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Climatic and anthropogenic control of surface pollen assemblages in East Asian steppes

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Abstract

Surface pollen samples along moisture and human impact gradients in the steppe zone in East Asia were collected and analyzed to investigate relative control of climatic and anthropogenic factors affecting pollen assemblages. The major pollen taxa are Chenopodiaceae, *Artemisia*, Gramineae, *Polygonum*, Compositae, Leguminosae, *Pinus* and *Betula*. The pollen assemblages of the meadow steppe zone are dominated by *Artemisia*, the typical steppe zone by both *Artemisia* and Chenopodiaceae, and the desert steppe zone by Chenopodiaceae and also *Artemisia*. The percentage of Chenopodiaceae and the ratio of Chenopodiaceae/*Artemisia* (C/A) increase from the meadow-steppe zone, through the typical steppe, to the desert-steppe zone. However, there are also great variances of pollen assemblages in each steppe zone. Canonical correspondence analysis showed that annual precipitation has the greatest influence on surface pollen assemblages in the study area, particularly on changes of *Artemisia* pollen abundance. Severe human disturbance also leads to changes in pollen assemblage, particularly resulting in the increase of Chenopodiaceae percentages. Pollen assemblages are indicative of the relative contributions of climatic and anthropogenic factors to regional vegetation degradation.

Keywords: surface pollen; climate; semi-arid Asia; steppe vegetation

1. Introduction

It is difficult to distinguish the role of human activities and climatic factors in causing vegetation degradation during the last several decades, due to complicated interactions between climatic and anthropogenic factors. Pollen data are valuable not only to reconstruct long-term vegetation development but also to infer the causes of vegetation degradation, as different pollen taxa have proved to be related to climate and human factors (Delcourt and Delcourt, 1991).

Relationships among surface pollen, modern vegetation and climate are critical in reconstructing the palaeoenvironment and palaeovegetation. Pollen of Chenopodiaceae and *Artemisia* are indicators of arid and semi-arid vegetation, respectively, and their ratio (Chenopodiaceae/*Artemisia* or C/A for short) is an indicator of climatic aridity. Increasing C/A indicates a dryer climate (El-Moslimany, 1990). Similar conclusions have also been drawn in the Near East (van Zeist and Bottema, 1991; Davies and Fall, 2001), in China (Liu et al., 1999), in Mongolia (Gunin et al., 1999) and also in North America (Cohen et al., 2000). Other investigators have used this ratio in Eurasia (e.g. Sun et al., 1994; Tarasov et al., 1997), particularly for large-

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scale biome reconstruction (Tarasov et al., 1998; Gunin et al., 1999; Yu et al., 2000).

On the other hand, vegetation degradation in semi-arid areas caused by human activities is indicated by the expansion of Chenopodiaceae plants, especially in sandy habitats. In the study of the desertification history of Horqin Sandy Land in eastern Inner Mongolia, Ren (1999) inferred from pollen diagrams that an increase of Chenopodiaceae pollen following an increase of *Artemisia* pollen and a decrease of *Quercus* pollen indicated human-caused vegetation degradation. An increase in Chenopodiaceae pollen in this semi-arid region indicating climatic drying or human disturbance is a dilemma in palaeoenvironmental reconstruction.

To assess the surface pollen indices in a semi-arid area quantitatively, we selected a Beijing to southern Mongolia transect, which shows evident gradients in both climate and human activities. Samples of surface pollen were collected in different climatic zones and under different human-disturbance regimes. Statistical analyses were used to distinguish the role of climatic factors as well as human disturbance in affecting surface pollen assemblages.

2. Study area

2.1. Physiogeographic conditions

The main part of the study area is located in the central Inner Mongolian Plateau of China and extended to southern Mongolia, with geographical coordinates of E110°21′–117°17′ and N41°18′–44°55′ (Fig. 1). Climatically, the region is semi-humid in the southeast, semi-arid in the central section and arid at the northwestern edge.

The study area is located at the transition from a continentally semi-humid climate to a semi-arid climate, the main part of which is in the marginal area of Pacific monsoon influences, with an annual precipitation between 150 and 400 mm. By using average climatic

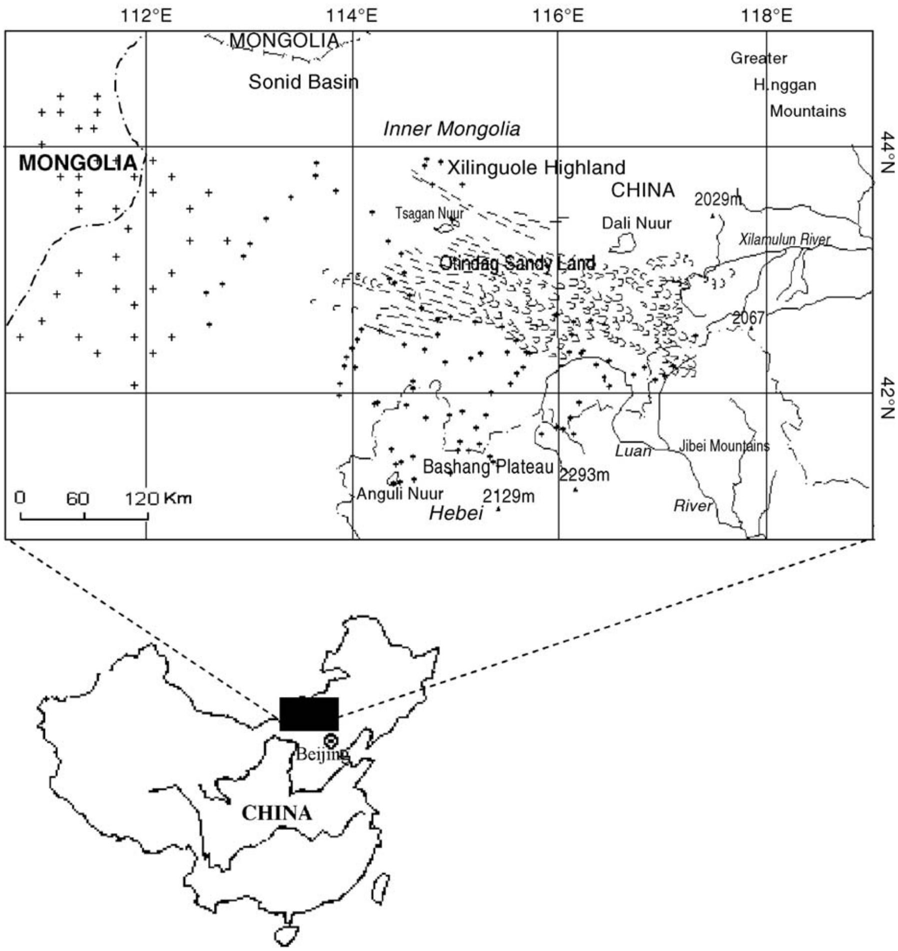

Fig. 1. Map of the study area and location of sample sites.

data from 1980 to 2000 from 30 meteorological stations in the study area and surrounding region, we produced contour maps of climatic variables. An obvious gradient of annual precipitation (Fig. 2) exists from the southeast to the northwest in the study area. Mean annual temperature does not show an obvious gradient.

The vegetation has a southeast-to-northwest distribution of meadow-steppe, typical steppe, desert-steppe and desert in the study region. The dominant plant species in the meadow-steppe are *Stipa baicalensis* and *Filifolium sibiricum* along with abundant forb species. Patches of woodlands dominated by *Quercus mongolica*, *Betula platyphylla*, *Betula dahurica*, *Populus davidiana*, *Pinus tabulaeformis* and *Picea meyeri* occur in the steppe. The most widespread vegetation type is typical steppe, also called dry steppe, in the central part of the study area. The dominant species are *Stipa grandis*, *Stipa krylovii* and *Leymus chinensis.* Shrubs of *Caragana microphylla* and *Caragana stenophylla* dominate locally under strong human disturbances. The dominants of the desert steppe are *Stipa gobica* and *Stipa glareosa*, accompanied by some shrubs such as *Salsola passerina* and *Reaumuria soongorica* from the desert zone.

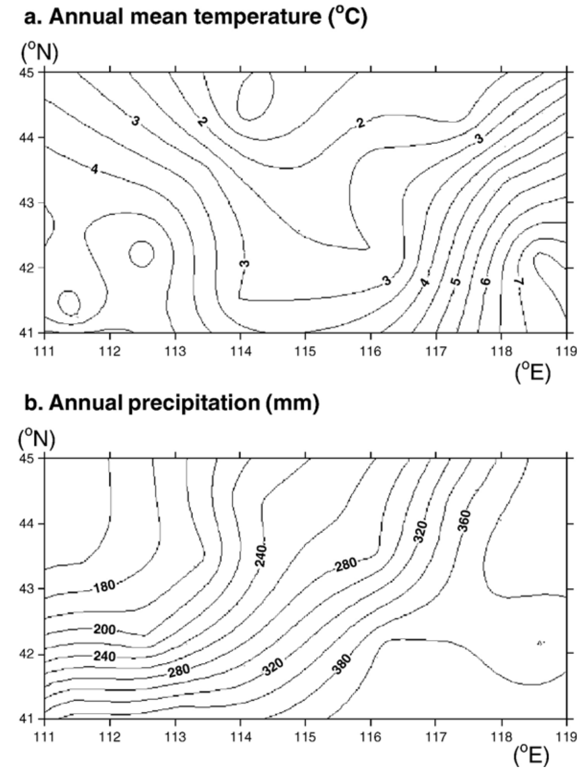

Fig. 2. Contour maps of annual mean temperature and annual precipitation.

2.2. Human land-use conditions

From the southeast to northwest, land use in the study area changes from farmland to pastureland, with a broad intervening agriculture–pasture transitional zone. The human population also follows this gradient. Because of large numbers of immigrants to southern Inner Mongolia during the last century, the agricultural area has suffered serious land degradation. Overgrazing in the northern portion of the study area has caused grassland degradation in differing degrees.

3. Methods

3.1. Field investigation

We collected vegetation data and surface pollen samples from different land-cover types with different degrees of degradation in our study (Fig. 1). A total of 249 relevés were surveyed, using a quadrat size of $2 \times 2\,m^2$ for grasslands and $4 \times 4\,m^2$ for shrublands. At each sampling site, we recorded abundance, cover and height for each species, and habitat conditions, such as slope gradient, slope exposure, soil parent material and human land use. The location of sampling sites was recorded with a global positioning system (GPS) receiver. We collected 187 surface pollen samples from litter and topsoil at these samples. Sites that lacked litter were omitted.

3.2. Laboratory methods

Surface pollen samples were treated in the laboratory with heavy liquid and acetolysis after sieving and chemical treatments (Moore et al., 1991). At least 500 pollen grains were counted for each sample under the microscope. For samples with low pollen concentration, 250 grains were counted. Samples with very low pollen concentration, most of which were from shifting sand dunes with little vegetation cover, were discarded, leaving 147 usable samples. We identified 15 pollen taxa: *Pinus*, *Betula, Corylus*, Chenopodiaceae, *Artemisia*, Gramineae, *Polygonum*, Compositae, Leguminosae, Caryophyllaceae, *Nitraria*, *Ephedra*, Amaranthaceae, Rosaceae and Umbelliferae.

3.3. Human disturbance index

Field records of relevés were quantified to calculate the importance value of each species in each sample as:

$$IV = \frac{RD + RC + RH}{3}$$

in which IV is the importance value, RD the relative abundance, RC the relative cover and RH the relative height of a species.

Based on previous investigations, the recorded 261 plant taxa were categorized into three groups according to their indications to human activities (Li,

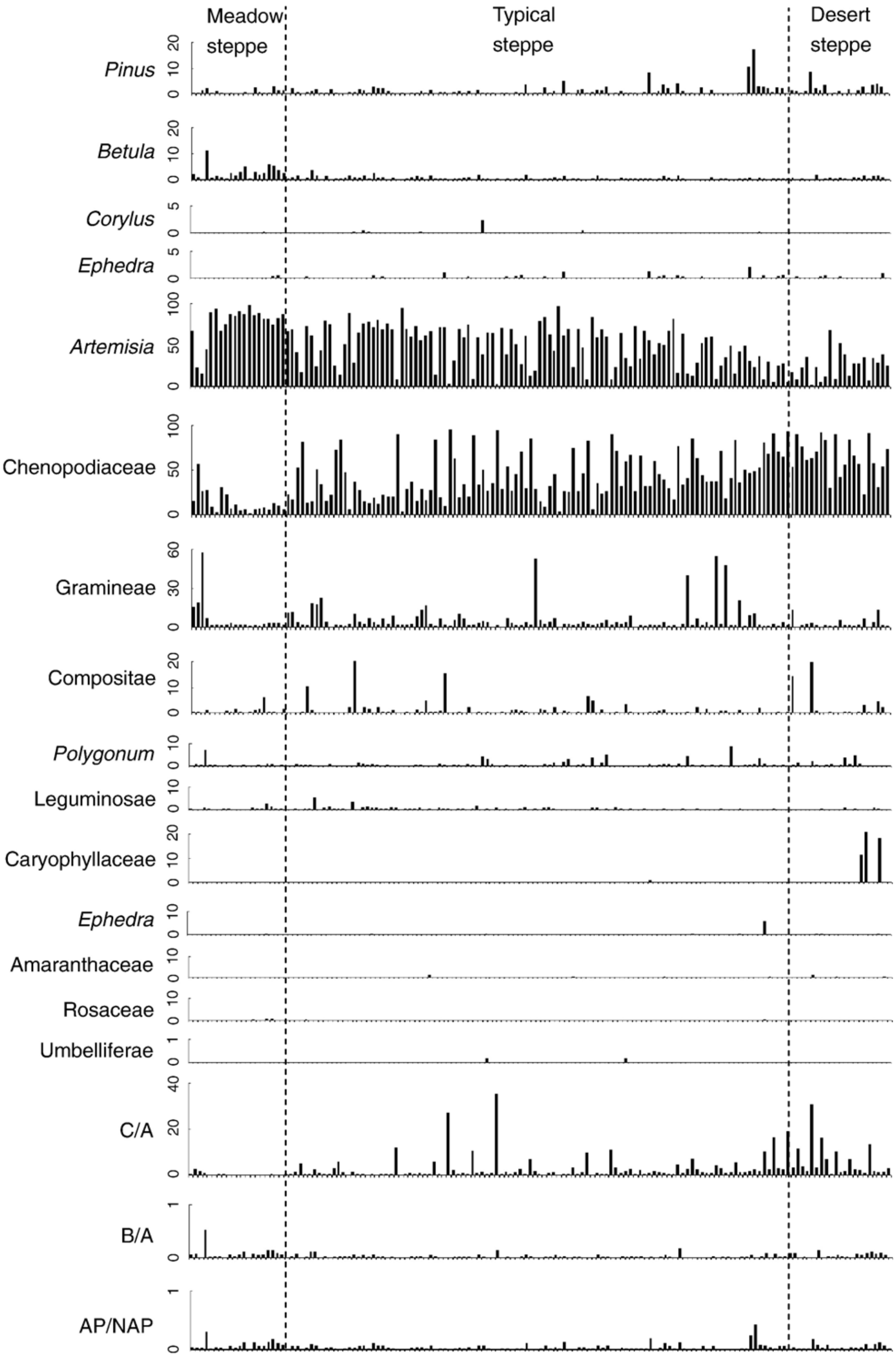

Fig. 3. Surface pollen composition of sample plots from the three steppe types. When ranking samples in the *X*-axis, a decreasing trend of precipitation was shown for each vegetation zone.

1997). The first group consists of pioneer species, indicating strong human disturbance, the second group indicates medium disturbance, and the third group consists of climax species, indicating slight human disturbance. We weighted each species in these groups as the first group 1/3, the second group 2/3 and the third group 1. According to the importance value and indicator classification of each species, the human disturbance index (HDI) of each relevé was derived from the following formula.

$$\mathrm{HDI} = 1/(A_1{*}1/3 + A_2{*}2/3 + A_3),$$

in which HDI is the human disturbance index of a sample; A_1, A_2 and A_3 represent the importance values of species in the three groups.

The HDI calculated by this method includes information about the abundances, the coverages and

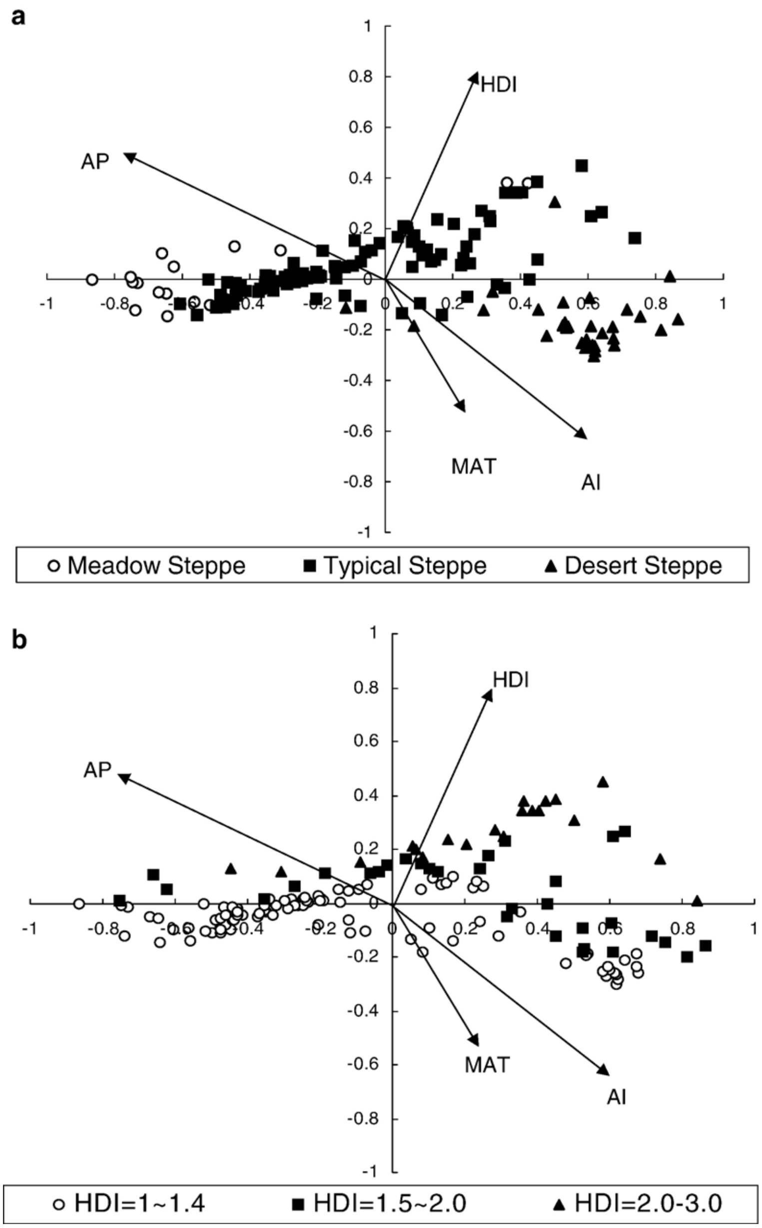

Fig. 4. CCA results of surface pollen sample plots and pollen taxa. (a) CCA results of sample plots indicated by vegetation types; (b) CCA results of sample plots indicated by human disturbance indexes; (c) CCA results of pollen taxa.

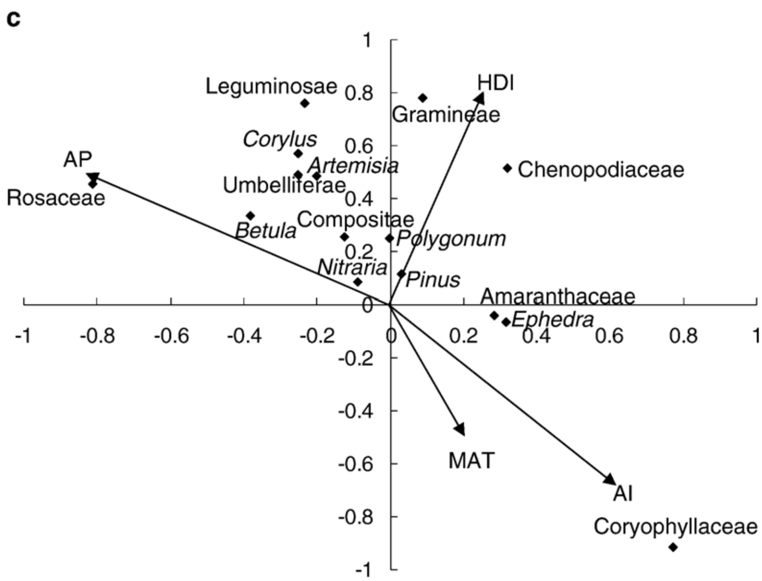

Fig. 4 (*continued*).

the heights of different species in a plot, and it is an index of local vegetation degradation caused by human activities. A higher HDI indicates higher anthropogenic vegetation degradation.

3.4. Canonical correspondence analysis (CCA)

CCA is a canonical form of correspondence analysis (CA) that includes environmental variables explicitly in the analysis. In our study, CCA ordination for both sample plots and pollen taxa was carried out using the software PCord. Four environmental variables, including mean annual temperature (MAT), annual precipitation (AP), aridity index (AI) and human disturbance index (HDI), were selected. The aridity index of each site was calculated as AP/(MAT+10).

4. Results

4.1. Pollen assemblage of different vegetation zones

Artemisia and Chenopodiaceae are two dominant pollen taxa in all steppe types of the study area. Although there are great variations among samples in a definite vegetation type, the average pollen assemblages of different vegetation zones can be summarized as follows. *Artemisia* pollen dominates in the meadow-steppe zone with a mean percentage of 75.1%, followed by Chenopodiaceae of 13.5%, Gramineae of 6.3%, *Betula* of 2.6% and *Pinus* of 0.8%. *Artemisia* also dominates the typical steppe, but with a percentage of 50.8%; Chenopodiaceae is 40%, Gramineae 5.8%, *Pinus* 0.8% and *Betula* pollen 0.4%. In the desert-steppe zone, *Artemisia* decreases to 24.7%, whereas Chenopodiaceae increases to 65%, Gramineae is 2.8% and *Betula* 0.4%. Although there is an increasing trend for *Artemisia* and a decreasing trend for Chenopodiaceae along the transect from meadow-steppe, through typical steppe, to desert steppe, great variances in each vegetation zone are also observed; similarly for the ratio of Chenopodiaceae to *Artemisia* (C/A). No trend in *Artemisia*/*Betula* (A/B) and arboreal/non-arboreal (AP/NAP) can be found.

4.2. CCA results

The CCA results of sample plots for vegetation types are shown in Fig. 3a. It is evident that there are great differences among surface pollen assemblages of the three steppe types. The annual precipitation and aridity index account for the surface pollen assemblages. The human disturbance index, which is not associated with vegetation types, is also not very closely associated with surface pollen assemblages along vegetation gradients. The results imply that regional pollen dispersion is the most important factor in surface pollen assemblages in the steppe vegetation.

The CCA results of sample plots according to different human disturbance conditions are shown in Fig. 3b. For low and medium HDI, pollen assemblages are not differentiated in various vegetation types for the associated annual precipitation and annual aridity.

However, highly disturbed samples are well distinguished, implying that strong human disturbance can also be identified from surface pollen assemblage in spite of different steppe types.

The CCA results for the order of pollen taxa indicated that *Artemisia* pollen is much more associated with annual precipitation than with other selected factors, whereas Chenopodiaceae pollen are much more correlated with the human disturbance index (Fig. 4c). These results imply that changes of *Artemisia* pollen may be most likely caused by climatic changes, whereas changes of Chenopodiaceae pollen are most likely caused by human disturbance.

We compared 12 paired groups of sample plots with high and low HDI values. Sample plots with higher HDI in general have higher percentages of Chenopodiaceae as well as a higher C/A ratio (Fig. 5).

5. Discussion

This study indicates that C/A increases along precipitation and vegetation gradients from meadow-steppe, through typical steppe, to desert-steppe, which agrees with previous investigations (El-Moslimany, 1990). However, we also observed great variation of C/A in each steppe type. The most powerful argument

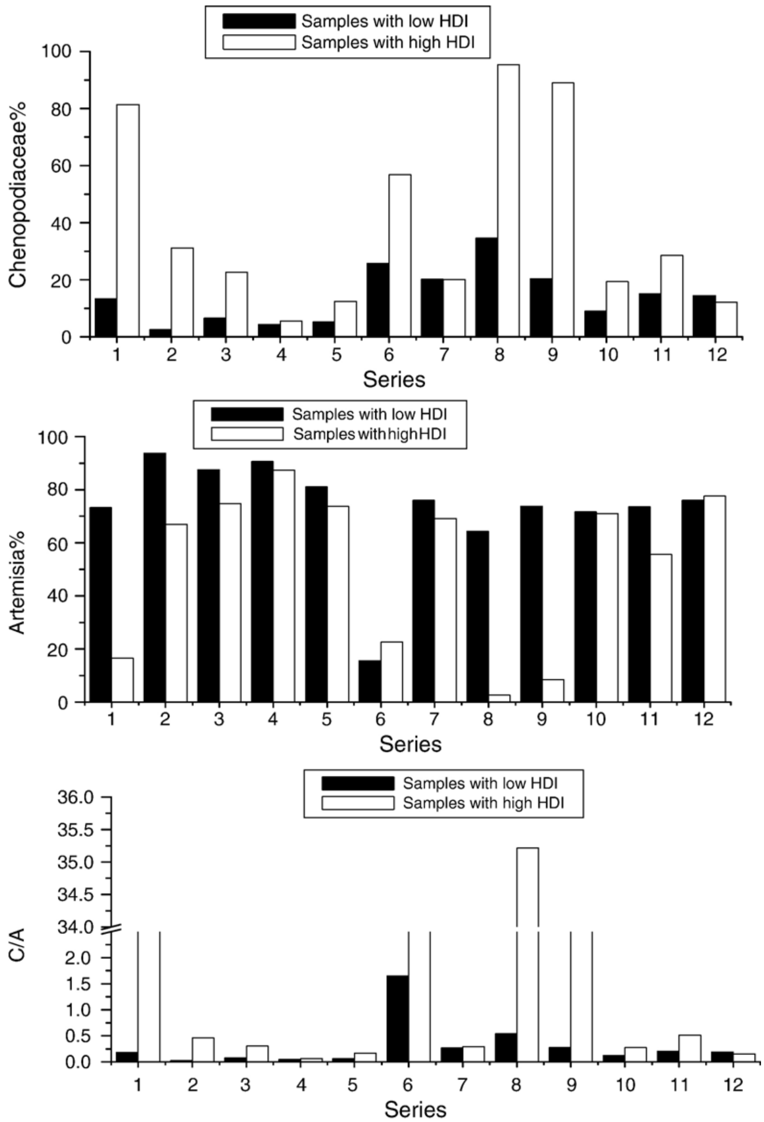

Fig. 5. Comparison of percentages of Chenopodiaceae and *Artemisia* and their ratio between serial samples under low and high human disturbance conditions.

for this phenomenon can be ascribed to the high Chenopodiaceae pollen concentration in highly disturbed plots on a local scale. Pollen sampled from a vegetation relevé included two kinds of signals: regional ones and local ones. Serial pollen samples from the same site should have the same regional signal but different very local signals. We took serial samples from the same site; they showed similar regional signals, but different local signals of vegetation composition, which should reflect the degree of human disturbance. Therefore, the "human disturbance index" based on species composition of vegetation samples is reasonable.

In reconstructing palaeovegetation developments and their driving forces, an increase of C/A is not necessarily linked to climatic drying; however, an increase of Chenopodiaceae percentage caused by human disturbance on a local scale can also lead to an increase of C/A. Therefore, when human disturbance is involved in interpreting pollen data from sediment sequences, the C/A ratio should be used with care.

From studies of the woodland-steppe ecotone in southeastern Inner Mongolia, Liu et al. (1999) suggested that the ratio of *Artemisia*/*Betula* (A/B) represented the precipitation gradient as well as the vegetation gradient from deciduous broadleaved woodland to steppe vegetation. A similar trend also exists for AP/NAP (Liu et al., 1999). However, ratios of A/B and AP/NAP showed no significant relationships with precipitation in this study. One explanation is that arboreal pollen are extra-regional in typical steppe and desert-steppe zones. Another explanation is that, because of the low deposition of non-arboreal pollen in the desert steppe zone, the percentages of extra-regional pine pollen and AP/NAP are higher.

Percentages of different pollen types are correlated with climatic variables in the study area. In the meadow-steppe zone, *Artemisia* accounts for 70% of the total pollen sum, whereas in the typical steppe zone, it declines to 50%. Percentages of extra-regional arboreal pollen taxa, for example *Pinus* and *Betula*, never exceed 1% in the typical steppe and desert-steppe zones. The pollen productivity of *Artemisia* is high relative to Gramineae and steppe vegetation dominated by Gramineae normally has high percentages of *Artemisia* pollen. Consequently, high percentages of *Artemisia* pollen do not necessarily indicate *Artemisia*-dominated vegetation (Liu et al., 1999). Nevertheless, the term "Chenopodiaceae–*Artemisia* desert-steppe" has appeared in recent works (Wick et al., 2003), possibly due to different species composition of grassland vegetation in different parts of the world. As for the desert-steppe in our study, the surface pollen assemblage is Chenopodiaceae–*Artemisia*, although the vegetation is dominated by Gramineae species, such as *Stipa glareosa* and *Stipa gobica*.

6. Conclusions

1. The major pollen taxa from surface samples were Chenopodiaceae, *Artemisia*, Gramineae, *Polygonum*, Compositae, Leguminosae, *Pinus* and *Betula*. The surface pollen taxa were correlated with the vegetation distribution in the study area.
2. The annual precipitation and aridity index accounted for the pollen assemblage differentiation in different steppe types. Pollen assemblages under high human disturbance index values were also well distinguished.
3. Strong human activities also caused changes in pollen assemblage in spite of different steppe types. High percentages of Chenopodiaceae pollen in human disturbed sites led to great variation of pollen assemblage in each of the steppe types.

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