Chin. Geogra. Sci. 2015 Vol. 25 No. 4 pp. 451–461
doi: 10.1007/s11769-015-0768-8

Springer Science Press
www.springerlink.com/content/1002-0063

Vegetation Development and Water Level Changes in Shenjiadian Peatland in Sanjiang Plain, Northeast China

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Abstract: This paper documents a 7800-year proxy record from the Shenjiadian peatland on the Sanjiang Plain in Northeast China. High-resolution plant macrofossil and colorimetric humification methods were used to reconstruct the vegetation and hydrologic history from a 193 cm-long sedimentary profile. Detrended correspondence analysis (DCA) was applied to transform the raw plant macrofossil data into latent indices of peatland water level. The vegetation community transited from an *Equisetum fluviatile* community to a *Carex lasiocarpa* community at approximately 3800 cal yr BP and was followed by a *Carex*-shrub community at approximately 480 cal yr BP. Based on the plant macrofossil DCA axis 1 scores and humification values, we distinguished four hydrologic periods: a wet period from 7800 cal yr BP to 4500 cal yr BP, dry periods up to 1600 cal yr BP, drier periods until 300 cal yr BP, and the driest period from 300 cal yr BP until the present. Through a comparison with other climate records, we suggest that the East Asian summer monsoon (EAM) was the main driving force for vegetation and water level changes to the Shenjiadian peatland through its impacts on precipitation.

Keywords: plant macrofossils; humification; Holocene; peatland; Northeast China

Citation: Wang Chunling, Zhao Hongyan, Wang Guoping, 2015. Vegetation development and water level changes in Shenjiadian peatland in Sanjiang Plain, Northeast China. *Chinese Geographical Science*, 25(4): 451–461. doi: 10.1007/s11769-015-0768-8

1 Introduction

Peat archives have been widely employed to provide high resolution information about vegetation history and the paleoenvironment of the Holocene (Barber, 1993; Charman, 2002; Barber *et al.*, 2003). Peat sediments not only record past climate change but can also be used to distinguish between the autogenic succession of peat and disturbance by humans, which have influenced local vegetation communities, hydrology and humification processes (Jakab *et al.*, 2009; Jong *et al.*, 2010; Pawlowski *et al.*, 2012).

The paleovegetation and paleohydrology of peatland ecosystems have been a topic of interest for many paleoecological and paleoenvironmental scholars. Plant macrofossils (Barber *et al.*, 2000; Barber *et al.*, 2003; Väliranta *et al.*, 2007; Galka *et al.*, 2013) and peat humification (Mauquoy and Barber, 1999; Chiverrell, 2001; Ma *et al.*, 2009) have been used as indicators of vegetation and peatland surface wetness. Owing to their characteristics, such as size and weight, plant macrofossils represent the historic vegetation of peat sediments *in situ* (Birks, 2002; Mauquoy and Van Geel, 2007). Moreover, the majority of plant microfossils can be identified to the species level, allowing more accurate paleovegetation and paleoenvironment reconstructions

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Received date: 2014-06-25; accepted date: 2014-09-30

Foundation item: Under the auspices of Chinese Academy of Sciences/State Administration of Foreign Experts Affairs (CAS/SAFEA) International Partnership Program for Creative Research Teams (No. KZZD-EW-TZ-07), National Basic Research Program of China (No. 2012CB956100), National Natural Science Foundation of China (No. 41271209, 41401099)

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(Birks, 2002). The studies of plant macrofossils in China began in the 1980s (Lang and Jin, 1984a; 1984b), but there have been few quantitative analyses (Hou, 1992; Jin and Lang, 1993; Zhao *et al.*, 2007; Zhao *et al.*, 2014). As an indicator of the degree of peat decomposition, peat humification has been thought to represent the environmental conditions at the time of peat accumulation, especially for surface wetness (Chambers *et al.*, 2012). Studies of peat humification recently began in China and presented key information about environmental changes during the Holocene (Ma *et al.*, 2009; Ma, 2010).

Analysis of peatland plant macrofossils could be used to reconstruct peatland vegetation history and determine the successional process of peatlands (Jasinski *et al.*, 1998; Branch *et al.*, 2012; Pawlowski *et al.*, 2012; Galka and Sznel, 2013), reconstruct peatland surface wetness (Väliranta *et al.*, 2007; Mauquoy *et al.*, 2008; Galka and Apolinarska, 2014; Zhao *et al.*, 2014), and distinguish between the relative influence of climate change and human disturbance on the process of peatland development (Chambers *et al.*, 2007a; 2007b; Tuittila *et al.*, 2007). Peat humification data can indicate the local surface wetness of peatlands and past regional climate change (Booth and Jackson, 2003; Borgmark, 2005; Chambers *et al.*, 2007c; Ma *et al.*, 2009). However, each proxy has its drawbacks, so plant macrofossils and humification should be used in combination to reconstruct the paleovegetation and paleoenvironment of peatlands (Yeloff and Mauquoy, 2006; Chambers *et al.*, 2012).

The Sanjiang Plain is the largest freshwater marsh in China, and it is sensitive to climate change. The amplitude of atmospheric temperature warming was 1.3℃ over the last century, which is higher than the national average (Sun *et al.*, 2006). To better understand this special climate phenomenon and predict future trends in the development of marshes, answering questions about the past is usually required. Vegetation history and paleoenvironmental changes can be reconstructed from the sediments deposited in this area. However, only a few researchers have carried out studies of the paleovegetation and the paleoenvironment of the peatlands in the Sanjiang Plain. Additionally, past research has mainly used pollen as a proxy to reconstruct vegetation history and climate change at a low resolution. Birks and Birks (2000) noted that the future use of proxy pollen must include plant macrofossils. However, most studies of plant macrofossils have only focused on the identification of type, and there has been neither semi-quantitative nor quantitative analysis in China.

In this study, we conducted high-resolution analysis of plant macrofossils and humification to reconstruct the history of the vegetation and the changes in water level from a sedimentary profile taken from the Shenjiadian peatland and which covers the last 7800 years. This study may be seen as a supplement to the paleovegetation and paleoenvironmental research in northeast China. The aims of this study were to 1) reconstruct the vegetation history, 2) detect changes in water level, and 3) identify the main driving factors that impact vegetation development and water level of the Shenjiadian peatland.

2 Methods

2.1 Study site

The study site is located in a peatland in the village of Shenjiadian in Huachuan County in Heilongjiang Province of China (46°34′52″N, 130°39′52″E) (Fig. 1). It is a valley peatland at an altitude of 65 m above sea level on the Sanjiang Plain in Northeast China. The climate is temperate continental with a mean annual temperature of 2.5℃, and the mean July and January temperature are 22.5℃ and –24.4℃, respectively. Total annual precipitation is approximately 476 mm, most of which falls in the summer and is primarily controlled by the East Asian summer monsoon (EAM). The frost season is approximately 232 days a year. The vegetation assemblages in this region are dominated by slender sedge (*Carex lasiocarpa*) communities, accompanied by *Carex pseudocuraica*, buckbean (*Menyanthes trifoliate*), marsh horsetail (*Equisetum fluviatile*), kingcup (*Caltha palustris*), kakitsubata (*Iris laevigata*), tufted loosestrife (*Lysimachia thyrsiflora*), and deyeuxialangsdorffii small reed (*Calamagrostis angustifolia*), as well as swamp willow (*Salix myrtilloides*), rosemary leaf willow (*Salix brachypoda*), and altai birch (*Betula fruticosa*) in the marginal areas of the peatland.

2.2 Field work

Peat sampling was conducted in June, 2011. Due to the geographical conditions, we dug an outcrop profile using a shovel, and the profile was photographed and

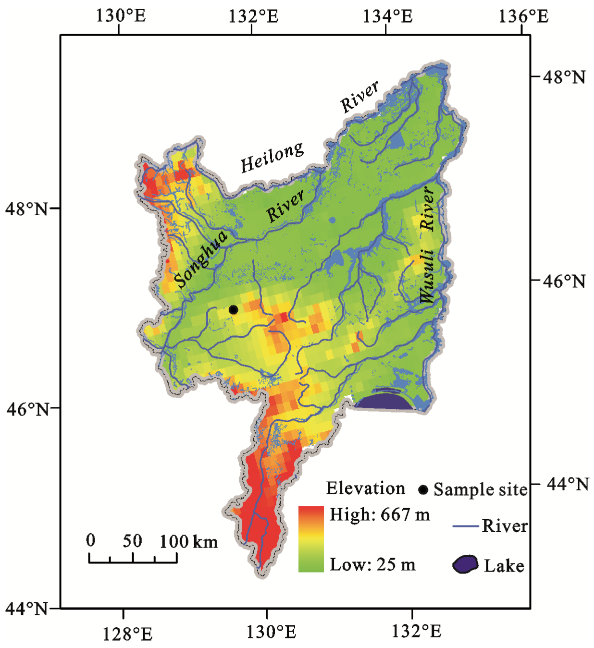

Fig. 1 Location of sample site in Shenjiadian peatland

documented in the field and then cut into contiguous 1 cm sub-samples using a stainless steel knife. Samples were placed in tagged, self-sealed plastic bags for transport to the laboratory and stored at 4℃ for further analysis. In total, 193 sediment samples were extracted.

2.3 Radiocarbon dating

Altogether, eight samples were analyzed at the Accelerator Mass Spectrometry Center in Xi'an, China (Table 1). The Accelerator Mass Spectrometry (AMS) ^{14}C data were converted to calibrated ages with CALIB version 7.0 (Stuiver and Reimer, 1993). Calibrated radiocarbon ages of years before present (cal yr BP) were used in the study. The AMS data at 105 cm, 124 cm and 143 cm were very similar. However, the depositional environment is relatively stable according to the lithology analysis and the plant macrofossil assemblages from 143 cm to 105 cm. Therefore, we suggested that the data at 124 cm and 143 cm were younger than the actual age, so those two dates were omitted. Linear interpolation was used to develop age-depth models and to further provide a calibrated age for each sedimentary sample (Telford *et al.*, 2004).

2.4 Plant macrofossil analysis

The Quadrat and Leaf Count protocol (QLC) was primarily employed to investigate changes in species composition during peatland development. Sub-samples of 5 cm^3 were taken from each sample. The sub-sample was first warmed in 5% NaOH for 1 hour and then rinsed with a gentle water jet in a 125 μm sieve. The selected plant macrofossils were studied under a low power (×10–×40) stereoscopic microscope and a light microscope (×100–×400). The percentages of the different plant components, e.g., brown mosses, herbs and shrub roots, were determined by microscopy, and seeds and fruits were counted as absolute numbers. Charcoal was also identified under a stereoscopic microscope. Plant macrofossil sub-samples were identified with the method of Mauquoy and Van Geel (2007) and a large collection of modern plant reference materials.

2.5 Humification analysis

Sub-samples of 0.125 g were taken from each ground sample at 1 cm intervals to determine humification using a modified version of the Bahnson colorimetric method (Blackford and Chambers, 1995; Chambers *et al.*, 1997). After treatment with 8% NaOH and filtration, a UV-2500 visible spectrophotometer fitted with a 540 nm filter was used to measure the light absorbance of the solution; absorbance values are characterized by the degree of peat humification. The mean absorbance

Table 1 Calibrated Accelerator Mass Spectrometry (AMS) radiocarbon dates (2σ range)

Depth (cm)	Lab No.	δ^{13}C (‰)	AMS ^{14}C age (yr BP)	Age (cal yr BP)	Material dated
24–25	XA7553	–37.78±0.51	550±24	541±20	Organic matter
57–58	XA7592	–38.64±0.48	1088±24	975±38	Organic matter
81–82	XA7542	–30.36±0.37	1381±26	1307±30	Organic matter
104–105	XA7543	–24.56±0.4	1673±32	1577±53	Organic matter
123–124	XA7554*	–22.74±0.56	1677±23	1577±44	Organic matter
142–143	XA7555*	–34.31±0.48	1731±30	1636±72	Organic matter
150–151	XA7570	–30.14±0.36	3542±26	3856±45	Organic matter
192–193	XA7571	–48.99±1.03	6982±90	7815±157	Organic matter

Note: * represents omitted data

values of three replicate samples were used, and data are expressed as a percentage of absorbance. When the absorbance value is higher, the degree of humification is higher and *vice versa*. A higher degree of humification indicates that the water level of the peatland is lower, and a lower degree of humification indicates that the water level of the peatland is higher (Ma *et al.*, 2009; Chambers *et al.*, 2012).

2.6 Data analysis

The plant macrofossils diagram was created using TILIA (version 5.12). A sum of squares cluster analysis was implemented using Constrained Incremental Sum of Squares (CONISS) within TILIA and produced a dendrogram that identified the most significant vegetation changes in the development of the wetland. Local macrofossil zones were defined with the aid of a cluster analysis. The plant macrofossil data were analyzed using DCA in CANOCO (version 4.5) to define the latent environment gradients.

Spectral analysis was performed on the plant macrofossil time series using REDFIT38 software (Scarton *et al.*, 2002) for unevenly spaced time series. We only conducted the analysis on the *Carex lasiocarpa* data because the *Carex lasiocarpa* community is dominant during the development process of the Shenjiadian peatland.

To obtain better comparisons between the humification data and the scores for the Detrended Correspondence Analysis (DCA) axis 1, we normalized the measures using the following equation (Branch *et al.*, 2012):

$$Z = \frac{X - \mu}{\sigma} \tag{1}$$

where Z is normalized value, X is raw value, μ is mean of all X, and σ is standard deviation of X.

3 Results

3.1 Stratigraphy and chronology of sediments

The bottom of the profile (193–163 cm) consists of black silty gyttja (Fig. 2). From 163 cm to the summit, the sediments consist of peat. Between 163 cm and 22 cm, the peat is mainly composed of herbaceous remains. The uppermost 22 cm consists of a small amount of shrub, but the peat remains herbaceous-dominated.

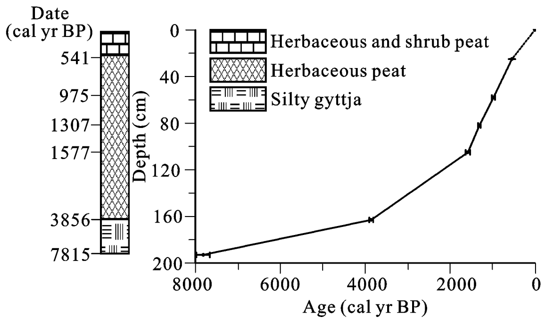

Fig. 2 Age-depth model of sedimentary profile

Data of 7800 cal yr BP were obtained at the bottom of the profile (Table 1, Fig. 2), and the peat started to accumulate at 3800 cal yr BP (163 cm) (Fig. 2). Three periods are distinguished according to the net peat accumulation rates after the silty gyttja accumulation period. A relatively high mean accumulation rate is evident between 3800 and 1500 cal yr BP (163–105 cm), and the mean peat accumulation rate is 0.025 cm/yr. This is followed by a significant rise, from 1500 cal yr BP to 540 cal yr BP (105–25 cm), and the mean peat accumulation rate is 0.078 cm/yr. The net peat accumulation rate then decreases from 540 cal yr BP to the present (25–0 cm), and the mean rate is 0.046 cm/yr, which is higher than in the first period.

3.2 Plant macrofossils

Sediment components quantified using the Quadrat and Leaf Count (QLC) method are presented in the macrofossil diagram (Fig. 3). Five main zones were identified based on the cluster analysis of the plant macrofossil assemblages.

Zone A (7800–5200 cal yr BP, 193–173 cm). This zone, at the bottom of the profile, corresponds to the accumulation of silty gyttja. Macrofossil assemblages dominated by unidentifiable herbaceous fragments remain. *Equisetum fluviatile* is the dominant species during this interval and is accompanied by a small amount *Carex lasiocarpa* and other *Carex* sp. A small amount of charcoal is present.

Zone B (5200–1600 cal yr BP, 173–105 cm). This zone corresponds to the onset of peat accumulation after the infilling of the pond. Local Macrofossil Zone B marks the rapid expansion of *Carex lasiocarpa* and the presence of small amounts of *Carex pseudocuraica*, *Menyanthes trifoliate* and *Carex* sp., which is not always present in the sediments. There was a significant increase in *Carex lasiocarpa* at the beginning of this zone that reached a maximum at 161 cm and was followed by a fluctuation state. *Equisetum fluviatile* is almost absent in this zone, and brown moss appeared at several specific depths. There was a decrease in charcoal during this interval. Plant Macrofossil Zone B shows that species were in a relatively steady state, although there were fluctuations during this zone.

Zone C (1600–900 cal yr BP, 105–55 cm). In this zone, *Carex lasiocarpa* is also the dominant species in the Shenjiadian wetland, and a slight increase in *Carex lasiocarpa* occurred during this interval. There was a decrease in *Carex* sp., and the amount of *Carex* sp. is relatively stable compared with the previous period. *Carex pseudocuraica* was found at the beginning of this zone, which subsequently almost disappeared. In contrast, *Menyanthes trifoliate* was absent at first and then reappeared at 90 cm. Charcoal is also present in this zone and experienced a slight increase.

Zone D (900–600 cal yr BP, 55–29 cm). A decline in *Carex lasiocarpa* occurred from 900 cal yr BP, but the percentage was still at a high level until 600 cal yr BP. *Carex pseudocuraica* occurred sporadically during this interval, and there was a sudden decline in *Menyanthes trifoliate*. *Carex* sp. was also present in this zone, and a minor increase in charcoal occurred.

Zone E (600–0 cal yr BP, 29–0 cm). There was a significant decline in *Carex lasiocarpa* in this zone, and shrub remains were discovered at 10 cm and then gradually increased. A strong increase in *Carex* sp. occurred, but the amount is not stable. Charcoal is present in this zone and shows an increasing trend. The percentage of charcoal reached a maximum at the top of the profile.

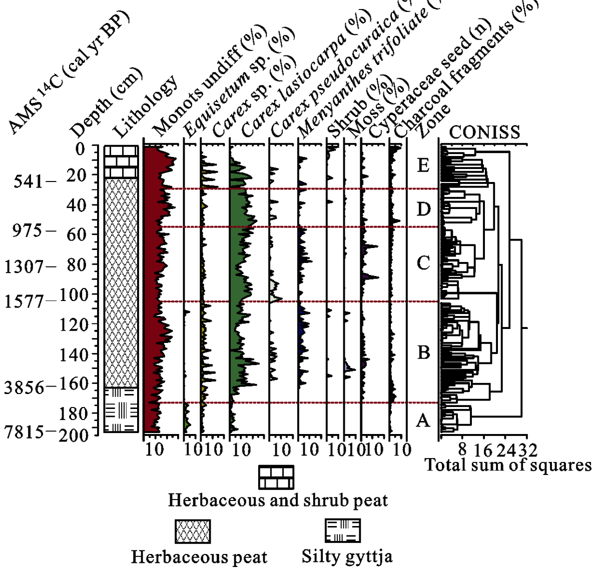

Fig. 3 Plant macrofossil diagrams from Shenjiadian profile. AMS: Accelerator Mass Spectrometry

3.3 Power spectrum analysis and Detrended correspondence analysis (DCA)

As shown in Fig. 4, the *Carex lasiocarpa* power spectrum shows periodicities ranging from 55 years to 578 years. Numbers above peaks indicate the corresponding periodicities (years). The periodicities of the power spectrum, such as 99 and 578 years, are similar to the periodicities in precipitation as inferred from Jinchuan peat δ^{13}C (Hong *et al.*, 2001).

The first and second axis coordinate charts of the DCA analyses are shown in Fig. 5. Axis 1 represents 21.8% of the cumulative variance and contrasts *Carex lasiocarpa*, *Carex pseudocuraica* and *Menyanthes trifoliate* with shrub. The first axis reflects water level

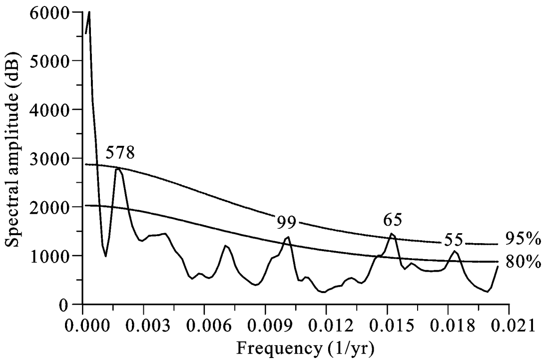

Fig. 4 Power spectrum of *Carex lasiocarpa* in plant macrofossils from Shenjiadian profile

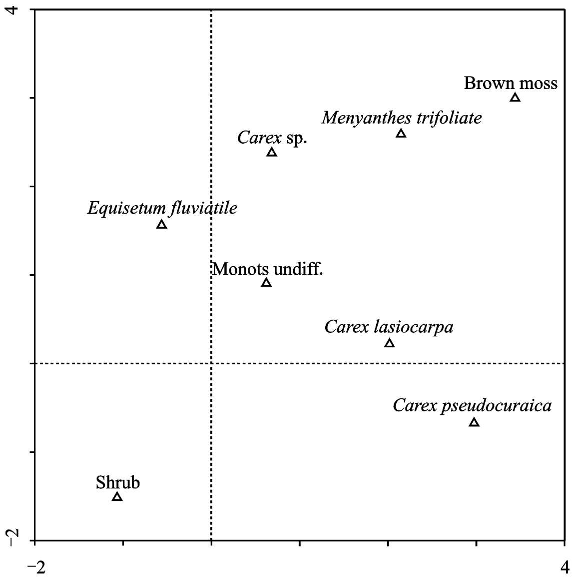

Fig. 5 Biplot of axis 1 and 2 scores from Detrended Correspondence Analysis (DCA) ordination of plant macrofossils from Shenjiadian profile

gradient because the species locate on the right part often grow on wet condition and shrub which locates on the left often distributes on drier land. Therefore, the DCA axis 1 scores could be interpreted as a record of water level fluctuations over the last 7800 years.

3.4 Humification

The humification data are presented in Fig. 6. Higher values denote that the water level is low, and lower values indicate the water level is high (Ma *et al.*, 2009). Between 7800 cal yr BP and 3800 cal yr BP, there is a gradual increase in the humification values suggesting a lowing of water level. The humification values show an oscillating pattern from 3800 cal yr BP to 1600 cal yr BP. Two obviously drier episodes were detected at 3800 cal yr BP and 1600 cal yr BP. The humidification values show sharply increase after 1600 cal yr BP and have been keeping high values till 1000 cal yr BP. A decline trend in the humification values occurred from 1000 cal yr BP to the present day.

3.5 Comparison of proxies

The normalized DCA axis 1 scores for the Shenjiadian peatland, in addition to the normalized humification data, have been plotted on the same axis against the calibrated ages (Fig. 6). High DCA axis 1 scores and low peat absorbance data indicate high water level and *vice versa*. Based on the two proxies, four phases of changing water level were identified in the Shenjiadian peatland.

The first phase is between 7800 cal yr BP and 3800 cal yr BP. This period appears to represent a wet phase. Wet conditions were implied by the evidence of *Equisetum fluviatile*, low humification values and high DCA axis 1 scores.

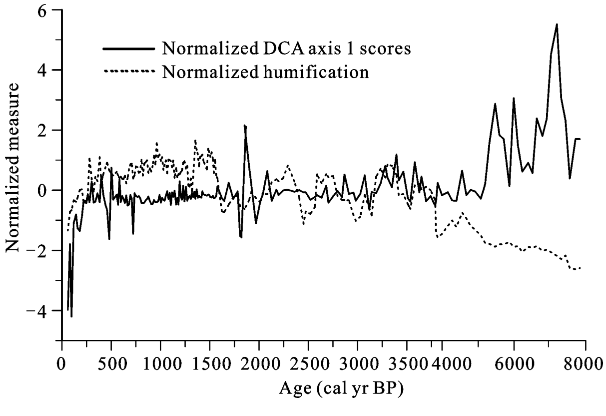

Fig. 6 Comparison of normalized humification dates and plant macrofossil Detrended Corredpondence Analysis (DCA) axis 1 scores from Shenjiadian profile against calibrated ages

The second phase is from 3800 cal yr BP to 1600 cal yr BP. The obviously greater humification values and reduced DCA axis 1 scores suggest a decrease in water level. The two proxies show fluctuations in frequency, and the amplitude is high, which indicates that the water level is in a fluctuation condition.

The third phase is between 1600 cal yr BP and 300 cal yr BP. The water level became lower than in the previous phase, which is inferred from the increase in humification values and the decrease in DCA axis 1 scores. The mean humification value is higher than in the second phase, and the mean value of the DCA axis 1 sores is slightly lower than in the prior phase. The two proxies oscillated at low amplitudes throughout this phase.

The last phase is from 300 cal yr BP to the present. A sudden decline in the humification values occurred during this interval, but the mean value is still at a high level. There was also a sudden decrease in the DCA axis 1 scores during this phase, and the value reached its minimum.

4 Discussion

4.1 Vegetation history and hydrological change

Plant community characteristics are a result of the combined effects of multiple environmental factors. However, the impact of each environmental factor on the plant community is different. Some researchers have carried out studies of the relationship between the plant community and environment factors in the Sanjiang Plain (Ji *et al.*, 2006; Zhou *et al.*, 2006; Luan *et al.*, 2013). The results of these studies suggest that water level is the main factor controlling the components of the vegetation community (Zhou *et al.*, 2012; Lou *et al.*, 2013). Therefore, changes in the water level of the Shenjiadian peatland can be reconstructed from the plant macrofossil assemblages and the degree of humification recorded in sedimentary sequences.

At approximately 7800 cal yr BP, the dominant presence of *Equisetum fluviatile*, an aquatic macrophyte, indicates that the Shenjiadian peatland originated from a shallow lake or pond (Pawlowski *et al.*, 2012). In addition, the higher DCA axis 1 scores and the lower humification values also support the presence of an open body of water. Subsequently, the pond gradually disappeared as a result of successional infilling processes, and the duration of the pond infilling stage was most likely 2600 years. The origin of the Shenjiadian peatland was mainly controlled by geomorphological characteristics (Qiu *et al.*, 2008).

By 5200 cal yr BP, an increase in *Carex lasiocarpa* indicates that the hydrological condition changed and peatland probably began to develop of the study region although the pond still existed at the site. The vegetation of study site initially transited into a rich fen dominated by *Carex lasiocarpa* and accompanied by *Carex pseudocuraica* and *Menyanthes trifoliate* with the occasional presence of brown moss. The *Carex lasiocarpa* community is also dominant in the Sanjiang Plain in the present day (Lou and Zhao, 2008). This increase in *Carex lasiocarpa*, combined with the lithology analysis, indicates that peat began to accumulate at 3800 cal yr BP. This stage persisted until approximately 600 cal yr BP, and within this period, the vegetation rapidly expanded to a maximum of *Carex lasiocarpa* and *Menyanthes trifoliate*. Although vegetation composition fluctuated during this interval, it was relatively stable overall. The humification data further support these changes in water level (Fig. 6), so the peatland developed during this period.

From approximately 600 cal yr BP to the present day, great changes have taken place in the vegetation communities. *Carex lasiocarpa* showed an obviously decreasing trend and disappeared at the top of the profile; *Carex pseudocuraica* and *Menyanthes trifoliate* are only present at specific depths. This conclusion is supported by the higher humification values. Additionally, the amount of charcoal detected in the near-surface peat suggests that fire was a regular occurrence throughout the last one thousand years (Jiang *et al.*, 2008). The occurrence of fire implies that the hydrological conditions of the peatland became drier (Tinner *et al.*, 2006). However, human activities in and near the peatland have not been significant until the last century (Sun *et al.*, 2006). Thus, the occurrence of fire was driven by climate changes rather than human activities.

4.2 Driving forces controlling development of Shenjiadian peatland

Peatland development is controlled by climate, hydrological factors and geology and geomorphology, and Holocene climate is the main driving force (Qiu *et al.*, 2008). Its geomorphological structure suggests that the Shenjiadian peatland is a valley peatland that originated from a shallow lake or a pond located in a depression at the study site. The main characteristic of the climate is cold/wet, which is conducive to the accumulation of peat and the development of peatland. Hydrological conditions are the main driving force of peatland development, and the study site is located in the continental monsoon climate zone. The water supply of the Shenjiadian peatland mainly originated from valley catchments and groundwater. Therefore, the valley catchments are mainly supplied by precipitation, which is induced by the EAM. Hence, to explore whether the EAM is a main driving force of the Shenjiadian peatland development, we compared our results to climate changes at two other sites with high temporal resolution and precise age, Hani (Hong *et al.*, 2005) and Jinchuan (Hong *et al.*, 2001). The Hani and Jinchuan peatlands are located in Jilin Province, northeast China, which is also located in the EAM region.

As shown in Fig. 7, humification values increased continuously from 7800 cal yr BP, indicating a gradual lowing water level until approximately 3800 cal yr BP. This also indicates the termination of the middle Holocene climatic optimum. Ample evidences from other peat archives also suggest a change in the climate to drier conditions at approximately 3800 cal yr BP in China (Zhou *et al.*, 2004; An *et al.*, 2005; Ma *et al.*, 2009), which demonstrates that the change was significant and geographically widespread. This result corresponds to the δ^{13}C record of Hani and Jinchuan peat (Fig. 7), which show an increasing trend that indicates that the strength of the EAM became weaker or precipitation declined between 7800 cal yr BP and 3800 cal yr BP (Hong *et al.*, 2001; Hong *et al.*, 2005). These comparative analyses suggest that the water level of the study site is controlled by EAM at this period, and the Shenjiadian peatland is sensitive to the climate changes. The reduced precipitation induced by weakened EAM is the main driving force for the origination of the Shenjiadian peatland.

In the following 2800 years, both the humification records and DCA axis 1 scores showed that the water level fluctuated around a mean value (Fig. 6), indicating that the water level was in a relatively stable condition. This was consistent with the δ^{13}C records from the Hani and Jinchuan peat, which indicate that the weakened

EAM was also in a relatively stable condition between 3800 cal yr BP and 1000 cal yr BP (Hong *et al.*, 2001; Hong *et al.*, 2005). This result also corresponds with the weakened ASM inferred from the Nuanhe Cave δ^{18}O (Wu *et al.*, 2011), but it is not entirely consistent because regional differences in monsoon precipitation occurred along the latitudinal transect at a centennial to decadal scale (An *et al.*, 2000). Through the comparison of these proxies, we suggest that the relatively stable EAM was conductive to the development of the Shenjiadian peatland during this stage.

After 1000 cal yr BP, the water level of the Shenjiadian peatland showed a decreasing trend based on plant macrofossil assemblages. Additionally, the humification values decrease gradually but the mean value was still higher than the previous, indicating that the water level was lower until 300 cal yr BP. During this interval, the δ^{13}C records of Hani and Jinchuan peat showed an increasing trend, indicating the EAM enhanced (Hong *et al.*, 2001; Hong *et al.*, 2005). The water level changes are inconsistent with the δ^{13}C records of the Hani and Jinchuan peat, which may indicate that the development of the Shenjiadian peatland was mainly affected by the other climatic and environmental factors during this period. The hypothesis requires further investigations.

It can be inferred that the water level decreased from the plant macrofossil assemblages during the following 300 years (Fig. 6). The δ^{13}C records of the Hani and Jinchuan peat both indicate that the strength of the EAM weakened, or precipitation declined within this period (Hong *et al.*, 2001; Hong *et al.*, 2005). This result is consistent with the reported findings of other proxies of different achieves (Wu *et al.*, 2011). Additionally, the δ^{18}O records of Jinchuan indicate that the temperature showed an increasing trend after 300 cal yr BP (Hong *et al.*, 2000). Both the decreasing precipitation and highing temperature make the water level became lower. However, a significant decrease in the humification values occurred at approximately 300 cal yr BP, which indicates that the water level of Shenjiadian peatland became higher than the previous period. It seems contradictory, but why would the humification data show the opposite trend? A possible reason for this discrepancy is that the plant remains in the upper part of the profile have not enough time to decompose. Another possibility is that the component of plant community is difficult to decompose because shrub gradually became dominant during this period (Yeloff and Mauquoy, 2006). In summary, the water level of the Shenjiadian peatland has been in a lower state over the past several hundred years. This confirms the importance of the multi-proxy reconstruction of paleoclimate and paleoenvironment.

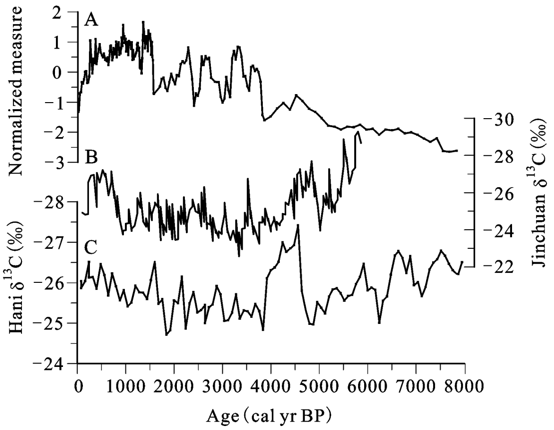

Fig. 7 Comparison of climate changes and Asian monsoons. A, humification record from Shenjiadian peatland; B, precipitation record from δ^{13}C of Jinchuan peatland (Hong *et al.*, 2001); C, proxy record for East Asion summer monoon (EAM) from δ^{13}C of Hani peat cellulose (Hong *et al.*, 2005)

In addition, the periodicities of the power spectrum detected for *Carex lasiocarpa*, such as 99 years (80% confidence level) and 578 (90% confidence level) years, are close to significant precipitation periods inferred from the δ^{13}C record of Jinchuan peat (95 years and 584 years) (Hong *et al.*, 2001). This correlation further supports the idea that the water level of the Shenjiadian peatland is mainly driven by precipitation induced by EAM (Hong *et al.*, 2001). However, there are differences between the records of the Shenjiadian peatland and the other records from different archives at decades to centennial timescale, which could be attributed to the different age resolution and regional characteristics (Zhou *et al.*, 2004; Pawlowski *et al.*, 2012).

5 Conclusions

The high-resolution plant macrofossil and humification records from the Shenjiadian peatland provide valuable information regarding the history of the vegetation and variations in water level. The Shenjiadian peatland originated from an open water body or pond and sequentially developed into a rich fen. The peat began to accumulate at approximately 3800 cal yr BP, and the vegetation community transitioned from an *Equisetum fluviatile* community to a *Carex lasiocarpa* community followed by a *Carex*-shrub community. The results show that the water level of the study site changed from high to low over the past 7800 years. Our study suggests that the vegetation community transition and water level changes were driven by precipitation induced by the EAM. The development of the Shenjiadian peatland was mainly driven by regional climate but also affected by other climatic and environmental factors.

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