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Late Holocene vegetation history suggests natural origin of steppes in the northern Mongolian mountain taiga

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Abstract

Insular occurrences of steppe vegetation are a common feature of the northern Mongolian mountain taiga. Steppe vegetation is limited here to southern slopes, whereas northern slopes and valley bottoms are principally wooded with light and dark taiga forests. In a case study in the valley of the river Eroo at Khonin Nuga Research Station in the western Khentey Mountains, we searched for evidence of an anthropogenic versus natural origin of steppe vegetation on the southern slopes. Pollen data of three profiles covering the last 2500 years showed continuous presence of steppe throughout the late Holocene with human influence restricted to the recent past. Virtual absence of charcoal in the soil on and beneath three steppe slopes suggested that the present steppe grasslands are not replacing former forests burnt by humans or lightning. The floodplains in the center of the Eroo valley were recently deforested. This is suggested by the pollen analysis and by interviews with local people on landuse history. Steppe grasslands of the study area have probably never been used as pastures. Pastoral nomads traditionally avoided the Eroo valley near Khonin Nuga because of difficult access and high densities of wolves and bears. All our data suggest that the present vegetation pattern of the western Khentey with steppes (and single small *Ulmus pumila* trees) on south-facing slopes occurring as islands in the mountain taiga is driven by climate and relief and is not the result of human activities as suggested for other regions of Asia.

Keywords: Meadow steppe; Taiga; Climate; Human impact; Mongolia; Palynology

1. Introduction

In northern central Asia, the Siberian taiga forests meet the Eurasian steppe belt. Mongolia's vegetation includes the transitional zone between the northern coniferous forest and the steppe. Since less than 1% of Mongolia's territory has been converted into farmland (CIA, 2004), the Mongolian landscape looks pristine with taiga forests in the northern third of the country, steppe in the central parts, and semi-desert and desert in the south (Hilbig, 1995; Vostokova and Gunin, 2005). However, naturalness of Mongolia's present vegetation pattern is a controversial issue, as Mongolia has long been inhabited by pastoral nomads (Hilbig, 2000; Dulamsuren et al., 2005a). Ancient nomad cultures included the Scyths (7th to 3rd century BC) and the Huns (3rd century BP to 4th century AD). Major human activities started in the 13th century when the Mongolian Empire was founded by Chingis Khan (Rösch et al., 2005).

The present transition between forest and steppe is a vegetation mosaic of sharply limited forests at relatively well water-supplied sites and grasslands at dry sites. The share of forest in the landscape increases with increasing water availability. In Mongolia, precipitation increases zonally with increasing latitude and azonally in the big mountain systems of, e.g., the Mongolian Altai, Khangay and Khentey (Sato et al., 2007). Forest-steppe transitions are found in two vegetation zones: the drier forest-steppe and the more humid mountain taiga (Vostokova and Gunin,

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2005). In the former, forests are limited to northern slopes and occur as islands in the steppe (Hilbig, 1995; Gunin et al., 1999). The mountain taiga is dominated by forest, whereas steppes are limited to sun-exposed southern slopes. Steppe outposts in the taiga are found in northern Mongolia, southern Siberia and Yakutia (Yurtsev, 1981; Dulamsuren et al., 2005a,b; Schlütz and Lehmkuhl, 2007).

Since climate is generally less arid in the mountain taiga than in the forest-steppe (Vostokova and Gunin, 2005; Sato et al., 2007), growth conditions for trees are generally better in the former (Gunin et al., 1999). Hence, grasslands in the mountain taiga are more likely of anthropogenic origin than grasslands in the forest-steppe. Therefore, we conducted a case study on vegetation history of the western Khentey Mountains in the northern Mongolian mountain taiga. The aim of our study was to test the principal hypothesis that steppe vegetation colonized sun-exposed slopes of the western Khentey after anthropogenic deforestation in the late Holocene. To reconstruct the Holocene vegetation history three methods were combined, viz. palynological analysis, charcoal sampling, and interviewing of local people.

The main focus was to analyze pollen profiles from the base of steppe slopes and from the center of the wide valley of the Eroo river. Palynology was employed to test the hypotheses that (1) the relative abundance of arboreal pollen decreased, and (2) the relative abundance of steppe plant pollen increased during the late Holocene indicating a deforestation of southern slopes due to the use as pastures by ancient tribes, such as Scythes, Huns and early Mongols. Soils at the base of and on the steppe slopes were searched for charcoal to clarify whether the slopes were deforested by fire. Deforesting of steep slopes as in the western Khentey Mountains would inevitably lead to soil erosion and archiving of any charcoal in the colluvia at the slope base. Local people were interviewed to obtain information on the recent history and oral tradition of the study area to assess utilization intensity.

2. Study area

2.1. Location, relief and climate

Field work was carried out in the western Khentey Mountains, northern Mongolia, Mandal county (Mandal somon) near Khonin Nuga Research Station (49°04′48″ N, 107°17′15″ E), run by the Center of Nature Conservation of the University of Göttingen and by the National University of Mongolia, Ulan

Fig. 1. Study area Khonin Nuga in the western Khentey Mountains, northern Mongolia. The area is characterized by a vegetation mosaic of steppes (and small, very open *Ulmus pumila* stands) on south-facing slopes (light colors) and mountain taiga forests on north-facing slopes and in most valleys (green colors). Arrows indicate southern slopes selected for charcoal sampling. BB, RT and SF mark the locations of the pollen profiles Bayou Bank, River Terrace and Slope Foot.

Bator. Khonin Nuga Research Station is located 130 km north of Ulan Bator in a valley, where the rivers Sharlan Gol and Khongiyn Gol unite and become the River Eroo (Fig. 1). The latter flows into the Orkhon River, then into the Selenge River and finally into Lake Baikal. The Khentey Mountains stretch across 200 km from Ulan Bator in north–eastern direction to the Russian border. In Russia, it further continues over 150 km to the northeast, changing its name to Chikoyskiy Khrebet and Khrebet Stanovik. North of these mountains arises the Transbaikalian Mountain System, the main ridges of which run in west–east direction. The Khentey Mountains are surrounded by the Mongolian–Daurian steppe in the west and in the south and by the Eastern Mongolian steppe in the east. A 50–80 km wide strip of the Mongolian–Daurian steppe and the river Orkhon separates the Khentey from the Khangay Mountains in the southwest.

Elevation of the study area ranges from 900 m in the river valleys up to 1600 m on the mountain tops. The central parts of the Khentey Mountains, east and southeast of the study area, generally exceed an elevation of 1500 m with the highest peak, Mt. Asralt-Khayrkhan, achieving 2799 m. Geologically, the Khentey mainly consists of Proterozoic and Paleozoic rocks, especially of granite. Permafrost is found under forests on northern slopes. Climate of the Khentey Mountains is characterized by the Asiatic anticyclone in winter, which typically has its center southwest of Lake Baikal and causes dry and cold winters with mean January temperatures as low as −23 to −28 °C (Tsegmid 1989; Tsedendash 1995). In summer, warm air masses from the south flow into northern Mongolia resulting in the formation of cyclones when they meet the cold air from Siberia. Mean July temperatures published from the Khentey range from 12 to 18 °C. Frost occurs from the end of August to early June on 280–300 days per year. Most of the annual precipitation of 250–290 mm is received in summer (Dulamsuren and Hauck, unpublished). Climate diagrams of neighboring climate stations are published in Dulamsuren et al. (2005b).

2.2. Current vegetation

Vegetation of the study area was currently surveyed by Dulamsuren (2004) and Dulamsuren et al. (2005a,b,c). Forest vegetation is divided into dark taiga (*Pinus sibirica*, *Abies sibirica*, *Picea obovata*) in the upper montane belt, light taiga (*Larix sibirica*, *Betula platyphylla*, *Pinus sylvestris*) in the lower montane belt and floodplain forests in the valley of the river Eroo. Floodplain forests are either mixed forests of *B. platyphylla* and *L. sibirica* or consist of *P. obovata*, *Populus laurifolia* or several *Salix* species. Southern slopes are covered with different types of steppe communities. Herb-rich short-grass meadow steppes prevail on gently to strongly inclined shallow soils. The most common association in the study area is the *Pulsatilla ambigua* meadow steppe with, e.g., *Bupleurum bicaule*, *Orostachys spinosa*, *Poa botryoides*, *Potentilla acaulis*, *Pulsatilla ambigua*, *P. turczaninovii*, and *Thymus gobicus*. Stony, steep soils are stocked with mountain steppe dominated by *Spiraea aquilegifolia*, *Heteropappus altaicus*, *H. biennis*, and *Artemisia frigida*. Further typical species of the mountain steppe are, e.g., *Alyssum lenense*, *Chamaerhodos erecta*, *Dontostemon integrifolius*, *Goniolimon speciosum*, *Koeleria cristata*, *Orostachys malacophylla*, *Patrinia sibirica*, and *Polygala tenuifolia*. Single trees or small groups of *Ulmus pumila* up to 5-m high are occasionally found on the southern slopes at similar sites as the mountain steppe. Forest edges on mountain ridges, where the grasslands border on the taiga, are characterized by the *Carex amgunensis* meadow steppe. Soils under this community are several dm deep. Typical species of the forest edge meadow steppe include *C. amgunensis* and *Elymus confusus*.

2.3. Present landuse

Presently, the Khonin Nuga region is only inhabited by the family of a ranger of the nearby Khan Khentey Strictly Protected Area. This family has got a small number of livestock (primarily horses and cattle), which browse the floodplain meadows south of the river Eroo. They sometimes access the light taiga forest on gently inclined northern slopes, but avoid the steppe (personal observations during 9 years of field work). The family's horses and horses belonging to the research station, browsing the floodplain in the direct surroundings of the station, are frequently attacked and many of them are killed by wolves throughout year. Therefore, no nomads live in the vicinity of Khonin Nuga. The closest nomads live 50 km SW of Khonin Nuga, where the mountain taiga gives way to the forest-steppe. Timber is presently not harvested in the Khonin Nuga area. Dark taiga forest 10–20 km N and E of Khonin Nuga are used for commercially collecting cones of *P. sibirica*, the seeds of which are regionally consumed as food or exported to China. Geothermal springs (Eroogiyn Khaluun Rashaan; 49°01′N, 107°33′E) located 20 km SE of Khonin Nuga are used for vacation by small groups of Mongolian tourists from the next town Zuun Kharaa in 70 km distance and from Ulan Bator. The geothermal springs have been used for therapeutic purposes since the late 17th century after their discovery by the Buddhist leader Zanabazar (1635–1723). Zanabazar, who was appointed to the first head lama of the Gelug tradition in 1640, approached Eroogiyn Khaluun Rashaan with 300 stalwarts fleeing from the Manchurian–Chinese invasion in 1688 into this remote area (Norovsambuu, 1995; Ichinnorov, 2005). He recognized the medical value of the geothermal springs and initiated the establishment of a small health resort as at other locations in Mongolia (Croner, 2006). Furthermore, the Khonin Nuga area is regularly approached by small groups of poachers. From 1978 to 1987, a prison was operated in Khonin Nuga with 1200 prisoners and 300 staff members. For that, the first and still only (unpaved) access road was constructed from Zuun Kharaa to Khonin Nuga in 1978. In addition forest roads were built in the Khonin Nuga area, which are out of use at present.

3. Materials and methods

3.1. Palynology

Three profiles were cored in 2005 in the Eroo valley near Khonin Nuga Research Station. Site "Bayou Bank" (BB) was located directly at the water margin of an 8-m wide bayou (cut-off meander). The opposite side of this bayou is situated at the foot of a southern slope with montane meadow steppe and *U. pumila* open woodland. 200 m E of site BB on the slope side of the bayou the profile "Slope Foot" (SF) was examined. The third site called "River Terrace" (RT) was located in the center of the Eroo valley 1.5 km SE of sites BB and SF on a treeless terrace about 5 m above the river level in a swampy part of a floodway. Site RT was south of, and sites BB and SF were north of, the river Eroo. The profile BB was 126 cm long in depth and consisted of loose reed peat in the upper 39 cm, Cyperaceae peat between 39 and 55 cm, and organic silt between 55 and 126 cm. The 71-cm deep profile SF had sandy reed peat in the upper 19 cm, strongly decomposed peat with sand and gravel between 19 and 46 cm and organic silt in the lowest part. The RT site consisted of reed peat in the upper 5 cm, strongly decomposed reed peat between 5 and 46 cm, and varying layers of sandy organic silt and reed peat to the base at 80 cm depth. Below rounded pebbles followed, building up most of the shore of the floodway with the exception of the drilling site.

Sediment samples of 1 cm^3 were taken from the profiles around every 5 cm. All samples were prepared for pollen analysis following the protocols of Erdtmann (1960) and Moore et al. (1999) using KOH, HF and acetolysis. Then the suspensions were sieved in an ultrasonic bath at 50 kHz on a 6 µm mesh, and stored in glycerine. Pollen preparation included addition of *Lycopodium* spores as an exotic marker to determine pollen concentration and pollen influx. Pollen counts were made at 500x, in ambiguous cases at 1250× magnification. On average, 800 (750–860) pollen grains of trees and shrubs (AP) per sample were counted from profile BB, and 520 (500–540) from SF. In profile RT only 100 AP could be counted per sample due to low pollen density.

The calculation of pollen percentages is based on the sum of AP, with quantities of non-arboreal pollen (NAP) and spores expressed as percentages of the AP. In addition, Iversen diagrams are given, where percentages are related to the total of all included groups and taxa. These Iversen diagrams are presented between the curves for AP and NAP in Figs. 2–4. The pollen collections of the Department of Palynology and Climate Dynamics at the University of Göttingen were used as a reference for identification. Identification and nomenclature of pollen types is based on Beug (2004), whereas spores were identified with the help of Moore et al. (1999) and van Geel et al. (1989, 2003). Some names of palynological taxa are adapted to the recent flora of the Khonin Nuga area (Dulamsuren 2004, 2005a,b,c). Taxa represented in the study area by a single species are named accordingly (e.g. *Pinus cembra*-type sensu Beug as *P. sibirica*). The pollen diagrams were produced with the software C2 version 1.4.3 (Juggins, 2003).

Taxa are arranged according to their ecology and chronological appearance. Most of the NAP and spore taxa are not presented individually. According to the species represented, the NAP taxa are part of the sums "steppe" (*Astragalus*, *Campanula glomerata*, *Campanula trachelium*, *Matricaria, Saussurea*, *Senecio*, and *Potentilla* types as well as Caryophyllaceae p.p., *Melandrium*, *Pulsatilla*), "floodplain" (*Aquilegia*, *Caltha*, *Lathyrus*, *Ranunculus acris*, *Rumex acetosa*, *Plantago lanceolata*, and *Polygonum bistorta* types as well as Apiaceae, Brassicaceae, *Cannabis*, Cichorioideae, Epilobium, *Polygonum alpinum*, *Polemonium racemosum*, Rubiaceae, *Sanguisorba officinalis*, *Thalictrum*, *Trollius asiaticus*, Urticaceae), "wetland" (*Lysimachia davurica*, *Persicaria maculosa*, *Rumex aquaticus*, and *Valeriana officinalis* types as well as *Filipendula*, *Parnassia palustris*) or "water" (*Alisma* group, *Potamogeton natans* type, *Myriophyllum spicatum*, *Typha laxmannii*). The Poaceae, *Artemisia*, and the Chenopodiaceae are difficult to assign to a certain habitat, as their different species occur in the steppe, forests and floodplains of Mongolia (Hilbig, 1995) and as their pollen is highly dispersible. In the case of Poaceae and *Artemisia*, the distribution in the current vegetation of the study area (Dulamsuren, 2004; Dulamsuren et al., 2005b,c), however, suggest that their pollen primarily derives from the steppe. Species of the Chenopodiaceae are today preferentially found at disturbed places on river banks or in the surroundings of rodent dens (Dulamsuren, 2004).

Based on major changes in pollen proportions, pollen diagrams were divided with statistical assistance (PCA) into local pollen zones (BB, SF, RT). Radiocarbon ages of the pollen fraction (Morgenroth et al., 2000) of 4–8 cm long sections of the pollen profiles were determined by accelerator mass spectrometry (AMS) at the University of Erlangen, Germany (Table 1). Dates were calibrated to calendar ages with Calib 5.0.2 (Stuiver and Reimer, 1993). Dates given in calibrated years AD or BC are interpolated on the assumption of a linear sedimentation rate.

3.2. Charcoal sampling

Three southern slopes with steppe vegetation north of the river Eroo in the surroundings of Khonin Nuga Research Station were selected for charcoal analysis. At the foot of each mountain slope, samples were collected along a 250-m long transect every 50 m. Each sample consisted of five subsamples collected in a distance of 2 m from the 50-m point. This means five replicates each with five pseudoreplicates were studied. In addition to the samples at the slope foot, ten randomly selected sampling points on each steppe slope were studied. At each sampling point, a soil profile was dug to the bedrock and searched for charcoal. The studied soils were Mollic Leptosols with a depth of mostly about 1 m at the footslope and shallow Eutric Leptosols on the open slopes. Since large fires leading to major deforestations leave noticeable remnants of charcoal, the entire soil profiles were studied macroscopically in the field. Small traces of potentially carbonized wood were collected for microscopic study. Charcoaled plant particles were also found in quite low number during pollen analysis, but these samples were not studied in detail.

3.3. Interviews with local people

To gather information on the local knowledge of landuse history, thirty people from the surroundings of Khonin Nuga were interviewed. People were living at Khonin Nuga (only one

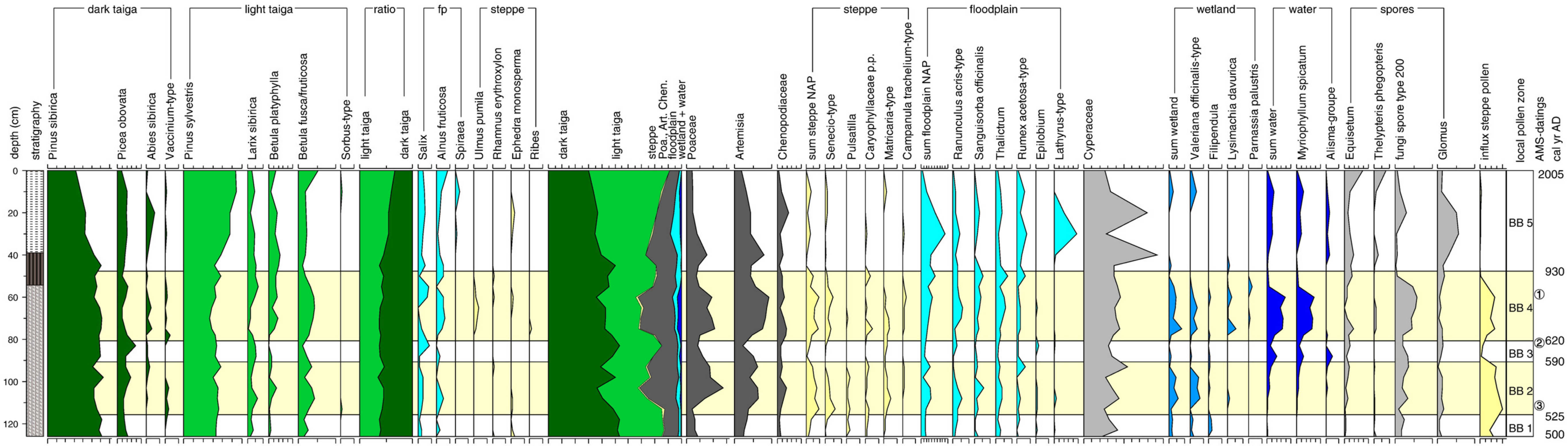

Fig. 2. Simplified pollen diagram from the profile Bayou Bank (BB). The diagram shows pollen values of trees and shrubs (AP) in the left part, of non-herbaceous plants (NAP) in the right part and an Iversen diagram in the center. Pollen values for AP and NAP are related to the sum of AP, whereas pollen values in the Iversen diagram refer to the total pollen sum except for the Cyperaceae. Influx of steppe pollen is given in pollen grains cm^{-2} a^{-1}. For numbers of AMS datings refer to Table 1. Abbreviations: fp, floodplain; Art., *Artemisia*; Chen., Chenopodiaceae.

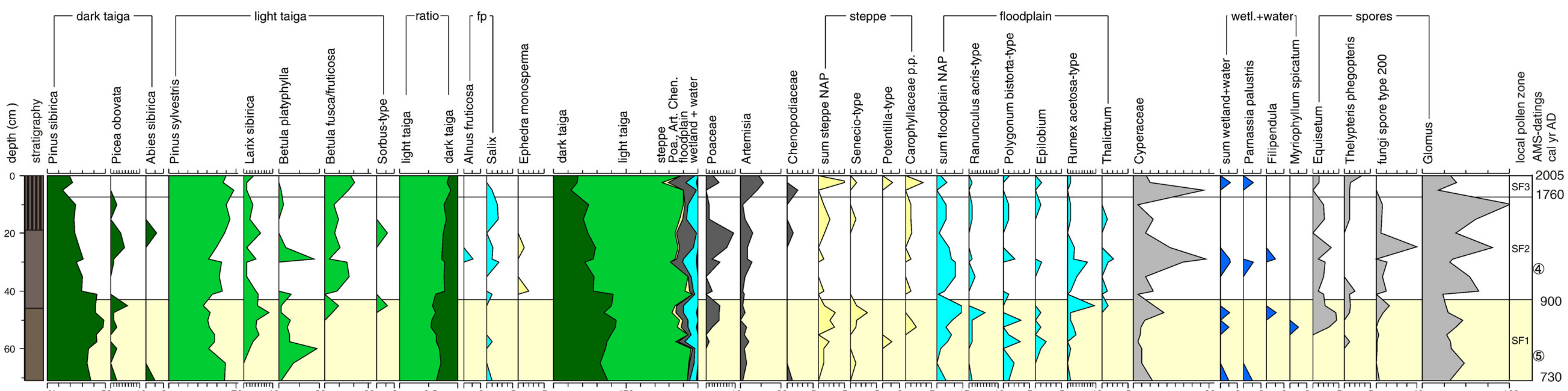

Fig. 3. Simplified pollen diagram from the profile Slope Foot (SF). The diagram shows pollen values of trees and shrubs (AP) in the left part, of non-herbaceous plants (NAP) in the right part and an Iversen diagram in the center. Pollen values for AP and NAP are related to the sum of AP, whereas pollen values in the Iversen diagram refer to the total pollen sum except for the Cyperaceae. Influx of steppe pollen is given in pollen grains cm^{-2} a^{-1}. For numbers of AMS datings refer to Table 1. Abbreviations: fp, floodplain; Art., *Artemisia*; Chen., Chenopodiaceae.

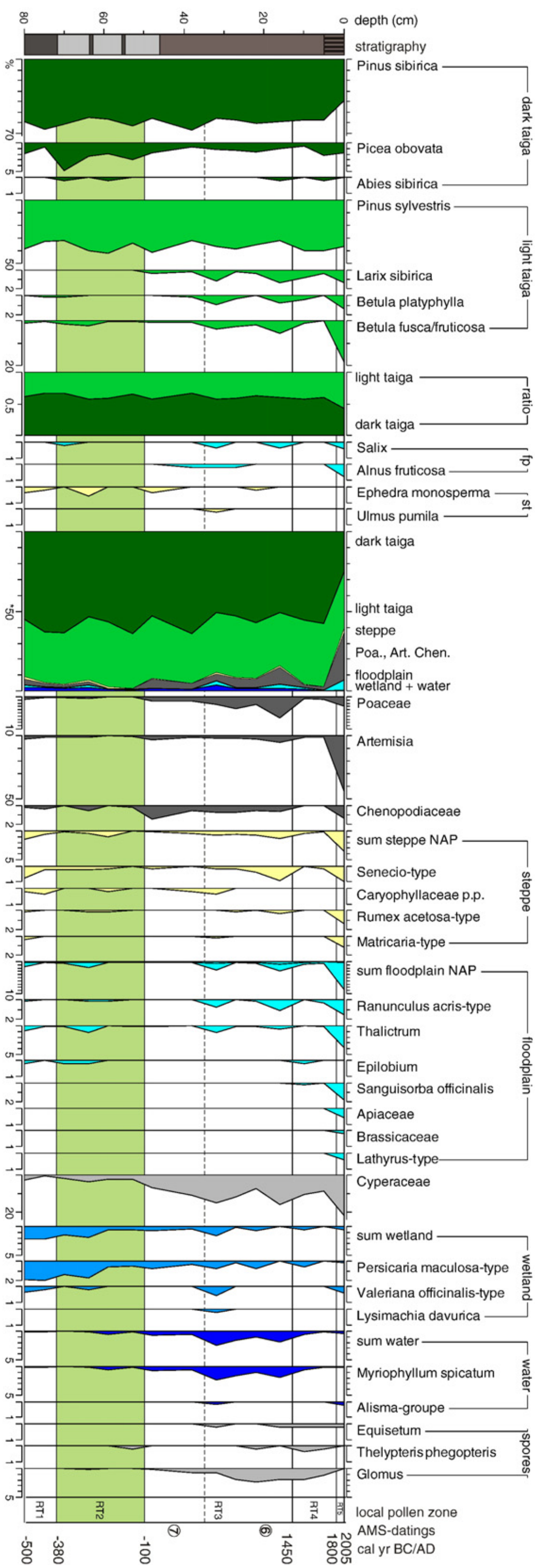

Fig. 4. Simplified pollen diagram from the profile River Terrace (RT). The diagram shows pollen values of trees and shrubs (AP) in the left part, of non-herbaceous plants (NAP) in the right part and an Iversen diagram in the center. Pollen values for AP and NAP are related to the sum of AP, whereas pollen values in the Iversen diagram refer to the total pollen sum except for the Cyperaceae. For numbers of AMS datings refer to Table 1. Abbreviations: fp, floodplain; Art., *Artemisia*; Chen., Chenopodiaceae.

person), from the nearest town to Khonin Nuga Research Station, Zuun Kharaa (70 km SW Khonin Nuga), or from Galsanbulag, a forest-steppe region located east of Zuun Kharaa along the way to Khonin Nuga (Table 2). One interviewee came from Ulan Bator, but was familiar with the area as a researcher. People interviewed included both perennial inhabitants of the town and nomads living east of Zuun Kharaa. Persons were non-randomly selected for interview, as people with professions related to utilization of the Khonin Nuga area and old nomads were preferred. Despite this bias, 18 out of the 30 interviewees were not able to contribute relevant information. Hence, only information of the remaining twelve persons is included in the results. Information to assess the personal background of the interviewees for providing information on the Khonin Nuga area is compiled in Table 2. Questions asked are given in Table 3; they were based on pre-information about local history obtained during nine years of field work.

4. Results

4.1. Description of the pollen diagrams

4.1.1. Profiles "Bayou Bank" (BB) and "Slope Foot" (SF) from the foot of a steppe slope

The profile BB dates back to 500 cal yr AD (Figs. 2, 5). Consistent with the other pollen diagrams, the pollen spectra are dominated by pine pollen. From 500 to 930 AD, pollen percent values amount to c. 60% for *Pinus sibirica* and 35% for *P. sylvestris* (BB 1–4). Since 930 AD, values for *P. sibirica* decrease to 30%, whereas those for *P. sylvestris* increase to 55% (BB 5). Pollen values of other conifers (i.e. *Larix sibirica*, *Picea obovata* and *Abies sibirica*) are all consistently below 5%. Deciduous trees achieved values up to 14%.

The transition from BB 1 (c. 500–525 AD) to BB 2 (c. 525–590 AD) is characterized by an increase of steppe plant pollen from 0.7 to 2%. Taxa most common in the steppes, but also appearing in the open vegetation of the floodplain, increase as well. For instance the values of the Poaceae increase in BB 2 from 7 to 28%, *Artemisia* from 7 to 13%, and Chenopodiaceae from 1 to 2%. Pollen of herbs mostly restricted to floodplains increase from 1.0–1.5% in BB 1 to 1.5–4% in BB 2. The zone BB 3 (c. 590–620 AD) is characterized by a decrease of steppe plant pollen to 0.1% as well as a decline of pollen percentages of Poaceae to 8%, of *Artemisia* to 5%, and of Cyperaceae from 55 to 30%. Furthermore, decreases are observed for *Betula fusca/fruticosa* (*Betula nana* type) and fern spores. In BB 4 (c. 620–930 AD), many plant taxa and ecological groups recovered to or even exceeded their pollen values of BB 2. These included steppe plants (2%), floodplain herbs (8%), Poaceae (21%), *Artemisia* (18%), and the aquatic *Myriophyllum spicatum* (4%). Among the steppe plants, occurrence of the otherwise lacking *Ulmus pumila* pollen (0.4%) is notable. Other tree or shrub species with increasing pollen values in BB 4 include *Abies sibirica* (0.5%), *Betula platyphylla* (2%), *B. fusca/fruticosa* (9%), and *Alnus viridis* subsp. *fruticosa* (0.6%). Pollen values of most taxa with peaks in BB 4, except *Betula platyphylla*, decreased at the end of this zone. In BB 5 (c. 930 AD to

Table 1
Radiocarbon dates

No.	Profile	Sample number	Depth (cm)	Age (^{14}C yr BP)	δ ^{13}C (‰)	Age (cal yr AD)	Mean age (cal yr AD)
1	BB	ERL-9585	56–60	1359±37	−27.7	609–767	688
2	BB	ERL-9586	76–80	1415±39	−27.0	568–666	617
3	BB	ERL-9587	109–113	1507±39	−27.1	433–639	536
4	SF	ERL-9588	30–35	1055±37	−26.7	894–1027	960
5	SF	ERL-9589	60–64	1228±42	−26.7	682–888	785
6	RT	ERL-9590	17–22	1001±42	−27.7	906–1155	1030
7	RT	ERL-9592	38–46	1952±45	−28.1	53 BC–203 AD	75

present), steppe plants record values near 1%. Since about 1300 AD, *Spiraea* pollen is present. Values of Poaceae and *Artemisia* increase around 1100 AD to 15%, but then decrease to 4% until present. *Glomus* spores achieve values of up to 11% between c. 1350 and 1550 AD.

Profile SF dates back to c. 730 AD (Figs. 3, 5) and matches, thus, with late BB 4 and BB 5. Due to low pollen concentration and thereby low pollen sums, the reliability of pollen percentages of the individual species is lower and the number of palynological taxa per sample is less. Nevertheless the results of diagram BB are supported by the data of profile SF. From c. 730 to 900 AD (SF 1), pollen values of *Pinus sibirica* vary between 35 and 45%; from about 900 AD on, they gradually decreased to 20%. In contrast to profile BB, the long-term trend to higher portions of *P. sylvestris* is obscured by high values of *P. sylvestris* at the very first beginning of SF 1. This hints at a very local appearance of *P. sylvestris* as a pioneer tree on the floodplain at the site of profile SF. The same seems to be true for the higher values of *P. sylvestris* in the lower part of SF 2, where the occurrence of pioneer habitats is already indicated by shrub birches (*Betula fusca/fruticosa*). Thereafter, pollen values of *P. sylvestris* increase from 40% to presently about 60%. Pollen of steppe species is more or less continuously present, but most common in SF 1. *Larix sibirica* values usually vary between 1 and 5% and have a peak of 9% around 880 AD coinciding with higher steppe values. After about 850 AD *Betula fusca/fruticosa* pollen occurs with values reaching up to 10 to 20%.

4.1.2. Pollen diagram River Terrace (RT) from the middle of the Eroo valley

The diagram RT covers the last 2500 years (Figs. 4, 5). Pollen of herbaceous steppe plants (sum steppe NAP in Figs. 4, 5) were more or less continuously present, starting with 1.5% in RT 1 and ending up with a maximum of 3.6% in RT 4. Pollen values of *Pinus sibirica* remained between 50 and 65% from c. 500 BC to about 1800 AD, but fall to 40% until present (RT 4). Pollen percentages of *P. sylvestris* vary between 30 and 45% without a clear trend. *P. obovata* pollen is continuously present with 1–2%, but with higher values between c. 380 to 100 BC (RT 2). *L. sibirica* pollen occurs in the profile with up to 2% since c. 2100 years (RT 4). Pollen values of several groups and taxa increased during the last 100 years. Absolute maxima are achieved here for *B. fusca/fruticosa* (19%), *Artemisia* (44%), Chenopodiaceae (1%), and the sum of floodplain herbs (8%) including *Sanguisorba officinalis* (2%) and *Thalictrum* (4%).

4.2. Charcoal evidence

Charcoal layers were absent from most soil profiles. At a single site, charcoal pieces of a few mm were found in the Ah horizon of one subsample in immediate vicinity to a light taiga forest.

Table 2
Participants of survey of local knowledge on human landuse history of the Khonin Nuga region, western Khentey

No.	Place of residence	Profession and additional information	Age	Stays in Khonin Nuga
1	Khonin Nuga	Ranger of Khan Khentey Strictly Protected Area	46	1995–present
2	Galsanbulag	Nomad, formerly truck driver	67	occasional visits since 1970
3	Galsanbulag	Retired worker at timber plant in Zuun Kharaa, responsible for the acceptance of timber deliveries from Khonin Nuga	65	1970–present, frequent visits
4	Galsanbulag	Craftsman	50	1970–present, frequent visits
5	Zuun Kharaa	Nomad	80	occasional visits since the late 1960s
5	Zuun Kharaa	Nomad, father was guard at the border to Russia	80	Lived with parents at the Minj river (49°00′ N, 108°02′ E) E Khonin Nuga from the late 1920s to the late 1930s, had contact to Buriats
7	Zuun Kharaa	Nomad	76	occasional visits since 1970
8	Zuun Kharaa	Railway staff member, responsible for water supply of Zuun Kharaa station	75	1962–1993, occasional visits
9	Zuun Kharaa	Nomad, parents lived near Khonin Nuga in the 1960s	58	c. 1960–1970
10	Zuun Kharaa	Director of the Environmental Office at Mandal Somon	45	occasional visits since 1990
11	Zuun Kharaa	Truck driver	50	1990–2006, frequent visits
12	Ulan Bator	Director of the Institute of Geoecology, National University of Mongolia	48	occasional visits since 1980

Table 3
Questions for interviews of local people on landuse history in the Khonin Nuga area, western Khentey

No.	Question
1	What is the origin of the name “Khonin Nuga”?
2	When was Khonin Nuga colonized by Buriat people?
3	Did the Buriats do livestock breeding in Khonin Nuga?
4	When and why did the Buriats leave Khonin Nuga?
5	Was the prison run in Khonin Nuga from 1978 to 1987 supplied by locally held livestock?
6	When was the Khonin Nuga area developed with forest roads?
7	How much wood has been harvested in the Khonin Nuga area?
8	Which tree species have been harvested?

4.3. Interviews on recent vegetation and utilization history

4.3.1. Early colonization history

According to 10 out of 12 interviewees (84%), the name ‘Khonin Nuga’ (i.e. the Mongolian expression for sheep meadow) dates back to the 17th century when Zanabazar (cf. Section 2.3.) discovered the geothermal springs (Eroogiyn Khaluun Rashaan) 20 km SE Khonin Nuga and established there a small health resort. The surroundings of the geothermal springs are not suited for livestock breeding, as they are located in a narrow valley and can only be approached through the forest. Therefore, the wide floodplain terraces of the river Eroo in Khonin Nuga were used as pasture. Two interviewees (16%) thought that the name ‘Khonin Nuga’ has its origin in livestock breeding started in the area by immigrants from Buriatia in the 19th or early 20th century. Knowledge of the interviewees on early landuse history of Khonin Nuga was based on oral tradition.

4.3.2. Colonization by immigrants from Buriatia

During the 19th century immigrants from Buriatia settled down in Khonin Nuga. Their number is not known, but was small. After the October Revolution in Russia, refugees from Buriatia came to Khonin Nuga in the 1920s and 1930s. They constructed dwellings of larch bark and used Khonin Nuga as winter camp, whereas locations up to a distance of 50–100 km away were used in summer at the rivers Minj and Yalbag. Two thirds of the interviewed persons believed that the Buriats only subsisted on hunting and gathering. One third of the interviewees stated that they would have lived from both hunting and livestock breeding. The Buriats were also said to have continued the tradition of supplying visitors and keepers of the geothermal springs with food during the mid 20th century.

Information on the duration of the colonization of the Khonin Nuga by Buriats is contradictory. The Buriats were said to have left Khonin Nuga already in the 1920s to 1930s (75% of the interviewees) or in the 1950s to 1960s (25%). The first group of people thought Khonin Nuga would have been abandoned due to political agitations spilling over from Russia into Mongolia, whereas the second group thought an order of the Mongolian government to migrate to the nearest towns (to ensure school attendance) was the reason for the Buriats leaving Khonin Nuga. In addition a flood of the river Eroo is said to have destroyed livestock and houses in Khonin Nuga in the 1950s. 25% of the 12 interviewees with utilizable statements had no information on the point in time when the Buriats moved away from Khonin Nuga.

4.3.3. Timber harvesting

Timber harvesting started in the 1980s, after Khonin Nuga was reachable by car since 1978, but intense logging was limited to the period from 1987 to 1989. All interviewees, including a staff member of a lumber mill in Zuun Kharaa (Table 2), stated that 120,000–130,000 m^3 $year^{-1}$ of timber were harvested in the Khonin Nuga catchment during this short period. Evidence of preferentially harvested tree species is inconsistent. Logging activities were focused on larch according to 50% of the interviewees, to pine (33% of the interviewees), or larch and pine (16%).

4.3.4. Food supply of the prison from 1978 to 1987

While 25% of the interviewees had no information on the organization of food supply in the prison that was run for nine years in Khonin Nuga, 75% of them stated that local sheep and goat husbandry was unsuccessful because of high losses due to predation by wolves. Therefore, most meat for consumption by the prisoners and staff was brought to Khonin Nuga from Zuun Kharaa. In Khonin Nuga, livestock breeding in Khonin Nuga was primarily limited to horses and cattle.

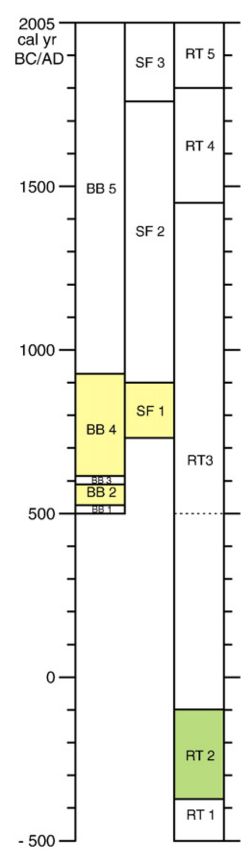

Fig. 5. Time correlation of the pollen zones of pollen diagrams Bayou Bank (BB), Slope Foot (SF) and River Terrace (RT) with a calibrated time scale. BB 2, BB 4 and SF 1 are steppe phases, whereas RT 2 is a phase of *Picea obovata*.

5. Discussion

5.1. Palynological data

The three pollen diagrams (Figs. 2–4) are consistent in showing continuous presence of steppe plants through the entire documented period. This covered 2500 years BP in profile RT, 1500 years BP in profile BB and 1270 years BP in profile SF. Throughout the last 2500 years, however, steppe plants contributed only up to around 2.5% of total pollen sum (Iversen diagrams). This low representation of steppes in the pollen spectra is attributed to the fact that insect-pollinated species prevail in the herb-rich meadow and mountain steppes of the western Khentey Mountains (Dulamsuren, 2004; Dulamsuren et al., 2005a,b,c). Prosperity of steppe plants was limited by drought during the late Holocene. This is inferred by a correlation of their pollen values with that of floodplain herbs in profiles BB ($r=0.43$, $P\leq0.05$) and RT ($r=0.70$, $P\leq0.001$). In profile BB, pollen values of steppe plants were also positively correlated with the aquatic plant *Myriophyllum spicatum* ($r=0.57$, $P\leq0.01$). Peaks in pollen values of a wide range of taxa, including the light taiga trees *Larix sibirica* and *Betula platyphylla*, the floodplain trees and shrubs *Alnus viridis* subsp. *fruticosa* and *Salix* spp., Poaceae, and *Artemisia*, occasionally coinciding with peaks of steppe plant pollen (Figs. 2–4) seem to suggest that the development of the entire vegetation of the study area was strongly dependent on precipitation, though these correlations might be overpronounced due to the dominance of *Pinus* pollen in the pollen spectra (van der Knaap and Leeuwen, 2003). The significance of precipitation for the temporal vegetation dynamics is plausible, as biomass production both of Mongolia's forests and grasslands is strongly correlated with water availability at present (Batima, 2006). The zones BB 1 and 3 mark short dry but cold intervals of about a few decades, with low pollen production on the steppe slopes but prolific flowering of the cold adapted *Pinus sibirica*.

Though AP values vary in a range of about 60–90% in the pollen records, a general trend towards increase or decrease was absent from profiles BB and SF at the northern side of Eroo valley. In profile RT, south of the river Eroo, AP decreased from 97 to 61% within the last 100 years. Most of the AP consisted of pine pollen (*Pinus sibirica*, *P. sylvestris*), as *Pinus* produces large amounts of well-dispersed pollen grains. If steppe vegetation spread during the last millennia to the disadvantage of forest, decreasing pollen values of the most drought resistant tree species should be noticeable concomitant with an increasing signal of steppe plants. Drought-resistant tree species, which are currently found at the lower tree border towards the steppe, include the light taiga species *Larix sibirica*, *Betula platyphylla* and *Pinus sylvestris* (Dulamsuren, 2004; Dulamsuren et al., 2005a). While pollen values of *L. sibirica* and *B. platyphylla* were low at the beginning and became more frequent in the last 2000 to 1500 years, *P. sylvestris* values were high throughout (Fig. 4) and increased in the past millennium at the steppe sites (Figs. 2, 3). Considered together with the continuous presence of steppe plants, this rules out a replacement of light taiga by steppe since 2500 BP, but even indicates a local spread of *P. sylvestris*. The local character of the spread of *P. sylvestris* is inferred from the absence of a trend for increasing pollen values in the profile RT (Fig. 4). As profile RT is located in the open valley of the river Eroo (Fig. 1), a change of the *P. sylvestris* signal due to long-distance transported pollen should be even more clearly visible (Fig. 4) than at the foothill of the steppe slope (Figs. 2, 3).

The tree species with the highest physiological potential to colonize the sun-exposed, southern slopes is *Ulmus pumila*, which is currently absent from the taiga, but found in savanna-like open woodlands on the southern slopes. Though presently widespread on the southern slopes of the western Khentey and even found on the steppe above sites BB and SF, the surface samples of the profiles are devoid of a signal of *U. pumila* (Figs. 2–4). From the past, *U. pumila* pollen occurs at first somewhat after 500 AD with a single pollen grain in RT 3 and continuously between 600 and 700 AD in BB 4. The occurrence of *U. pumila* pollen in BB 4 is correlated with relatively high pollen values of some floodplain herbs, Poaceae, *Artemisia*, and *Myriophyllum spicatum* (Fig. 2). This suggests that *U. pumila* only flowers during series of relatively wet years. Trees on the southern slopes of the western Khentey do usually not exceed 5 m. This suggests that the steppe slopes have probably never been a preferred habitat of *U. pumila*. Aside from sun-exposed grassland slopes in the Khentey, Khangay, and Mongolian Dauria, an important habitat of *U. pumila* in Mongolia is found in the floodplains of steppes and semi-deserts (Hilbig, 1995), where large trees grow in contact with the groundwater table. Except for particularly wet periods, spread of *U. pumila* on the sun-exposed slopes is probably clonal, as observed in the study area. In Europe, too, *Ulmus* pollen is highly indicative of high rainfall (Grandjouan et al., 2000).

The recent decrease of *Pinus sibirica* pollen in all three profiles indicates an increase in aridity (Fig. 2). As a dark taiga species, *P. sibirica* has higher moisture requirements than *P. sylvestris* or other light taiga species (Gunin et al., 1999). All *P. sibirica* pollen in the profiles derives from long-distance transport, as the most proximate dark taiga forests are today 10 km away from the sampling points (Dulamsuren, 2004). The same is true for *Abies sibirica*, whereas *Picea obovata* is also found in riverine forests in the vicinity of the profiles (Dulamsuren, 2004; Dulamsuren et al., 2005b). Whether recent declines of pollen values of the dark taiga trees *P. obovata* and *A. sibirica*, starting at sites BB and SF in the latest centuries (Figs. 2, 3), reflect a decline of spruce and fir, is hard to assess because of their low pollen values. However, such a decline would agree with the similar water requirements of *P. obovata*, *A. sibirica* and *Pinus sibirica* and with former climate-driven declines from more arid areas of Mongolia (Gunin et al., 1999) and southern Siberia (Blyakharchuk et al., 2004, 2007). *Picea obovata* performed best from c. 380 to 100 BC. This indicates a phase of higher river activity leading to stands of *P. obovata* as can be observed sporadically today in the floodplain. It is unlikely that the increase of *Picea* values indicates the spreading of dark taiga forest, as the percentages of *Abies* remain low.

The start of the archive BB at 500 AD may be linked to the end of a cold and wet climate period observed in most of northern Eurasia (Schlütz and Lehmkuhl, 2007). Possibly this period was connected with unstable conditions in the floodplain leading to the loss of older sediments by river erosion.

5.2. Charcoal data

Virtual absence of charcoal from the soil of the three slope bases studied suggests that deforestation of the slopes by fire and consequent encroachment onto the afterwards eroded soils by grasslands is not a probable scenario for the origin of the current vegetation pattern.

5.3. Local knowledge of landuse history

The interviews with local people consistently suggest that Khonin Nuga was never used as regular pasture land by Mongolian nomads. Thereby, the study area differs from Mongolia's forest-steppe belt, which was utilized by pastoral nomads from the beginning of the late Holocene first by the Scythes, followed by the Huns and the Mongolian Empire (van Geel et al., 2004; Zaitseva et al., 2004; Rösch et al., 2005). Causes of this are the traditional preference of the Mongolian nomads for open grasslands and the high density of wolf (*Canis lupus*) in the Khonin Nuga area. In addition bears (*Ursus arctos*) were relevant predators, which were frequent in the Khonin Nuga area until the political changes in 1990 (Tsogtbaatar, pers. comm.) and are, despite a decline due to poaching, still widespread in the study area. Therefore, Khonin Nuga was apparently never subject to grazing by large herds of livestock, as is commonplace in Mongolia's forest-steppe and steppe since millennia. Intense logging was limited to a short period of time only 20 years ago. Remnants of timber harvesting, i.e. clear-cuts and stumps, are still visible, but are absent from the steppe slopes.

6. Conclusions

Pollen and charcoal evidence suggests that our main hypothesis that the steppes, located on southern slopes within the mountain taiga of the western Khentey, derive from anthropogenic deforestation has to be rejected. Rejection of this hypothesis is supported by oral tradition of landuse history in the study area. Palynology shows constant occurrence of steppe plant pollen during the last 2500 years and constant values for total AP until most recent times. Pollen values of the most drought-resistant light taiga tree species, which are often found at the treeline towards the steppe in the study area (Dulamsuren et al., 2005a,b), either remained constant (*Larix sibirica*) or even increased (*Pinus sylvestris*) during the last 1000 years. This contradicts a replacement of former light taiga forests on the southern slopes by steppe grasslands. Rather, southern slopes probably consisted of a mosaic of montane meadow and montane steppe with interspersed *Ulmus pumila* open woodlands throughout the younger Holocene.

Oral tradition of local history suggests that the study area has never been used by pastoral nomads for livestock breeding, as the isolated steppe outposts on the southern slopes were only accessible through the closed forest and because of high population densities of predators including wolf and bear. Evidence from narratives dates back till the 17th century and suggests only local use of the floodplains at and west of the present Khonin Nuga Research Station for pasture since that time. Pollen analyses support oral traditions in this point, as a decline of trees concomitant to an increase of shrubs and meadows in the youngest past was found in the floodplain south, but not north of the river Eroo. This agrees with the browsing habit of the few horses and cows currently kept in the Khonin Nuga region and with the oral tradition saying that grazing intensity was never more intense than today or in the late 20th century. Because of Mongolia's low human population density, more intense use in the early or middle Holocene than in the last three millennia is not probable. The virtual lack of charcoal in the soil at the footslope of the steppe hills supports this assumption, as charcoal should be detectable if former forests of the southern slopes were destroyed by either intended fire to gain pasture land or by escaped campfires sometime during the Holocene. Since the densest vegetation cover of northern Mongolia during the Holocene was found in the last 3000 years (Feng et al., 2007), southern slope steppes of the mountain taiga in the western Khentey have probably always been devoid of forest during the entire Holocene. Due to the extreme conditions on the south-facing slopes with high irradiation and sparse soil cover (Dulamsuren et al., 2005a,b, 2008), it seems plausible that these slopes never carried other trees than *U. pumila* at least since the Last Glacial Maximum (around 20 ka BP).

Our conclusions are limited to the special situation of the steppe outposts on southern slopes within the northern Mongolian mountain taiga (Dulamsuren et al., 2005a,b). This region has apparently hardly been used by humans until the most recent centuries. This assumption agrees with conclusions from pollen data from the Lake Baikal area, which borders on the western Khentey in the north. At Lake Baikal, human influence on vegetation was subordinate until the 19th century (Tarasov et al., 2005). Despite this, steppe vegetation was present throughout the Holocene as well as the last glacial and interglacial periods (Demske et al., 2002; Granoszewski et al., 2005; Shichi et al., 2007).

Our results from a mountain taiga-steppe ecotone are not generally transferable to the aspect-dependent pattern of forests on northern slopes within a grassland landscape, which is found in large parts of Eurasia, including the Mongolian forest-steppe belt, where a long-lasting, more intense human influence is involved. Typical examples are the surroundings of the old and current Mongolian capitals, Karakorum and Ulan Bator, where human landuse is thought to have considerably contributed to the present spatial pattern of vegetation types (Hilbig et al., 2004; Rösch et al., 2005). Even in the remote Gobi Altai mountains of southern Mongolia humans played an important role on the forest disappearance in the last around 3500 years (Miehe et al., 2007). In the forest-steppe of north-eastern China, however, Tarasov et al. (2006) showed that transformation of forests into steppes during the mid-Holocene was due to decreases in precipitation. These different results from the forest-steppe suggest the existence of strong regional variation of human influences in early historic times on the modern distribution of forest and steppe. Anthropogenic deforestations have also been suggested for the Tibetan plateau (Miehe and Miehe, 2000; Miehe et al., 2000, 2006) or for the Himalayas (Schlütz, 1999; Miehe et al., 2002). Under the extreme climate of the Himalayas, mid-Holocene people are thought to have decidedly burnt down forest vegetation of sun-exposed slopes to gain pasture lands in the narrow Himalayan valleys (Beug and Miehe, 1999). Such intentional burning of sun-exposed slopes is not probable for the northern Mongolian mountain taiga, as charcoal layers were not found and as plenty of better pasture was available for the livestock of the small Mongolian population in the wide forest-steppe and steppe. In conclusion, neither the results from the Tibetan plateau and the Himalayas, nor from long-since inhabited areas of the Mongolian forest-steppe, nor from the steppe outposts in the present study are transferable to the whole of central Asia. Rather, different causes led to superficially similar vegetation patterns with forest on northern slopes and grasslands on southern slopes. In the case of the northern Mongolian mountain taiga, the present results suggest a climate-driven and relief-dependent origin of this pattern. We are not aware of any other study in this part of Asia where no human influence (beside the youngest past) was detected despite detailed pollen analysis.

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