly by the over-representation of *Betula* pollen, especially for 10 ka BP.

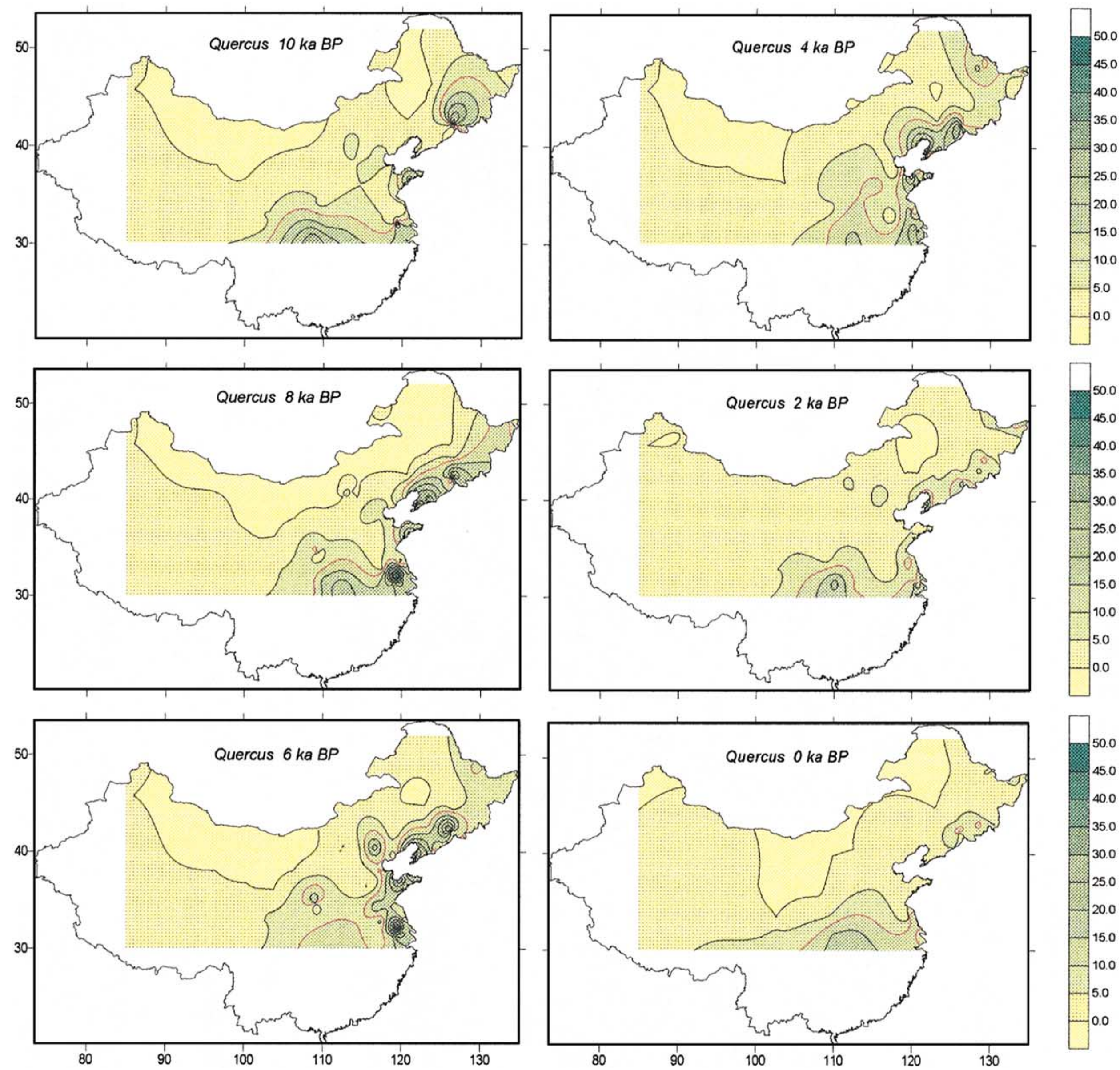

Fig. 10. Isopoll maps of *Quercus* for 10, 8, 6, 4, 2 and 0 ka BP in China north of the 30th parallel. Interval of isopolls is 5 percentages. Pink lines indicate 10% isopoll.

The time of 8 ka BP witnesses a significant rise for the southeastern half of the study area and a notable drop in parts of the northwestern arid regions. As a result, the gradient of AP percentages from southeast to northwest was steeped. An evident increase in AP occurred in the Liaodong Peninsula, the southern Inner Mongolia Plateau, and the eastern Qinghai-Tibet Plateau, while the western Loess Plateau and the NE China Plain experienced a general decrease. Isopoll 40% seems to move eastward in the NE China Plain, and it expanded toward northwest in the northern North China Plain, the southern Inner Mongolia Plateau, the eastern Loess Plateau, and the Qinghai-Tibet Plateau.

The largest increase is seen at 6 ka BP, and this is best illustrated in the southeastern regions. For most of the regions the highest values of the Holocene were reached. Isopoll 40% displays the most inland position of all the times, though there were still a few small low centers in the North China Plain and the basin plain between the Loess Plateau and the Qinling Mts. Changes in Northeast China seem less obvious compared to the other regions. An increase in the Daxingan Mts. should be treated with caution because of the lack of data for 8 and 6 ka BP.

Consistent decline in the MLRYR started at 4 ka BP. A definite decreasing zone extends from the Loess Plateau and the southern Inner Mongolia Plateau to the

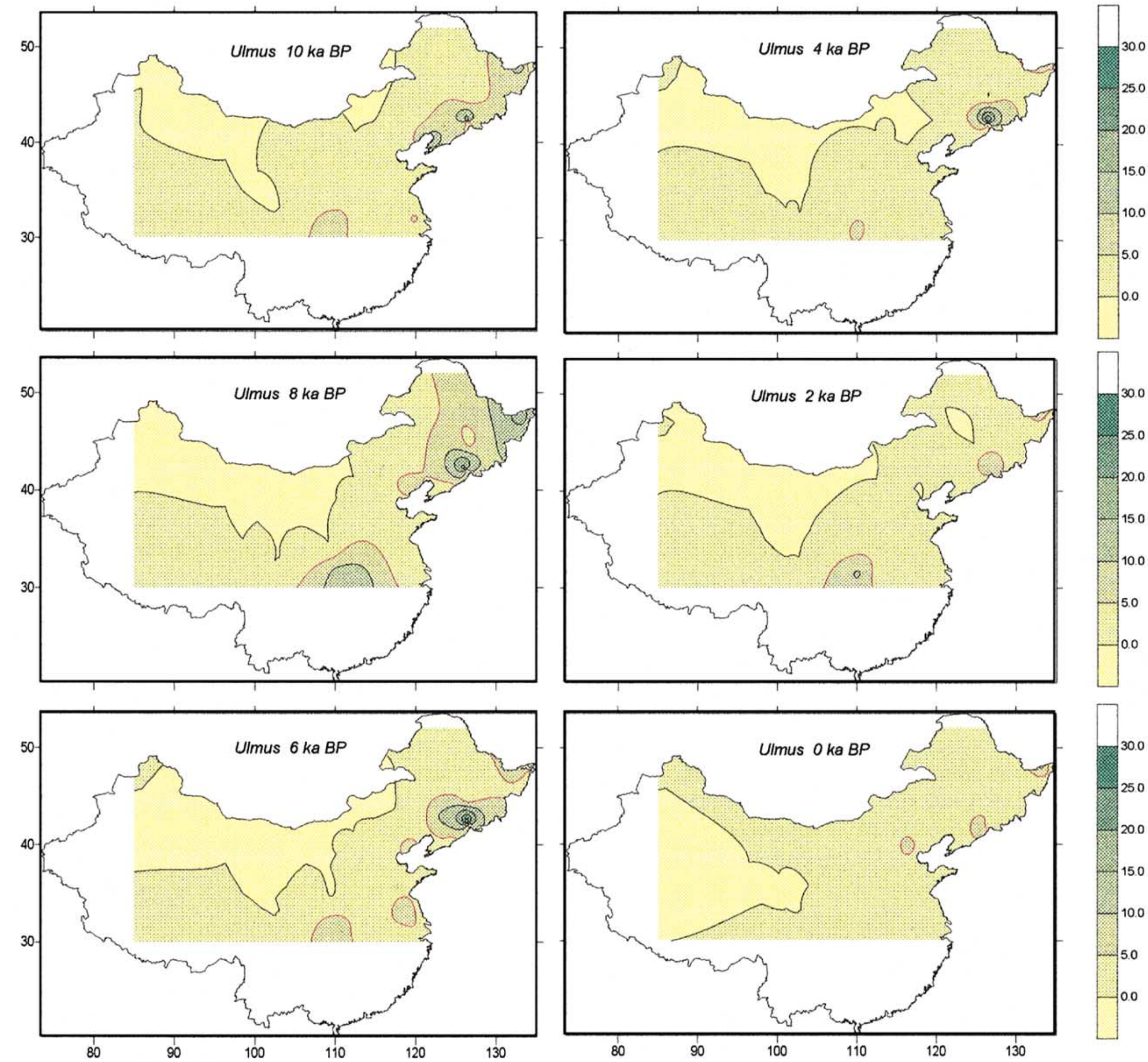

Fig. 11. Isopoll maps of *Ulmus* for 10, 8, 6, 4, 2 and 0 ka BP in China north of the 30th parallel. Interval of isopolls is 5 percentages. Pink lines indicate 10% isopoll.

southwestern North China Plain and the northern Yangtze River Plain. The most tremendous drop occurred in the southeastern Loess Plateau and southwestern North China Plain, where AP decreased from 50–70% at 6 ka BP to around 40% or less. Other regions, such as the Liaodong and Shandong Peninsulas, northern North China Plain, and the eastern Qinghai-Tibet Plateau, also experienced a drop to a varied degree. A significant increase in AP, however, can be spotted in the Changbai Mts. and the Xiaoxingan Range, which at some sites continued until the present day.

At 2 ka BP, the trend which started between 6 and 4 ka BP continued, and more regions were involved in the declining process of AP. Percentages had dropped below 40% for the first time in the southern Inner Mongolia, the northern Taihang Mts., and the North China Plain. Other decreasing sites in AP can be found in the Liaodong and Shandong Peninsulas, the southern NE China Plain, and the eastern Qinghai-Tibet Plateau, though in the Changbai Mts. and the Xiaoxingan Range, the AP values remained stable or displayed a slight rise.

A further decrease in AP after 2 ka BP occurred mainly in the North China Plain, the western NE China Plain, the Yangtze River Plain, and the eastern Qinghai-Tibet Plateau. More sites are being included in the area where AP percentages are lower than 40%, and a vast area which extends towards the southwest from the western NE China Plain to the eastern Loess Plateau

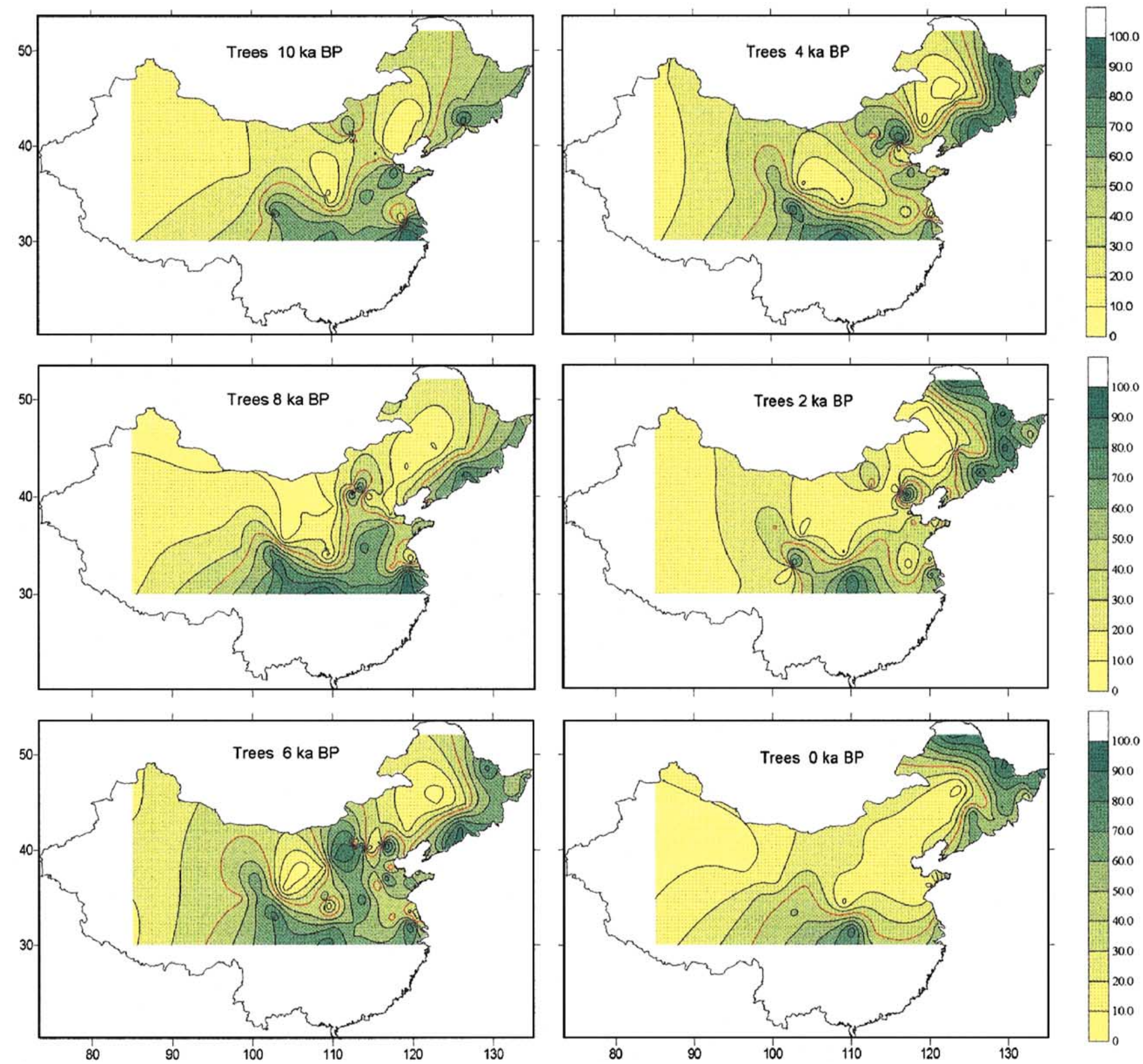

Fig. 12. Isopoll maps of total arboreal pollen (AP) for 10, 8, 6, 4, 2 and 0 ka BP in China north of the 30th parallel. Interval of isopolls is 10%. Pink lines indicate 40% isopoll.

and southern North China Plain has as low as value of 20% today. Drop in AP percentages is discernible for the first time at 0 ka BP in the Changbai Mts., though they still remain more or less stable in the Xiaoxingan Range and Daxingan Mts.

5.7. *Artemisia*

Artemisia is one of the most important herbaceous pollen in the north of China throughout the Holocene. Percentages of *Artemisia* usually surpass 20% in most regions, and can be well above 40% in the centers of maximum values, much higher than in other regions of the Northern Hemisphere. Owing to its importance in the pollen spectra, changes in *Artemisia* percentages generally correlate negatively with AP percentages.

At the beginning of the Holocene (10 ka BP), high values were recorded in the north except for Northeast China where the lowest percentages of the Holocene occurred (Fig. 13). A notable decrease came forth at 8 ka BP in the Loess Plateau, and the opposite change appeared in Northeast China. In fact, *Artemisia* percentages in eastern Northeast China reached the highest level at this time. The time slice of 6 ka BP is conspicuous in that it witnesses a large drop in *Artemisia* in the Loess Plateau and western Inner Mongolia Plateau, and to a lesser extent in eastern Northeast China.

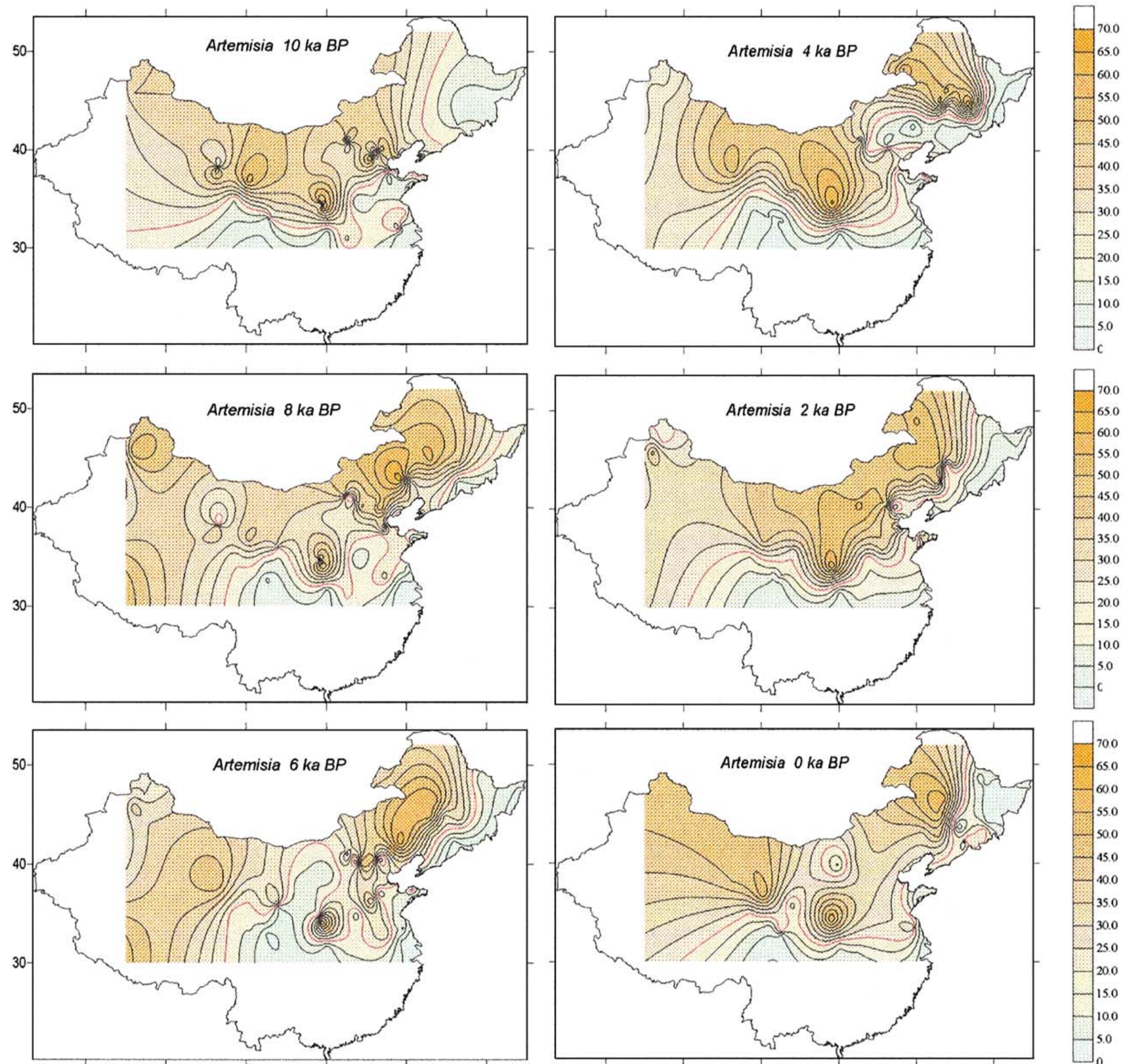

Fig. 13. Isopoll maps of *Artemisia* for 10, 8, 6, 4, 2 and 0 ka BP in China north of the 30th parallel. Interval of isopolls is 5 percentages. Pink lines indicate 20% isopoll.

By 4 ka BP, decrease in southern Northeast China is striking, but the Loess Plateau was experiencing a remarkable increase. The increase generally continued to the present in spite of the fact that a return to a lower level occurred at 0 ka BP at a few sites. Rising trend in southern Northeast China is also notable for the last two time slices.

5.8. Chenopodiaceae

Changes in Chenopodiaceae percentages are mostly opposite to those of *Artemisia* in the three earliest time slices, but similar to *Artemisia* in the later time slices (Figs. 13 and 14). For example, Chenopodiaceae increased from 10 to 6 ka BP in the western Loess Plateau where a generally decreasing trend was recorded for *Artemisia* during the same period. The lowest values of Chenopodiaceae in Northeast China at 8 ka BP contrast with possibly the most abundant occurrence of *Artemisia* of the Holocene as well. On the other hand, the striking increasing trend after 6 ka BP is basically consistent with *Artemisia*. Presently, isopoll 15% embraces the largest area.

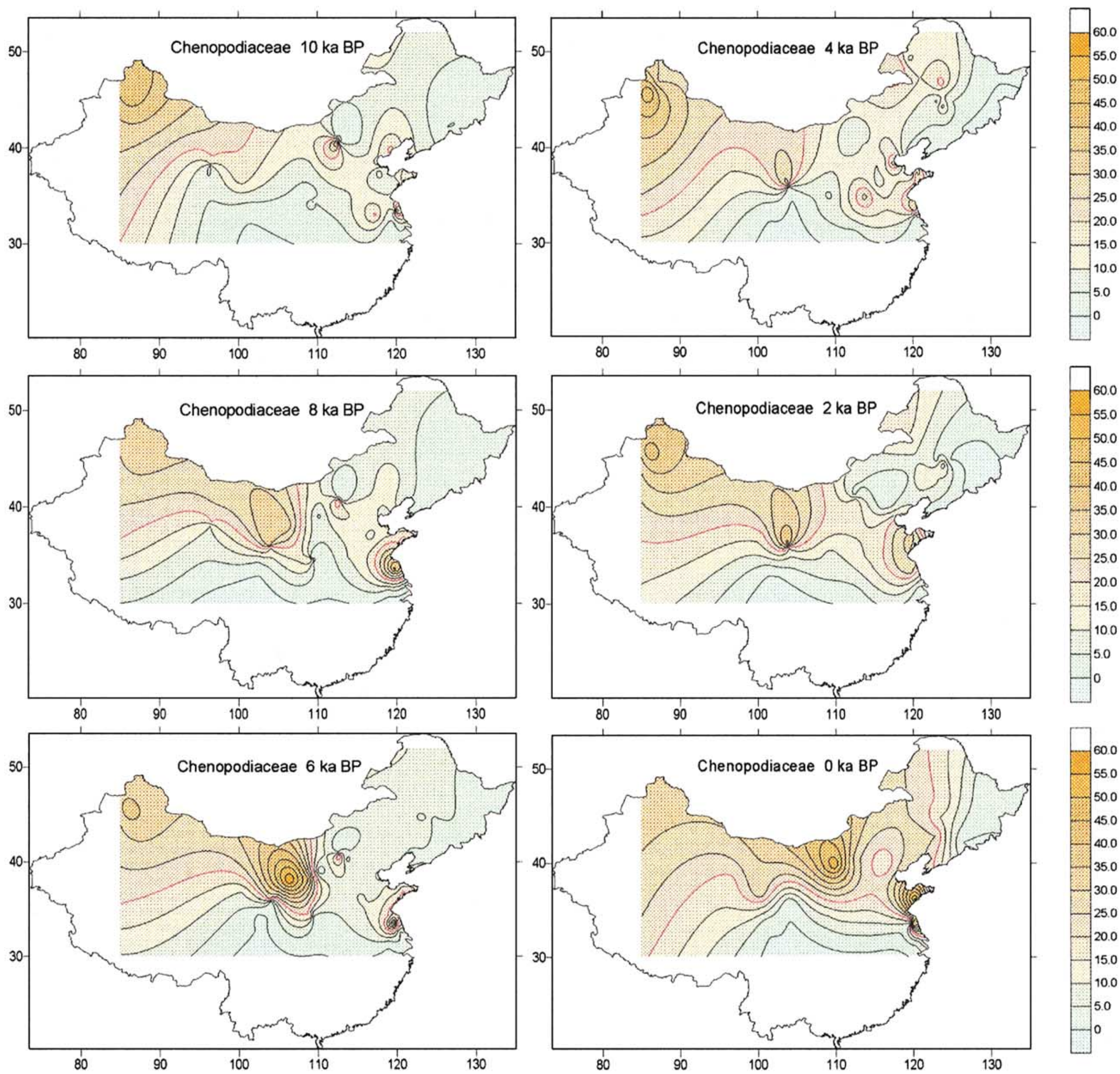

Fig. 14. Isopoll maps of Chenopodiceae for 10, 8, 6, 4, 2 and 0 ka BP in China north of the 30th parallel. Interval of isopolls is 5 percentages. Pink lines indicate 20% isopoll.

6. Reconstruction of vegetation history

Vegetation reconstruction using isopoll maps is not an easy task. The pollen representation has to be taken into account, which in turn depends on the varied production, dispersal, sedimentation and preservation of pollen grains of different taxa (Andersen, 1970; Huntley and Birks, 1983). The limited taxa selected for mapping does not encourage a perfect reconstruction of the past vegetation either. In spite of the difficulty, there is still a possibility to give a tentative and macro-scale reconstruction for the selected time slices. The possibility is enhanced by the fact that the taxa selected are the important components of the biomes in the study area, which are usually indicative of the biomes.

6.1. *Taxon evolution*

Presence and abundance of major taxa in the vegetation can be approximately determined by the knowledge of their pollen representation in sediment samples. By referring to the studies from North America and Europe (Andersen, 1970; Birks and Birks, 1980; Davis, 1983; Huntley and Birks, 1983; Webb et al., 1983; Prentice, 1988) as well as from China (Sun and Wu, 1988; Li, 1993; Weng et al., 1993; Liu et al., 1999), and taking into account the specific palynological and vegetation circumstance in the study area, certain pollen criteria values are assumed here to indicate the presence and the abundance of major taxa (Table 2). Based on those criteria values, the presence and abundance of the taxa in vegetation can be inferred.

Of course, various factors complicate the inference. An example is from the representative difference of taxa between forests and steppes. A pollen value of more than 20% might point to the presence of pine trees in a closed forest, but can say nothing about local or regional presence of pine trees in a steppe or tundra environment. The same is true to a lesser extent for birch. Another example is for differentiated sedimentation and preservation of pollen grains among various sediment types (Huntley and Birks; 1983; Davis et al., 1984), which is not reflected in the representative factors listed above. Preliminary analysis shows that the percentage difference of a few taxa between surface peat and surface soil may be significant (Ren and Zhang, 1997). It is thus important to bear in mind the uncertainties when one tries to determine the presence and abundance of taxa in the past vegetation.

(1) *Picea/Abies*: Spruce/fir were present and somewhat abundant from 10 to 4 ka BP around the eastern rim of the Qinghai-Tibet Plateau (Fig. 7). It is possible that spruce/fir were dominant in the mountain valley forests in the region. At the same time, they were basically absent in most of Northeast China though there were sparse spruce or fir trees in the Changbai Mts. and Xiaoxingan Range. Since 4 ka BP, however, the abundance of spruce/fir has decreased in the eastern Qinghai-Tibet Plateau, and the minimum has been reached in present times. In Northeast China, the most flourishing spruce/fir forests developed at 2 ka BP, but they have declined since then in the Changbai Mts. Spruces and firs also grew in a few other mountainous regions before 2 ka BP, where they have almost disappeared today.

(2) *Pinus*: Pine trees may have only grown in the North China Plain and eastern Yinshan Mts. at 10 ka BP (Fig. 8). By 8 ka BP, the eastern Yangtze River Plain and eastern Qinghai-Tibet Plateau were also locally covered by pine forests. However, nowhere were pine trees the most important taxa in the early Holocene. Pine abundance significantly increased from 8 to 6 ka BP in the North China Plain, the eastern Loess Plateau, the southern Inner Mongolia Plateau, and the northeastern Qinghai-Tibet Plateau. In Northeast China, pine forest may not have developed during the first 4000 years, while pine trees may have grown sparsely in a few places. After 6 ka BP, however, Northeast China experienced rapid increase in pine abundance, and pine forests may well have established its place and dominated the landscape between 4 and 2 ka BP in some places of the Changbai Mts. and Xiaoxingan Range.

A decrease in pine abundance first started at 4 ka BP in the North China Plain and the Loess Plateau, then at 2 ka BP in the southern Inner Mongolia Plateau and the eastern Qinghai-Tibet Plateau, and finally in the Changbai Mts. and the Yangtze River Plain. Pine forest has now almost disappeared in southern North China Plain and northern Yangtze River Plain, but it still grows in large amounts in the Xiaoxingan Range.

(3) *Betula*: Birches widely grew in Northeast China at 10 ka BP (Fig. 9), though the populations may have consisted of dwarf trees or shrubs (Xia, personal communication). They were also present in the Inner Mongolia Plateau, the Shandong Peninsula, the Qinling Mts., and the eastern Qinghai-Tibet Plateau. Birch abundance obviously declined at 8 ka BP in Northeast China, but this trend was reversed at 6 ka BP when they appeared in the Xiaoxingan Range. Here caution should be taken because pollen values are lacking for the Xiaoxingan Range at the proceeding time slices. However, birch trees may have been the dominant component of the forests in the Xiaoxingan Range between 6 and 4 ka BP. In regions outside Northeast China, a noticeable change is the decreasing trend of birch abundance after 6 ka BP.

(4) *Quercus*: At present, oaks mainly occur in the Yangtze River Plain and the Changbai Mts. (Fig. 6). During the Holocene, however, oak forests had a wider distribution in eastern China, especially along the coastal regions. At 10 ka BP, oaks grew in the Changbai Mts., the Shandong Peninsula, the Liaodong Peninsula, and the Yangtze River Plain, and consistently increased their extent and abundance from 10 to 6 ka BP (Fig. 10). Oak trees must have been dominant at 6 ka BP in many locations of the Liaodong Peninsula, Shandong Peninsula and the eastern Yangtze River Plain. A decline in oak forests is evident from 6 to 4 ka BP, and that trend continued up to the present day. The most obvious drop in oak abundance occurred along the coastal regions. Presently, few mature oak forests can be found in the Liaodong and the Shandong Peninsulas which were major centers of oak population during the mid-Holocene.

(5) *Ulmus*: The present distribution and the temporal change of elms are similar to those of oak though they

Table 2
Pollen criteria values for the presence and abundance of major taxa

Taxon name	Present (%)	Abundant (%)	Dominant (%)
Picea/Abies	> 5	> 15	> 25
Pinus	> 25	> 40	> 55
Betula	> 10	> 20	> 40
Quercus	> 3	> 15	> 30
Ulmus	> 2	> 10	> 25
Artemisia	> 10	> 25	> 60
Chenopodiaceae	> 5	> 20	> 40
Trees	> 40	> 60	> 80

lack the tendency to concentrate along the coastal zone throughout the Holocene (Fig. 11). The highest abundance is reached at 8 and 6 ka BP when elm trees were abundant in the Changbai Mts., the northeastern most part of Northeast China, and the western Yangtze River Plain. A continuous decline in abundance is seen after 6 ka BP. Although elm trees are still present in a vast area, it is less possible to find a piece of natural elm forest with some extent of maturity today.

(6) *Artemisia*: Being one of the most important herbaceous taxa, *Artemisia* grew in most parts of the study area throughout the Holocene (Fig. 13). At 10 ka BP, it was abundant in the north outside Northeast China which conversely saw the lowest occurrence in the Holocene. A decrease in *Artemisia* abundance is evident from 8 to 6 ka BP in the Loess Plateau, but the opposite change is seen during the same period in Northeast China. By 4 ka BP, the Loess Plateau saw a marked rise in abundance and extent, and this trend generally continued to present time. An increase in abundance is notable in southern Northeast China during the late Holocene. Since 4 ka BP, two high abundance centers have been maintained in the southern Loess Plateau and the western NE China Plain respectively.

(7) Chenopodiaceae: Unlike *Artemisia*, Chenopodiaceae abundance increased from 10 to 6 ka BP in the western Loess Plateau (Fig. 14). Following a drop at 4 ka BP, Chenopodiaceae abundance regained in the late Holocene in that region. Today Chenopodiaceae are very important and even dominant in some locations of the western Inner Mongolia Plateau and the coastal zone. In Northeast China, the abundance reached its lowest level at 8 ka BP, and it then rose significantly. Today's presence of Chenopodiaceae is the most widespread of the Holocene in northeast China.

6.2. Forest cover change

Total AP percentages can be taken as a proxy for changes in forest cover in the Holocene. It experienced a remarkable long-term change in most regions, indicating that the forest cover never remained stable during the last 10,000 years.

Forest cover was generally lower at the beginning of the Holocene. Exceptionally, the lower reaches of the Yangtze River and the Changbai Mts may have been more densely covered by forests (Fig. 12). Steppe and shrub communities may have occurred more extensively in the other regions. At 8 ka BP, a significant increase in forest cover can be seen in most regions, though the opposite may have been true for the NE China Plain and the northwestern arid regions. The increasing trend continued till 6 ka BP when the largest forest cover was reached for most parts of southeastern China.

The time slice of 4 ka BP serves a closer notification in that it witnessed the first drop in forest cover in an extensive area of central and northern China, particularly in the MLRYR. The Liaodong and Shandong Peninsulas, the northern North China Plain, and the eastern Qinghai-Tibet Plateau also experienced a decrease, though a notable increase may have occurred in the Changbai Mts. and the Xiaoxingan Range. By 2 ka BP, the trend which started at least at 4 ka BP continued, and more regions have been included in the forest declining area. The Changbai Mts. and the Xiaoxingan Range, however, still remained stable or even experienced a slight expansion. Today, a vast area extending from the western NE China Plain to the eastern Loess Plateau and the southern North China Plain reached its minimum of the Holocene, and for the first time during the last 8000 years, forest cover in the Changbai Mts. started to decrease.

6.3. Biome evolution

Palaeo-biome reconstruction needs the assumption that the relation between pollen and vegetation remained unchanged through time. It also needs calibration by modern pollen data in terms of modern biomes. In Europe and North America, large changes in the vegetation structure have taken place due to the migration of species during the Late-glacial and postglacial periods following the retreat of the ice sheets and improvement of climatic conditions, leading to the disparity of the pollen-vegetation relations through time and to the sometimes non-analog nature of the past vegetation (Beug, 1962, 1982; Davis, 1983; Webb et al., 1983; Huntley, 1990a, b). In spite of the possibility that a few species in Northeast China may have experienced a south-to-north migration as well (Ren, 2000a, b), the vegetation structure in China as a whole may have been relatively less variable during the last 10 ka. Compared to Europe and North America, therefore, better opportunities could be assumed in China for palaeobiome reconstruction based on pollen maps.

Of course, more work should be conducted to investigate the changes in pollen and vegetation during the Last Glacial and the Lateglacial. Undoubtedly, data from before 10 ka BP would enable us to better understand questions of glacial refugia and of processes leading to the vegetation pattern of 10 ka BP. Due to the lack of data, it is less possible at present to produce pollen maps for the periods. Other problems with the reconstruction come from the lack of detailed knowledge of modern vegetation and from the limited number of taxa used for mapping. The available modern vegetation maps of China neither totally represent the actual vegetation nor truly show the potential or natural vegetation. They are usually mixtures of both. Since we do not know what the present vegetation would exactly look like, our ability to describe the present pollen-vegetation relations remains limited. The inefficiency of pollen taxa selected does not allow a fully satisfying reconstruction either. In spite of these problems, a preliminary macro-scale reconstruction might be attempted.

Here we principally use the modern vegetation map of Wu (1980) to determine relations between modern pollen and vegetation (Fig. 3), with the awareness that warm temperate deciduous forest on the map basically represents the potential vegetation distribution. Actually, warm temperate deciduous forest is present only locally on the Liaodong and Shandong Peninsulas today. The mapped extent of modern temperate mixed conifer and deciduous forest is also too large. They mainly occur in the southeastern Changbai Mts. and the southern Xiaoxingan Range, and the other parts assigned to that biome are actually covered by relatively open temperate deciduous forest consisting of trees like *Quercus*, *Tilia*, *Ulmus*, and *Acer*. In addition, alpine vegetation in the Qinghai-Tibet Plateau should be further divided into alpine valley forest in its eastern fringe, alpine steppe in the central part, and alpine desert in the northwest.

By comparing the modern vegetation and the isopoll maps, a set of pollen percentage criteria values is presented for each of the biomes (Table 3), which can be used to further determine the boundaries between the biomes for the time slices. This is a simple analog procedure, but it is of coherence and the biome distribution at different times could be compared with each other. A biome named "other forest" is added where no modern analog was found, which mostly appeared in the southern and eastern Loess Plateau, the western North China Plain, and in the regions near the eastern fringe of the Qinghai-Tibet Plateau. Our confidence is relatively high for the reconstruction of forest-steppe ectones, but it is not so for assignment of the boundaries between different forest biomes. Still, biome reconstruction in regions with poor data coverage, such as in the Daxingan Mts., the central and western Qinghai-Tibet Plateau, and the northwestern arid area, should be treated with caution.

Fig. 15 shows the reconstructed biomes. The biomes can be distinguished through the abbreviations of the names on the maps, with those for non-forest biomes being given in italic bold capitals. The reconstructed biomes for 0 ka BP are similar to the actual vegetation distribution, with forests being restricted to the remote regions such as northern and eastern Northeast China and the eastern fringe of the Qinghai-Tibet Plateau. The vast temperate steppe includes most of the pastures and the major rain-fed farmlands. The type "other forest" appears at 0 ka BP in the eastern Qinghai-Tibet Plateau and western Qinling Mts. because a strict definition for the Picea/Abies percentages (>10%) is used for the alpine valley forest.

10 ka BP (Fig. 15A): Cold temperate conifer forest (ctf) and temperate mixed conifer and deciduous forest (tmf) may not have come into existence at this time. A relatively open temperate deciduous forest (tdf) developed in the eastern Northeast China, with *Ulmus*, *Betula* and *Quercus* as the important components. It is not clear whether *Ulmus* and *Betula* grew in the region as shrub. The warm temperate deciduous forest (wtf) was restricted in the Shandong Peninsula, while much of the North China Plain and the Qinling Mts. were covered by a forest consisting mainly of *Pinus* and *Quercus* (of). The subtropical mixed evergreen and deciduous forest (smf) may have occurred along the middle and lower reaches of the Yangtze River, and their extent seems to be similar to that of present times. The alpine valley forest (avf) was well developed, but in a position displaced slightly eastward. The temperate steppe (TS) may have obtained large areas though we cannot explicitly define the boundary between temperate steppe and temperate desert (TD). The same is true for the alpine steppe (AS) and the alpine desert (AD) in the Qinghai-Tibet Plateau, and this is mainly due to the eastward displacement of alpine valley forest (avf).

Table 3
Pollen percentage criteria values for different biomes[a]

Forest		Non-forest	
AP > 40%		AP < 40%	
ctf	*Picea*/*Abies* > 10%, *Betula* > 10%	TS	AP > 15%, Chenopodiceae < 20%
tmf	*Picea*/*Abies* 3–10%, *Pinus* > 25%, *Quercus* 3–10%	TD	AP < 15%, Chenopodiceae > 20%
tdf	*Picea*/*Abies* < 3%, *Pinus* < 25%, *Quercus* 3–10%	AS	AP > 15%, Chenopodiceae < 20%, elevation > 2000 m
wtf	*Picea*/*Abies* < 3%, *Pinus* 15–30%, *Quercus* 5–15%, *Ulmus* > 3%	AD	AP < 15%, Chenopodiceae > 20%, elevation > 2000 m
smf	*Picea*/*Abies* < 3%, *Betula* < 5%, *Pinus* < 25%, *Quercus* 10–40%, elevation < 2000 m		
avf	*Picea*/*Abies* > 10%, elevation > 2000 m		
of	AP > 40%		

[a] Note: ctf: cold temperate conifer forest; tmf: temperate mixed conifer and deciduous forest; tdf: temperate deciduous forest; wtf: warm temperate deciduous forest; smf: subtropical mixed evergreen and deciduous forest; avf: alpine valley forest; of: other forest; TS: Temperate Steppe; TD: Temperate Desert; AS: Alpine Steppe; AD: Alpine Desert.

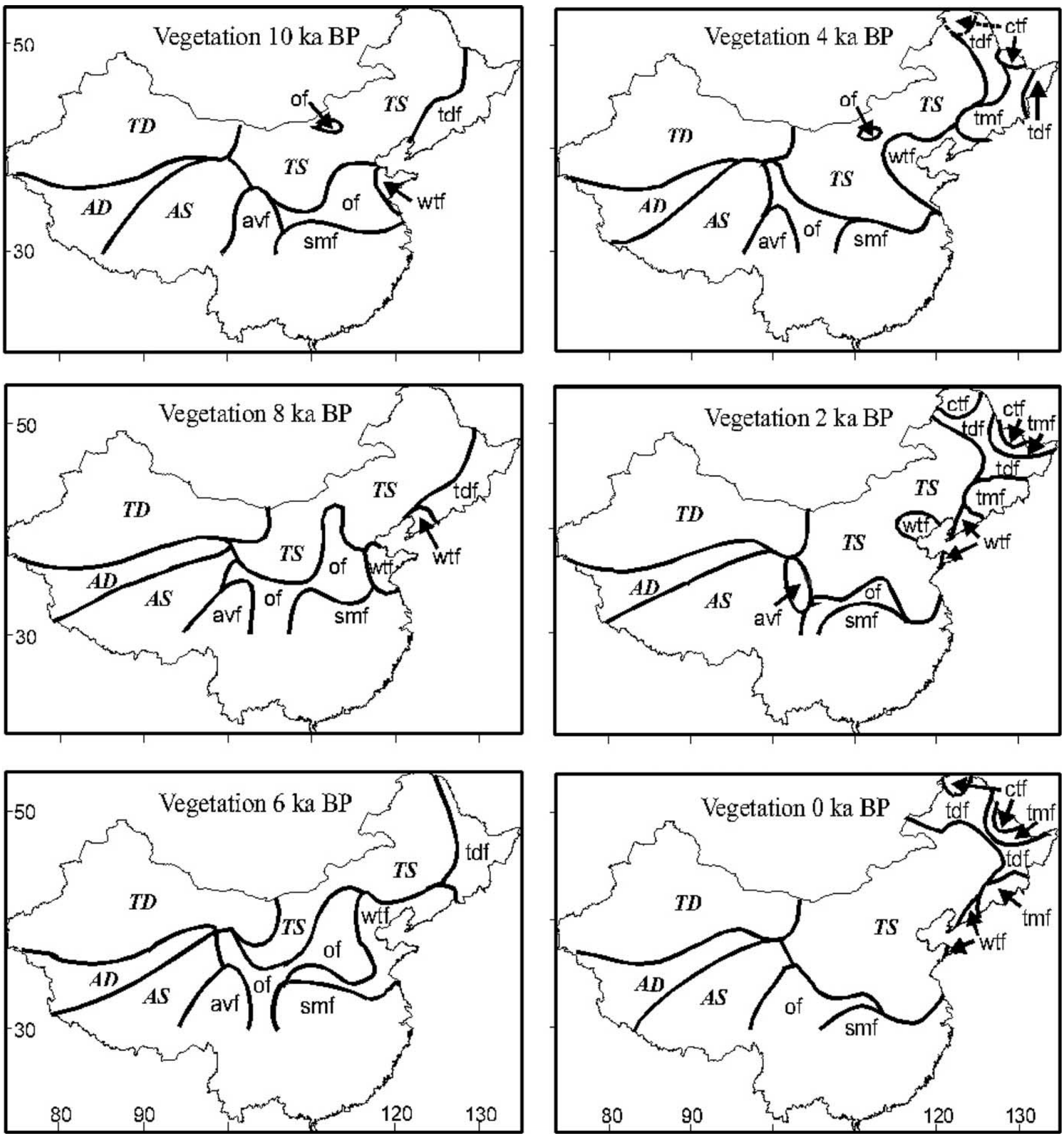

Fig. 15. Reconstructed vegetation types of the study area for the six specific time slices based on the pollen maps. The six time slices are 10, 8, 6, 4, 2 and 0 ka BP, respectively. ctf: Cold temperate conifer forest; tmf: temperate mixed conifer and deciduous forest; tdf: temperate deciduous forest; wtf: warm temperate deciduous forest; smf: subtropical mixed evergreen and deciduous forest; avf: alpine valley forest; of: other forest; TS: Temperate Steppe; TD: Temperate Desert; AS: Alpine Steppe; AD: Alpine Desert.

8 ka BP (Fig. 15B): Major changes in Northeast China are due to the first appearance of the warm temperate deciduous forest (wtf) on the Liaodong Peninsula and an increase in the *Ulmus* and *Quercus* population in the temperate deciduous forest (tdf). The warm temperate deciduous forest (wtf) on the Shandong Peninsula and the forest mainly consisting of *Pinus* and *Quercus* (of) expanded toward west and north. Alpine

valley forest (avf) in the eastern rim of the Qinghai-Tibet Plateau expanded westward and upward. While the area of the temperate steppe (TS) in the Loess Plateau and the western Inner Mongolia Plateau shrank, the extent of TS in Northeast China may have enlarged. In the Qinghai-Tibet Plateau, the alpine steppe may have been reduced as a result of the expansion of the alpine valley forest.

6 ka BP (Fig. 15C): Cold temperate conifer forest (ctf) and temperate mixed conifer and deciduous forest (tmf) had not yet appeared at this time, and the temperate deciduous forest (tdf) still occupied most of the Changbai Mts. and the Xiaoxingan Range. Further expansion of the warm temperate deciduous forest (wtf) and the other forest (of) in regions surrounding the Bohai Sea and in the Loess Plateau can be found. *Pinus*, which reached its Holocene maximum in the North China Plain and the Loess Plateau, remained as the dominant component of the other forest (of). The alpine valley forest (avf) in eastern Qinghai-Tibet Plateau was also at its maximum. On the other hand, the extent of the temperate steppe (TS) and the alpine steppe (AS) may have been largely reduced.

4 ka BP (Fig. 15D): For the first time, a cold temperate conifer forest (ctf) and a temperate mixed conifer and deciduous forest (tmf) appeared in the Xiaoxingan Range and the Changbai Mts. The former probably developed also in the northern Daxingan Mts. Forests of Northeast China as a whole expanded westward, though warm temperate deciduous forest (wtf) in the south may have shrunk. In the other regions, however, every forest biomes had been significantly reduced in its distribution area. The other forest (of) with *Pinus* as its dominant member had almost disappeared in the southeastern Loess Plateau and in the western North China Plain. As a result, temperate steppe (TS) and alpine steppe (AS) had largely expanded.

2 ka BP (Fig. 15E): Further reduction in the warm temperate deciduous forest (wtf) surrounding the Bohai Sea is evident, leading to a continuous retreat of the forest-steppe ecotone in the North China Plain. Also evident is a decrease in the extent of the alpine valley forest (avf). In contrast, the distribution areas of various forest types in central and northern Northeast China remained relatively stable or were even rising slightly in some parts.

0 ka BP (Fig. 15F): Almost no forest has been left in a vast area extending from the Loess Plateau to the North China Plain. The cold temperate conifer forest (ctf) may have been the only forest biome that has not experienced a decline in North and Northeast China. The temperate mixed conifer and deciduous forest (tmf) and the temperate deciduous forest (tdf) began to shrink in extent, and the warm temperate deciduous forest (wtf) was restricted to the tip of the Shandong Peninsula and in the easternmost Liaodong Peninsula only. The subtropical mixed evergreen and deciduous forest (smf) was at its minimum. The alpine valley forest (avf) has not existed or is not registered according to the definition given in this study. On the other hand, the temperate steppe (TS), which also includes large areas of pastures and farmland in central and northern China, has developed to a maximum since 10 ka BP.

7. Discussion and conclusions

7.1. Discussion

We present preliminary results of pollen mapping and macro-scale vegetation reconstruction for the Holocene in China north of the Yangtze River. It is beyond doubt that the quality and quantity of data will be better in the future, and the pollen maps and the reconstruction of vegetation will be further improved as well. The present result, however, is encouraging because it not only gives a consistent presentation of the data and vegetation, but it also raises a series of palaeo-ecological and palaeo-climatological questions which need to be answered by future studies.

Forest decline: One of the most interesting questions is connected with the decline of forests and its possible causes during the last 6000 years in the study area, especially in the MLRYR (Fig. 12). The forest decline seems to start first in the southeastern Loess Plateau, the southern Taihang Mts. and in the western North China Plain, and seems then to spread from there. It is also obvious that all of the tree taxa experienced a decline though more evident drop can be found for pine and oak in the MLRYR and the Liaodong and Shandong Peninsulas (Figs. 8 and 10), and for spruce/fir in the eastern Qinghai-Tibet plateau (Fig. 7). In previous studies, Ren et al. recognized the temporal and spatial pattern of forest decline in the mid-to late Holocene by analyzing site data, and attributed the temporal and spatial change to the geographical expansion of farming since the Yangshao Culture (6–5 ka BP) (Ren, 1994, 2000a, b; Ren and Zhang, 1998). In spite of the different time resolution, the present pollen maps generally support the previous explanation.

Climate reconstruction: If the vegetation has been disturbed by human activities in the middle and late Holocene, could Holocene climate change of the study area be reconstructed using pollen data? The answer is "no" and "yes". It would be improper to do so in the MLRYR and the neighboring regions for varied time lengths of the last 6000 years. The previous climate reconstruction based mainly on pollen data in the regions needs to be reassessed. However, pollen-based Holocene climate reconstruction could still be attempted in the Xiaoxingan Range, the Daxingan Mts., and other remote regions where human interference with vegetation has been absent or very weak (Ren, 1994, 1999). It is interesting to note that it is in the latter regions that the reconstructed Holocene climate history (Ren, 1994, 1999) is radically different from the previous studies (Chen et al., 1977; Kong et al., 1982; Zhou et al., 1984; An et al., 1990; Shi and Kong, 1992; Winkler and Wang, 1993; Xia et al., 1993) because it shows no general drying trend in the late Holocene as claimed by majority of Chinese Quaternary scientists.

Palaeo-climate reconstruction was also conducted using other proxy data than pollen in central and northern China (Zhou, 1984; Shi and Kong, 1992; Qiu et al., 1992; Gao et al., 1993). The reconstruction led to conclusions similar to those obtained from palynological data. Similarly, caution should be drawn in this case. Vegetation is the core element of the environmental system, and such proxy data as sediments, lake level status, micro landform, buried soil and geochemical indicators all depend on or are connected with changes in vegetation. If radical vegetation change has taken place due to human interference, we should not expect these proxy data to independently indicate climate changes.

Potential vegetation: What would be the natural or potential vegetation like without human interference in regions like the MLRYR? This is one of the most frequently asked questions among Chinese ecologists and resource managers due to its relevance to ecological engineering and environment planning. If we take into account the long-term impact of human being on vegetation, if climate remained less changeable in the last 6000 years, and if the equilibrium of vegetation with climate had been reached prior to the beginning of human interference, then the vegetation at 6 ka BP would be the closest scenario to the present natural or potential vegetation in the MLRYR. Of course, climate changes during the last 6000 years may have complicated this picture. Considering the pollen maps and reconstructed palaeo-biomes, however, human influence on the landscape may have predominated over climate changes for at least 4000 years in the MLRYR. In this case, the biomes at 6 ka BP would correspond more to the present potential vegetation than the present actual vegetation. Anyhow, palaeo-ecological studies including point analysis and spatial mapping, in combination with palaeoclimatic reconstruction and ecological modeling, will contribute to the final solution of the scientific question.

Species' migration: The pollen maps also speak for the possibility that some species undertook migrations when the climate conditions changed in the Holocene. *Picea/Abies* and the alpine valley forest in the eastern fringe of the Qinghai-Tibet Plateau, for example, seem to have migrated westward and upward in the early Holocene. This may be considered as being a response to the rise in temperature. *Pinus* in the North China Plain and in the eastern Northeast China may have also experienced some northward migration. Of course, the 2000-year time interval of the pollen maps is too long for investigating possible migration of species. High resolution pollen profile analyzing and pollen mapping are needed to tackle this question.

7.2. Conclusions

Using the available data, we have produced a series of Holocene pollen maps in an interval of 2000 years for China north of the Yangtze River. A tentative reconstruction of the palaeo-vegetation was also attempted on the basis of maps. Main conclusions are as follows.

(1) The present data set can allow a preliminary and macro-scale pollen mapping research for the concerned area. Both the data quality and quantity need to be improved in order to obtain a more satisfying mapped summary of Holocene pollen pattern and vegetation development. Major spatial gaps in data coverage, which urgently need to be filled, are in the eastern Inner Mongolia Plateau, the Daxingan Mts., the northwestern arid zone, the central and western Qinghai-Tibet Plateau, and the Sichuan Basin.
(2) Comparison between the modern pollen maps and vegetation map shows that the isopolls basically reflect the macro distribution of the taxa, which indicates the effectiveness of the methods used and the usefulness of the pollen maps produced for reconstructing the vegetation history.
(3) Large changes in vegetation occurred during the Holocene. For most of the southeastern regions, arboreal taxa and forest biomes generally expanded with time in the early Holocene, reached the maximum development at 6 or 4 ka BP, and then shrank in the late Holocene. An exception was found for the eastern and northern Northeast China where the lush growth of arboreal taxa and forests seems to be in the last 4000 or 2000 years.
(4) The drop in AP percentages and forest cover after 6 ka BP in the MLRYR is one of the most striking features the pollen maps display. Outside the MLRYR, the decrease in forest cover started later, and was less significant. No forest decline ever took place in the last 6000 years in the northernmost Northeast China. The tempo-spatial pattern of the forest decline is in line with the spreading scenarios of ancient agriculture, supporting a previous claim that human activity is the cause.
(5) In the southeastern Loess Plateau and western North China Plain, a forest mainly consisting of *Pinus* and *Quercus* developed from 8 ka BP to 6 ka

BP, but it came to an end at about 4 ka BP. On the other hand, cold temperate conifer forest and temperate mixed conifer and deciduous forest in Northeast China did not exist before 6 ka BP. They appeared at 4 ka BP and continued to develop until the present. Alpine valley forest in the eastern Qinghai-Tibet Plateau started to decline at 4 ka BP, and it has now almost disappeared.

(6) The potential implications of the Chinese forest cover decline in the last 6000 years, no matter how it was induced, needs to be further explored. Especially, its possible effects on historical global carbon cycle, long-term regional climate change, and decline in regional bio-diversity are worth future investigation.

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