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Surface pollen assemblages of human-disturbed vegetation and their relationship with vegetation and climate in Northeast China

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Pollen assemblages of 53 surface pollen samples from farmlands and wastelands in Northeast China were analyzed. Tree pollen percentages were usually higher than 30%, with *Pinus* (26.9%), *Quercus* (0.9%), *Betula* (0.9%) and *Populus* (0.7%) as the major types, and herb pollen percentages were usually higher than 50%, with weedy Poaceae (8.7%), Chenopodiaceae (7.1%), *Artemisia* (1.9%) and Compositae (3.5%) as the major taxa. Thus, the pollen assemblages were consistent with the regional vegetation compositions. However, there were differences in pollen assemblages among regions, especially among different geomorphological units. For example, in the mountains, there were more types of tree pollen and higher total percentages (average 42%) than in other areas, while cereal pollen percentages were lowest (11.2%). In the hills and high plains, herbs made up more than 60% of the pollens, with cereals (average 53.6%) the dominant type. In the low plains, pollen types were similar to those in the hills and high plains, but total pollen concentrations and the proportion of *Concentricystes* were much higher, while cereal pollen percentages were slightly lower (average 41.6%). Pollen assemblages in different land use types also differed. For example, in farmland, cereal pollen percentages were more than 40% and Chenopodiaceae was usually less than 2.5%, while in wasteland, weedy Poaceae was usually less than 10% and Chenopodiaceae was usually higher than 25%. Total pollen concentrations in farmland (average 3909 grains/g) were much lower than in wasteland (average 15074 grains/g). Redundancy analysis revealed that pollen assemblages were significantly negatively correlated with mean annual temperature (–0.73) and July mean temperature (–0.81) and significantly positively correlated with mean annual precipitation (0.48), indicating that pollen assemblages in the artificial or human-disturbed vegetation reflect regional climate well.

Comparison of pollen assemblages in different areas of northern China showed that pollen concentrations reflect the intensities of human impact to some degree. For example, pollen concentrations decrease as human impacts increase in intensity. The cereal pollen proportions in farmland differed by area. In Northeast China, cereal pollen proportions were distinctly higher than in most other areas of northern China, suggesting differences in planting habits and climate.

Northeast China, farmlands, wastelands, pollen assemblages, human impact, climate

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Pollen is an important proxy for past environment change. Modern pollen assemblages, and their relationships to vegetation and climate, are essential to the reconstruction of paleoenvironments [1–7]. Research in recent years has shown that human impacts are not only driving current and future environmental changes, but have also played significant roles in environmental changes over the past 8000 years [8–10]. Palynologists are becoming increasingly interested in the pollen assemblages of human-disturbed or -impacted vegetation types, so as to better recognize past human impacts and to predict future environmental changes. For example, Court-Picon identified pollen types that could indicate different artificial vegetation types by comparing modern surface pollen assemblages in natural and artificial

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vegetation in the French Alps [11,12]. Based on grass pollens in the French Pyrenees, Buttler et al. argued that pollen assemblages reflect differences in vegetation caused by differing intensities of human activities [13]. Liu [14] studied the pollen assemblages of different vegetation types in the steppes of East Asia and concluded that changes in the proportions of Chenopodiaceae pollen within a steppe type reflected the degree of interference by human activities.

Within China, studies of pollen assemblages in different regions and different types of farmland have provided insight into past human activities [15,16]. Pang et al. [17] thought that farmland pollen assemblages reflected regional vegetation characters and that variations in the proportions of pollen among agricultural units were mainly due to the intensity of human impact or to different planting habits. Ding et al. [18] found that the assemblages and spatial distributions of major pollen taxa could reflect the impact of human activities and changes in the natural environment in the warm temperate hilly areas of eastern China. Nevertheless, compared with the study of natural vegetation, research on pollen assemblages in artificial or human-disturbed vegetation types is still insufficient and has been focused on only a few geographic regions.

Northeast China is one of the cradles of Chinese civilization. Six thousand years ago, humans began to live and multiply in this area, thus creating the Northeastern Neolithic Xinkailiu Culture [19]. In modern times, large-scale reclamation has resulted in artificial and human-disturbed vegetation types being the most important, but there are no reports on modern pollen assemblages. We analyzed 53 modern surface pollen samples from farmlands and wastelands with different terrains and different intensities of human impact. We correlated these pollen assemblages to local vegetation and regional climate to provide basic scientific data with which to better recognize human activities in the Holocene and to predict future environmental changes in Northeast China.

1 Study area

The study area is located at N 40°02′-49°14′, E 119°50′-125°10′, including Liaohe Plain, Songnen Plain, and Daxinganling Mountains. The locations of sampling sites are shown in Figure 1. The study area has a temperate continental monsoon climate (ranging from warm temperate in the south to mid-temperate in the north), with local conditions influenced by latitude, distance from the sea, topography, and other factors. The elevation ranges from 2 to 931 m in the study area. Average annual temperatures vary from −1.5 to 8.1°C and annual precipitation from 350 to 700 mm. Rainfall mainly occurs in July and August [20–23].

The natural vegetation in the study area includes temperate coniferous and broad-leaved mixed forests, temperate deciduous forests, and warm temperate deciduous broad-leaved forest. Vegetation composition changes with elevation [21–23]. In the low plains below 200 m a.s.l., farmland dominated the landscape. The natural vegetation was very

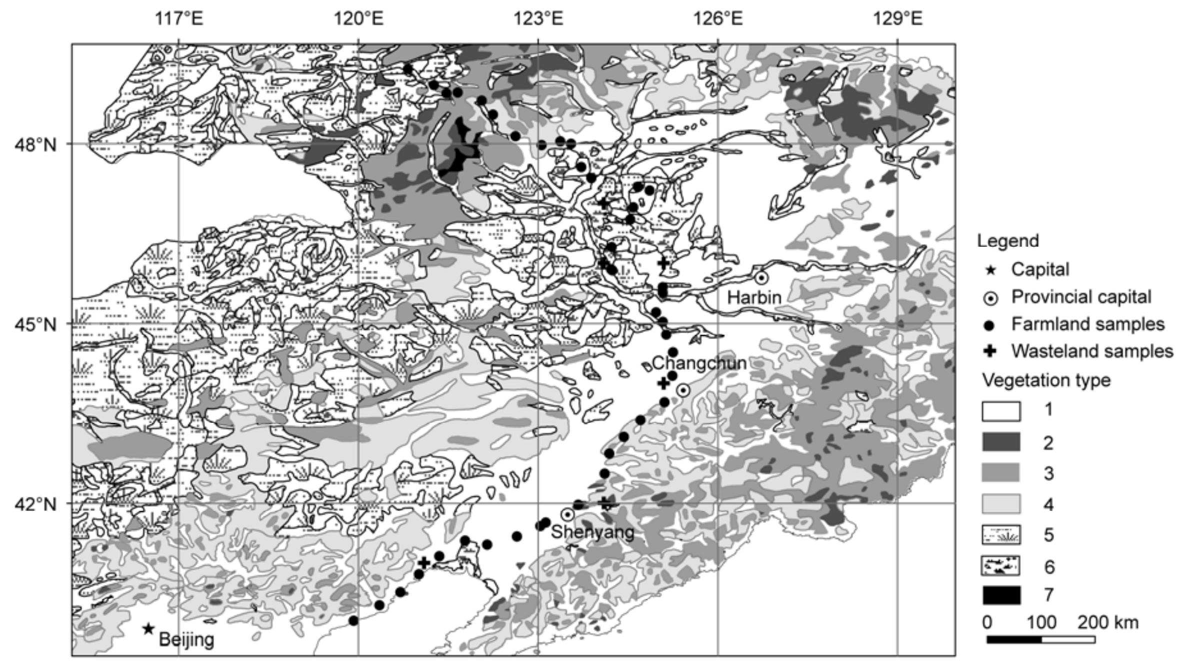

Figure 1 The vegetation types in the study area and the locations of sampling sites. Vegetation type: 1, Farmland; 2, boreal temperate mountain deciduous needle-leaf forest; 3, warm temperate deciduous broad-leaved forest; 4, temperate deciduous shrubland; 5, temperate steppe; 6, temperate meadow; 7, lakes, swamps.

rare, consisting of scattered trees of *Pinus tabuliformis, Quercus liaotungensis*, *Q. mongolica* and so on. In recent years, the areas planted with *P. tabuliformis* and *Robinia pseudoacacia* have increased substantially. *Populus*, *Ulmus*, *Salix*, *Sophora japonica* and other species were scattered along roadsides and in cities and villages.

In the hills and high plains from 200 to 500 m a.s.l., farmland was still abundant and natural vegetation has been seriously degraded. On south-facing slopes, natural forests were usually dominated by *Q. liaotungensis* and *Q. mongolica,* and mixed with *P. tabuliformis* and small numbers of *Q. acutissma*, *Q. dentata*, *Fraxinus rhynchophylla*, and other species. *Lespedeza bicolor* and *Zizyphus sativa* mostly represent the understory shrubs. On south-facing slopes, shaws and shrubs were often mixed together. The most common trees were *Betula dahurica*, *Ulmus japonica*, and *Acer mono. Corylus heterophylla* and *Spiraea* spp. were common shrubs, while. *Stipa grandis*, *Leymus chinensis*, *Cleistogenes squarrosa* and *Potentilla* dominated the herbs [22,23].

Farmland was rare in the Daxinganling Mountains between 500 and 900 m a.s.l., where more nature vegetation can be found. The dominant trees were *Larix gmelinii*, *P. tabuliformis*, *Juniperus rigida*, *Quercus variabilis*, *Q. acutissma*, *Q. mongolica*, *Betula dahurica*, and *Platycladus orientalis*. The most common understory shrubs were *Rhododendron dauricum*, *Vitex* spp., *Jujube* spp., and *Stipa baicalensis* [20,24].

Artificial vegetation consists mainly of farmland. The main crops include *Zea mays*, *Triticum aestivum*, *Oryza glaberrima*, *Sorghum vulgare*, *Glycine max*, *Vigna radiata*, and *Arachis hypogaea.* Common fruit trees include *Malus* spp. and *Prunus persica*, and common vegetable crops include *Brassica oleracea*, *Lycopersicon esculentum*, *Capsicum frutescens*, *Raphanus sativus*, and *Solanum tuberosum.*

The "wastelands" in this paper mainly refer to the abandoned crop and pasturelands where trees and shrubs are very rare and herbs predominate. The most common species were *Vitex* spp., *Lespedeza bicolor*, *Artemisia* spp., *Typha orientalis*, Chenopodiaceae, C*yperus rotundus*, *Xanthium sibiricum*, *Humulus japonicas*, *Sanguisorba officinalis*, *Helianthus annuus*, Umbelliferae, *Melissitus rutenica*, *Erodium stephanianum*, and *Amorpha fruticosa.*

2 Methods

2.1 Field work

In total (Table 1), 53 surface soil samples were collected in June 2008. Samples included 44 from farmland (21 corn fields, 4 rice fields, 2 wheat field, 1 sorghum field, 3 orchards, 6 vegetable fields, 7 mixed crop fields) and nine wastelands. Samples were usually collected from the upper centimeter of soil, and every sample was a mixture of 4–5 points within a 9×9 m^2 sampling plot. Major plant taxa and community composition were recorded and the location (latitude, longitude, and elevation) of each plot was measured by GPS.

2.2 Pollen analysis

For each sample, 10 g of soil (dry weight) was prepared for pollen analysis. Pollen was extracted by treatment with a modified HCl-NaOH-HF method [25]. A tablet of *Lycopodium* (containing 27637±563 spores) was added as a tracer to each sample. Pollen was identified and counted with a BX-51 Olympus light microscope (made in Japan) at 400× magnification. For each sample, at least 3–4 slides were checked, and more than 400 pollen grains were counted (excluding *Concentricystes*). *Concentricystes* were not included in the total pollen sums, rather we recorded the proportion of *Concentricystes* to total pollen. In keeping with previous studies, Poaceae were sorted into three pollen types based on size, diameter of the circular pore, and ornamentation [26,27] as follows: Grass pollen grains larger than 75 μm with morphology and shape similar to modern corn pollen were identified as *Zea mays* pollen. Pollen grains that were 35–50 μm (usually similar in shape and size) with distinct ornamentation and circular pores were considered to be cereal Poaceae (mostly wheat or rice pollen). Pollen grains smaller than 35 μm with thinner walls and different sizes and shapes were identified as weedy Poaceae.

2.3 Data processing

The pollen percentages and pollen concentrations were processed with Excel 2003 software (manufactured by Microsoft Corporation), and pollen diagrams were drawn with Tilia software (manufactured by Eric. C. Grimm). The spatial distribution of sampling sites was evaluated with ArcGIS software (manufactured by ESRI, Inc, Arcmap version 9.3).

To investigate similarities and differences among pollen assemblages from different sites, clustering analysis (CA) was performed on the pollen data using MVSP software (manufactured by Kovach Computing Services). CA is a multivariate statistical analysis that is commonly-used in paleontology and palynology. Clustering analysis quantitatively determines the similarities among samples and then groups the samples into a classification tree [28].

Principal component analysis (PCA) can effectively distinguish the main pollen types [29]. We used redundancy analysis (RDA) to further investigate the relationships among vegetation, pollen assemblages and environmental conditions. PCA and RDA were performed using CANOCO version 4.5 (manufactured by Biometris-Plant Research International) [30,31].

Meteorological data were taken from China Meteorological Statistical Annals (supplied by China National Weather Service) and averaged for the 30-year period from 1961 to

Table 1 Location and vegetation composition of the sampling sites in Northeast China

Sample site	Sample type	Latitude (N)	Longitude (E)	Altitude (m)	Major plant taxa
DB01	Corn field	40.03	119.84	17	*Zea mays*, *Oryza glaberrima*, weedy Poaceae, *Prunus persica*, *Ulmus*
DB02	Orchard	40.29	120.27	32	*Malus*, *Prunus persica*, *Arachis hypogaea*, *Glycine max*, weedy Poaceae
DB03	Wasteland	40.51	120.61	33	*Pinus tabuliformis*, *Vitex negundo*, *Sophora*, *Ulmus*, *Artemisia*, Chenopodiaceae
DB04	Mixed crop field	40.51	120.62	17	*Zea mays*, *Arachis hypogaea*, Cupressaceae, *Sophora*, weedy Poaceae, *Artemisia*
DB05	Wasteland	40.81	120.93	20	*Vitex negundo*, Cyperaceae, weedy Poaceae, Cupressaceae, *Sophora*
DB06	Corn field	40.81	120.93	19	*Zea mays*, weedy Poaceae, *Artemisia*, Cyperaceae, Chenopodiaceae
DB07	Corn field	41.11	121.27	37	*Zea mays*, *Glycine max*, Cyperaceae, weedy Poaceae, *Artemisia*, *Sophora*
DB08	Wasteland	41.13	121.31	23	*Pinus tabuliformis*, *Vitex negundo*, Cupressaceae, Cyperaceae, *Artemisia*, Chenopodiaceae
DB09	Corn field	41.37	121.70	9	*Zea mays*, *Populus*, Compositae, *Artemisia*, Chenopodiaceae
DB10	Rice field	41.30	122.07	2	*Oryza glaberrima*, *Glycine max*, *Phragmites australis*, *Compositae*, *Artemisia*, *Salix*, *Sophora*
DB11	Corn field	41.44	122.57	10	*Zea mays*, *Populus*
DB12	Corn field	41.44	122.57	10	*Zea mays*, *Populus*, weedy Poaceae, Cyperaceae, Labiatae, *Phragmites australis*, *Typha orientalis*
DB13	Rice field	41.61	122.96	20	*Oryza glaberrima*, *Glycine max*, *Salix*, *Artemisia*, Chenopodiaceae, Compositae, *Populus*, *Salix*
DB14	Corn field	41.67	123.05	24	*Cleistogenes*, Cyperaceae, Compositae, Umbelliferae, Polygonaceae, *Artemisia*, Chenopodiaceae
DB15	Corn field	41.97	123.59	64	*Zea mays*, *Carex tristachya*, *Fraxinus chinensis*
DB16	Wasteland	42.19	123.74	64	Crassulaceae, Cyperaceae, *Humulus japonicus*, Compositae, Labiatae, *Artemisia*, Chenopodiaceae
DB17	Mixed crop field	42.49	124.03	88	*Oryza glaberrima*, *Zea mays*, *Populus*, Cyperaceae, Compositae, *Humulus japonicus*
DB18	Corn field	42.82	124.11	160	*Zea mays*, Compositae, weedy Poaceae, Cyperaceae, *Humulus japonicus*
DB19	Corn field	43.10	124.35	203	*Zea mays*, *Populus*, Compositae, Labiatae, Leguminosae, *Artemisia*, weedy Poaceae
DB20	Orchard	43.38	124.63	225	*Malus*, *Glycine max*, *Zea mays*, *Artemisia*, Compositae, Chenopodiaceae, weedy Poaceae
DB21	Wasteland	43.50	124.85	239	*Artemisia*, weedy Poaceae, *Ulmus*, Asclepiadaceae, Compositae
DB22	Corn field	43.68	125.03	231	*Zea mays*, *Populus*, weedy Poaceae, *Artemisia*, Chenopodiaceae, Compositae
DB23	Corn field	44.12	125.16	209	*Zea mays*, *Populus*, *Pinus tabuliformis*, *Syzygium aromaticum*, Cyperaceae, weedy Poaceae, Compositae
DB24	Wasteland	44.46	125.16	180	weedy Poaceae, Cyperaceae, *Artemisia*, Chenopodiaceae, Crassulaceae, Compositae, *Populus*, *Ulmus*
DB25	Corn field	44.51	125.17	183	*Zea mays*, *Helianthus annuus*, weedy Poaceae, *Populus*, Compositae, *Artemisia*, Chenopodiaceae
DB26	Mixed crop field	44.81	125.06	268	*Sorghum vulgare*, *Zea mays*, *Populus*, *Salix*, *Syzygium aromaticum*, weedy Poaceae, *Artemisia*, Compositae
DB27	Rice field	45.02	125.00	135	*Oryza glaberrima*, *Populus*, weedy Poaceae, Cyperaceae, Compositae, *Artemisia*, Chenopodiaceae
DB28	Corn field	45.18	124.89	141	*Zea mays*, *Populus*, weedy Poaceae, Compositae, Chenopodiaceae, Malvaceae
DB29	Corn field	45.51	125.00	124	*Zea mays*, *Cleistogenes*, Compositae, *Artemisia*, Chenopodiaceae, Leguminosae, Polygonaceae
DB30	Sorghum field	45.60	125.00	126	*Sorghum vulgare*, Cyperaceae, Compositae, weedy Poaceae, Polygonaceae
DB31	Wasteland	45.75	124.58	125	weedy Poaceae, Cyperaceae, Compositae, *Artemisia*, Chenopodiaceae, *Melissitus rutenica*
DB33	Orchard	45.88	124.16	130	*Malus*, *Glycine max*, weedy Poaceae, Chenopodiaceae, *Helianthus annuus*
DB34	Mixed crop field	45.90	124.14	136	*Zea mays*, *Sorghum vulgare*, *Vigna radiata*, Chenopodiaceae, *Populus*, Cyperaceae, Leguminosae
DB35	Mixed crop field	46.27	124.15	138	*Zea mays*, *Glycine max*, *Populus*, *Sophora*, weedy Poaceae, *Artemisia*, *Compositae*, *Chenopodiaceae*
DB36	Wasteland	46.30	124.15	133	weedy Poaceae, *Artemisia*, Compositae, Chenopodiaceae, *Potentilla aiscolor*, *Sophora*
DB37	Wasteland	46.62	124.42	142	*Sophora*, *Pinus tabuliformis*, *Ulmus*, *Populus*, *Artemisia*, Cyperaceae, *Melissitus rutenica*, *Allium*
DB38	Corn field	46.73	124.46	145	*Zea mays*, *Sophora*, *Populus*, *Ulmus*, weedy Poaceae, Compositae, Cyperaceae, *Artemisia*, Chenopodiaceae
DB39	Corn field	46.93	124.51	142	*Zea mays*, *Helianthus annuus*, Cyperaceae, Chenopodiaceae, Compositae, *Populus*
DB41	Vegetable land	47.21	124.78	151	*Zea mays*, *Brassica oleracea*, *Phaseolus*, *Lycopersicum esculentum*, *Capsicum annuum*, weedy Poaceae
DB42	Rice field	47.27	124.59	150	*Oryza glaberrima*, *Populu*, weedy Poaceae, Cyperaceae, Leguminosae, Compositae, *Artemisia*
DB44	Mixed crop field	47.42	123.81	149	*Zea mays*, *Oryza glaberrima*, *Helianthus annuus*, *Glycine max*, *Capsicum frutescens*, weedy Poaceae
DB45	Corn field	47.60	123.64	155	*Zea mays*, *Glycine max*, *Populus*, *Salix*, *Artemisia*, Compositae, weedy Poaceae, Cyperaceae
DB46	Corn field	47.99	123.47	238	*Zea mays*, *Populus*, Compositae, *Artemisia*, weedy Poaceae, Cyperaceae, *Melissitus rutenica*
DB47	Corn field	47.99	123.47	238	*Zea mays*, *Potentilla aiscolor*, Cyperaceae, Compositae, weedy Poaceae, *Xanthium sibiricum*
DB50	Vegetable land	48.03	123.29	234	*Zea mays*, *Solanum tuberosum*, *Lycopersicum esculentum*, weedy Poaceae, Compositae, Chenopodiaceae
DB52	Mixed crop field	47.97	122.98	322	*Phaseolus*, *Corylus*, *Quercus liaotungensis*, weedy Poaceae, *Compositae*, *Polygonaceae*, *Chenopodiaceae*
DB54	Corn field	48.12	122.54	427	*Zea mays*, *Vigna angularis*, *Cucurbita moschata*, *Helianthus annuus*, Chenopodiaceae, Compositae
DB56	Vegetable land	48.48	122.17	540	*Solanum tuberosum*, *Glycine max*, Compositae, *Artemisia*, Polygonaceae, Labiatae, weedy Poaceae
DB58	Vegetable land	48.71	121.98	757	*Solanum tuberosum*, Polygonaceae, Chenopodiaceae, *Artemisia*, weedy Poaceae, Compositae, *Larix*
DB60	Vegetable land	48.85	121.58	931	*Solanum tuberosum*, *Raphanus sativus*, *Betula*, Compositae, weedy Poaceae, *Artemisia*, Chenopodiaceae
DB61	Wheatland	48.83	121.39	820	*Triticum aestivum*, *Betula*, *Larix*, *Radix Sanguisorbae*, Cyperaceae, Compositae, weedy Poaceae, *Artemisia*
DB63	Wheatland	48.97	121.18	761	*Triticum aestivum*, *Solanum tuberosum*, *Betula*, *Avena*, weedy Poaceae, Cyperaceae
DB65	Vegetable land	49.24	120.75	741	*Glycine max*, *Raphanus sativus*, *Solanum tuberosum*, weedy Poaceae, Compositae, Labiatae

1990. The mean annual precipitation (MAP), the mean annual temperature (T_a), and the mean temperature of the warmest month (T_w) for each sampling site were calculated by the parabolic interpolation using the inverse square distance as the weighting factor with the Polation 1.0 program[1)], and the altitudinal temperature gradient was corrected using the universal temperature lapse rate of 0.60°C/100 m.

3 Results

A total of 55 pollen types and four fern spore types were identified from 53 samples. Twenty tree pollen types were recorded, with an average of 31.5% of total pollen and a maximum of 71.5%. Tree pollen was dominated by *Pinus* (26.9%), *Larix* (1.5%), *Quercus* (0.9%) and *Betula* (0.9%). *Populus, Ulmus, Tilia, Fraxinus,* Anacardiaceae and *Salix* were common but with lower percentages. Five shrubs were identified with percentages less than 1%. Elaeagnaceae and Rosaceae were common. Thirty herbaceous pollen types were identified. They constituted an average of 59.7% of total pollen, with a maximum of 95.6%. Common types include Poaceae (cereals, 34.4%; weeds 8.7%), Compositae (3.5%), *Artemisia* (1.9%), Chenopodiaceae (7.1%), Polygonaceae (0.4%), Cyperaceae (1.4%), Typhaceae (0.5%), *Humulus*, Urticaceae, Ranunculaceae and Cruciferae. The average percentage of four fern spore types was 8.6%, and the maximum was 40.4%, with Trilete spores and *Selaginella sinensis* as the dominant type. Moreover, we found a lot of *Concentricystes* in low plains farmland (Figure 2).

3.1 Differences in pollen assemblages in farmland among different geomorphic units

To study the effects of landform on pollen assemblages, the farmland samples were divided into three groups: low plains (28 samples, 0–200 m), hills and high plains (10 samples, 200–500 m) and mountains (6 samples, >500 m). The differences in pollen assemblage among the three groups were obvious:

Tree pollen percentage was about 28.5% in the low plains and was dominated by *Pinus* (25.9%), *Populus* (0.8%), *Ulmus* (0.2%), *Quercus* (0.6%) and *Betula* (0.6%). Shrubs were much less common (average 0.3%) and were dominated by Rosaceae. Herbs predominated (average 60.6%) in the pollen assemblages, especially cereals (41.6%), weedy Poaceae (7.6%), Chenopodiaceae (3.6%) and Compositae (3.0%). Cyperaceae (1.3%), *Artemisia* (1.3%) and Typhaceae (0.9%) were also common. Trilete spores (8.2%) and *Selaginella sinensis* (1.8%) dominated fern spores.

In the hills and high plains, the tree pollen types were similar to those in the low plains, but the overall percentages (average 26.5%) were slightly lower. Rosaceae was the only shrub type found, with the exception of a single Elaeagnaceae pollen grain recorded at one site, and occurred at much lower percentages (average 0.1%). Herbaceous pollen types were similar to those in the low plains, but the cereal pollen percentages (average 53.6%) were distinctly higher than in the low plains or mountains, and the weedy Poaceae percentages (average 4%) were also slightly lower than in the low plains. The fern spore percentages (average 5.3%) were slightly lower than in the low plains, with Trilete spore and *Selaginella sinensis* decreasing to 4.17% and 0.6% respectively.

The tree pollen percentages in the mountains (average 41.7%) were distinctly higher than that in the other two landforms. *Larix* (average 13%) was only recorded in the mountains, and the percentages of *Quercus* (average 1.8%) and *Betula* (average 2.8%) were notably higher. However, the percentages of *Pinus* (23.3) decreased slightly. The herbaceous pollen percentages also declined relative to the other two landforms. Cereals (average 11.2%) were distinctly more common, whereas weedy Poaceae (average 15.9%), Compositae (average 7.3%), *Artemisia* (average 3.3%), Chenopodiaceae (average 4.9%), Cruciferae (average 1.5%), Convolvulaceae (average 2.3%), Cucurbitaceae (average 0.3%) and Caryophyllaceae (average 0.4%) were slightly less common. The fern spore percentages (average 5.4%) were very similar to those in the hills and high plains, and *Selaginella sinensis* was very rare.

3.2 Pollen assemblages in different land-use types

We demonstrated that different geomorphic units have different pollen assemblages. To better understand the impacts of humans and to determine whether different land use types within the same geomorphic unit had different pollen assemblages, we compared all nine wasteland samples with nearby farmland samples. The sample pairs, as listed in Table 1, were: (DB03, DB04), (DB05, DB06), (DB07, DB08), (DB15, DB16), (DB20, DB21), (DB24, DB25), (DB30, DB31), (DB35, DB36) and (DB37, DB38).

Trees (25.1%) and herbs (63.3%) dominated the pollen assemblages in the farmlands. *Pinus* (23.06%) was the most abundant tree pollen type; *Betula*, *Populus, Ulmus* were also common. Rosaceae (0.26%) was the dominant shrub. Herbs were dominated by cereals (49.9%), with other species recorded with lower percentages such as weedy Poaceae (5%), Compositae (2.1%), Chenopodiaceae (2.5%) and *Artemisia* (1.5%). Most fern spores were Trilete spore (8.9%) or of *Selaginella sinensis* (2.0%).

The major pollen types of wasteland were similar to those of farmland, with were present at different percentages. For example, most tree pollen percentages (average 39.4%) (e.g. *Pinus*, *Betula*, *Quercus*) were markedly higher

1) Takishi. Nakagawa, 2005. Polation1.0 program, Unpublished.

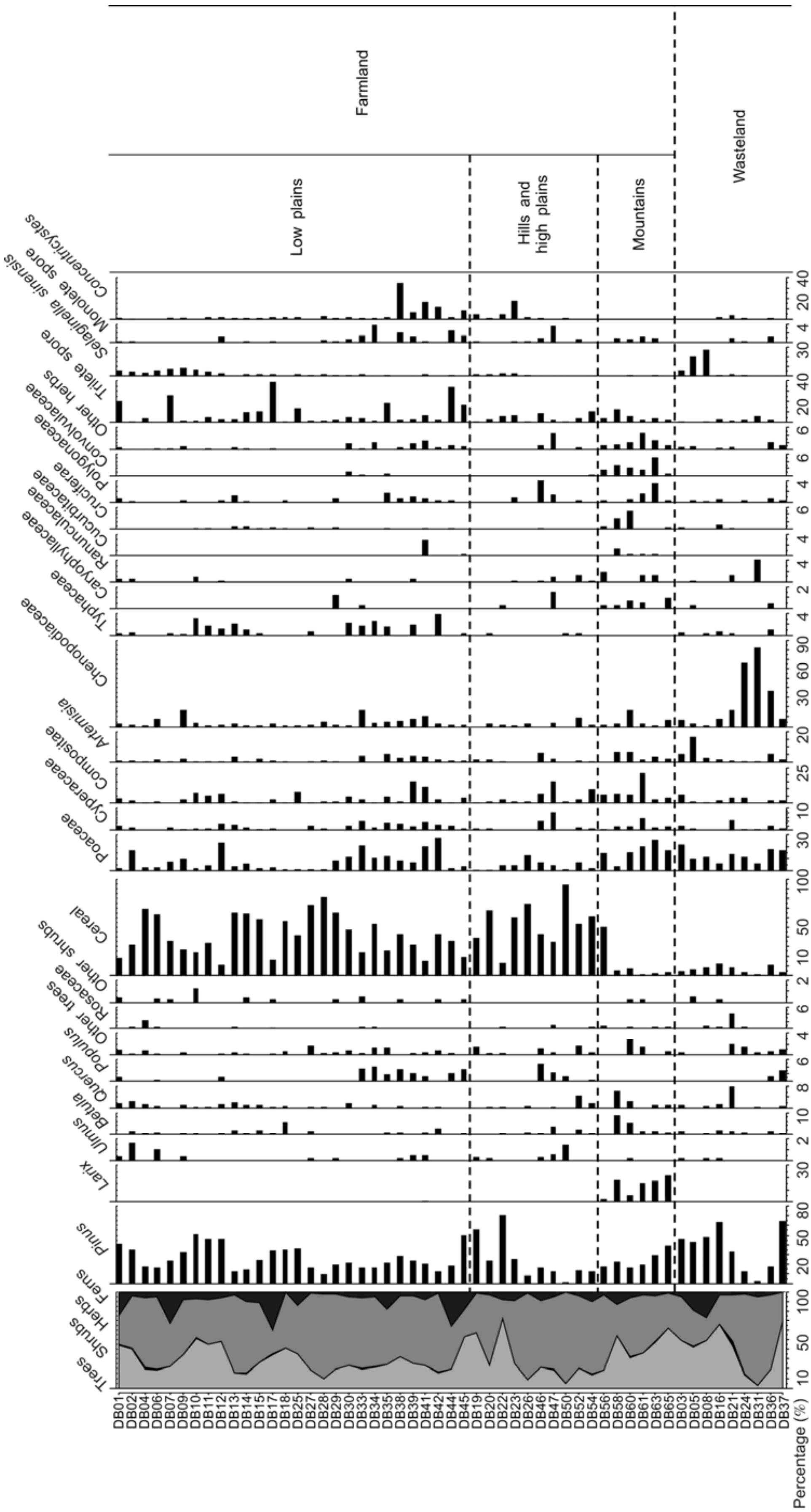

Figure 2 The pollen percentages of major pollen taxa in Northeast China.

than in the farmlands, although *Populus* and *Ulmus* were slightly less common. Herbaceous pollen percentages were distinctly lower, especially for cereals (6%), although weedy Poaceae (12.4%), *Artemisia* (3.7%), and Chenopodiaceae (25%) increased notably (Figure 3).

Clustering analysis (CA) of the main pollen types found

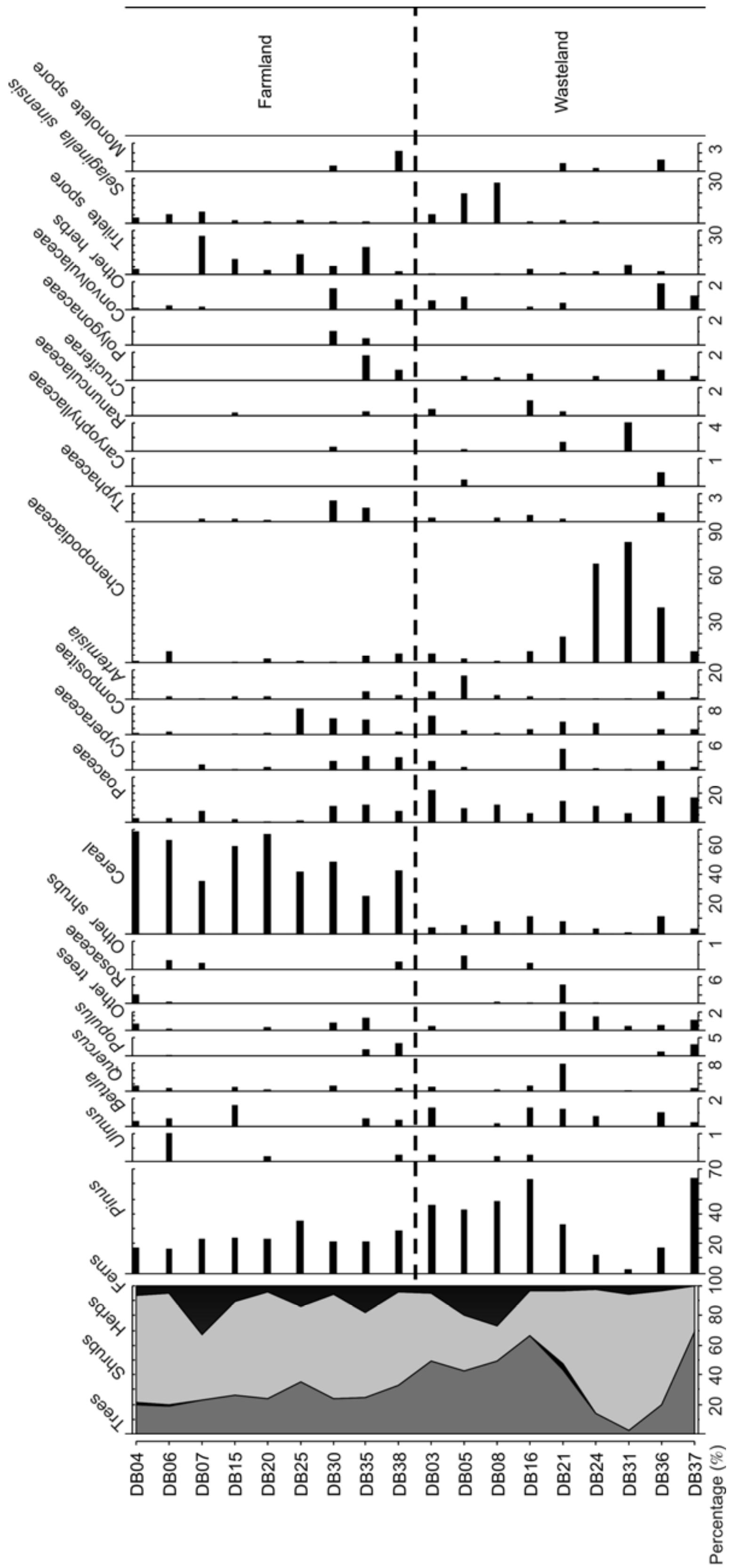

Figure 3 Percentages of major pollen taxa in the farmlands and wastelands.

obvious differences in the pollen assemblages of 18 farmlands and wastelands. Samples from the two land use types were clearly divided into distinct groups (Figure 4).

3.3 PCA and RDA

(i) PCA. To understand the relationship between climate and pollen assemblages in the human-disturbed vegetation, 22 main pollen types (together making up to 99% of the pollen) were used for PCA and RDA (Figure 5). The PCA eigenvalues were 0.28 and 0.14, respectively, for the first and the second principal components, while the third and fourth principal components were 0.12 and 0.09, respectively.

The ordination results for the main pollen types (Figure 5(a)) showed that *Larix*, *Quercus*, *Betula* and other tree pollen types, as well as some herbaceous taxa such as Compositae, Cyperaceae, Ranunculaceae and Cruciferae, were located in the first quadrant. *Pinus*, Rosaceae, Chenopodiaceae, and weedy Poaceae, which were all common in wasteland, were scattered in the second quadrant. Cereals, *Ulmus,* Typhaceae and *Selaginella sinensis*, which mainly appeared in the low plains, were distributed in the third and the fourth quadrants.

The ordination results for samples are shown in Figure 5(b). Three groups could be identified from the 53 samples. Group 1 included 34 samples, most from the farmlands in the low plains, hills, and high plains, which were mainly distributed in the second and the third quadrants. Group 2 included five samples mainly from farmland in the mountains; all were scattered in the first quadrant. Group 3 included nine samples mainly from wastelands and distributed in the second quadrant. Thus, PCA can differentiate samples from farmland and wasteland and can also distinguish samples from the mountains, plains, or hills. These results are consistent with those of the clustering analysis (Figure 4).

(ii) RDA. To better understand the relationship between climate and pollen assemblages in the human-disturbed vegetation in Northeast China, RDA was used. T_a, MAP, and T_w were selected as the main climate parameters, and 22 major pollen types (the same as in the PCA) represented the pollen assemblages. RDA analyses (Table 2) indicated that all three climatic parameters were significantly related to the sample scores in axes 1 and 2 (eigenvalues were 0.45 and 0.18, respectively).

T_a and T_w were significantly negatively correlated (p=0.01) with axis 1, with coefficients −0.73 and −0.81, respectively. On the contrary, MAP was positively correlated to sample scores in axis 2 (r=0.48, p=0.01). Therefore, it seems that the pollen assemblages in the study areas were mainly influenced by temperature, then precipitation.

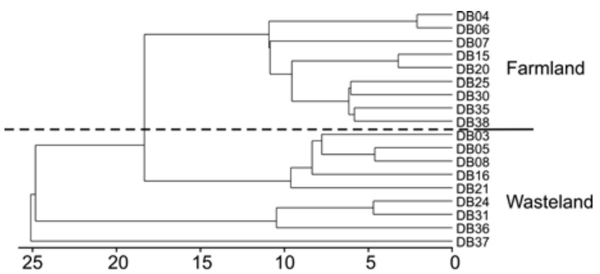

Figure 4 Clustering analysis results for the samples from the farmlands and wastelands.

4 Discussion

4.1 Pollen assemblages and vegetation in different geomorphic units

Farmland pollen assemblages from different geomorphic units were similar. For example, major pollen types were the same, tree pollen usually constituted more than 30% of the pollen, and cereal usually made up more than 40%. However, there were some differences among the different geomorphic units. For example, the tree pollen percentages (average 41.7%) in the mountains were markedly higher than in either the low plains (average 28.5%) or the hills and high plains (average 26.5%). The tree pollen percentages, including *Quercus*, *Betula*, and *Larix*, increased with elevation. Weeds, e.g. weedy Poaceae, Compositae and *Artemisia*, normally grow better in the understory or in wasteland; the percentages of these pollens were higher in the mountains than in the low plains (7.6%) or hills and high plains (4.0%). Cereal pollen percentages also differed in different geomorphic units. The cereal pollen percentage was much lower in the mountains than in the other geomorphic units. This is because cereal crops were common in the lower farmlands. Typhaceae pollen was often recorded in rice fields. *Populus* and *Ulmus* were only recorded in low plains and hills and high plains, never in the mountains. *Populus* and *Ulmus* are common street trees in northern China, which explains the distribution of their pollens in lower areas near populations.

In the study area, the easiest way to convert natural landscapes to farmland is to clear herbs and shrubs first. As a consequence, the tree pollen assemblages represent the natural regional vegetation much better than the assemblages of herbs and shrubs. For example, *Larix* pollen was only recorded in the mountains, and the percentages of *Pinus, Quercus,* and *Betula*, which are usually montane taxa, were higher in the mountains than in the other areas. *Ulmus* and *Populus*, which are often planted in the plains, were not recorded or very rare in the mountains, indicating that pollen assemblages are consistent with the regional vegetation composition.

4.2 Pollen assemblages in different land use types and human impacts

Herbaceous pollen percentages were higher in the farmlands

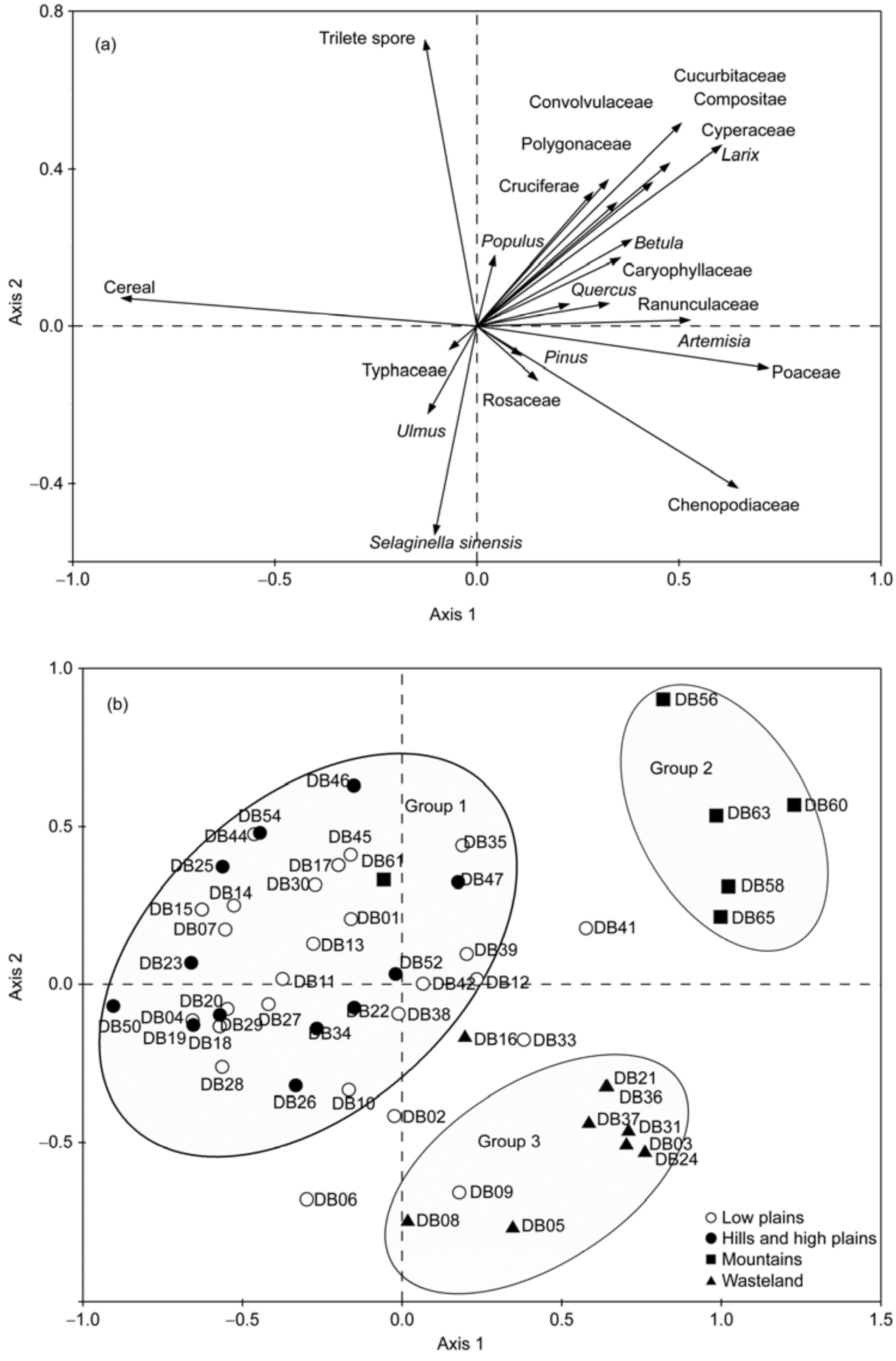

Figure 5 Ordination results of principal component analysis (PCA) for major pollen types (a) and samples (b) in Northeast China.

Table 2 The results of RDA

Parameter	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalue	0.45	0.18	0.03	0
T_a	–0.73	0.35	–0.01	0
MAP	–0.40	0.48	0.31	0
T_w	–0.81	0.03	–0.02	0

than that in the wastelands. Cereal (average 49.9%, 25.4%–68.6%) was the major pollen type in the farmlands; other herbs types were much rarer. In contrast, the wastelands had many more pollen types, and the pollen percentages of cereal (average 2.5%, 0.3%–7.6%) were much lower. Chenopodiaceae (average 25%, 0.86%–81.3%) in wasteland increased markedly compared with farmland (average 2.5%, 0.3%–7.6%). The pollen percentages of *Artemisia,* Compositae and Cyperaceae were higher than that in the farmlands. During fieldwork, we found more Chenopodiaceae plants growing along the roads and in wasteland, which could explain the higher percentages of this family in the wastelands than in the farmlands. Obviously, humans have seriously influenced farmland vegetation, and the vegetation composition was much less diverse, while the wastelands were less strongly impacted by humans and the vegetation included more taxa in more complicated assemblages.

Surveys of the pollen assemblages of human-disturbed vegetation from Northwestern China [16], the central and southern parts of Northern China and the northern parts of Central China [18], and the subtropical rice areas [15] showed similar patterns. The pollen types in the farmlands were similar to those in the nearby wastelands, but the farmland herbs pollen assemblages were dominated by cereals, while Chenopodiaceae and weedy Poaceae had higher pollen percentages in the wastelands.

Nevertheless, the degree of difference in cereal pollen percentages between wasteland and farmland varied by region. In the subtropical rice areas [15], the average percentage of *Oryza*-type pollen in rice fields was generally 20% higher than in dry areas 5–10 m from the rice fields. In the central and southern parts of Northern China and the northern parts of Central China [18], the average cereal pollen percentage in farmland was about 15% higher than in dry lands. In northwestern China [16], the cereal percentage in the farmlands was 11% higher than in nearby wasteland. In this paper, the average cereal pollen percentage in the farmlands was 28.35% higher than the wastelands. There were significant differences in the cereal pollen contents between different land use types in the subtropical rice regions and in Northeast China and lesser differences in the Northwest. The scale of farmland in these areas may explain these results. The barren soil and poor climate (lower temperature and moisture) in Northwestern China are not conducive to crop growth, and the scale of farmland there is less than in other areas. Therefore, the cereal pollen percentages were lower overall in Northwestern China than in eastern China, and the degree of change between farmland and wasteland was consequently less than in eastern China.

In farmland where different types of crops were planted, the pollen assemblages were different. Pollen assemblages in the cereal farmlands were dominated by cereals; weedy Poaceae were still rich in vegetable plots, but the pollen percentages of Cucurbitaceae, Cruciferae, and other common vegetables were higher than in the cereal farmlands (although still less than 5%). Vegetables such as *Daucus carota* and *Brassica oleracea* are usually harvested before blooming, which could explain the lower vegetable pollen percentages [17,32]. Moreover, the pollen productivities of some plants, such as *Solanum tuberosum*, *Lycopersicum esculentum*, *Capsicum frutescens*, *Cucurbita pepo* and *Phaseolus* [32,33] are usually lower. Finally, smaller crop fields can also result in lower percentages of vegetable pollens.

In Anyang, middle-south region of Hebei Province, the central and southern parts of Northern China, and the northern parts of Central China, Pollens from some entomophilous plants are only recorded in the farmlands where those plants grow. For example, Malvaceae pollen was only found in the cotton-growing areas [17]; Solanaceae pollen only appeared in tobacco field at less than 1%, in addition, legume pollen was recorded in fields of *Arachis hypogaea* and *Glycine max* at very low percentages [18]. Therefore, to better evaluate historical human impacts, potential crop and vegetable pollens must be carefully assessed. Even very low pollen percentages might still indicate human agricultural activities.

Moreover, total pollen concentrations were also quite different between farmland and wasteland. Concentration averaged 3909 grains/g in the farmlands, far lower than in the wastelands (15074 grains/g average, 87446 grains/g maximum) (Figure 6). This result could be related to the dominant plant pollen productivities as well as the farming methods. In the wastelands, the herbs pollen assemblages were dominated by Chenopodiaceae, which have high pollen productivities [31,34]. However, in the farmlands, the pollen assemblages were dominated with Poaceae, which has much lower pollen productivity than Chenopodiaceae [29]. In addition, the artificial removal of weeds by farmers results in fewer herbs (other than crop plants), which also contributes to the lower pollen concentrations in farmland. Finally, different pollen preservation environments could influence pollen concentrations, as well. For example, tillage would enhance surface soil oxidation, and fertilizing and spraying pesticides would change the soil properties; both factors would reduce pollen preservation and decrease surface pollen concentrations [18].

In other areas of China (Table 3), pollen concentrations in wasteland were always higher than in farmland, though patterns varied by crop type and human impact levels. This suggests that human activities are the main cause of low pollen concentrations and that pollen concentration is an important indicator of the intensity of human impacts.

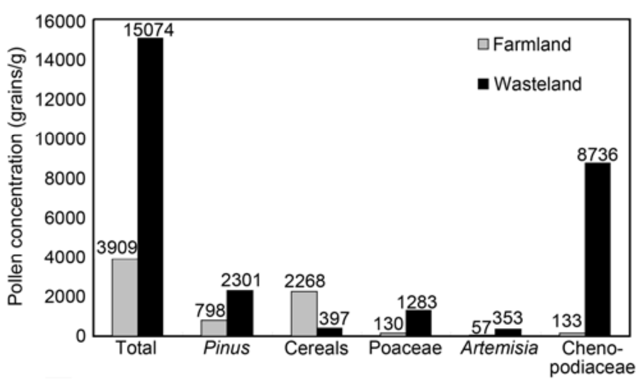

Figure 6 Average pollen concentrations in the farmlands and wastelands.

Table 3 Pollen concentrations in farmland and wasteland in different areas of China (grains/g) [16–18]

	Northeast China	Hebei Province	Northern China	Southern parts of Northern China and northern Central China
Wasteland	15074	–	32704	26333
Farmland	3288	3612	7227	6943

4.3 Indications of human activities in pollen assemblages of human-disturbed vegetation

To better understand the influence of human activities on the pollen assemblages of human-disturbed vegetation in Northeast China, we compared our results to those of studies of farmland in Anyang, the middle-south region of Hebei Province, and the central and southern parts of Northern China and the northern parts of Central China (Table 4). We found some common features in the pollen assemblages of different regions of northern China:

(1) In farmland at 0–200 m a.s.l., tree pollen levels were about 30%, with *Pinus* the dominant taxon. Herbaceous pollen percentages were usually higher than 50%, with cereals most common at more than 20%. Cruciferae (0.1%–15.5%), *Artemisia* (1%–15.8%) and weedy Poaceae (5.0%–7.4%) were also quite common.

(2) In farmland at 200-500 m a.s.l., tree pollen percentages were slightly higher than at 0–200 m a.s.l., while cereal and Cruciferae levels were lower over elevation. *Artemisia*, Chenopodiaceae and Poaceae became more common over elevation, indicating a decline in human impact.

(3) At elevation 500–1000 m a.s.l., both the tree pollen types and total percentages increased dramatically (more than 40% on average) and the cereal pollen percentages were usually less than 15%, indicating that natural vegetation was more common and human impact had declined.

There were also some differences in cereal pollen percentages in farmland of different areas. For example, the cereal pollen percentages below 500 m a.s.l. in Northeast China (more than 40%) are much higher than in other areas (usually lower than 30%). A main cause of this difference is regional climate. The climate is drier and warmer in North China than in Northeast China, so dry farming predominates, and oxidation is stronger in the surface soil. Northeast China is relatively humid and cooler, and oxidation in the surface soil is weaker. These climatological conditions could result in more pollen grains being preserved in Northeast China than in North China and could explain both the higher percentages and concentrations of cereal pollens in the former.

Differences in pollen assemblages might also be caused by the crops planted and the relative areas of cultivation. Maize and wheat are ideal dry-farming crops and are planted across very large geographic scales in Northeast China. In North China [17,33] and Central China [18], the weather is much warmer, permitting more crops, like *Gossypium hirsutum* and *Brassica campestris*. The cultivation of other crops will decrease the proportion of cereal grains and affect pollen percentages proportionately. Therefore, pollen assemblages in farmland would be influenced by crop type, planting habits, and tillage techniques. Crop pollen assemblages can reflect farming habits and technology to some degree.

The pollen assemblages of human-disturbed vegetation also differed among the different areas. In Northeast China, cereals and regional tree vegetation (such as *Pinus*, *Betula* and *Quercus*) were abundant in the pollen assemblages. In

Table 4 The differences of pollen percentages in farmland of different altitudes and areas [17,18,33]

	Altitude (m)	Tree	shrub	Herb	*Pinus*	*Artemisia*	Chenopodiaceae	Cruciferae	Cereal	Weedy Poaceae	*Selaginella sinensis*
Northeast China	0–200	28.5	0.3	60.6	25.86	1.3	3.6	0.15	41.6	7.6	1.8
	200–500	26.5	0.1	68.0	23.5	1.3	2.0	0.02	53.6	4.0	0.6
	500–1000	41.7	0.3	52.6	23.3	3.3	5.0	1.48	11.2	15.9	0.1
Hebei Province	0–200	29.9	1.2	60.6	22.6	2.4	19.7	2.6	19.9	6.9	6.9
	200–500	48.4	1.8	38.3	36.1	3.8	5.6	0.3	18.8	4.8	11.1
	500–1000	49.5	2.7	40.9	44.4	3.9	11.4	0.4	15.2	4.9	6.5
Anyang	0–200	15.9	1.3	71.4	13.7	15.8	1.7	8.8	22.5	5.3	9.2
	200–500	–	–	–	–	–	–	–	–	–	–
	500–1000	–	–	–	–	–	–	–	–	–	–
Southern parts of Northern China and the northern parts of Central China	0–200	31.6	1.0	57.4	23.2	1.0	2.5	15.5	25.0	5.0	7.0
	200–500	37.5	1.1	55.5	25.8	2.6	14.8	6.6	15.9	5.2	4.2
	500–1000	41.7	2.8	39.5	27.9	6.2	7.4	0.4	11.4	4.5	14.6

Hebei Plain, cereals and Chenopodiaceae dominated the pollen assemblages, and the percentages of *Selaginella sinensis* spores were higher than in other areas. In the Anyang area, the tree pollen percentages were lower than in the other areas and cereals and Cruciferae were the most important herbs, reflecting long and intense human impact. Weeds, such as *Artemisia*, were also more common than in other areas. In the central and southern parts of Northern China and the northern parts of Central China, cereals, Cruciferae, Chenopodiaceae, *Artemisia*, and weedy Poaceae were the dominant pollen taxa. Thus, pollen assemblages of human-disturbed vegetation differ due to regional vegetation, crop types, and the degree of human activity.

4.4 The ecological significance of *Concentricystes*

Concentricystes were quite common in the pollen assemblages of farmland in Northeast China (Figure 2). The distribution of *Concentricystes* shows some regional characteristics: In the plains and hills below 500 m a.s.l., the *Concentricystes* content was about 3.4% on average, with a maximum of 33.7%. Above 500 m a.s.l., almost no *Concentricystes* was recorded. *Concentricystes* are thought to be a freshwater alga with a wide ecological range within humid terrestrial environments. They can also grow in cold freshwaters [35,36]. Our samples with the highest percentages of *Concentricystes* were usually taken near wetland nature reserves and lakes and were probably distributed to the farmlands via irrigation water taken from the lakes and wetlands. Such farmlands are usually wetter than nearby wasteland; seasonally humid environments are suitable for the growth of *Concentricystes* and may also have contributed to the higher percentages of *Concentricystes* in some farmlands. Historically, wetlands and marshes were common throughout the plains of Northeast China, so *Concentricystes* would have been widespread. Many of these wetlands have now been transformed into farmland. Whether *Concentricystes* were preserved in the surface soil during the transition to farmland should be investigated further.

4.5 The relationship between pollen assemblages and climate

Climate is a main factor limiting the distribution of plants, including crops and how they are planted. We found that pollen assemblages of human-disturbed vegetation reflect the influence of climate. In the mountains, climatological factors (especially temperature) limit the distribution of cereals and promote the cultivation of vegetables that can endure cold, both of which were reflected in the increased percentage of vegetable pollens and the dramatically decrease of cereal pollens in the assemblages. *Larix* and other cold-tolerant plant pollens only appeared at high levels in the mountains. The pollen proportions of some common montane plants, such as *Quercus*, *Betula* and *Pinus*, were also higher than in other areas. On the contrary, plants that prefer warmer climates, such as *Ulmus,* had higher pollen percentages in the plains than in the colder mountains, and *Larix* and *Betula* were very rare or absent in the plains. RDA showed that the pollen assemblages in Northeastern China had significant negative correlations with T_a (mean annual temperature, –0.73) and T_w (July mean temperature, –0.81) and were also significantly positively correlated with MAP (mean annual precipitation, 0.48). To summarize, the pollen assemblages of human-disturbed vegetation reflect regional climates well.

5 Conclusions

Northeast China is located in the forest vegetation zone. The pollen assemblages of human-disturbed vegetation usually contained more than 30% tree pollen. Moreover, the major taxa in the pollen assemblages were consistent with the vegetation, suggesting that the pollen assemblages of human-disturbed vegetation reflect the regional vegetation composition.

There were differences among pollen assemblages in different geomorphic units. In the mountains, there were more types of tree pollens, at higher percentages, than in other areas. The percentage of cereals was distinctly higher in the plains than in the mountains. The proportions of *Pinus* and *Concentricystes* were highest in the low plains. Pollen assemblages were notably different between farmland and nearby wasteland in the same region. Wasteland had many more types of pollen and higher pollen concentrations (average 15074 grains/g, maximum 87446 grains/g) than did farmland. Cereal pollens in wasteland usually made up less than 10% of the total. On the contrary, in farmland, total pollen levels were much lower (average 3910 grains/g), and fewer pollen types were recorded, but the cereal pollen percentage was 49.9% on average. PCA and RDA analyses indicated that wasteland and farmland samples could be readily distinguished, as could farmland samples from mountains versus plains. Human activity was probably a major cause of the lower pollen concentrations in farmland, suggesting that pollen concentration is an important indicator of human activities. More attention should be paid to the pollens of vegetables and other crops, even when their percentages are low, in fossil pollen assemblages to recognized historical human activities.

Artificial or human-disturbed vegetation reflects regional climate well. RDA showed that the pollen assemblages in Northeast China were significantly negatively correlated with T_a (mean annual temperature, –0.73) and T_w (July mean temperature, –0.81) and were significantly positively correlated with MAP (mean annual precipitation, 0.48).

Our study and other investigations of pollen assemblages in northern China demonstrated that the major pollen types and percentages are closely correlated to latitude and altitude.

The pollen assemblages of human-disturbed vegetation in different areas differed due to the regional vegetation, the types of crops, human impact intensities, and other factors. Cereals and Cruciferae both increased in frequency with declining altitude. Cereals pollen concentrations and percentages in farmland varied with geographic area due to differences in planting habits and climate.

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