

Changes in forest cover in China during the Holocene

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Received: 8 September 2005 / Accepted: 4 April 2006 / Published online: 27 October 2006
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Abstract Pollen map data at 2000-year intervals are used to reconstruct changes in Holocene forest cover in China north of the Yangtze River. In almost all regions, the early Holocene from 10 ka B.P. to 6 ka B.P. is characterised by an increase in forest cover although there was a reversal to lower forest cover at 8 ka B.P. in the eastern monsoon regions. A maximum of forest cover was reached at 6 ka B.P. in all regions except for Northeast China where forest cover peaked in the late Holocene. All regions except for Northeast China experienced a marked decline in forest cover after 6 ka B.P. Since 6 ka B.P., forest cover has decreased by about 92% in the middle and lower reaches of the Yellow River, 64% in the easternmost part of the Qinghai-Tibet Plateau and 37% between the Yangtze River and the Huaihe River. In contrast, forest cover in Northeast China increased significantly from 6 ka B.P., but has declined between 2 ka B.P. and the present. Changes in forest cover prior to 6 ka B.P. were probably caused by climate, but the evident drop in forest cover since that time in most regions may have been induced predominantly by human activities.

Keywords Forest cover · Pollen data · Holocene · China · Climatic change · Human impact

Introduction

Terrestrial forest is one of the major factors in the global carbon balance, and therefore in global climate change (Francey

et al. 1995; Peng and Apps 1997; Peng et al. 1998; Phillips et al. 1998; Joos et al. 1999; Houghton et al. 1999; Casperson et al. 2000; Fang et al. 2001; Ruddiman 2003). The increase in atmospheric CO₂ concentration in the last 200 years is attributed to the use of fossil fuels as well as the net loss in global forest reserves (IPCC 2000, 2001), in spite of the fact that a large uncertainty exists in estimating the forest or land-cover change for the last centuries. Reconstruction of Holocene atmospheric CO₂ concentration shows a more notable change than expected in atmospheric concentration of CO₂ in the Holocene period (Indermuhle et al. 1999; Beerling 2000; Ruddiman 2003). The mid- to late Holocene increase in atmospheric CO₂ concentration is partly attributed to changes in land cover in northern Africa and the Arabian Peninsula, but other terrestrial sources are likely to play a role and require identification (Indermuhle et al. 1999).

Change in forest cover may also have affected past climates on regional or sub-continental scales. Holocene forest or vegetation changes in northern Eurasia and northern Africa may have amplified the climate changes due to the bio-geophysical feedback from the vegetation (Texier et al. 1997; Brostroem et al. 1998; Ganopolski et al. 1998; Levis and Foley 1999; Braconnot et al. 1999; Wang 1999; Fu 2001). Forest cover or land-cover change therefore need to be taken into consideration if we are to understand the complete spectrum of factors in the past and future climate changes on regional or sub-continental scales.

Palaeo-data on past forest cover are therefore of key importance for understanding the Holocene global carbon cycle and regional climatic dynamics. Verification of the changes in forest cover and of the driving forces for the changes is thus urgently needed. In the last decade, progress was made in reconstructing past biome distributions for the mid-Holocene and the last glacial maximum (Prentice et al. 1996; Hoelzmann et al. 1998; Tarasov et al. 1998; Yu et al. 2000).

Communicated by F. Schlütz

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Although these studies focus only on 6 ka B.P. and 18 ka B.P., and regard the differences in the biome of 6 ka B.P. from that of the present-day as being the result of climate change alone, they have facilitated the compilation of much palaeo-vegetation data.

Forest changes in the late Holocene in China have long been noted among Chinese palaeoecologists (An et al. 1990; Sun and Chen 1991; Winkler and Wang 1993; Liu and Qiu 1994; Ren 1994; Ren and Zhang 1998) and Chinese historians (Shi 1991; Zhu 1992; Fang and Xie 1994). Most of the scientists, however, regard the decrease in arboreal pollen or forest cover in the last 5000 years as an indicator of climatic drying, though historians have found documentary evidence showing that many forests have been destroyed by human activities since ca. 2 ka B.P. In previous studies, Ren et al. investigated the tempo-spatial pattern of arboreal pollen changes in the mid-to late-Holocene in the country, concluding that the forest decline of the last 5000 years is in step with the ancient agricultural expansion in time and space (Ren and Zhang 1998; Ren 2000; Ren and Beug 2002).

This paper further discusses the issue of Holocene forest-cover changes in China north of the Yangtze River based on mapped pollen data. It supports our previous claim that Chinese forest cover has declined since 5000 B.P., most probably due to human interference. The implications of the forest-cover change for the global carbon cycle of the mid- to late-Holocene and for regional climate change are also discussed.

Data and methods

This work is mainly based on the output of Holocene pollen mapping research completed by Ren and co-workers (Ren 1994; Ren and Zhang 1998; Ren and Beug 2002). A pollen data-set of 142 sites in China north of the Yangtze River was used to produce a series of Holocene pollen maps for six time slices at 2000 year intervals and for ten taxa including total arboreal pollen. Figure 1 shows the distribution of the pollen sites.

As pointed out previously, Holocene pollen data of good quality are relatively rare in China, especially from work in the decades prior to 2000 (Liu and Qiu 1994; Ren and Beug 2002). This is mainly due to the discontinuous nature of the sediments used for pollen analysis, the coarse sampling intervals and low time resolution, the lack of radiocarbon-dating control and the relatively out-of-date analytical methods and equipment in many domestic laboratories (Sun and Chen 1991; Liu and Qiu 1994; Ren and Zhang 1998). For some regions, even such poor-quality data are difficult to find. These factors hinder the production of pollen maps with a fine temporal and spatial resolution, and hence any detailed investigation of the temporal-spatial patterns of

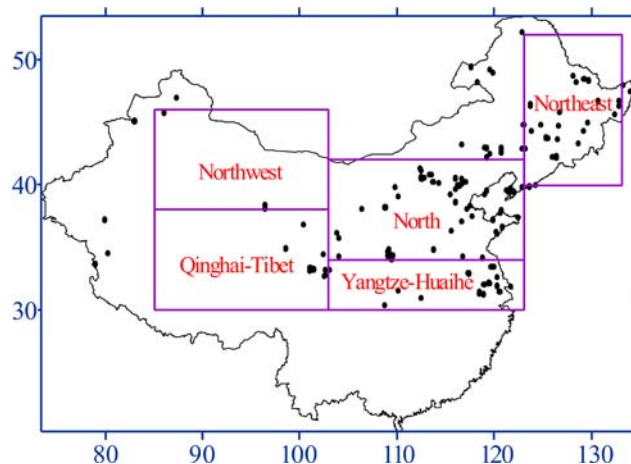


Fig. 1 The five regions as defined in the text and the distribution of pollen sites

Holocene forest cover change in the country. However, the available pollen data and the series of pollen maps based on the data can still allow some indication of the macro temporal-spatial patterns of forest-cover change in the area analysed.

Pollen percentages are calculated relative to a common pollen sum, which includes the total pollen grains from terrestrial plants excluding Cyperaceae. Cyperaceae pollen is excluded because it is not representative of highland plant taxa for comparability among sites. Here pollen map data for total arboreal pollen (AP) are used. AP percentage is preferred because it may be one of the best criteria for indicating the change in forest cover. In the study area, the modern AP isopoll of 40% coincides with the potential border between forest and steppe. This was verified especially for the Northeast China Plain where human interference with vegetation has been relatively slight (Ren 1994, 1998). The criterion value of AP percentage on the forest-steppe border, however, is a little lower than those in North America and Europe (Webb et al. 1983; Huntley and Birks 1983; Huntley and Webb 1988), mainly because shrub types were included in herbaceous pollen rather than in total arboreal pollen in the Chinese pollen mapping work. Therefore, 40% AP indicates the existence of an open forest in a region, and 70% AP implies the development of a more or less closed forest. Because my focus is mainly on the temporal change in forest cover, the value of the isopoll threshold is less important than its consistent application across time.

Two methods are used to investigate the change in forest cover. One is by presenting the AP isopolls above 40% for the study area, and the other is by showing the graphical pattern of AP changes through time for different regions. The original AP isopoll maps (Ren and Beug 2002) are modified to show the isopolls higher and lower than 40% for the 6 specific time slices (Fig. 2), and the AP isochrone map is

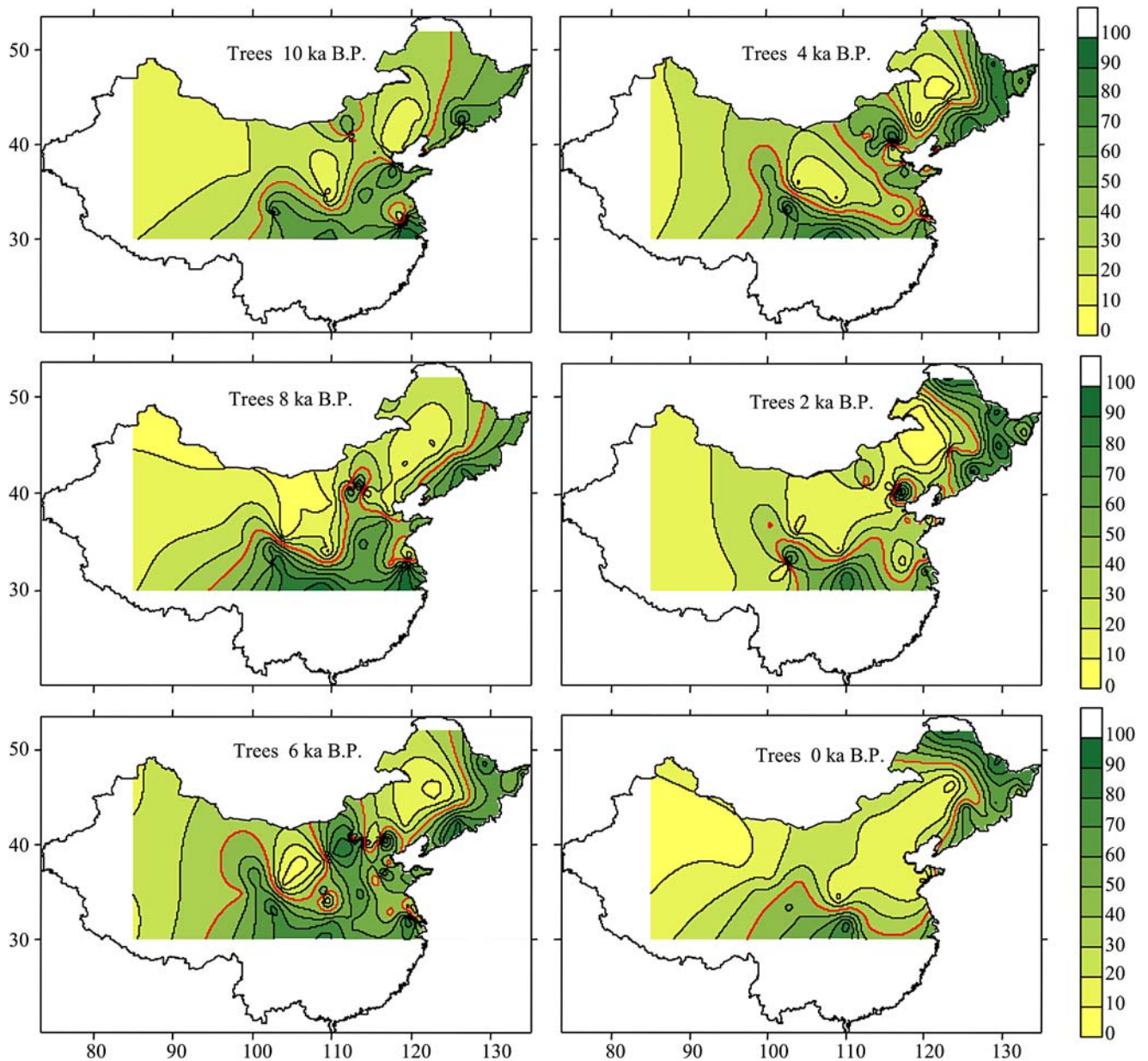


Fig. 2 AP isopoll maps of the Holocene for China. Red lines indicate the positions of AP 40% isopoll (modified from Ren and Beug 2002)

presented to indicate the spatial change of the 40% isopolls for the six time slices investigated (Fig. 3). In order to facilitate the visualisation of the temporal change and to reveal the regional difference of the changes, five regions are defined. Forest cover for each of the regions as well as the regions as a whole is calculated and given in Fig. 4. Southern China is not included because the pollen data there are extremely scarce and the region had been excluded from the maps of previous research (Ren and Beug 2002). The regional division is made on the basis of longitude \times latitude grids, but the physical and human characteristics as well as data sites have been taken into account in doing so (Table 1, Fig. 1). Thus, for example, Northeast represents a region normally called

Northeast China, with relatively uniform physical and political features. The westernmost part of China and the eastern part of Inner Mongolia are not included in the five regions because relatively fewer data sites are available there.

Forest land (i.e. woodland) here is defined as any places (sites) where AP percentages are more than 40%, and forest cover (FC hereafter) is defined as the ratio of forest-land area to total area within a given region. Because the pollen maps were automatically produced with the computer program Surfer 5.01 for Windows, which can perform the calculation of area and volume for mapped variables, it is easy to obtain FC for every time slice specified. FC is calculated as the area within the 40% isopoll (A_{40}), divided by the total area of the

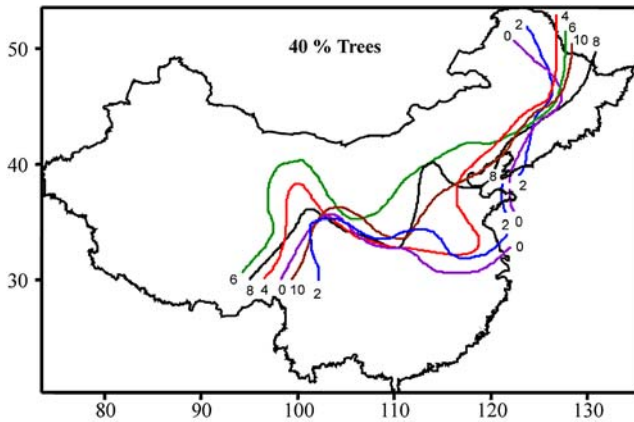


Fig. 3 AP isochrone map of the Holocene for China (modified from Ren and Beug 2002)

region (A_{tot}), minus the area in the region outside the national boundary or shoreline (A_{blank}):

$$FC = A_{40}/(A_{tot} - A_{blank}) \times 100\%$$

The FC thus estimated from the modern pollen data is different from that calculated from forest-inventory data. Because the area with AP percentages above 40% represents only the region where forest has grown at least on some stands, the FC thus estimated for a given region is generally higher than the inventory data published officially. It is possible to obtain the comparable forest-cover through a calibration process on the basis of modern pollen data and the statistically based FC, but this was not done in the present work because our focus is mainly on the temporal change in FC.

If not specified, the ages given in this paper are all uncalibrated radiocarbon dates. 0 ka B.P. as used in this paper denotes any time between the present and 0.5 ka B.P.

Fig. 4 Changes in forest cover during the Holocene for five regions in China

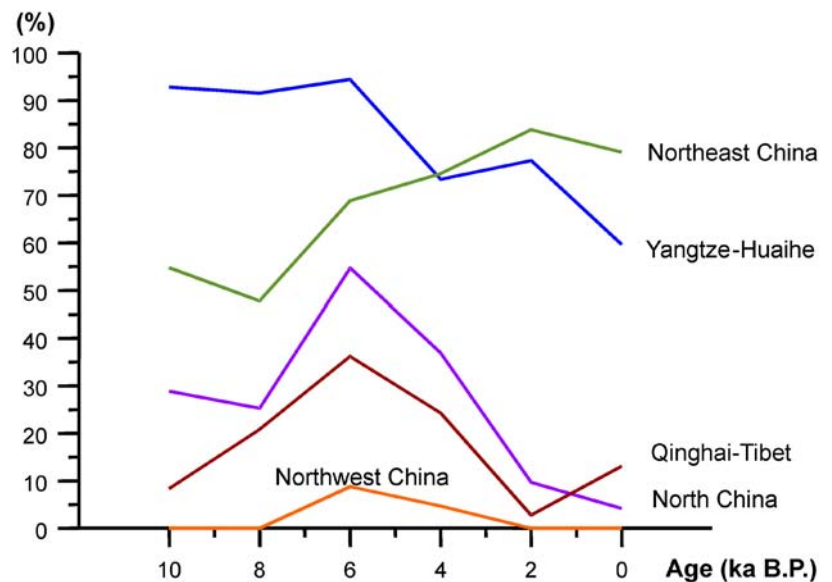


Table 1 Boundaries of the five regions in the study area; Q-T: Qinghai-Tibet; Y-H region: Yangtze-Huaihe

| | NE China | North China | NW China | Q-T Plateau | Y-H region |
|----------------|----------|-------------|----------|-------------|------------|
| Longitude (°E) | 123–133 | 103–123 | 85–103 | 85–103 | 103–123 |
| Latitude (°N) | 40–52 | 34–42 | 38–46 | 30–38 | 30–34 |

Results and illustration

Figures 2 and 3 show the AP isopoll maps and isochrone map respectively. In spite of a more westerly position for the 40% isopoll, AP percentages in the forest regions were generally lower at 10 ka B.P. as compared to the following time slices. AP values more than 70% occurred on the delta of the Yangtze River and in the Changbai Mts. of Northeast China at 10 ka B.P., indicating that only in these two regions could closed forests develop. At 8 ka B.P., a significant increase in area with forest occurred, as indicated by the inland migration of the AP 40% isopoll to the northern North China Plain, southern Inner Mongolia Plateau, eastern Loess Plateau and Qinghai-Tibet Plateau. The largest increase in FC was at 6 ka B.P. for most of the study area, when the AP isopoll 40% reached its most inland position during the Holocene, except in Northeast China.

4 ka B.P. witnessed a marked decrease in FC in the Yellow River basin, most notably in the southeastern Loess Plateau and southwestern North China Plain. The Liaodong and Shandong Peninsulas, northern North China Plain and eastern Qinghai-Tibet Plateau also experienced a drop in AP percentages in varying degrees. A significant rise in AP percentages and therefore in forest closure, however, occurred in the Changbai Mts. and Xiaoxingan Range at that time. These trends generally continued until the present. Today,

Table 2 Percentage changes of forest cover relative to preceding time slices

| Period (ka B.P.) | NE China | North China | NW China | Q-T Plateau | Y-H Region | Five Regions |
|------------------|----------|-------------|----------|-------------|------------|--------------|
| 10–8 | –13 | –13 | | 148 | –1 | 4 |
| 8–6 | 44 | 116 | | 74 | 3 | 54 |
| 6–4 | 8 | –33 | –47 | –33 | –22 | –22 |
| 4–2 | 12 | –74 | | –89 | 5 | –32 |
| 2–0 | –6 | –57 | | 368 | –23 | –7 |
| 6–0 | 15 | –92 | | –64 | –37 | –50 |

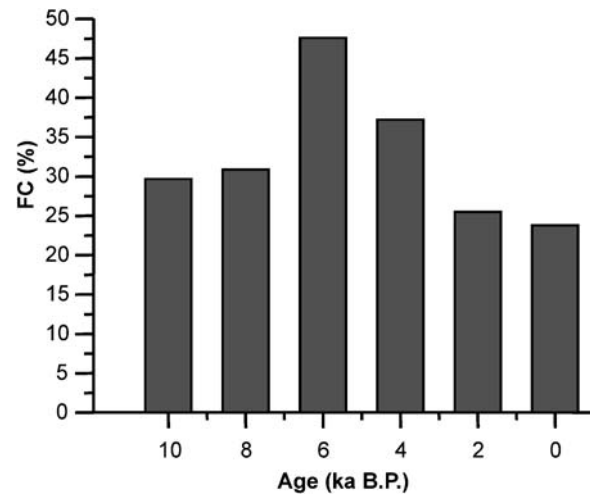
almost all of the Loess Plateau and the North China Plain are no longer covered by forests, but the FC in northernmost Northeast China may have reached the maximum for the Holocene. The tremendous drop in FC on the Loess Plateau and the North China Plain can be illustrated by the fact that the AP 40% isopoll (corresponding to the forest-steppe ecotone) migrated towards the southeast by about 500 km after 6 ka B.P.

Figure 4 shows the changes in FC for the five regions as defined in Table 1 and Fig. 1. Confidence for Northwest China is low because of the poor data coverage and the high abundances of herbaceous pollen throughout the Holocene. In the Northwest region, only at 6 ka and 4 ka B.P. were there some places covered by forests, which accounts for only 9% and 5% of the total area of the region. Nowhere could forests be found in this region after this.

FC in the North region was 29% at 10 ka B.P., but rose rapidly to 55% at 6 ka B.P. after a slight decrease at 8 ka B.P. A tremendous drop in FC occurred consistently after 6 ka B.P. in the North region, with the minimum for the Holocene being reached in the 0 ka B.P. map. Since 6 ka B.P., FC in the region has decreased by 92% (Table 2). A similar but smaller change in FC occurred in the Qinghai-Tibet and Yangtze-Huaihe regions where FC has declined by 64% and 37% respectively since 6 ka B.P. The Qinghai-Tibet region, however, had its lowest FC at 2 ka B.P., while the Yangtze-Huaihe region recovered slightly at 2 ka B.P. It should also be pointed out that even at present more than half of the area of the Yangtze-Huaihe region is still covered by forests.

A rather different change occurred in Northeast China. FC in this region before 6 ka B.P. changed in the same way as in the North region, but after 6 ka B.P. a general increase rather than a decrease is noted, with only 0 ka B.P. showing a slight drop. From 6 ka B.P. to 2 ka B.P., FC in the Northeast increased by 22%, and from 6 ka B.P. to 0 ka B.P. it increased by 15%.

For the five regions as a whole, an early Holocene increase in FC and a late-Holocene decline can be detected (Fig. 5). Between 10 and 8 ka B.P., FC in the five regions was around 30%. After it increased to 48% at 6 ka B.P., it steadily declined, and the lowest value of the Holocene, 24%, was

**Fig. 5** Changes in forest cover during the Holocene for the study area as a whole

reached at 0 ka B.P. Since 6 ka B.P., FC has dropped by 50% (Table 2), but much of the decrease had occurred by 2 ka B.P.

Discussion

For most regions of the study area, the early Holocene (10–6 ka B.P.) is the time period when FC evidently increased. The most obvious increase is found in the Qinghai-Tibet region and the North region. It can be also clearly seen in the Northeast and Northwest regions. Of course, most of the Qinghai-Tibet region has low data coverage, and the change of FC shown in the figures mainly represents the eastern part of the Qinghai-Tibet Plateau. Data coverage is even scarcer for the Northwest region, and the determination of FC change is obviously affected by the availability of few data sites in the northern Qinghai-Tibet region. In the Yangtze-Huaihe region, which had the highest FC of all the five regions at the beginning of the Holocene, the increase is not so significant, probably because of the buffering effect of the closed forests in response to disturbances. This regional difference supports the long-held view among ecologists that ecotones and semi-arid regions are very sensitive to climate change and/or human interference (Cui 1993; Allen and Breshears 1998).

The forest cover in most of the study area has decreased significantly since about 6 ka B.P., with an exception in the northern and eastern Northeast region where the decline of FC only appears in the most recent time slice mapped and is very small. It is also notable from Figs. 2–4 that the most impressive drop in FC occurred in the North region, which corresponds geographically to the middle and lower reaches of the Yellow River. Other regions experiencing a marked decrease in FC include the Yangtze-Huaihe region and the

Qinghai-Tibet region. In the light of percentage decrease, the Yangtze-Huaihe region seems less remarkable than the North and Qinghai-Tibet regions, but it is similarly significant when taking into consideration the small variance of FC in the region.

In a previous work, Ren (2000) pointed out the abnormal mid-to late Holocene decline of forests in some regions, especially in the middle and lower reaches of the Yellow River. Because that study analysed profile data with a high temporal resolution, it could identify the time-transgressive nature of the forest decline from the middle and lower reaches of the Yellow River towards the surrounding regions. The present research is basically consistent with the previous results, as seen from the tremendous drop in FC in the North and the tiny and most recent decline of FC in the Northeast. The later decline in FC of the other regions can be also partly detected in Figs. 2 and 3 despite the large time interval of the maps. Much of the time-transgressive pattern, however, is obscured in this study by the coarse temporal and spatial resolution.

Climate change and human interference are two likely causes for the change in FC in the study area. More robust evidence needs to be unearthed to tackle this question, but from the present and previous research results it is very likely that FC change prior to 6 ka B.P. was caused mainly by climatic change, while the subsequent decline in FC was predominantly induced by human activities. In the three eastern regions shown in Fig. 1, similar FC changes in the early Holocene are visible, with a general increasing trend and a return to lower values at 8 ka B.P. to varied extents (Fig. 4). The more or less concurrent changes imply that they were more probably under the influence of the spatially coherent factor of climate change. In addition, human disturbance generally leads to a decrease of FC, but the opposite is seen between 8 and 6 ka B.P., while for the period between 10 and 8 ka B.P. there is no evidence for major human settlements. In fact, a drying of the climate in Northeast China at 9–8 ka B.P. and a subsequent increase in wetness have been revealed by a multi-proxy data based reconstruction of Holocene climate change (Ren 1999). In this part of the country, the last millennium may have been the wettest period of the Holocene, and the driest period may have occurred between 9 and 8 ka B.P. This reconstruction was made mainly on the basis of fossil pollen data, but other lines of evidence from buried soils, bog formation, loess deposition and black-soil development, and lake evolution were also taken into consideration. The change in wetness in Northeast China was attributed to the combined effects of summer radiation/temperature and the transgression of the Bohai Sea and the Yellow Sea with global sea-level rise (Ren 1999). It is therefore very possible that the decrease in FC in the early Holocene and the general rising trend after 8 ka B.P. in Northeast China were induced by climate change.

The change in FC after 6 ka B.P., however, is asynchronous across the different regions. Although it is difficult to determine the difference in the timings of the onsets of FC decline among the North, Qinghai-Tibet and Yangtze-Huaihe regions from Fig. 4 because of the low time resolution, the regional difference in timing of FC decline is detectable from Figs. 2 and 3. This was also pointed out in the previous work based on the profile data (Ren 2000). From Fig. 4, however, the difference in the initial times of FC decline between the Northeast region and the other regions is highly significant, which could be best explained by the fact that Northeast China was only exploited in the last centuries. The forest decline of the last 5000 years has been attributed to the agricultural expansion from the middle and lower reaches of the Yellow River towards the surrounding regions (Ren 1994, 2000). Rain-fed agriculture originated in the North region, and the region was the political and economic centre of China for much of historical time (Tan 1982; An 1991; Meyer 1994; Loewe and Shaughnessy 1999). From the Yellow River basin to the surrounding regions, population spread and technology diffused. This scenario generally matches the extent and timing of FC decline in the study area.

No matter how the decline of FC in the study area was caused, the change in FC in such a vast area may have had significant impacts on the past global carbon cycle and regional climatic and environmental changes. The decline in FC may have contributed, in part, to the increase in Holocene atmospheric CO₂ concentration as revealed from ice-core records (Indermuhle et al. 1999). It is also possible that the FC change affected the historical climate in the Yellow River basin through the mechanics of bio-geophysical feedback. These questions require further investigation.

Conclusions

This work reconstructs Holocene changes in forest cover in China north of the Yangtze River based on mapped pollen data of total arboreal taxa. The result shows a generally increasing trend in FC from 10 to 6 ka B.P. in all regions, but a reversal to a lower level at 8 ka B.P. in the eastern monsoon regions, especially in the Northeast and North. FC peaks at 6 ka B.P. in all regions except for the Northeast which reached a maximum at 2 ka B.P. After 6 ka B.P., a marked decline in FC occurred in most regions. In the North region, which approximately corresponds to the middle and lower reaches of the Yellow River and the Huaihe River basin, FC dropped by about 90% after 6 ka B.P. In the easternmost part of the Qinghai-Tibet Plateau and the region between the Yangtze and Huaihe Rivers it decreased by 64% and 37% respectively after 6 ka B.P. However, FC in the Northeast region has increased by 15% since 6 ka B.P. even including a notable drop between 2 ka B.P. and present. For the study

area as a whole or northern China, FC has decreased by 50% from 6 ka B.P. to the present.

The spatial and temporal pattern of the FC change, and its correlation with ancient agricultural development, suggest that the decline in FC after 6 ka B.P. may have been caused predominantly by human activities, although the FC change before that time was probably caused by climate change. Regardless of the causes, the FC changes in China as demonstrated here may have significantly affected the global carbon cycle and the regional climatic changes of the Holocene.

Acknowledgements Special acknowledgement and sincere thanks are due to Professor H.-J. Beug for his tireless efforts in facilitating the collaborative research on Holocene vegetation history of northern China. This fruitful research was initiated in the spring of 1998 when I first visited the former Institut für Palynologie und Quartärwissenschaften, Göttingen University, as a Humboldt Fellow (Alexander von Humboldt Foundation, Germany) under the supervision of H.-J. Beug.

L.S. Zhang and H.-J. Beug were involved in the earlier studies upon which this work is based. I also thank H. J. B. Birks, F. Oldfield, K.-B. Liu, S.-M. Wang, P. Xiao and N. Shi for their constructive comments on this paper. This study was partly supported by the 10th Five-Year Gongguan Program of China (2001BA611B-01) and the Special Climate Change Fund of CMA.

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