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RESEARCH ARTICLE

Surface pollen and its relationship to vegetation in the Zoige Basin, eastern Tibetan Plateau

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Abstract We use a data set of 23 surface pollen samples from moss polsters in the Zoige Basin to explore the relationship between modern pollen assemblages and contemporary vegetation patterns. The surface pollen samples spanned four types of plant communities: *Carex muliensis* marsh, *Stipa* and *Kobresia* meadow, *Carex*-dominated forb meadow and *Sibiraea angustata* scrub. Principal-components analysis (PCA) was used to determine the relationships between modern pollen and vegetation and environmental variables. The results show that the pollen assemblages of surface moss samples generally reflect the features of the modern vegetation, basically similar in the vegetation types and the dominant genera; however, they don't show a very clear distinction between different communities. Our results also demonstrate that pollen representation of different families or genus varied. Some tree taxa, such as *Pinus* and *Betula*, and herb types, such as *Artemisia* are over-represented, while Asteraceae, Ranunculaceae and Cyperaceae are moderately represented, and Poaceae and Rosaceae are usually under-represented in our study region. PCA results indicate that the distribution of vegetation in the Zoige Basin is mainly controlled by precipitation and altitude.

Keywords modern pollen assemblages, principal-components analysis, Zoige Basin, eastern Tibetan Plateau

1 Introduction

Climate change and global warming are the most urgent issues that people are facing today. The Tibetan Plateau, due to its important role in the atmospheric circulation in Asia, becomes the hot region for the global change research. To better predict the future climate, the trend of past climate change, which has been documented in various proxy records in sediment, should be understood first. Among these records, pollen archives provide accurate environmental information and are widely used in paleo-vegetation and paleo-climate reconstruction (Liu et al., 1998; Herzschuh et al., 2004; Zhao et al., 2007), which provide valuable insights into understanding the vegetation and climate history of the Tibetan Plateau. However, representation of pollen to vegetation could be complex due to the complicated process of pollen precipitation. In early 1960s, palynologist pointed out that much of the uncertainty in the interpretation of the Late Quaternary pollen assemblages can be removed by the judicious use of pollen surface samples from a variety of vegetation formations (Wright and Cushing, 1967). Thus, understanding the relationship between modern pollen spectra and present-day vegetation is critical to the reconstruction of vegetation. A series of modern pollen studies have been carried out to help interpret fossil pollen records, paleo-vegetation and paleo-climate reconstruction (e.g., Wright and Cushing, 1967; Liu et al., 1999; Yu et al., 2001; Shen et al., 2006; Luo et al., 2009; Zhao and Herzschuh, 2009).

The vegetation on the Tibetan Plateau, unlike that of the lowlands of eastern China, is less disturbed by human activities and therefore provides an excellent test of the assumptions that modern surface pollen samples reflect the natural vegetation of the region (Yu et al., 2001). However, our understanding of the fundamental relationships between vegetation and pollen deposition in this area remains sketchy. Yu et al. (2001) analyzed and discussed surface pollen assemblages from different vegetation types in the Tibetan Plateau. Shen et al. (2006) studied the relationships between modern pollen rain and climate from forests, shrublands, meadows, steppes, and deserts in the Tibetan Plateau. Zhao and Herzschuh (2009) explored the relationship between modern pollen assemblages and contemporary vegetation patterns of four vegetation zones—alpine meadow, steppe, steppe desert and

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desert—under different climatic/elevational conditions in north-eastern Tibetan Plateau. Modern pollen rain based on the distribution of river systems and the topography around Lake Qinghai was studied by Shang et al. (2009). The Zoige Basin is located on the transitional region of modern summer monsoon and Tibetan Plateau, not only the west margin of south-east monsoon influenced region, but also the north margin of south-west monsoon influenced region. Due to its sensitivity to the climate change, it is an ideal place for the research of the global climate change. However, no surface pollen study in this region (but see Cai et al., 2007) has been done to explore the relationship between surface pollen and modern vegetation, particularly for individual taxa from different communities.

We present modern pollen spectra of 23 surface samples from moss polsters from different kinds of floristic communities in the Zoige Basin, eastern Tibetan Plateau. To understand the relationships between surface pollen and modern vegetation, ordination techniques and pollen representation of some plant taxa were used.

2 Regional setting

The Zoige Basin (102°10′–103°55′E, 32°20′–34°05′N) is located on the eastern margin of the Tibetan Plateau (Fig. 1), upstream of the Yellow river. It has an area of 30800 km^2. It is a Neozoic fault basin surrounded by mountains higher than 5000 m asl., and the average altitude of the basin is 3400–4000 m.

Mean annual precipitation of the basin is 560–860 mm, of which about 70% falls from May to August, The mean annual temperature is 0.6°C–1.2°C, the average temperature of the warmest month, July, is 10.9°C–12.7°C, and that of the coldest month, January, is −8.2°C to −10.9°C. Heavy wind blows every season, which was mainly affected by south-west and north-east monsoons.

There are two main vegetation types in our study sites: alpine meadow and marsh vegetation. The alpine meadow, which is influenced by the vertical distribution of the vegetation, is scattered in the hilly slopes, river floodplain

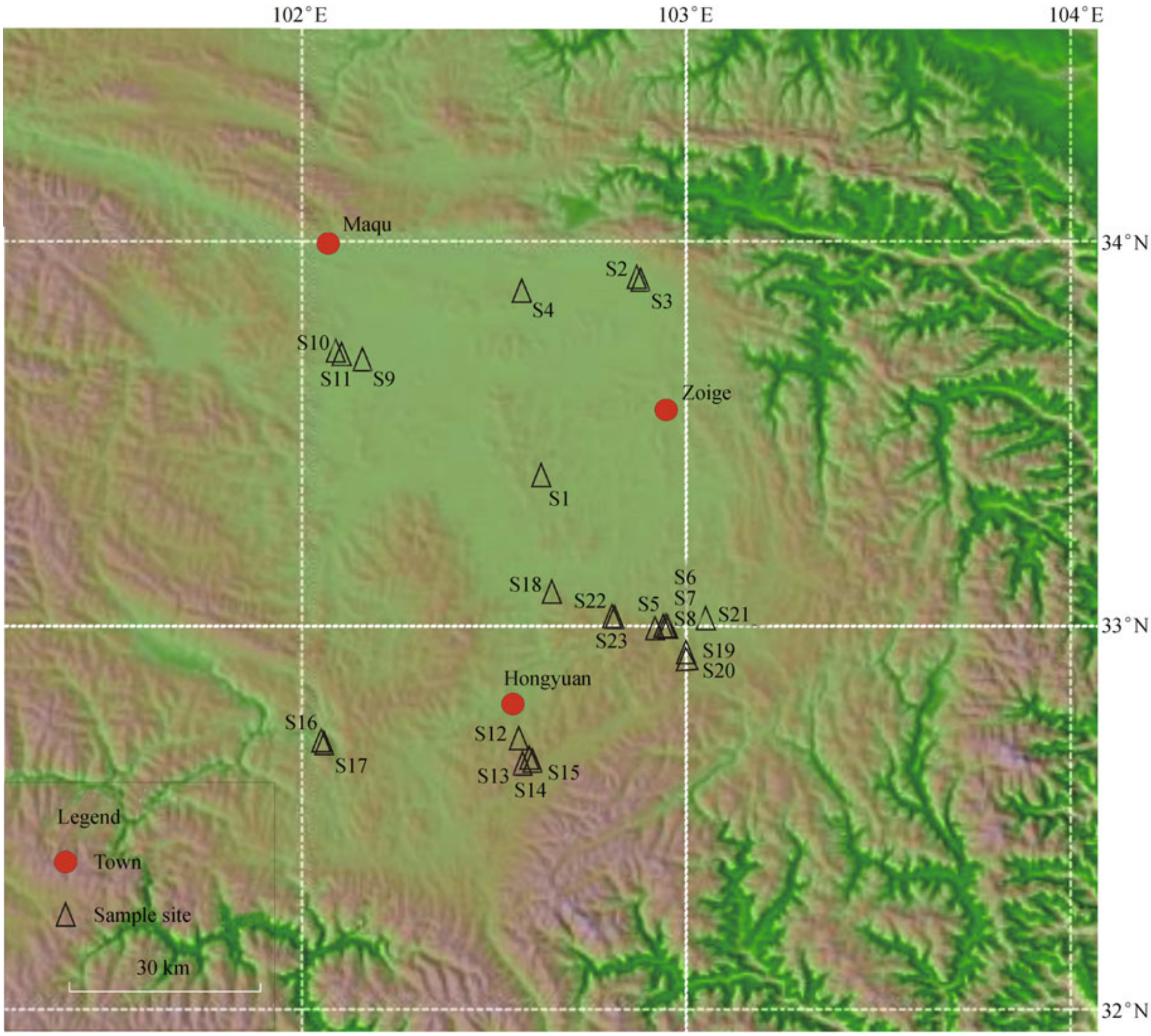

Fig. 1 The location of the modern pollen samples from the Zoige Basin, the eastern Tibetan Plateau

and terraces where drainage conditions are better. Plant types in alpine-meadow are mainly composed of Cyperaceae (mainly including *Kobresia pygmaea* and *Carex muliensis*) and Poaceae (including *Stipa capillacea*, *S.aliena*, *S.purpurea* and *Roegneria nutans*). Besides, *Polygonum viviparum*, *Polygonum* sp., *Trollius farrei*, *Pedicularis oederi* var. *sinensis*, *Anemone demissa*, *Gentiana* sp., *Thalictrum alpinum*, *Gentiana macropphylla*, *Rheum palmatum* are also common taxa. The marsh vegetation, which is formed from excessive surface water, is distributed in the lowlands between the hills. The vegetation is dominated by Cyperaceae (*Carex muliensis*), with some *Cremanthodium lineare*, *C. Plantagineum*, *Caltha scaposa*, *Sanguisorba filiformis*, *Chamaesium paradoxum*, *Ranunculus batrachium*, *Stipa purpurea* and *Roegneria nutans* (Fig. 2).

There are also some other vegetation types covered around the basin and the surrounding mountains, including four main vegetation types: the sub-alpine broadleaf forest, sub-alpine needle leaf forest, scrub and meadow. These plant data are based on the vegetation units that recognized in Hou (2001) and the vegetation types recorded in the Editorial Board of Sichuan Vegetation (1980). The sub-alpine broadleaf forest sporadically scattered in the eastern Zoige Basin at altitudes of 2800–4200 m a.s.l., and the vegetation patterns are mainly consisted of *Betula utiliz* forest and *Populus davidiana*, *Betula platyphylla* var. *Szechuanica* forest. The sub-alpine needleleaf forest mainly distributed in the north-eastern part of the Zoige Basin, and surrounding the Hongyuan peat at altitudes of 2400 to 3800 m, mainly consisting of the *Abies faberi* forest, *Picea purpurea* forest, small area of *Pinus densata* forest and *Larix potaninii* forest. The scrubs are frequently distributed in the eastern Zoige Basin and around Hongyuan peat. They are mainly composed of *Salix vaccinioides* scrub, *Rosa sericea* scrub, *Dasiphora fruticosa* scrub and *Rhododendron telmateium* scrub. The meadows are the most common vegetation types around the Zoige Basin, covering a large area of the Zoige Basin and surrounding mountains at altitudes of 3000–4800 m,

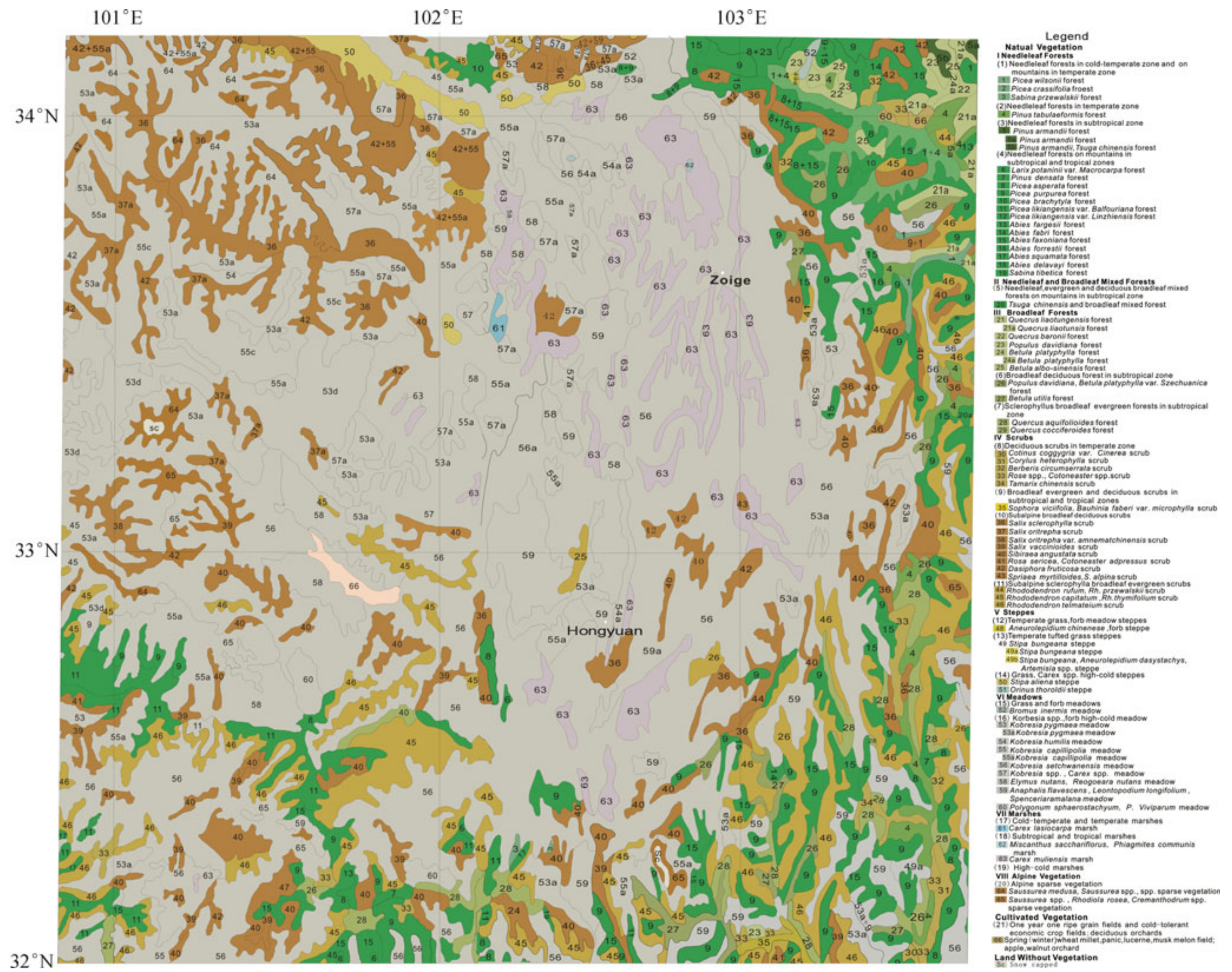

Fig. 2 The modern vegetation of Zoige Basin, the eastern Tibetan Plateau

among which the *Carex muliensis* marsh meadow and the *Kobresia* spp. meadow are the most common patterns.

3 Material and methods

We collected 23 surface samples from moss polsters in July 2008, as samples from mosses are found to provide the most accurate representation of the contemporary vegetation (Zhao et al., 2009). At the same time, fresh flowers of some plants were collected for pollen identification reference. The location of each plot was determined by GPS. Major plant taxa at each sampling site were also recorded in the field. 20 major modern plant taxa were found in the study area, and the sample sites can be classified as four community types — *Carex muliensis* marsh, *Stipa* and *Kobresia* meadow, *Carex* dominated forb meadow and *Sibiraea angustata* scrub community. Table 1 gives a summary description of relevés and surface pollen samples.

All surface samples were treated to extract the pollen grains (Faegri and Iversen, 1989) including HCl, KOH, HF and acetolysis treatments, and fine sieving to remove clay-sized particles. Pollen was identied and counted at 400 × magnication. At least 400 pollen grains were counted and used as the pollen sum for pollen percentage calculations. Pollen diagrams were plotted using TGView 2.0 (E. Grimm, Illinois State Museum, Springeld, Illinois, USA).

Principal-components analysis (PCA) is an ordination procedure that calculates the distances between samples in a way that approximates their Euclidean distance in a multidimensional space (Lamb, 1984). In this study, a PCA of all samples was performed on pollen percentages using the CANOCO program (ter Braak, 1988). Only the percentages of 13 pollen types that reached a value of at least 2% in any sample were included in PCA. We designed two PCA runs. Firstly, a PCA of all samples based on surface pollen samples was implemented to explore the similarity of sites in the same plant community. Secondly, a PCA of all samples based on surface pollen taxa was performed to infer the different taxa, so as to explore the main patterns of pollen taxonomic variation among samples.

4 Results

4.1 Pollen percentages of the surface samples

Pollen spectra of the surface samples are shown in Fig. 3. Four pollen assemblage groups can be distinguished corresponding to the four plant community types. The modern pollen spectra are dominated by herb pollens, and the pollen assemblages are mainly consisted of Cyperaceae, Ranunculaceae, Poaceae, Asteraceae, Cruciferaceae, *Artemisia, Polygonum*, Fabaceae and Rosaceae. Tree pollens such as *Betula*, *Pinus, Picea,* and *Abies* are present with high frequency. The spore is rare, and only a few Polypodiaceae are found, with total percentages less than 1%. The different taxa in pollen samples show varying degrees of correspondence with their abundance in phytocommunity types.

1) Pollen assemblages in *Carex muliensis* marsh

We collected 11 samples in this type of community, whose contemporary vegetation is mainly composed of *Carex muliensis*, Ranunculaceae, Asteraceae, Fabaceae, and *Gentiana*. This pollen group is characterized by Cyperaceae (22.1% to 81.1%). Other herbs including Poaceae (0.2% to 40.5%), Ranuncu1aceae (0.9% to 9.6%), *Polygonum* (0.4% to 28.4%), non-*Artemisia* Asteraceae (0.6% to 10.4%), Cruciferae (0 to 20.7%), *Artemisia* (0.5% to 4.7%) and Fabaceae (0 to 3.8%). Tree pollens are mainly from *Betula* (7.3%), *Pinus* (3.7%), *Picea* (1.2%) and *Abies* (0.9%).

2) Pollen assemblages in *Stipa* and *Kobresia* meadow

Six samples are from this community. Poaceae and Cyperaceae are the most abundant taxa in modern vegetation, accompanied by some Asteraceae, *Polygonum*, Fabaceae, Rosaceae, Ranunculaceae and *Artemisia* taxa. Corresponding with the contemporary vegetation, the pollen are also dominated by these taxa. But the percentage of Cyperaceae pollen is apparently lower than that of in group 1. However, the average percentage of Poaceae in this group is as high as 9.2%, showing its highest value in all four groups.

3) Pollen assemblages in *Carex*-dominated forb meadow

We obtained four samples within this type of community, in which the temporary plant have larger diversity than the above-mentioned communities. Cyperaceae, Ranunculaceae, Cruciferae, *Artemisia*, Asteraceae, *Polygonum*, Poaceae, Fabaceae and *Thalictrum* were the dominant pollen taxa, but the percentage of different taxa varies from sample to sample.

4) Pollen assemblages in *Sibiraea angustata* scrub

Only two samples were obtained from this type of community. *Sibiraea angustata* was the most abundant taxa in scrub layer, while the herb layer was dominated by Asteraceae, *Ranunculus*, *Artemisia* and *Carex* sp. The pollen proportions of Asteraceae, Cyperaceae, Fabaceae, *Polygonum*, Ranunculaceae, Poaceae, Cruciferae, *Artemisia* become more important compared to previous groups. The percentage of Rosaceae is low (only 0.4%), although *Sibiraea angustata* occupied a relatively high percentage in modern vegetation.

4.2 Ordination of pollen data

The results of the PCA analysis are shown in Figs. 4(a) and 4(b). The first two axes explain 44.13% of the total variance in the pollen data set. Most of *Carex muliensis* marsh samples are distributed in the second quadrant due to their high percentage of Cyperaceae and Poaceae

Table 1 Location and surrounding vegetation types of regional surface pollen samples from the Zoige Basin, eastern Tibetan Plateau

Sample code	Latitude (N)	Longitude (E)	Elevation/m	Sample type	Major plant taxa	Community type
S1	33°27′43.3″	102°38′3.6″	3467	Moss	*Carex muliensis*, *Equisetum*, Ranunculaceae, *Hippuris vulgaris*, *Oenanthe javanica*	*Carex muliensis* marsh
S2	33°55′30.3″	102°52′10.6″	3435	Moss	*Carex muliensis*, Ranunculaceae, *Gentiana*, Asteraceae, *Allium*, Fabaceae	*Carex muliensis* marsh
S3	33°55′30.3″	102°52′10.6″	3435	Moss	*Carex muliensis*, Ranunculaceae, *Gentiana*, Asteraceae, *Allium*, Fabaceae	*Carex muliensis* marsh
S4	33°48′02.6″	102°34′22.2″	3435	Moss	*Carex muliensis*, Asteraceae, *Gentiana*, Poaceae, Leguminosae	*Carex muliensis* marsh
S5	33°04′38.6″	102°51′19.3″	3572	Moss	*Carex muliensis*, *Ranunculus*, Asteraceae, *Papaver,* Rosaceae, *Tsuga*	*Carex muliensis* marsh
S6	33°04′38.6″	102°51′19.3″	3562	Moss	*Carex muliensis*, *Ranunculus*, Asteraceae, Rosaceae, *Tsuga*	*Carex muliensis* marsh
S7	33°04′38.6″	102°51′19.3″	3562	Moss	*Carex muliensis*, *Ranunculus*, Asteraceae, Rosaceae, *Tsuga*	*Carex muliensis* marsh
S8	33°04′38.6″	102°51′19.3″	3552	Moss	*Carex muliensis*, Poaceae, *Ranunculus*, Asteraceae, Rosaceae, *Tsuga*	*Carex muliensis* marsh
S9	33°42′58.6″	102°07′10.4″	3457	Moss	Poaceae, *Carex muliensis*, Fabaceae	*Carex muliensis* marsh
S10	33°42′58.9″	102°07′01.1″	3448	Moss	*Carex muliensis*, Fabaceae, *Ranunculus*, *Cremanthodium lineare*, Poaceae, *Plantago, Leontopodium*	*Carex muliensis* marsh
S11	33°42′58.9″	102°07′01.1″	3448	Moss	*Carex muliensis*, Fabaceae, *Ranunculus*, *Cremanthodium lineare*, Poaceae, *Plantago, Leontopodium*	*Carex muliensis* marsh
S12	32°43′59.9″	102°24′21.2″	3536	Moss	Poaceae, Carex, *Artemisia*, Rosaceae, Asteraceae, *Polygonum*, Fabaceae	*Stipa* and *Kobresia* meadow
S13	32°43′32.8″	102°35′19.7″	3618	Moss	Poaceae,*Carex*, *Leontopodium*, Asteraceae, *Cremanthodium lineare*, *Ranunculus*, *Polygonum*, *Pedicularis*	*Stipa* and *Kobresia* meadow
S14	32°43′27.6″	102°35′27.3″	3648	Moss	*Carex*, Poaceae, Ranunculus, *Polygonum*, Asteraceae, *Cremanthodium lineare*, *Leontopodium*	*Stipa* and *Kobresia* meadow
S15	32°43′25.9″	102°35′27.8″	3654	Moss	Poaceae,Rosaceae,Fabaceae,*Ranunculus*, *Carex muliensis*, Asteraceae, *Gentiana*	*Stipa* and *Kobresia* meadow
S16	32°40′42.3″	102°05′42.8″	3473	Moss	Carex, Fabaceae, Asteraceae, Poaceae, *Artemisia*, *Ranunculus*	*Stipa* and *Kobresia* meadow
S17	32°40′42.3″	102°05′42.8″	3473	Moss	Carex, Fabaceae, Asteraceae, Poaceae, *Artemisia*, *Ranunculus*	*Stipa* and *Kobresia* meadow
S18	33°05′43.5″	102°39′53.9″	3482	Moss	*Carex*, Fabaceae, Asteraceae, *Cremanthodium lineare*, *Gentiana*, *Ranunculus*	*Carex* dominated forb meadow
S19	32°57′48.0″	103°00′32.9″	3608	Moss	Poaceae, Carex muliensis,Fabaceae, *Artemisia*, Asteraceae, *Gentiana*, *Saussurea*, *Plantago major*, *Leontopodium*	*Carex* dominated forb meadow
S20	32°57′49.2″	103°00′30.0″	3593	Moss	*Carex*, *Cremanthodium lineare*, Asteraceae, *Leontopodium*	*Carex* dominated forb meadow
S21	33°04′29.8″	103°02′02.1″	3504	Moss	*Cremanthodium lineare*, *Ranunculus*, *Carex muliensis*, *Leontopodium*, Compositae, *Artemisia*	*Carex* dominated forb meadow
S22	33°05′35.4″	102°46′07.5″	3558	Moss	Rosaceae, Asteraceae, *Ranunculus*, *Artemisia*, *Leontopodium*, *Carex* sp.	*Sibiraea angustata* scrub
S23	33°05′35.4″	102°46′07.5″	3558	Moss	Rosaceae, Asteraceae, *Ranunculus*, *Artemisia*, *Leontopodium*, *Carex* sp.	*Sibiraea angustata* scrub

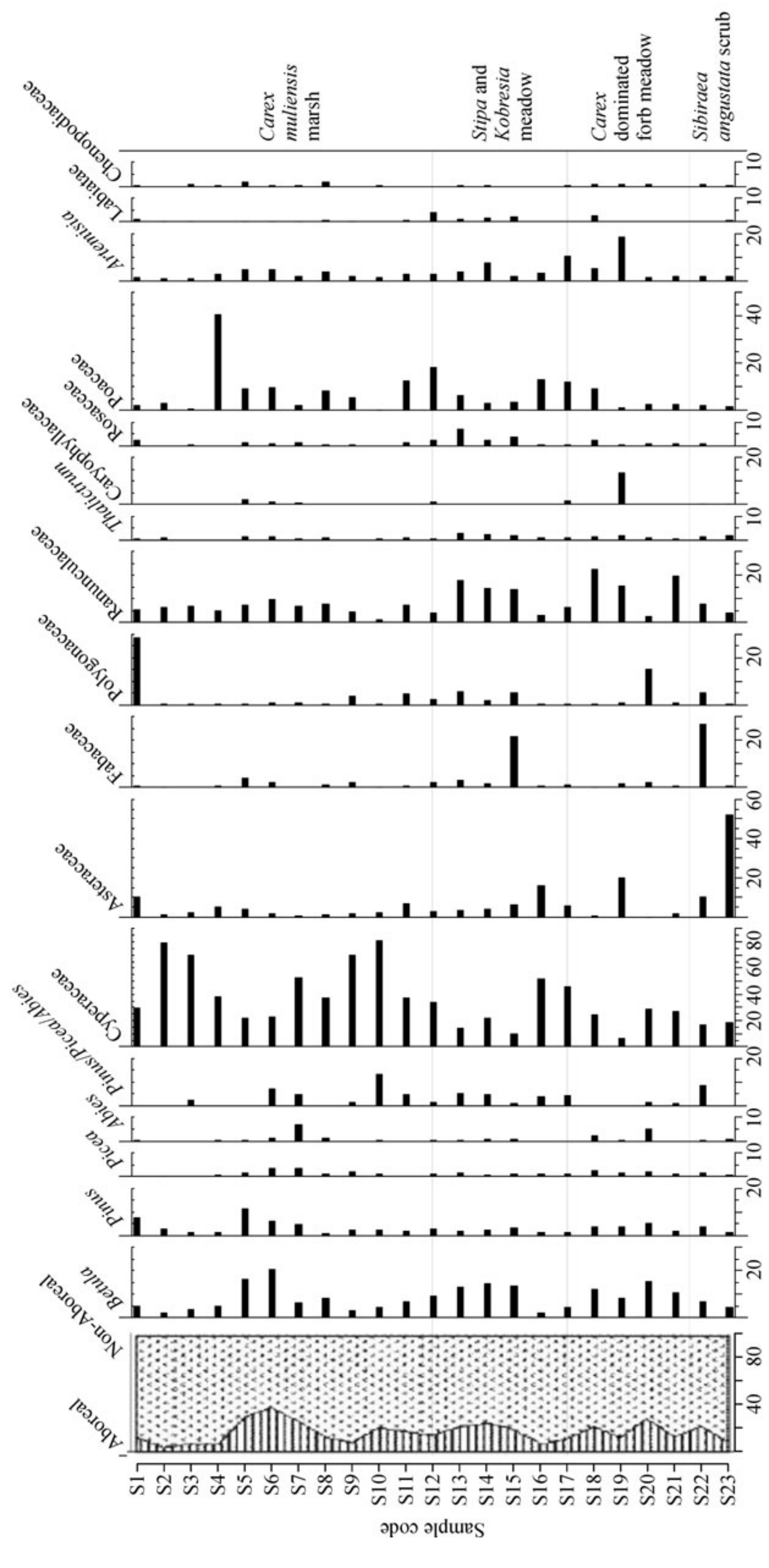

Fig. 3 Surface pollen percentages from the Zoige Basin, the eastern Tibetan Plateau

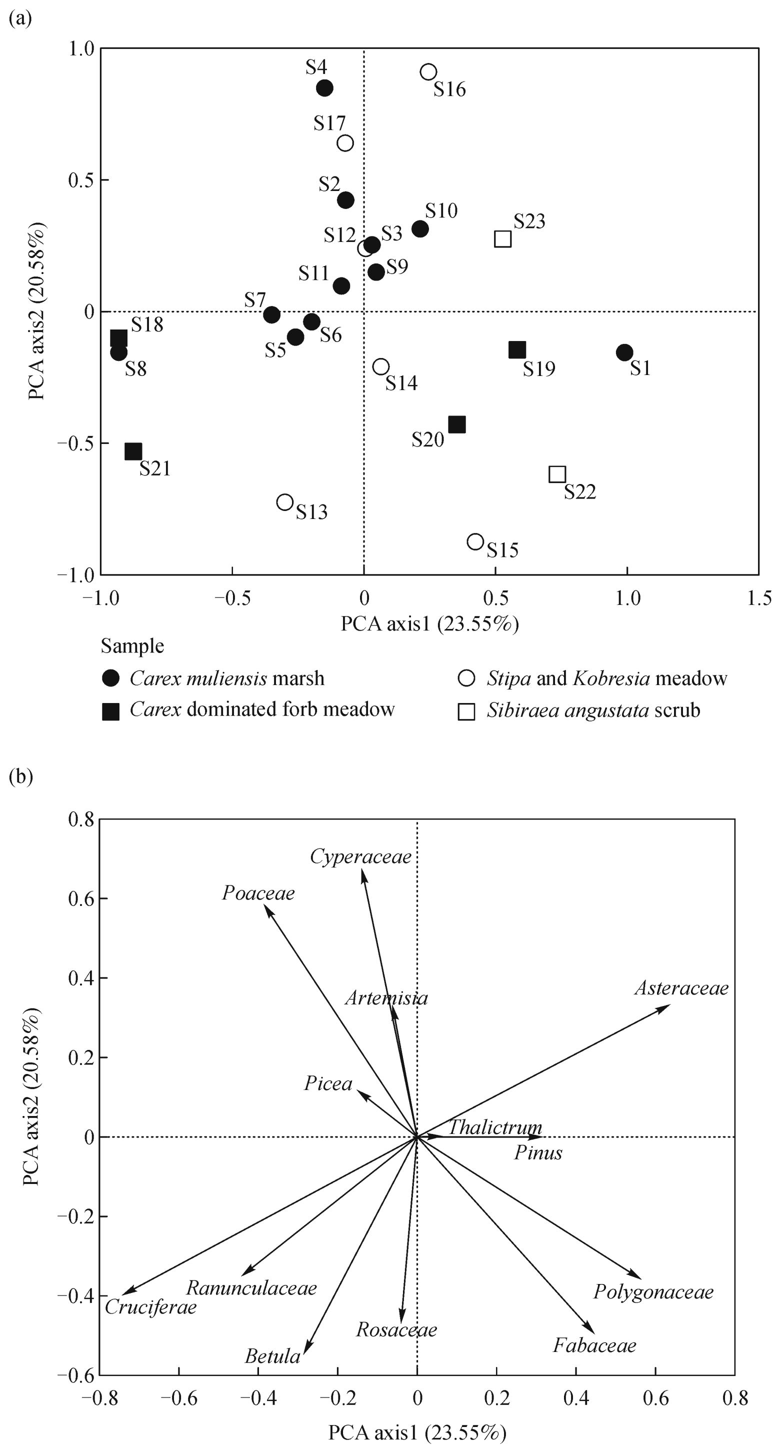

Fig. 4 Biplot of PCA results based on surface pollen samples (a) and taxa (b) from the Zoige Basin, the eastern Tibetan Plateau

pollens. *Stipa* and *Kobresia* meadow samples which coincide with their pollen taxa distributed near the axis 2. *Carex* dominated forb meadow community samples are scattered due to their complex floristic composition. Pollen of Asteraceae is the most characteristic pollen in *Sibiraea angustata* scrub community, but S22 and S23 is departed due to high percentage of Fabaceae pollen in S22 and high Asteraceae pollen value in S23.

5 Discussion

5.1 Representation of main pollen taxa

There are four main types of tree pollens in pollen assemblages, *Betula*, *Pinus*, *Picea* and *Abies*, among which *Pinus* and *Betula* are the most two abundant taxa. *Betula* is present in all samples and its value varies from 2 to 20%. There are no *Betula* trees in our study sites, so the high value and broad distribution may indicate over-representation of *Betula* pollen. Similar results could be seen in other studies (Yan and Xu, 1989; Cheng et al., 2004; Ma et al., 2008). Two factors can explain this phenomenon in our study region. First, *Betula* pollen may be originated from the up-currents and winds from the lowlands, for there were *Betula* trees under the treeline in low altitude. Secondly, *Betula* pollen is widely dispersed and well preserved. *Pinus* pollen presented in all samples with a low value (mostly less than 10%), in spite of no *Pinus* tree occur in the whole study region. In general, *Pinus* pollen is over-represented due to its high pollen production and effective dispersals (Li, 1993; Li et al., 1993).

Cyperaceae pollen occurs with high percentages in alpine meadows and marsh vegetations (the highest value as high as 81%) in the Zoige Basin, north-east Tibetan Plateau. Other surface pollen spectra from eastern-central Tibet (Yu et al., 2001) also shows that the highest percentages of Cyperaceae ($>50\%$) are found in areas characterized by alpine meadows in eastern-central Tibet (Yu et al., 2001). Compared with its vegetation, Cyperaceae pollen corresponds well with its parent plant (Xu et al., 2007) and shows moderate representation.

Poaceae is another dominant plant in the Zoige Basin. However, Poaceae pollen is present with low percentages (around 10%) at almost all sites, except sample #4 with high value up to 40%, suggesting that Poaceae pollen in the Zoige Basin is under-represented. Similar results have been reported in the Tibetan Plateau and other regions (Liu et al., 1999; Yu et al., 2001; Li et al., 2005; Shen et al., 2006). The low-representation of Poaceae pollen might be associated with its thin pollen-wall that is deteriorated relatively rapidly after initial deposition (Cushing, 1967).

Asteraceae, which is an important plant type in alpine meadow vegetation, distributed widely in the Zoige Basin, though it is not the dominant taxa. Corresponding with its vegetation cover, non-*Artemisia* Asteraceae pollen is common but with low value, except for *Sibiraea angustata* scrub community, which is situated at high elevations with many *Leontopodium* growing in the herb layer. Similar results have been reported previously from the Tibetan Plateau (Zhao and Herzschuh, 2009). It suggests that Asteraceae pollen is moderately represented in the Zoige Basin.

Although we obtained 2 samples from Rosaceae dominated vegetation (*Sibiraea angustata* scrub community), the percentage of Rosaceae pollen is low in almost all samples, suggesting that Rosaceae pollen is under-representation in our study region. *Polygonum* plants (such as *Polygonum sphaerostachyum* and *Polygonum viviparum*) are frequent in our study sites. However, *Polygonum* pollen is not very high in pollen spectra, suggesting its low representation of *Polygonum* pollen. Ranunculaceae and Fabaceae pollen are common and Cruciferae, Caryophyllaceae as well as Labiatae are present in alpine meadows in the Zoige Basin.

5.2 Identification of the community types by pollen assemblages

The PCA scatter plot based on pollen percentages can identify the marsh type samples from meadow ones. It shows good correlation between surface pollen assemblages and modern vegetation. The PCA scatter plot based on pollen percentages basically separate the different taxa from others that may subject to different control of the main factors (see Figs. 4(a) and (b).) It shows that marsh vegetation pollens are associated with the taxa that require high soil effective moisture (such as *Carex muliensis* and *Artemisia*), while alpine meadows are associated with the taxa suitable for living in areas at high altitude (such as *Polygonum* and Asteraceae) (see Figs. 4(a) and (b).) These relationships suggest that altitude and soil effective moisture are the two most important factors that influence the plant distribution on the Zoige Basin.

However, such identification is not easy to establish for different communities that are consisted of different plant taxa. The difficulty in the statistical distinction is partly due to the complex floristic composition of the community and the process of pollen precipitation. The pollen assemblages show that the pollen composition from different communities have varied correlations with the modern vegetation. In our field observation, we identified the community types according to the main composition taxa and plant diversity of the modern vegetation. However, the identification based on surface pollen assemblages is not conspicuous. For the frequency of each pollen type is also dependent on the frequency of the other types in the pollen sum (Pardoe, 2001). And the correlations varied for different communities. Our results displayed that the *Carex* dominated forb meadows, which has more complicated plant composition than other communities, show less correlations between surface pollen assemblages and modern vegetation. It demonstrates that the relationships between surface pollen assemblages and modern vegetation are less relevant in complex floristic composition.

From the pollen assemblages based on pollen percentages, we can also get the conclusion that the difficulties existed in the statistical distinction may be also due to the fact that different taxa have varied representation to their plants. For instance, the pollen assemblages obtained from *Sibiraea angustata* scrub community (S22 and S23), are dominated by Asteraceae and Cypeaceae, although the community is mainly consisted of Rosaceae according to our field observation. This may be due to the low representation of Rosaceae pollen. For the pollen precipitation is not restricted to local plant communities, the pollen percentage in surface sediment can be affected by a variety of factors, such as the pollen production, the process of pollen dispersal, the ornament of pollen wall, the microclimate and topography of the sample sites and so on. These parameters contribute to the low correlations between surface pollen and contemporary vegetation and made the identification of different communities more difficult. As a result, different communities are not easy to be identified by pollen assemblages. Thus, it is almost impossible to reconstruct the community composition according to pollen data, which confirms the results suggested by other studies (Li, 1993; Liu et al, 1999).

In spite of these difficulties, the good consistence of dominant taxa between pollen assemblages and modern vegetation can also provide good evidence in the reconstruction of paleo-vegetation and paleo-climate.

6 Conclusions

1) The pollen assemblages suggested that the representation varies in different plant taxa and it must be considered when using fossil pollen records to reconstruct paleo-vegetation.

2) The pollen assemblages can identify the marsh and meadow types; however, the communities are not easy to be identified. This may be due to the complicated relationship between pollen and vegetation which made it almost impossible to reconstruct the community composition using pollen record, so careful consideration is needed when using pollen data to reconstruct paleo-vegetation communities.

3) The PCA scatter plot based on pollen percentages suggests that the distribution of the vegetation in the Zoige Basin is mainly influenced by altitude and precipitation.

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References

Cai Y, Wang Y, Jiang F C, Li C Z (2007). Characteristics of pollen assemblages in surface soil in the Maqu, Hongyuan area, Zoige Plateau, Northern Sichuan. J Geom, 13(4): 333–339 (in Chinese)

Cheng B, Zhu Y, Chen F H, Zhang J W, Huang X Z, Yang M L (2004). Relationship between the surface pollen and vegetation in Shiyang River Drainage, Northwest China. Journal of Glaciology and Geocryology, 26(1): 81–88 (in Chinese)

Cushing E J (1967). Evidence for differential pollen preservation in late quaternary sediments in Minnesota. Rev Palaeobot Palynol, 4: 87–101

Editorial Board of Sichuan Vegetation (1980). Vegetation of Sichuan. Chengdu: Sichuan People's Press, 128–308 (in Chinese)

Faegri K, Iversen J (1989). Text Book of Pollen Analysis. 4th ed. London: John Wiley & Sons Inc

Herzschuh U, Tarasov P, Wunnemann B, Hartmann K (2004). Holocene vegetation and climate of the Alashan Plateau, NW China, reconstructed from pollen data. Palaeogeogr Palaeoclimatol Palaeoecol, 211: 1–17

Hou X Y (2001). Vegetation Atlas of China. Beijing: Science Press, 94–100 (in Chinese)

Lamb H F (1984). Modern pollen spectra from Labrador and their use in reconstructing Holocene vegetational history. J Ecol, 72: 37–59

Li W (1993). Some problems of Holocene pollen analysis. In: Zhang, L, ed. Research of the Historical Change of the Environment for Human Survival in China. Beijing: Ocean Press, 4–10 (in Chinese)

Li W, Yao Z, Liu G (1993). Research of the Quaternary Vegetation and Environment in the Northern and Middle Subtropical Zone in China. Beijing: Ocean Press (in Chinese)

Li Y C, Xu Q H, Zhao Y K, Yang X L, Xiao J L, Chen H, Lü X M (2005). Pollen indication to source plants in the eastern desert of China. Chin Sci Bull, 50: 1632–1641

Liu H Y, Cui H T, Pott R, Speier M (1999). The surface pollen of the woodland-steppe ecotone in southeastern Inner Mongolia, China. Rev Palaeobot Palynol, 105: 237–250

Liu K B, Yao Z J, Thompson L G (1998). A pollen record of Holocene climatic changes from Dunde ice cap, Qinghai-Tibetan Plateau. Geology, 26: 135–138

Luo C X, Zheng Z, Tarasov P, Pan A D, Huang K Y, Beaudouin C, An F Z (2009). Characteristics of the modern pollen distribution and their relationship to vegetation in the Xinjiang region, northwestern China. Rev Palaeobot Palynol, 153: 282–295

Ma Y Z, Liu K, Feng Z D, Sang Y L, Wang W, Sun A Z (2008). A survey of modern pollen and vegetation along a south–north transect in Mongolia. J Biogeogr, 35: 1512–1532

Pardoe H S (2001). The representation of taxa in surface pollen spectra on alpine and sub-alpine glacier forelands in souther Norway. Rev Palaeobot Palynol, 117: 63–78

Shang X, Li X Q, An Z S, Ji M, Zhang H B (2009). Modern pollen rain in the Lake Qinghai basin. Science China (Series D): Earth Sciences, 52 (10): 1510–1519

Shen C M, Liu K, Tang L Y, Overpeck J T (2006). Quantitative relationships between modern pollen rain and climate in the Tibetan Plateau. Rev Palaeobot Palynol, 140: 61–77

ter Braak C J F (1988). CANOCO—A FORTRAN program for canonical community ordination by (Partial) (Detrended) (Canonical) Correspondence analysis, principal components analysis and redundancy analysis version 2.1. Agricultural Mathematics Group, Wageningen

Wright H E, Cushing E J Jr (1967). Quaternary Paleoecology. New Haven, Conn.: Yale University Press, 275–301

Xu Q H, Li Y C, Yang X L, Zheng Z H (2007). The qutitative relationship between some main pollen taxas and vegetation in north China. Science China (Series D): Earth Sciences, 37(2): 192–205 (in Chinese)

Yan S, Xu Y (1989). Spore-pollen association in surface soils in the Altay Mountains, Xinjiang. Arid Zone Research, 6: 26–33 (in Chinese)

Yu G, Tang L Y, Yang X D, Ke X K, Harrison S P (2001). Modern pollen samples from alpine vegetation on the Tibetan Plateau. Glob Ecol Biogeogr, 10: 503–519

Zhao Y, Herzschuh U (2009). Modern pollen representation of source vegetation in the Qaidam Basin and the surrounding mountains, north-eastern Tibetan Plateau. Vegetation History and Archaeobotany, 18: 245–260

Zhao Y, Xu Q H, Huang X Z, Guo X L, Tao S C (2009). Differences of modern pollen assemblages from lake sediments and surface soils in arid and semi-arid China and their significance for pollen-based quantitative climate reconstruction. Rev Palaeobot Palynol, 156: 519–524

Zhao Y, Yu Z C, Chen F H, Emi I, Cheng Z (2007). Holocene vegetation and climate history at Hurleg Lake in the Qaidam Basin, northwest China. Rev Palaeobot Palynol, 145: 275–288