Reconstruction of the Holocene vegetation and fire history in the different forest types of Kyrgyzstan, Central Asia

Inauguraldissertation
der Philosophisch-naturwissenschaftlichen Fakultät
der Universität Bern

vorgelegt von

Ruth Beer
von Trub

Leiter der Arbeit:
PD Dr. W. Tinner
Institut für Pflanzenwissenschaften

Von der Philosophisch-naturwissenschaftlichen Fakultät angenommen.


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Prof. Dr. P. Messerli
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Introduction

In grey ancient times when there were no states nor borders and humans lived on earth as a big family, God wanted to separate them into peoples and states and decided to give these peoples own ground according to their skills. While the ancestors of the Kyrgyz slept sweet dreams, the folks came to God and were given different spots on earth – stony places, green meadows, or ice covered areas. When God had ended splitting up the whole earth he became aware of the sleeping Kyrgyz, who hadn’t bothered about the sharing like the others. His naiveté touched God so much that he decided to give something very special to this man: “Because you are such a lazy dreamer I will give you the best and most productive grounds, lush meadows, and crystal clear streams, so that you will never have to bother about your daily bread.” And God gave the Kyrgyz the land of today’s Kyrgyzstan – the place he had intended to keep for his own in the first place. (Kyrgyz tale)

Kyrgyzstan covers an area of ca. 198,500 km². The country shares its borders with Kazakhstan in the north, China in the east, Tadzhikistan in the south, and Uzbekistan in the west. The land is a high mountainous region: the altitude ranges from 401 meters in the Fergana valley to 7437 meters at the summit of Peak Pobeda. Just over 90 per cent of the territory is above 1500 meters, and 41 per cent is above 3000 meters. About a third of the country is permanently under snow. Water plummets constantly from Kyrgyzstan’s mountains and glaciers into a myriad of streams, which converge to form some of Central Asia’s major water sources. The Naryn River, the most important, rises in the At Bashy Range and joins the Kara Darya in the Fergana valley to become the Syr Darya, which waters Kazakhstan. The Naryn River supports seven power stations. The Chui River is channelled into a major irrigation canal along the Kazak border before fanning out into the arid Kazak steppe. The Sary Jas, Inylchek and Ak Shyrak rivers flow east to China’s thirsty Tarim basin (Stewart, 2002).

Kyrgyzstan is one of the poorest countries in regard to forest cover in Central Asia, for only 4.2% of the land surface is covered by forests (Musuraliev, 1998). In wide areas of the Kyrgyzstan lowlands and mountains, steppes as well as subalpine and alpine meadows dominate the landscapes (Gottschling et al., 2005). Non-linear vertical gradients of temperature and precipitation (Böhner, 1996; Esper, 2000) confine forest growth to a narrow band or patches on mountain slopes (Miehe et al., 1996). The upper limit of tree growth is primarily controlled by temperature, whereas the lower limit is restricted by precipitation (Miehe et al., 1996). Kyrgyzstan lies at a latitude of ~40° N, where insolation on the south-exposed slopes is very strong. Therefore forests are mostly found on slopes of northern aspect (Walter, 1974) and in gullies (Cermak et al., 2005). Walnut-fruit forests in Kyrgyzstan cover an area of 230,000 ha, of which 40,500 ha are stands with walnut trees (Musuraliev, 2004). They occur in spatially disconnected areas on the southwest-facing slopes of the Fergana Range north and east from Jalal-Abad and on the southeast-facing slopes of the Chatkal Range (Gottschling et al., 2005) at an altitudinal range between 700 and 2100 m a.s.l (Kolov, 1998). These forests consist of Juglans regia admixed with Crataegus turkestanica A. Pojark., Malus kirghisorum Al. et An. Theod., Prunus mahaleb L., and Prunus sogdiana Vass., which are found predominantly on north-facing slopes. Stands of Acer turkestanica Pax. admixed with the above mentioned tree and shrub species are found in the upper belt of the walnut-fruit forest complex, while Pistacia vera L. forms thickets on the driest patches at the lowest and driest sites. Forests of juniper (Juniperus zezavschanica Kom., J. semiglobosa Rgl., and J. turcestanica Kom.) grow on south-facing slopes in the northern territories of the
country and on north-facing slopes in the south. In the northeast of the country, i.e. north of the Naryn River, forests of spruce (*Picea schrenkiana* F. et M.) are found.

Because of the concern about the state of the forests in Kyrgyzstan, the Kyrgyz-Swiss Forestry Support Programme (KIRFOR), a project of Intercooperation (Switzerland), was started in 1995 with the aim to develop modern forestry management tools, to promote the handing-over of productive activities in forest management to private sectors, and to support adequate education and research in forest management. It is now (2004-2007) in a consolidation phase with declining financial input, focusing on finishing various aspects of the continuing transformation in the forestry sector. Started in 2003, a common research project by KIRFOR and the paleoecological group of the Institute of Plant Sciences (IPS) of the University of Bern was set up to reconstruct the Holocene vegetation and fire history of the different forest types in Kyrgyzstan, as almost nothing is known about them at present. A special focus was to be put on the vegetation history of *Juglans regia*, as it has been suggested that the walnut-fruit forests of Kyrgyzstan might be a relict place of this tree. In the frame of this project, special attention is paid to human impact and the natural potential of these forests. In the records presented in this PhD study we reconstruct the late-Holocene vegetation history, fire history, and human activity on a millennial scale for different sites in Kyrgyzstan by means of pollen, macrofossils, lithostratigraphic evidence, and microscopic charcoal. At Kichikol, a small lake in the south of the country, additional evidence was achieved by the analysis of Chironomid and other invertebrate remains.

Paleoecology, once perhaps regarded as a quaint but irrelevant specialty, is on the verge of joining mainstream ecology (Davis, 1994). Paleoecological records (e.g. fossil pollen, seeds and fruits, animal remains, tree rings, charcoal) spanning tens to millions of years provide valuable long-term perspectives on the dynamics of contemporary ecological systems. They had been considered too descriptive and imprecise, and therefore of little relevance to the actual processes of conservation and management. Such criticisms may have been valid 30 years ago, but there is a wealth of information in paleoecological records providing detailed spatial and temporal resolutions that match in detail most records currently used in conservation research (Willis and Birks, 2006). It is speculated that increasingly sophisticated theoretical work will illuminate the way in which fossil pollen reflects vegetation and thus can enhance the power of this research technique (Davis, 1994).

We hope that our research work presented in this PhD study will help to consolidate the management tasks of our project partners in Kyrgyzstan. It is a part of the environmental studies carried out in the region by different international research teams, such as e.g. Vygodtsev (1970); Walter (1974); Grosswald *et al.* (1994); Hemery and Popov (1998); Esper (2000); Epplle (2001), Rickets *et al.* (2001); Esper *et al.* (2002, 2003); Gottschling *et al.* (2005); Gottschling (2006); Schmidt (2005); Schmidt (2006), and many others.
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Pollen representation in surface samples of the *Juniperus, Picea, and Juglans* forest belts of Kyrgyzstan, Central Asia

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Abstract

Surface pollen deposition at five sites (Kichikol, Karakol, Nishneye Ozero, Verkhneye Ozero, and Bakaly) in four different forest types (*Juniperus, Picea, Juglans*, and mixed forests) in Kyrgyzstan have been investigated to assess the relationship between modern vegetation and pollen composition in order to calibrate the pollen representation. Vegetation surveys with an estimation of the tree-crown cover (%) were made in 10 x 10 m plots to relate the vegetation to surface pollen of moss polsters. Correlation calculations show a close relationship between vegetation (tree-crown cover) and pollen for the *Juniperus* site (e.g. $r^2 = 0.76$ between crown cover and arboreal pollen, AP) and the *Picea* site ($r^2 = 0.85$), whereas the linkage is weaker at the *Juglans* site ($r^2 = 0.35$) and in mixed forests ($r^2 = 0.32$). The results of the surface samples of moss polsters are compared and discussed with surface samples of lake sediments that were taken at the same locations. We use vegetational maps from around the lakes to discuss the link between vegetation and pollen at extra-local scales (800 m around the sites). These comparisons show that AP underestimates the effective tree cover around all sites, with in extreme cases densely forested areas corresponding to AP values as low as < 30%. We explain this finding by the prevalent background pollen load which derives from the dry lowland and slope steppes (*Artemisia, Chenopodiaceae, Poaceae*). Our investigation may improve the reconstruction of Quaternary vegetation and climate history of these forest belts in Kyrgyzstan (Central Asia) on the basis of fossil pollen assemblages from mire and lake sediments. They provide new insights in the pollen reflection of forest isles (e.g. on humid slopes or mountain tops) which are surrounded by continental steppes; a vegetational situation which may be used as an analogue for the conditions during the Full-Glacial.

**Key Words:** surface samples, tree-crown cover, palynology, Kyrgyzstan
Introduction

Much of the uncertainty in the interpretation of late Quaternary pollen assemblages can be removed by the judicious use of pollen surface samples from a variety of vegetation formations. The technique is especially useful in new regions of investigation, where not much is known of the vegetation imprint on the pollen sequence (Wright, 1967). A special focus is the separation of pollen sources from local to regional scales (Wright, 1967). In Europe such efforts were undertaken more than fifty years ago to better understand the linkages between vegetation and pollen (e.g. in treeline situations; Firbas, 1934; Welten, 1950). More recently, several studies on pollen source area, pollen productivity estimates, and pollen dispersal have been carried out in America (Janssen, 1967; Calcote, 1995; Jackson and Kearsley, 1998) and in Scandinavia, where modelling studies are used to calibrate vegetation cover and pollen (Sugita, 1994; Sugita et al., 1999; Bunting et al., 2004; Broström et al., 2004, 2005). Near our study region, Wright et al. (1967) studied the relationship of modern plant cover and pollen rain in western Iran. Bottema and Barkoudah (1979) studied the modern pollen rain and its relation to vegetation in Syria and Lebanon. El-Moslimany (1990) investigated sites in the Middle East. Kvavadze and Stuchlik (1990) studied the sub-recent spore and pollen spectra and their relation to recent vegetation belts in north-western Georgia. Liu et al. (1999) made a study of the woodland ecotone in relationship to surface pollen in the Inner Mongolian Plateau, China. Recently a study was made on the quantitative relationship between modern pollen rain and climate in Tibet (Shen et al., 2006).

However, so far no investigation on modern pollen rain in relation to vegetation has been made in Kyrgyzstan, Central Asia. The pollen sequences available from Kyrgyzstan (data not yet published) are made from mire and lake sediments in the different vegetation belts. Surface samples of lake sediments are presented here in comparison with the data
obtained by surface samples of moss polsters. The results may prove to be useful to improve the interpretation of the Quaternary vegetation and climate history of this region.

Material and Methods

Study sites

Kichiko (N 39°59′, E 73°33′) is a lake located at 2554 m a.s.l. on the northern slope of the Alay range (Fig 1). The surface of the lake is 10 ha; it has no major inlet or outlet. The present forests of Juniperus turkestanica Kom. and J. semiglobosa Rgl. are restricted to north-facing slopes and are rather open. Pastures and meadows occur in open patches of the forest and on south-facing slopes. Karakol (N 42°50′, E 77°23′) is a subalpine lake located at 2353 m a.s.l. on the south-facing slope of the Kungey Alatau (Fig. 1). It has a surface of 5 ha and has an outlet at its eastern border. Dense stands of Picea schrenkiana F. et M. form the forests in this area. Pastures and meadows extend around the lake. The nearest climatic station at a comparable altitude for these two sites is located at Naryn (N 41°43′, E 76°00′, 2039 m a.s.l.), where mean January and July temperature of -15.8 and 17.3 °C and a mean annual temperature of 3.65 °C are recorded. The mean annual precipitation is 285.5 mm (World Climate 2006). Bakaly lake (N 41°52′, E 071°58′) lies south of Chatkal Range at 1880 m a.s.l. in the Sary Chelek Reserve (Fig. 1) at the upper altitudinal limit of Juglans regia L. It has a surface of approx. 1 ha with no major inlet or outlet. The forests consist of a mosaic of Juglans regia, Juniperus turkestanica, J. semiglobosa, Picea schrenkiana, Abies semenovii Hill., Acer turkestania Pax., Malus kirghisorum Al. et An. Theod., Prunus spp., and Crataegus spp. and are rather open. Nishneye (N 41°18′, E 72°57′; 1371 m a.s.l.) and Verkhnyeye Ozero (N 41°18′, E 72°57′; 1440 m a.s.l.) are two lakes located in the Arslan-Bob region on the south-facing slope of the Fergana Range (Fig. 1). Both lakes have a surface of 3
ha and have no major inlet or outlet. They lie in the core-region of the so-called walnut-fruit forests. The local forests around the lakes are dense (Fig. 2). Forests with *Juglans regia*, *Crataegus turkestanica* A. Pojark., *Malus kirghisorum*, *Prunus mahaleb* L., and *Prunus sogdiana* Vass. are dominant on north-facing slopes. Stands of *Acer turkestanica* together with the above-mentioned tree species are found on south-facing slopes, while *Pistacia vera* L. forms thickets on the driest patches. For a thorough description of the walnut-fruit forests see Blaser *et al.* (1998) and Epple (2001). At Ak Terek Gava (1748 m a.s.l.; N 41°17’, E 72°5’, the nearest climatic station to Bakaly, Nishneye, and Verkhneye Ozero, mean January and July temperatures is -3.1 and 20.5 °C and mean annual temperature is 8.9 °C. The mean annual precipitation is 1020 mm (data provided by Intercooperation).

**Selection of sampling sites and vegetation maps**

The collection of samples of moss polsters was made along transects laid around five lakes located in forests which are characteristic for Kyrgyzstan, i.e. *Juniperus* forests around Kichikol, *Picea* forests around Karakol, *Juglans* forests around Nishneye and Verkhneye Ozero, and mixed forest stands around Bakaly. Vegetation maps were made by the vegetation typology group of Intercooperation Bishkek and allow defining characteristic vegetation units on the basis of local conditions (topography, geo-morphology, soils) and vegetational relevés that were made to determine the tree-crown cover and the forest structure (Typology group KIRFOR, 2004). The following standard methodology was applied at the four sites Kichikol, Karakol, Nishneye, and Verkhneye Ozero. An overview survey in the field allowed the identification of the main vegetational complex of a site. Subsequently, detailed field surveys were used to delimit polygons of homogenous vegetation types on the basis of the local physiognomy and morphology of the vegetation, (coloured) aerial photographs, overview pictures of the landscape, and/or topographic maps. A vegetational relevé 10 x 10 m (including e.g. species composition, tree cover, slope aspect, inclination, degradation,
coordinates) was then made in a representative part of the vegetational unit (polygon). The same was repeated for all polygons at a site. Polygons representing the same vegetation type (see Table 1) were assigned to already mapped vegetational units. Topographic maps at scale 1:10,000 were used at Kichikol and Karakol to map the vegetation. At the latter site aerial photographs provided additional information. The vegetation maps of Nishneye and Verkhneye Ozero were made by using Quick bird satellite images (1 m pixel definition). The vegetation map of Bakaly dates back to 2002 and was made by the State Forest Service of the Kyrgyz Republic. This map is part of the forest management documentation for the Sary Chelek Zapavednic (= protected territory) and similarly to the other maps delimits units of characteristic vegetation types (State Forest Service of the Kyrgyz Republic, 2002).

**Sampling of surface samples**

Moss polsters have been found to be effective natural pollen traps. A recent comparison between pollen collected in Tauber traps and moss polsters in Finland showed that pollen assemblages in the green part of the moss polsters represent only one year, or possibly two years of deposition (Broström et al., 2004). A total of 43 surface samples of moss polsters or the top 2 cm of Ah soil horizons were collected during coring expeditions in 2003 and 2005 on a radius of 0.5 m. Sugita (1994) states that the relevant source area of pollen (i.e. the area beyond which the correlation between pollen loading and plant abundance in the surrounding vegetation does not improve) in lakes in simulated landscapes is within 50-100 m from the lake edge for forest hollows (Radius (R)=2 m), 300-400 m for small lakes (R=50 m), and 600-800 m for medium-sized lakes (R=250 m). This is in agreement with empirical studies (e.g. Conedera et al., 2006). Among these, moss polsters correspond most to forest hollows where much of the pollen derives from vegetation close to the sampling spot. Therefore vegetation releves were made in plots of 10 x 10 m around the surface sample (Mazier et al., 2006). Distance weighting was not applied for the vegetation data, because detailed spatial
information of species distribution in the plots was not available. Tree-crown cover was estimated by means of percentages. Surface samples of lake sediments have been analysed for the five lakes from cores taken during the coring campaigns in 2003 and 2005.

**Laboratory work and analysis**

Surface samples were treated with KOH and sieved with a mesh of 1mm, then treated with HCL, HF, and acetolysis (Moore *et al.*, 1991), and suspended in glycerine. In each sample at least 600 pollen grains were identified with pollen keys (Moore *et al.*, 1991; Beug, 2004), pollen atlases (Reille, 1992; 1998), and the reference collection of the Institute of Plant Sciences of the University of Bern. Spores and Cyperaceae pollen were excluded from the pollen sum. Pollen diagrams were made including all the important pollen types for each site. Sketches of the sites were drawn according to the vegetation surveys along the axis of the pollen diagrams to visualize the landscape and the vegetation. Altitudinal variation was integrated, but the distance to the lake is approximated. Correlation coefficients (r) and determination coefficients (r²) were calculated to assess the relationship between pollen representation (AP) and vegetation cover (tree-crown cover and forest cover).

**Results**

**Kichikol: Juniperus forests** a) Tree-crown cover (KKO1): Fig. 3

Five samples were taken from sites ranging from a single Juniperus tree (sample 1, crown cover 10 %) to closed Juniperus forest (sample 5, crown cover 100 %). The results (Table 2, Fig. 3; 4) show that vegetation and pollen are in very good agreement, e.g., AP values increase with increasing tree-crown cover. The linear correlation between AP (*Juniperus*) and tree cover (Fig. 4) attains a determination coefficient of 0.76. Samples 1 and 2, from sites
with Juniperus tree-crown covers of 10 and 20%, both show Juniperus pollen values around 25%, in association with low stomata finds. Sample 3 represents a crown cover of 45% and yields 35% of Juniperus pollen. Only a few Juniperus stomata were found. In sample 4 a crown cover of 80% is reflected by 80% Juniperus pollen and many stomata. In the vegetation plot 5 dense stands of Juniperus turkestanica and J. semiglobosa form a closed canopy. They are represented by 65% Juniperus pollen in association with numerous stomata. Single pollen grains of Prunus- and Sorbus-type pollen cannot be related to trees growing in the vegetation plots. Artemisia pollen shows increasing values up to 45% with diminishing tree-crown covers of the Juniperus forest, although not present locally in the relevés. Chenopodiaceae pollen reaches 10% only in sample 1. Poaceae pollen reaches 15% in sample 2 and 10% in samples 1 and 3. High percentages of Cyperaceae pollen recorded in samples 1 to 3 may be related in part to the riparian vegetation around the lake.

b) Transect Juniperus forest to meadows (KKO2): Fig. 5

Five samples were taken along a transect from dense Juniperus stands (samples 1 and 2) on the west-facing slope of the lake to the meadows on the east-facing slopes (samples 3, 4, and 5). Fig. 5 shows decreasing Juniperus pollen percentages with increasing distance to the forest. In vegetation plot 1 Juniperus turkestanica and J. semiglobosa form dense stands with a crown cover of 75% on the steep slope above Kichikol. Juniperus pollen reaches 35%, and numerous stomata were found. In plot 2 Juniperus trees form open stands with 30% crown cover. Here the values of Juniperus pollen drop to 20%, without any stomata finds. In samples 3 to 5 Juniperus pollen reaches 10%. Artemisia pollen is present throughout the transect with 45-55%. The Artemisia pollen may originate from local plants in the meadows. Pollen of Chenopodiaceae is represented by low but constant values around 5-10%. Except for sample 1 the pollen of Poaceae shows constant values around 10%. Cichorioideae pollen shows a peak of 10% in sample 3, whereas Mentha-type pollen is found in high amounts in
sample 4. Both types may mirror the meadows and pastures around the lake on the east-facing slopes. The pollen of Cyperaceae shows not only a peak in sample 3 near the lake but also in sample 5. This is easily explainable by the fact that Cyperaceae such as Carex are growing in both upland and wetland communities.

**Karakol: Picea forest (KAO): Fig. 6**

Six samples were taken along a N-S transect at Karakol extending from closed Picea forest stands on the north-facing slope to the meadows around the lake and into the forests of the south-facing slope (Fig. 6). Fig. 7 shows that a determination coefficient of 0.85 is reached implying a very good agreement between the pollen percentages and the tree-crown cover. Closed forest stands of Picea schrenkiana with a crown cover of 100% are recorded in the vegetation plots 1 and 6. A crown cover of 75% is found in plot 5, whereas plots 4 and 2 represent semi-open stands. The pollen percentages in association with many Picea stomata reflect the density of the stands with 80, 70, and around 50% of tree-crown cover, respectively. Sample 3 was taken in a meadow without Picea schrenkiana trees. It still shows a value of 30% Picea pollen. Juniperus pollen is recorded throughout the transect, probably deriving from the Juniperus stands on the south-facing slopes in the area. A slightly higher percentage value is found in sample 4, where a single Juniperus tree is recorded. The steppe plants Artemisia and Chenopodiaceae are not present in the local vegetation but they are represented by constant pollen values of 10-20 and < 10%, respectively, probably again originating from the drier south-facing slopes. In sample 3 high percentage values of Asteroideae, Cichorioideae, *Ranunculus acris*-type, and 10% Poaceae pollen reflect local meadows and pasturelands. The pollen of Cyperaceae may mirror both the meadows and the riparian vegetation.
Bakaly: Mixed forests a) N-S transect (BAO2): Fig. 8

Six samples were taken from a N-S transect in the mixed forests around Bakaly (Fig. 8). Generally, more tree species form more complex woodland communities than in the southern *Juniperus*- and the northern *Picea* forests. *Juniperus turkestanica* and *J. semiglobosa* are present in plot 1 together with *Crataegus turkestanica*, *Malus kirghisorum*, and *Prunus mahaleb*. They build communities with a tree-crown cover of 70%, but AP only reaches 25% and is dominated by *Juniperus* pollen. Though no trees are recorded in vegetation plots 2 and 3 AP still accounts for 25% in sample 2, but then drops to 10% in sample 3. In plot 6, where *Juniperus turkestanica* grows together with *Picea schrenkiana*, AP reaches 30% and is dominated by *Juniperus* and *Picea*. *Picea schrenkiana* grows in plot 5 and 6, but high pollen values, associated with finds of *Picea* stomata, are only reached in sample 6, where the tree-crown cover attains 80%. *Juglans* pollen has low values in all the samples, although the tree does not grow in the vegetation plots. This pollen originates from the trees growing in the catchment (see W-E transect BAO, Fig 9). *Prunus mahaleb*, *Malus kirghisorum*, and *Crataegus* grow in plot 1. *Malus kirghisorum* and *Crataegus turkestanica* are found in plot 4 as well as *Prunus mahaleb* in plot 6. Single grains of *Sorbus*-type may partly represent these trees. *Acer turkestanica* grows in plot 6, but no pollen is found. Single finds of *Acer* pollen occur in the samples 1 and 4. Pollen of taxa growing in the meadows and steppes, such as *Artemisia* and Chenopodiaceae, is present throughout the transect, with values around 15 and 10%, respectively, although these plants are locally missing in the vegetation plots. Poaceae pollen shows its lowest percentage (10%) in sample 6, where the crown cover of the forest stand with *Picea schrenkiana*, *Acer turkestanica*, *Prunus mahaleb*, and *Juniperus turkestanica* reaches maximum values of 80%. In plot 3 with open vegetation they reach 30% along with high values of Cyperaceae.
b) W-E transect (BAO): Fig. 9

Ten samples were taken along a W-E transect at Bakaly, integrating the different types of mixed forests with different crown covers (Fig. 9). *Juniperus turkestanica* and *J. semiglobosa* are present in the vegetation plots 1, 3, 6, 8, 9, and 10 where they form semi-open stands together with other tree species. Except for sample 5, the *Juniperus* trees are represented by percentage values from 10 to 40%. Although not present in the local vegetation releves, the highest percentage of *Juniperus* pollen is found in sample 7 (40%). In sample 6 it reaches only 15% in association with many stomata. *Juniperus turkestanica* and *J. semiglobosa* form an open stand together with *Malus kirghisorum* in this vegetation plot. *Betula* pollen reaches 40% in sample 4 and 15% in sample 5 in association with high finds of Cyperaceae pollen. It mirrors a stand of *Betula alba* growing near the shore on upland soils at sampling site 4. *Juglans regia* is found in plots 1, 8, and 9, but only in sample 1 does it reach higher values (20%). As the forest stands are open (tree-crown cover 30-40%), with only single *Juglans regia* trees, a higher abundance of *Juglans* pollen in sample 8 and 9 might be masked by the conspicuous presence of Poaceae pollen (55 and 40% respectively). *Picea* pollen is constantly found throughout the transect with rather low values (< 10%), though the tree is not present in the vegetation releves. *Sorbus*-type pollen is found in all samples except 8 and 10. Rosaceae shrub and tree species are found throughout the transect, except for those samples near the lake shore (samples 4 and 5). *Acer turkestaniae* is found in vegetation plots 1, 3, and 8, but doesn’t show up in the pollen samples. Pollen of *Artemisia* and Chenopodiaceae is constantly represented with 10-20% and 3-10%, respectively, although locally not recorded in the vegetation plots. Combining the plots of both Bakaly transects into a linear correlation attains a correlation coefficient of 0.56 and a determination coefficient of 0.32 (Fig. 10).
Nishneye and Verkhneye Ozero: *Juglans* forests (NOVO): Fig. 11

Eleven samples were taken around the two lakes with the aim to cover the different local vegetation types. *Juglans regia* dominates the forests in this region, but thickets of several species of Rosaceae and stands of *Acer* are interspersed as well (Table 2, Fig. 2). Fig. 11 shows that *Juglans regia* pollen dominates the AP throughout the transect. The highest percentage (85%) of the species is found in sample 3, where the tree constitutes a mono-specific stand in the vegetation plot. Samples 3, 6, 9, and 11 show *Juglans* pollen values around 70%, where *Juglans regia* forms mixed stands. In samples 2, 4, 5, and 7 the pollen percentages reach 35-40%, although *Juglans* is locally present only in the plots 5 and 7. Sample 10 shows a value of 18% and sample 8 10%, with *Juglans regia* being absent in both plots. *Juniperus* pollen is present throughout the pollen spectrum with values from 5-12%, although lacking in the local vegetation releves. Single pollen grains of *Acer* were found in samples 2, 4, 5, 7, 9, and 11, whereas the tree was recorded in the vegetation plots 2, 4, 7, 8, and 11. Trees of *Crataegus turkestanica* and *Crataegus* spp., *Malus kirghisorum*, *Prunus sogdiana*, and *Prunus mahaleb* were found in all the vegetation plots except in plot 1. The corresponding *Prunus-* and *Sorbus*-type pollen occurs as single finds in samples 4, 5, and 11. *Hippophaë rhamnoides* reaches 5% in plot 4. Except for sample 1, *Artemisia* shows constant values around 10%. Pollen of Chenopodiaceae has values of 8-15% throughout the diagram. The highest percentage is recorded in sample 8, where it reaches 25%. Pollen of Poaceae consistently shows values of 5-10%. A slightly higher value (18%) is recorded in sample 10. Pollen of Asteraceae (Asteroideae and Cichorioideae) shows values up to 5% in samples 2, 8, and 10, probably reflecting grazed meadows. Very high values of Cyperaceae are found in samples 8 and 10. A correlation coefficient of 0.59 and a determination coefficient of 0.35 are attained when AP is correlated with tree-crown cover (Fig. 12). When correlating the AP with tree-crown cover over all the samples a determination coefficient of 0.44 is recorded (Fig. 13).
Comparison of pollen in surface lake sediments and vegetation maps

The comparison between AP in surface lake sediment samples and forest cover in a radius of 800 m around the site (Table 3) suggest a positive correlation between pollen and vegetation at an extra-local scale ($r = 0.48; r^2 = 0.23$; Fig. 14). At Kichikol the area covered with Juniperus forest within a radius of 800 m around the lake is 25.5% (Table 1, Table 3) and 23.7% of Juniperus pollen is recorded. At Karakol 34% of the area is covered with forest of Picea but only 10.3% of Picea pollen is recorded. At Bakaly 46% of the area within a radius of 800 m of the lake is covered by open forest stands and 44.8% of AP is recorded. Juniperus yields the greatest share (32.2%), whereas Picea achieves only 1.3% and Juglans 2.8% (Table 3). At Nishneye and Verkhneye Ozero the forest cover reaches 100% (Fig. 2) but only 25.5% AP is recorded at Nishneye Ozero, whereas for the same forest cover 59.8% AP is recorded at Verkhneye Ozero.

Discussion

The different taxa growing in the Kyrgyz forest belts are represented very heterogeneously in the pollen data. Some taxa such as Picea are well represented, whereas others such as Acer are almost completely missing, though present in the local vegetation. Similar observations were made in previous studies from other areas of the world (Wright, 1967; Wright et al., 1967) and emphasize that pollen does not mirror vegetation in a linear way (Wright, 1967; Prentice, 1985; 1986, Faegri and Iversen; 1989, Moore et al., 1991).

The best fits between vegetation and pollen were obtained where the dominant tree taxa are wind-dispersed pollen producers such as Picea and Juniperus. In cases where insect-pollinated arboreal taxa were co-dominant or abundant (e.g. Rosaceae, Acer) the linkage is blurred, probably due to the smaller quantities of pollen produced and to the selectivity of the
dispersal vector (Prentice, 1985). The pollen percentages in our terrestrial surface samples can be compared with those in the lake surface sediments if we take account of the difference in pollen catchment and the relative source area of pollen (Sugita, 1994). Much of the pollen in the terrestrial surface samples is of local and extra-local origin, i.e. within tens of m from the sampling point, which contrasts with the lake surface-sediment samples where most pollen has an extra-local to regional origin with a minor proportion of local pollen, especially from tree taxa that do not grow directly on the lake shores (Bradshaw and Webb, 1985; Prentice et al., 1987). The pollen percentages of trees in lake surface-sediment samples will therefore be lower than in terrestrial surface samples. However, the vegetation plots (10 x 10 m) on an average have the same tree-crown covers as the surroundings of the lakes (1-2 km). The relation between pollen percentages and tree-crown cover in the terrestrial surface samples is shown in Figures 4, 7, 10, 12, and 13.

Considering the huge differences of pollen representation in the surface samples among the taxa, we discuss the relationship between plant occurrence and pollen individually for each important taxon.

**Juniperus spp:** In the region of Kichikol Juniperus pollen percentages follows more or less the vegetation cover of Juniperus trees at the local level, i.e. from within 20 m (sensu Prentice, 1985) (Fig 3; 5). Pollen values of 65 to 80% may indicate pure, dense stands of Juniperus. At KKO2 (Fig. 5) pollen values of Juniperus as low as 35% indicate a tree-crown cover of 75%. Pollen values of 15-30% may reflect local stands of Juniperus trees, and pollen values around 10% may represent the pollen of extra-local (from within 20 m to 2 km, sensu Prentice, 1985) stands. Finds of stomata corroborate the proximity of the Juniperus stands, as they are only found regularly near the trees. The interpretation of Juniperus pollen percentages in mixed stands is less straightforward. Juniperus pollen percentages may be lowered by other pollen types, as in the case of Karakol (Fig. 6) and the Bakaly N-S transect
(Fig. 8), or they may reach high values without being present in the local vegetation plots as seen at the Bakaly W-E transect (Fig. 9). The surface sample of lake sediment (Table 3) shows that 23.7% *Juniperus* pollen represents the modern vegetation around Kichikol, where *Juniperus* forests cover 25.5% of the area within a radius of approx. 800 m (Table 1; Table 3; corresponding about to the relevant source area of pollen, *sensu* Sugita (1994) for a lake of this size). It seems therefore, that the pollen of *Juniperus* is moderately under-represented in the pollen rain. In agreement, in Europe shrubs of *Juniperus* produce relatively high amounts of pollen but are underrepresented in the sediments. Values of 5% can represent an appreciable share in the vegetation (Burga and Perret, 1998).

*Picea schrenkiana*: In the almost mono-specific stands around Karakol (Fig. 6) the diminishing tree cover is correctly mirrored by reduced pollen percentages, whereby 80% pollen values represents a 100 % tree-crown cover, and 50% pollen values a 50% tree-crown cover of the species. However, the plots with meadows and no *Picea* trees still show *Picea* pollen values of 30%; the intercept of the regression plot gives us a value of 42%. This gives us an estimate of the background value of the extra-local (20 m-2 km) and possibly regional (2-200 km) stands of *Picea* (*sensu* Prentice, 1985). Similar to *Juniperus*, stomata finds corroborate the density of the *Picea* stands. Minor values of *Picea* pollen (< 10%) in the mixed forests around Bakaly (Fig. 8; 9) reflect *Picea* trees in the vicinity and form a low background signal. In the surface sample of the Karakol lake sediment (Table 3) 10.3% of *Picea* pollen reflect the modern vegetation formed by dense stands of *Picea schrenkiana* covering 34% of the area (Table 1; Table 3). Applying the linear relationship between releves and moss polsters a value of 50% pollen would be expected (Fig. 7). This suggests that *Picea* forests are reflected in a weaker way in the lake sediments than in surface samples of moss polsters. From several studies of pollen and macrofossils it is known that *Picea abies*, a close relative of *Picea schrenkiana*, can be under-represented in the pollen rain, as it produces less
pollen than pine, birch, alder, or hazel, although it can be over-represented as well due to long-distance transport (Latałowa and van der Knaap, 2006). Janssen (1966) calculated R values for several arboreal taxa at different sites in Minnesota and found that the pollen of *Picea* is moderately under-represented in the pollen rain. In the results presented here *Picea* pollen seems to represent the *Picea schrenkiana* forest accurately at a local scale (moss polster data). Yet the low percentage of *Picea* in the surface sample of the lake sediment suggests that, at extra-local to regional scales, the tree may be strongly under-represented in the fossil pollen records, especially in times of open to semi-open landscapes.

*Juglans regia:* In the closed stands around Nishnaye- and Verkhneye lakes (Fig. 11) *Juglans* pollen can reach percentages that reflect the density of the forest. Up to 85% was recorded in a closed mono-specific stand. The anemophilous pollen is produced in rich amounts (Zoller, 1981), and our results suggest that it is transported rather well, as it is found in relatively high amounts in samples where the tree was not present locally. At Bakaly (Fig. 8; 9), where *Juglans regia* is at its upper altitudinal limit, less abundant pollen is found. Pollen values as low as 1-2% may reflect the scattered distribution of the *Juglans* trees in the regional vegetation. In the surface samples of the lake sediments (Table 3) *Juglans regia* is represented by 13.1 % pollen in Nishnaye Ozero and 34.2 % in Verkhneye Ozero although > 50% of vegetation consists mostly of this tree (Table 1, Fig. 2). We conclude that *Juglans regia* is under-represented in the pollen rain, especially at extra-local to regional scales.

*Acer turkestanica:* *Acer* pollen apparently does not reflect the occurrence of the species in the vegetation accurately, neither in surface samples of moss polsters nor in the lake sediment. Pollen is present where no *Acer* tree occurred in the vegetational surveys and *vice versa.* Generally, only single pollen grains were found. It is known that insect-pollinated trees like *Acer* and Rosaceae are strongly under-represented in the pollen rain (Janssen, 1967; Wright *et*
al., 1967; Faegri and Iversen, 1989). Very low *Acer* percentages in pollen spectra may therefore point to an appreciable share of this tree in the forest vegetation (Wright et al., 1967).

**Rosaceae:** *Sorbus*-type and *Prunus*-type were distinguished but could not yet be assigned to the various tree species of the Rosaceae family. It is striking to see that the trees play a considerable role in the vegetation although their pollen only occurs very rarely in the surface samples of moss polsters and in the lake sediment. For further discussion of the *Sorbus*-type see Faegri and Iversen (1989).

**Artemisia:** Though not regularly present in the local vegetation releves around the lakes, *Artemisia* is an important pollen type at all sites. Its pollen shows high values up to 55% in the region of Kichikol (Fig. 3; 5), increasing with diminishing abundance of *Juniperus* trees, i.e., increasing with landscape openness. At Karakol (Fig. 6) and at Bakaly (Fig. 8; 9) percentages around 10-20% are found. Such values may therefore already reflect the background signal of the *Artemisia* steppes of the dry lowlands. The high pollen values at Kichikol probably also reflect the local regular occurrence of the taxon in the meadows near the lake, although the plant was not co-dominant there.

**Chenopodiaceae:** Pollen of Chenopodiaceae is present with rather low but constant values throughout the different transects. Since not regularly recorded in the vegetation releves around the lakes its pollen signal may primarily reflect the background pollen signal of the *Artemisia* – Chenopodiaceae steppes of the lowlands. Our results support Liu et al. (1999), who found that *Artemisia* and Chenopodiaceae both are overrepresented in the pollen spectra in Inner Mongolia and in western Iran. High *Artemisia* pollen values can indicate the existence of steppe, but the dominant species is not certain in regions where grass-dominated
steppe co-occur, as Poaceae pollen is underrepresented in the pollen spectra (Wright et al., 1967; Liu et al., 1999). In the Middle East El-Moslimany (1990) has shown that Artemisia dominates in the steppe vegetation in the semi-arid zone, while Chenopodiaceae and Plantago dominate in the arid zone. Both Artemisia and Chenopodiaceae are characteristic of highly continental climates with cold winters and dry summers. Because Artemisia pollen increases and Chenopodiaceae decreases with decreasing aridity the ratio of their pollen (C/A) is used as a moisture indicator within a narrow geographical range and within non-forested areas (El-Moslimany, 1990).

Poaceae: At Kichiko (Fig. 3; 5) and Karakol (Fig. 6) the pollen of Poaceae reaches only 10-15% in the meadows, where it is dominant in the herbaceous vegetation. Grass pollen is clearly underrepresented in this type of vegetation and is probably masked by the high pollen representation of Artemisia and Chenopodiaceae. At Bakaly (Fig. 8; 9) Poaceae pollen reaches 30 and 55% at its maximum, therefore providing strong evidence of the low tree-crown density (30-40%) on the spot. Poaceae pollen is consistently underrepresented in percentage values (Wright et al., 1967; Liu et al., 1999). Broström et al. (2004) argue that landscape openness may be underestimated, as herb taxa (including Poaceae) produce 6-8 times less pollen than tree taxa.

Cyperaceae: The pollen of Cyperaceae is mostly found in high amounts closest to the lake shore, therefore mostly reflecting the wetland vegetation around the lake. But species belonging to the Cyperaceae family are also found in meadows and to some extent in the undergrowth of forests. As this pollen type cannot be broken down to the genus or species level it is difficult to interpret the pollen values, and we excluded it from the pollen sum, as often done in palynology.
Sum of AP: Vegetation patterning can affect the pollen representation (Bunting et al., 2004) and several factors, such as species composition, spatial pattern, and structure of the vegetation influence the spatial scale of provenance of pollen (Sugita et al., 1999). As trees with good pollen production (Picea, Juniperus, and Juglans) are interspersed with low pollen producers (Acer, Rosaceae, and Pistacia) these factors may come to play a more important role in vegetation types of mixed forest stands and semi-open landscapes. If all forest types are pooled together, the correlation coefficient (r) is 0.66, and 44% of the variability of AP is explained by the tree-crown density (Fig. 13). We therefore conclude that AP percentage is a good proxy to estimate the tree crown cover on the spot.

The correlation coefficient (r) of 0.48 and the determination coefficient ($r^2$) of 0.23 between AP in surface lake sediment and forest cover are rather low (Table 1; Table 3; Fig. 14). Our data show that the forest cover is conspicuously and systematically underrepresented in the pollen imprint of the Kyrgyz sites. This is in contradiction to the situation in forested biomes, such as the temperate or boreal forests of Eurasia. There 70-80% of AP may already indicate treeless conditions such as above treeline or forest openings (see discussion in e.g. Zoller and Haas, 1995; Tinner and Theurillat, 2003). The seeming contradiction is explained by the fact that the forest stands of Kyrgyzstan are isolated isles surrounded by continental lowland and highland steppes. Here the overwhelming producers in the total pollen source area (10-50 km in radius around lakes of this size; e.g. Bradshaw and Webb, 1985; Prentice et al., 1987; Sugita, 1994; Conedera et al., 2006) are non-arboreal steppic plants (e.g. Artemisia, Chenopodiaceae, Poaceae). The local production of forests in rather narrow bands on the top of the mountains and on shady slopes is therefore partially masked by the regional pollen transport, indeed the contrary of the situation in temperate and boreal forests, where local production of non-arboreal plants is obscured by the pollen production of forests.
Conclusions

Quantitative reconstructions of past and present plant abundance and distribution from fossil and sub-fossil pollen records have been the goal of palynological research since the earliest days, yet they remain elusive (Bunting and Middleton, 2005). Empirical (Janssen, 1967; Calcote 1995; Jackson and Kearsley, 1998; Liu et al., 1999; Shen et al., 2006, and many others) and modelling studies (Sugita 1994, Sugita et al., 1999, Bunting et al., 2004; Broström et al., 2004, 2005, and many others) have shown that the relationship between vegetation and pollen imprint is not straightforward but is affected by pollen productivity, pollen dispersal, vegetation patterning, the degree of landscape openness, and species composition (Prentice, 1985; Sugita et al., 1999, Bunting et al., 2004). The present work will help improve the reconstruction of the Quaternary history of Kyrgyzstan and Central Asia by means of fossil pollen records. The specific spatial scale of vegetation represented by pollen will be critical for reconstruction of vegetation using fossil pollen from lakes with reference to the surface pollen data from moss polsters. The results presented in this paper can be used as a source of information for pollen representation for hollows and small bogs. Our estimates for lakes are only tentative, and more sites should be investigated to draw more reliable conclusions. Nonetheless, the results indicate that Juniperus spp. is under-represented in the pollen deposition, Picea schrenkiana pollen reflects the vegetation cover accurately in the moss polsters but is under-represented in the lake surface samples of Karakol, Juglans regia produces average pollen but is under-represented in the pollen rain, whereas Acer and tree species of Rosaceae (e.g. Prunus-type and Sorbus-type) are strongly under-represented in the pollen spectra. Although AP and NAP percentages give only an approximation of the percentage of forest or open land, respectively (e.g. Sugita et al., 1999), we can state that one implication of the results presented in this paper is that in contrast to other previously investigated areas, forests (including parklands) are underestimated in the pollen representation at the Kyrgyz sites. This implies that isolated forests in steppic environments
are not easy to trace by pollen records alone. In this sense, our results may be used to better understand the situation during the Full-Glacial in Eurasia and Northern America. Due to the climatic setting at that time, trees and possibly small forest patches were restricted to small micro-environmental “oases” (Willis et al., 2000; Willis and McElwain, 2002) in a steppe biome, a situation which is in part comparable with that in Kyrgyzstan.

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Table 1 Spatial area covered by vegetation units represented by surface samples within a radius of approx. 800 m around the lakes.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Plot numbers</th>
<th>Vegetation units</th>
<th>Area (ha) of units</th>
<th>Area (%) of units</th>
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<tbody>
<tr>
<td>Kichikol</td>
<td>1; 2</td>
<td>Juniperus on steep slopes, with shrubs</td>
<td>12</td>
<td>9.5</td>
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<td></td>
<td>3; 4; 5</td>
<td>meadows and pastures</td>
<td>84</td>
<td>68</td>
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<td></td>
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<td>Juniperus on stony debris</td>
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<td>Juniperus wide apart, with shrubs</td>
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<td>meadows with a few Juniperus</td>
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<td>4; 5; 6</td>
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<td>Juniperus stands (single trees)</td>
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<td>7</td>
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<td>Malus with Juglans</td>
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<td>Juglans with Malus</td>
<td>3.5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Malus with Crataegus</td>
<td>5.5</td>
<td>8</td>
</tr>
<tr>
<td>Verkhneye Ozero</td>
<td>5; 8</td>
<td>Mixed shrub forest with Malus and Acer on very steep slopes</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>6; 9</td>
<td>Juglans, Malus, Crataegus on northern slopes</td>
<td>22</td>
<td>33.5</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Juglans on northern slopes</td>
<td>4.5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Juglans</td>
<td>2.5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Malus with scattered Juglans</td>
<td>7</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juglans and Malus</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juglans with Crataegus</td>
<td>5</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juglans with Malus</td>
<td>7.5</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juglans</td>
<td>2.5</td>
<td>4</td>
</tr>
</tbody>
</table>

Bakaly plot numbers: a: N-W transect (BAO2); b: W-E transect (BAO)

(Numbers of samples that were taken in the marsh vegetation around the lakes are not recorded in this table)
Table 2 Dominant plants and tree-crown cover (%) in the vegetation plots studied for pollen of surface samples

<table>
<thead>
<tr>
<th>Locality</th>
<th>Plot number</th>
<th>Dominant plant species</th>
<th>TCC (%)</th>
<th>Locality</th>
<th>Plot number</th>
<th>Dominant plant species</th>
<th>TCC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KKO1</td>
<td>1</td>
<td>Juniperus turkestanica, J. semiglobosa</td>
<td>10</td>
<td>KAO</td>
<td>1</td>
<td>Picea schrenkiana</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Juniperus turkestanica, J. semiglobosa</td>
<td>20</td>
<td></td>
<td>2</td>
<td>Picea schrenkiana</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Juniperus turkestanica, J. semiglobosa</td>
<td>45</td>
<td></td>
<td>3</td>
<td>Poaceae, upland herbs</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Juniperus turkestanica, J. semiglobosa</td>
<td>80</td>
<td></td>
<td>4</td>
<td>Picea schrenkiana, Juniperus</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Juniperus turkestanica, J. semiglobosa</td>
<td>100</td>
<td></td>
<td>5</td>
<td>Picea schrenkiana</td>
<td>75</td>
</tr>
<tr>
<td>KKO2</td>
<td>1</td>
<td>Juniperus turkestanica, J. semiglobosa</td>
<td>75</td>
<td>BAO2</td>
<td>1</td>
<td>Crataegus turkestanica, Malus kirghisorum, Juniperus turkestanica, J. semiglobosa, Prunus mahaleb</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Juniperus turkestanica, J. semiglobosa</td>
<td>30</td>
<td></td>
<td>2</td>
<td>Exochorda tianschanica, Lonicera nummularifolia, Malus kirghisorum</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Artemisia, Poaceae, upland herbs</td>
<td>0</td>
<td></td>
<td>3</td>
<td>Cyperaceae</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Artemisia, Poaceae, upland herbs</td>
<td>0</td>
<td></td>
<td>4</td>
<td>Malus kirghisorum, Crataegus turkestanica</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Artemisia, Poaceae, upland herbs</td>
<td>0</td>
<td></td>
<td>5</td>
<td>Picea schrenkiana, Crataegus turkestanica</td>
<td>70</td>
</tr>
<tr>
<td>NOVO</td>
<td>1</td>
<td>Juglans regia</td>
<td>50</td>
<td>BAO</td>
<td>1</td>
<td>Juglans regia, Prunus mahaleb, Acer turkestanica, Juniperus turkestanica</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Acer turkestanica, Crataegus turkestanica, Malus kirghisorum, Prunus sogdiana</td>
<td>30</td>
<td></td>
<td>2</td>
<td>Cotoneaster multiflora, Rubus caesius, Spiraea hypericifolia</td>
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</tr>
<tr>
<td></td>
<td>3</td>
<td>Juglans regia</td>
<td>60</td>
<td></td>
<td>3</td>
<td>Juniperus turkestanica, Acer turkestanica, Crataegus turkestanica</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Acer turkestanica, Crataegus turkestanica, Malus kirghisorum, Prunus mahaleb</td>
<td>30</td>
<td></td>
<td>4</td>
<td>Betula alba</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Prunus mahaleb, Juglans regia, Prunus sogdiana</td>
<td>40</td>
<td></td>
<td>5</td>
<td>Cyperaceae</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Juglans regia, Prunus mahaleb, Crataegus, Prunus sogdiana</td>
<td>80</td>
<td></td>
<td>6</td>
<td>Juniperus turkestanica, J. semiglobosa, Malus kirghisorum</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Acer turkestanica, Juglans regia, Crataegus</td>
<td>40</td>
<td></td>
<td>7</td>
<td>Exochorda tianschanica, Berberis heteropoda</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Acer turkestanica, Crataegus turkestanica, Malus kirghisorum</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Prunus mahaleb, Crataegus turkestanica, Juglans regia, Malus kirghisorum, Prunus sogdiana</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Crataegus sp., Malus kirghisorum</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Acer turkestanica, Crataegus turkestanica, Juglans regia, Malus kirghisorum, Prunus sogdiana</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Acer turkestanica, Crataegus turkestanica, Juglans regia, Malus kirghisorum, Prunus sogdiana</td>
<td>60</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

TCC: Tree-crown cover
Table 3 Forest cover and pollen representation of AP and corresponding tree species of surface lake samples

<table>
<thead>
<tr>
<th>Locality</th>
<th>FC (%)</th>
<th>AP (%)</th>
<th>Tree species (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kichikol</td>
<td>25.5</td>
<td>24.6</td>
<td>Juniperus (23.7)</td>
</tr>
<tr>
<td>Karakol</td>
<td>34</td>
<td>23.4</td>
<td>Picea (10.3); Juniperus (9.2)</td>
</tr>
<tr>
<td>Bakaly</td>
<td>46</td>
<td>44.8</td>
<td>Juniperus (32.2); Juglans (2.8); Picea (1.3)</td>
</tr>
<tr>
<td>Nishneye</td>
<td>100</td>
<td>25.5</td>
<td>Juglans (13.1); Juniperus (10.4); Acer (0); Prunus-type (0); Sorbus-type (0)</td>
</tr>
<tr>
<td>Verkhneye</td>
<td>100</td>
<td>59.8</td>
<td>Juglans (34.2); Juniperus (17.0); Acer (0.2); Prunus-type (0); Sorbus-type (0.2)</td>
</tr>
</tbody>
</table>

FC: Forest cover
AP: Arboreal pollen
Figure captions

Fig 1: Map of Kyrgyzstan and location of the four studied sites: 1) Kichiko (KKO1, KKO2); 2) Karakol (KAO); 3) Bakaly (BAO2, BAO); 4) Nishneye and Verkhneye Ozero (NOVO)

Fig. 2: Verkhneye Ozira. The site is situated in the Juglans-Acer forests of Kyrgyzstan. Closed forests are reflected by 59.8 % of arboreal pollen. The lowlands in this area are dominated by treeless dry steppes.

Fig. 3: Pollen percentages of selected pollen types at Kichiko, sampled along a gradient of crown densities in a Juniperus forest. Tree-crown cover is 10% in plot 1, 20% in plot 2, 45% in plot 3, 80% in plot 4, and 100% in plot 5. Black bars are percentage values; white bars are x10 exaggeration.

Fig. 4: Correlation between tree-crown cover and pollen percentages of arboreal pollen (AP) in the Juniperus forest at Kichiko.

Fig. 5: Vegetation transect and pollen percentages of selected pollen types at Kichiko, sampled along a W-E transect. Tree-crown cover of Juniperus is 75% in plot 1, 30% in plot 2, 0% in plots 3 to 5. Legend: Symbols of the tree types used in the figures.

Fig. 6: Vegetation transect and pollen percentages of selected pollen types at Karakol, sampled along a N-S transect. Tree-crown cover of Picea schrenkiana is 100% in plot 1, 50% in plot 2, 0% in plot 3, 25% in plot 4, 75% in plot 5, and 100% in plot 6.

Fig. 7: Correlation between tree-crown cover and pollen percentages of arboreal pollen (AP) in the Picea forest at Karakol.

Fig 8: Vegetation transect and pollen percentages of selected pollen types at Bakaly along a N-S transect. Tree-crown cover is 70% in plot 1, 0% in plots 2 and 3, 50% in plot 4, 70% in plot 5, and 80% in plot 6.

Fig. 9: Vegetation transect and pollen percentages of selected pollen types at Bakaly, W-E transect. Tree-crown cover is 60% in plot 1, 0% in plot 2, 50% in plot 3, 80% in plot 4, 0% in plot 5, 40% in plot 6, 0% in plot 7, 40% in plot 8, 30% in plot 9, and 40% in plot 10.
**Fig. 10:** Correlation between tree-crown cover and pollen percentages of arboreal pollen (AP) in the mixed forest at Bakaly.

**Fig. 11:** Vegetation transect and pollen percentages of selected pollen types at Nishnaye- and Verkhneye Ozero. Tree-crown cover is 50% in plot 1, 30% in plot 2, 60% in plot 3, 30% in plot 4, 40% in plot 5, 80% in plot 6, 40% in plot 7, 50% in plot 8, 60% in plot 9, 40% in plot 10, and 60% in plot 11.

**Fig. 12:** Correlation between tree-crown cover and pollen percentages of arboreal pollen (AP) in the *Juglans* forest at Nishnaye- and Verkhneye Ozero.

**Fig. 13:** Correlation between tree-crown cover and pollen percentages of arboreal pollen (AP) of all four sites in Kyrgyzstan.

**Fig. 14:** Correlation between forest cover and pollen percentages of arboreal pollen (AP) from surface lake samples.
Fig 5
Fig. 6

Fig. 7
Fig. 8
Fig. 10

Fig. 11
Vegetation history of the walnut-fruit forests in Kyrgyzstan (Central Asia): natural or anthropogenic origin?

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Abstract

Extensive forests of common walnut (*Juglans regia* L.) occur in the mountains of the Fergana and the Chatkal ranges of Kyrgyzstan (Central Asia), where they form a rich cultural landscape with a mosaic of natural and planted forest stands, fields, pastures, and drier open areas. These remote forests are likely to be an important genetic resource for *J. regia*, not only for *in situ* conservation but also as a resource for tree breeding (Hemery and Popov, 1998; McGranahan, 1998). Pollen and charcoal analysis of the sediment of four lakes and two peat bogs in the core regions of the walnut forests provide new data to infer the vegetation history of the last 6800 years in the Fergana and Chatkal ranges in Kyrgyzstan. Our results suggest that the potential natural forests or woods in the modern walnut-fruit forest region were dominated by *Juniperus* together with trees of *Betula, Fraxinus, Rosaceae*, and possibly *Acer*. A special focus was put on the vegetation history of *Juglans regia*, as it has been suggested that the walnut-fruit forests of Kyrgyzstan might be a refuge for this tree. However, our results suggest that the stands of *Juglans regia* are at the most 2000 years old, most of them even only about 1000 years old, and therefore probably of anthropogenic origin, confirming an old legend that is still orally transmitted in Kyrgyzstan. As with other old and widespread cultivated plants, it is not easy to reconstruct the original distribution and determine the borders of the past natural ranges. A review of paleoecological data points to refugia in southern Europe, Syria, and the Himalaya, where *Juglans* possibly outlived the last glaciation.

**Key words:** *Juglans regia*, pollen, Holocene, Central Asia
Introduction

Walnut-fruit forests in Kyrgyzstan cover an area of 230,000 ha, of which 40,500 ha are stands with walnut trees (Musuraliev, 2004). Official data on walnut forest areas strongly vary from 1960 (25,400 ha) to 2004 (40,500 ha) due to the amplitude of the territory under the control of the State forestry bodies (Venglovsky, 2006). The real extent of walnut forest remains unclear. The forests occur in spatially disconnected areas on the southwest-facing slopes of the Fergana Range north and east of Jalal-Abad and on the southeast-facing slopes of the Chatkal Range (Gottschling, 2005) at an altitudinal distribution between 700 and 2100 m a.s.l (Kolov, 1998). The Chatkal Range is characterized by steep slopes and scree, as well as by rocky outcrops. The relief of the Fergana Range is smoother, with extensive forest cover (Sherbinina, 1998). These forests consist of *Juglans regia* admixed with *Crataegus turkestanica* A. Pojark., *Malus kirghisorum* Al. et An. Theod., *Prunus mahaleb* L., and *Prunus sogdiana* Vass., found predominantly on north-facing slopes. Stands of *Acer turkestanicum* Pax. admixed with the above-mentioned trees and shrubs are found in the upper belt of the walnut-fruit forest complex, while *Pistacia vera* L. forms thickets on the driest patches at the lowest and driest sites. The walnut-fruit forests form a rich cultural landscape, a mosaic of natural and planted forest stands, fields, pastures, and drier open areas. Today, this forested landscape is predominantly used in ways that reflect, in the widest use of the terms, agroforestry and silvopastoral practices. For a thorough description of the walnut-fruit forests see Blaser et al. (1998), Epple (2001), and Gottschling et al. (2005). Besides the harvest of agricultural and forest products being of great socio-economic value, the walnut-fruit forests protect the soil and water, for they are a natural regulator of water draining from the Fergana and Chatkal ranges. Numerous mountain rivers flow across the territory of the walnut-fruit forests, most of them being tributaries of rivers such as the Naryn and Kara-Dariya, which flow into Central Asia’s Syr-Dariya river system of the Aral Sea basin. Therefore the forests contribute to maintaining an even flow of river water for the irrigation of the fields in the
Fergana Valley and other areas. Furthermore, they prevent landslides and rock falls (Musuraliev, 1998).

Some of these forests are under heavy grazing pressure, as cattle are abundant and roam mostly uncontrolled in the forests. Other human impacts include agro-forestry activities like hay-making in open patches of the forest, harvesting of nuts, fruits, other non-timber products, and firewood, and, to a limited extent, exploitation of timber (Kolov, 1998; Venglovsky, 1998; Gottschling et al., 2005). Thus, forest and agricultural products harvested from forested areas play a significant role in the livelihoods of local people during the current difficult process of transition to a market economy (Schmidt, 2005; Schmidt, 2006). Since Kyrgyz Republic became independent in 1991 and as a consequence of the socio-economic difficulties of the transition period, pressure on the walnut-fruit forests has increased, and the area of the forest has diminished, partly due to the lack of regeneration following the over-exploitation of the forests (Musuraliev, 1998), but also due to altered climatic conditions, i.e. more drought stress (Gottschling, 2005). At present, efforts are made to protect the forests of this region (Blaser, 1998).

The origin of the walnut forests has been a subject for debate among foresters, botanists, biogeographers, and other scientists in Central Asia. The forests are isolated in the mountain regions by the surrounding semi-desert areas (Hemery and Popov, 1998) and therefore have a special scientific attraction. It is reported that many researchers consider the walnut-fruit forests to be an impoverished relict of mesophyllic forests of the Tertiary period (Ashimov, 1998; Kolov, 1998). Yet the current consensus is that the *Juglans* forests of southern Kyrgyzstan originated at the end of the Pleistocene (Vyhodtsev, 1970) and can therefore be considered natural. This paper presents the first palynological results for the past 6800 years in the area of the walnut-fruit forests of southern Kyrgyzstan and shows that the forests are far younger and very likely established as a consequence of human land-use.
Regional setting

Nishneye (1371 m a.s.l.; N 41°18’; E 72°57’) and Verkhneye Ozero (1440 m a.s.l.; N 41°18’; E 72°57’) (Fig. 1) are two lakes lying only one kilometer apart very close to Arslan-Bob. Both lakes have a surface of approx. 3 ha and have no major inlet or outlet. Water depth was 6.65 m and 6.3 m, respectively. The two lakes lie in the core region of the walnut (*Juglans regia*) forests in the Arslan-Bob region, Fergana Range, and at present the stands are closed and rather dense. Ak Terek is a sloping-mire (1748 m a.s.l.; N 41°17’; E 72°50’) not far away from Arslan-Bob (3 km) (Fig. 1). It lies close to a village surrounded by forests and plantations of *J. regia* trees and fruit orchards. Ortok is a lake that is gradually converting into a mire at 1786 m a.s.l. (N 41°14’; E 73°15’), approx. 10 km away from Arslan-Bob (Fig. 1). A mat 50-100 cm thick of *Phragmites* and *Telypteris* roots covers the lake surface. Water depth beneath the root mat was 3.85 m. The village of Ortok can be reached by car only during the warm season. The north-facing steeper slope of the lake shore is covered by a forest of *J. regia* and *Malus kirghisorum*, whereas *Acer turkestanicum* and *Crataegus* spp. are important on the south-facing slope. To the west (150 km) in the Chatkal Range a spring-mire called Kosh Sas (1786 m a.s.l.; N 41°51’; E 71°58’) was cored (Fig. 1). The mire is surrounded by a belt of *Phragmites*. The hills around the mire are covered by open mixed forests of *Juniperus turkestanica* Kom., *J. semiglobosa* Rgl., *Picea schrenkiana* F. et M., *Acer turkestanica*, and *Juglans regia*. Near (2 km) Bakaly is a small lake at 1879 m a.s.l. (N 41°52’; E 71°58’) in the Sary Chelek Biosphere Reserve (Fig. 1). Lake surface is about 1 ha and water depth was 5.2 m. The forests around the site are rather open and consist of a mosaic of *Juniperus turkestanica*, *J. semiglobosa*, *Picea schrenkiana*, *Abies semenovii* Hill., *Juglans regia*, *Acer turkestanica*, *Betula alba* L., *Malus kirghisorum*, *Prunus* spp., and *Crataegus* spp.

The Fergana and the Chatkal ranges mark the western border of the Tien Shan Ranges which covers large parts of Kyrgyzstan. The occurrence of forest in this rather arid zone of
Central Asia is possible due to orographic precipitation. In the winter half year the Tien Shan lies in the sphere of influence of the west-wind circulation (Weischet and Endlicher, 2000). Especially during spring and autumn humid air-masses are transported into the region and therefore a maximum of precipitation is found during this time in the western border ranges of the Tien Shan. During summer dryness is accentuated. Winters are relatively mild as the Tien Shan forms a shield against the northern cold from Siberia. Annual precipitation of 700 to 1200 mm is recorded in the region of the walnut-fruit forests (Atlas Kirgizkoy SSR, 1987, Gottschling et al., 2005). Meteorological data are available from the research station Ak Terek (1748 m a.s.l.). A maximum of precipitation occurs during March to June, and a dry period from July to September. Mean annual precipitation is 1020 mm. At Jalal-Abad (771 m a.s.l., N 40°55’ and E 72°57’) mean July and January temperatures of 33.3 and -6.1 °C, respectively, are recorded, and a mean annual temperature of 13.5 °C. The mean annual precipitation is 440 mm (Worldwide Bioclimatic Classification System, 2006).

**Material and Methods**

**Coring**

One short core (NO3) was taken with a Plexiglas tube from Nishneye Ozero. For older sediment two parallel long cores (NO1, NO2) were taken with a modified Streif-Livingstone corer (Merkt and Streif, 1970) in the center of the lake two meters apart. At Verkhneye Ozero a short core (VO3) and two long parallel cores two meters apart (VO1, VO2) were taken, and at Ak Terek two long cores (AKA1, AKA2). For AKA2 50 cm of the surface peat was dug away. At Ortok two parallel long cores (ORT1, ORT2) were taken near to the center of the lake and at Kosh Sas two long cores (KOSA, KOSB). For KOSB 50 cm of the surface peat was dug away. At Bakaly two short cores (BAK1, BAK2) and two long parallel cores one meter apart (BAK3, BAK4) were taken.
Dating

AMS (Accelerated Mass Spectrometry) $^{14}$C ages (Tab. 1 – 6) were obtained from terrestrial plant macrofossils from the sediments. The $^{14}$C dates were converted to calibrated ages (years cal. BP) with the program Calib version 5.0.1 (Stuiver & Reimer, 1993). Given the moderate number of dates per site the age-depth models were based on linear interpolation of the median values of calibrated $^{14}$C dates (Olsson, 1986).

Pollen and microscopic-charcoal analysis

Pollen preparation followed standard procedures for glycerine samples (Moore et al., 1991). Lycopodium tablets (Stockmarr, 1971) were added to sub-samples of 1 cm$^3$ to estimate pollen concentrations (grains cm$^{-3}$) and accumulation rates (grains cm$^{-2}$ yr$^{-1}$). Pollen types were identified with pollen keys (Moore et al., 1991; Beug, 2004), pollen atlases (Reille, 1992; 1998), and the reference collection of the Institute of Plant Sciences of the University of Bern. A minimum of 600 pollen grains, excluding aquatic pollen and spores, were counted at each level except at levels where pollen concentrations were extremely low. The identification of non-pollen objects in the pollen slides followed van Hoeve and Hendrikse (1998) and for spores of ascomycetes van Geel and Aptroot (2006). The pollen diagram was subdivided into local pollen assemblage zones (LPAZ) by using the zonation method of optimal partitioning (Birks and Gordon, 1985) as implemented in the program ZONE, version 1.2, written by Steve Juggins. To determine the number of statistically significant zones in diagrams, we used the program BSTICK (Bennett, 1996).

Microscopic charcoal particles, i.e. black, completely opaque, and angular fragments (Clark, 1988) longer than 10 μm (or area > 75μm$^2$), were counted in pollen slides following Tinner and Hu (2003), and Finsinger and Tinner (2005). Charcoal number concentration (particles cm$^{-3}$) and influx (particles cm$^{-2}$ yr$^{-1}$) were estimated by use of the same approach as for pollen (Stockmarr, 1971).
Results

Chronology and lithology

At Nishneye Ozero all five \(^{14}\)C dates were accepted (Table 1, Fig. 2). At Verkhneye Ozero one date was rejected as it seems too old compared with the neighbouring dates (Table 2, Fig. 3). At Ak Terek only two dates were obtained (Table 3, Fig. 4), and the older date seems rather old but is accepted. At Ortok all three dates were accepted (Table 4, Fig. 5). At Kosh Sas only one date is available (Table 5, Fig. 6), and at Bakaly all four dates were accepted (Table 6, Fig. 7).

The sediment of Nishneye Ozero consists mainly of gyttja from 0-239 cm. From 239-279 cm peat is prevalent. The material in the lowest part from 279-450 cm is sandy silt (Fig. 8). At Verkhneye Ozero mainly gyttja was deposited from 0-109 cm, and from 109-363 cm reddish silt with sand (Fig. 9). The sediment of Ak Terek is peat and gyttja from 0-224 cm, calcareous gyttja from 224-534 cm, and silt in the lowest part (Fig. 10). At Ortok gyttja and calcareous gyttja forms the sediment from 0-69 cm, and gyttja, silty gyttja, and silt is found in layers from 69-491, whereas from 491-860 cm the material is sandy silt (Fig. 11). Herbaceous peat was deposited in the top section of Kosh Sas from 0-190 cm. From 190-285 cm the sediment consists of lake marl, and from 285-326 cm of gyttja. Between 326-385 cm marl was deposited together with sand. Pollen was only found down to the depth of 284 cm (Fig. 12). At Bakaly the sediment consists of gyttja from 0-38 cm, calcareous gyttja from 38-180 cm, silty gyttja from 180-287 cm, and from 287-456 again calcareous gyttja. Silty gyttja was deposited between 456-498 cm, calcareous gyttja at 498-646 cm, silt and calcareous gyttja at 646-915, and sand and silt at 915-1183 cm (Fig. 13).
**Pollen and charcoal**

**Nishneye Ozero (Fig. 8)**

The stratigraphies of Nishneye and Verkhneye Ozero are approx. 1600 years old, so only the youngest Holocene vegetation history can be inferred from these sediments. Between LPAZ NO-1 and NO-3 (1550-800 cal. yr BP) pollen of herbaceous taxa was dominated by e.g. *Artemisia*, Chenopodiaceae, Poaceae, and Cichorioideae. *Juniperus* pollen testifies to the presence of arboreal taxa. *Plantago lanceolata*-type pollen is present from LPAZ NO-3 onwards; a peak is recorded in the depth of 190 cm (1000 cal. yr BP). Two marked peaks of charcoal concentration and influx occur in LPAZ NO-2 (around 1150 cal. yr BP) and in LPAZ NO-3 (950-800 cal. yr BP). From 1100 cal. BP upward a continuous curve of pollen of *Juglans regia* is recorded. In LPAZ NO-4 (850-0 cal. yr BP) the pollen of *Juglans regia* attains high values up to 30% and pollen of *Betula, Prunus*-type, *Sorbus*-type, *Acer*, and *Morus alba*-type is present. The rise of pollen of arboreal taxa is accompanied by a decline in herbaceous taxa (e.g. Chenopodiacea and Poaceae).

**Verkhneye Ozero (Fig. 9)**

The longest part of the stratigraphy of Verkhneye Ozero (LPAZ VO-1 to VO-5: 1550-650 cal. yr BP) is dominated by pollen of herbaceous taxa (e.g. *Artemisia*, Chenopodiaceae, Poaceae). The pollen of arboreal taxa is dominated by *Juniperus*. Other arboreal taxa are represented by low pollen values of *Betula, Prunus*-type, *Sorbus*-type, *Acer, Morus alba*-type, and *Platanus*. The pollen of *Plantago lanceolata*-type is present from VO-2 onwards and shows a peak of 15% in the depth of 80 cm (1000 cal. yr BP). A marked peak of charcoal concentration and influx is recorded in LPAZ VO-3 (1150 cal. yr BP). In the uppermost 50 cm (LPAZ VO-6: 650-0 cal. yr BP) an increase of *Juglans regia* pollen peaks to 35% at the end of the zone. A minor peak of *Morus alba*-type occurs at a depth of 10 cm (150 cal. yr BP). Whereas
Juniperus remains at constant levels, the pollen of herbaceous taxa (e.g. Artemisia, Chenopodiaceae, Poaceae) declines.

Ak Terek (Fig. 10)
LPAZ AKA-1 (7700-7400 cal. yr BP) is characterized by high pollen values of Eleagnus angustifolia. The pollen of herbaceous taxa is represented by steppe elements (e.g. Chenopodiaceae, Poaceae, Ephedra, Artemisia, and several pollen types from the Asteraceae family). At the beginning of LPAZ AKA-2 (7400-800 cal. yr BP) the pollen of Eleagnus angustifolia disappears, while single pollen finds of Juniperus, Sorbus-type, and Juglans regia are found. The pollen of herbaceous taxa accounts for almost 100% of the pollen sum. In LPAZ AKA-3 (800-0 cal. yr BP) the Juniperus pollen curve becomes closed as does Juglans regia. Only briefly afterwards in the uppermost part (around 150-100 years ago), total tree pollen attains 15% dominated by Juglans. As for the pollen of herbaceous taxa, many formerly abundant pollen types decrease, with exception of Artemisia, Chenopodiaceae, Poaceae, and Cyperaceae. Occurring for the first time in the pollen record, are Rumex, Plantago lanceolata-type, Urtica, and Cerealia.

Ortok (Fig. 11)
During LPAZ ORT-1 (840-750 cal. yr BP) pollen of herbaceous taxa characteristic for steppe environments (e.g. Artemisia, Chenopodiaceae, Poaceae, and different pollen types of the Asteraceae) attains almost 100%. Single pollen grains of Juniperus and Juglans regia are present. In LPAZ ORT-2 (750 -640 cal. yr BP) Juniperus and Juglans regia pollen forms continuous curves with low values. The pollen of Asteraceae decreases markedly, while Cerealia, Plantago lanceolata-type, Rumex-type, Urtica, and Cannabis become more important. Cyperaceae pollen reaches its maximum in this zone. Arboreal pollen increases slightly in LPAZ ORT-3 (640 -440 cal. yr BP) and reaches values around 5%. Populus,
Crataegus, Sorbus-type, Morus alba-type, and Salix appear. The pollen of Juglans regia increases markedly during LPAZ ORT-4 (440-0 cal. yr BP), while pollen of other arboreal taxa (e.g. Juniperus, Picea, Betula, Populus, and Acer) attain constant but minor values.

Kosh Sas (Fig. 12)
In the lowest part of the sediment (LPAZ KOS-1: 3700-2550 cal. yr BP) the pollen of herbaceous taxa (e.g. Artemisia, Chenopodiaceae, and Poaceae) is dominant. The pollen of arboreal taxa is dominated by Juniperus, while Picea and Betula show constant but very low values. In LPAZ KOS-2 (2550-1250 cal. yr BP) the pollen of Juniperus declines and the first pollen grains of Juglans regia are recorded. The herbaceous taxa (e.g. Artemisia and Poaceae) keep stable values or increase (e.g. Plantago lanceolata-type). The pollen of Cyperaceae increases markedly at the border of sedimentary transition from marl to peat (190 cm, 2500 cal. yr BP). A small peak of charcoal concentration and influx occurs at a depth of 150 cm (around 2000 cal. yr BP). During LPAZ KOS-3 (1250-100 cal. yr BP) the pollen of Juglans regia becomes continuous, and a small peak of Morus alba-type is recorded around 1000 cal. BP. A marked peak of charcoal concentration and influx is recorded at 82 cm (around 1200 cal. yr BP).

Bakaly (Fig. 13)
In the lowest part of the sediment (LPAZ BAK-1: 6800-6400 cal. yr BP) herbaceous taxa (e.g. Poaceae, Chenopodiaceae, and Cichorioideae) are dominant in the pollen record. Towards the end of the zone a rise of pollen of Juniperus occurs. LPAZ BAK-2 and BAK-3 (6400-5000 cal. yr BP) are characterized by a peak of pollen of Juniperus and relatively high values of Betula and Fraxinus, whereas Poaceae and Cichorioideae reach only low values. In LPAZ BAK-3 the pollen values of Juniperus decline, whereas Artemisia shows increasing values. In LPAZ BAK-4 (5000-3000 cal. yr BP) pollen of herbaceous taxa (e.g. Artemisia,
Cichorioideae, Chenopodiaceae, and Poaceae) is dominant. LPAZ BAK-5 and BAK-6 (3000-1300 cal. yr BP) are again characterized by a sharp rise in Juniperus pollen, accompanied by a decline in Chenopodiaceae and Cichorioideae. The pollen of Abies is recorded from LPAZ BAK-5 (2500 cal. yr BP) onward. The first pollen finds of Juglans regia are recorded in LPAZ BAK-6 (i.e. at 1800 cal. yr BP). LPAZ BAK-7 (1300-300 cal. yr BP) shows a large peak of pollen of Plantago lanceolata-type, which is accompanied by a decline of pollen of arboreal taxa (e.g. Juniperus) and herbaceous taxa (e.g. Artemisia). During LPAZ BAK-8 (300-0 cal. yr BP) a sharp rise of pollen of arboreal taxa (e.g. Juniperus) occurs and higher values of Juglans regia and Betula are recorded as well. The rise of pollen of arboreal taxa is accompanied by a decline in herbaceous taxa (e.g. Plantago lanceolata-type and Cichorioideae).

**Discussion**

**Holocene climatic conditions**

Forest environments of Kyrgyzstan were subject to major oscillations during the past 7000 years. Some of them were probably triggered by climatic change. Given the general course of Holocene climatic conditions in the northern hemisphere (e.g. climatic optimum at ca. 10,000-5000 cal yr BP) (Kremenetski et al., 1998) we must assume that forest taxa (e.g. Juniperus, Picea at Bakaly) were resilient enough to cope with temperatures slightly or considerably above today’s average. Asian macrofossil studies (e.g. Kremenetski et al., 1998; MacDonald et al., 2000) show that forests across northern Russia developed at the onset of the Holocene at 11,500 cal yr BP. Maximum polar tree line positions were reached at 10,000-5000 cal. yr BP, probably in response to summer temperatures 2.5-7.0º C warmer than modern. These results are in agreement with European and American tree line studies, which,
however, suggest that the climatic optimum was more moderate in those regions (ca. 2° C warmer summers, if compared with today, Tinner, 2006). Between 5000 years ago and today the high summer temperatures gradually fell to today’s level, though they were subject to centennial-scale oscillations of ca. ± 1 ° C (Tinner, 2006). This finding is in agreement with the Greenland ice core records, which suggest rather stable Holocene climatic conditions, though a declining trend throughout the late Holocene (Grootes et al., 1993; Dansgaard et al., 1997; Willemse and Törnqvist, 1999).

The Bakaly record shows that climatic conditions during (at least) the past 4000 years were rather stable and certainly permitted the growth of forests or woods in the study areas. Nevertheless, minor climatic oscillations may have influenced vegetational development, as e.g. shown by the expansion of Abies semenovii in the Sary Chelek region ca. 2500 years ago (see results). Considering these presumably rather stable climatic conditions, we assume that the past 4000 years can be used to assess today’s natural potential vegetation.

Vegetation history and potential natural vegetation of the Juglans regia forests in Kyrgyzstan

Our paleobotanical results suggest that the potential natural forests or woods in the modern walnut-fruit forest region were dominated by Juniperus together with Betula, Fraxinus, and Rosaceae trees (most probably the species that are found today belonging to the genera of Malus, Pyrus, Prunus, and Crataegus). It is also very likely that Acer was important, but we are not able to track this tree with our methods, since its pollen production and dispersal are extremely low (Beer et al., accepted). Around Bakaly (the lake with the longest stratigraphy covering 6800 years) but also at Nishneye Ozero, Verkhneye Ozero, and Kosh Sas, Picea schrenkiana has always been present in minor amounts, while Abies semenovii was able to expand naturally approx. 2500 years ago only in the Bakaly area.
The earliest unambiguous evidence suggesting the local occurrence of *Juglans regia* (continuous pollen curve, also called empirical limit, see Huntley and Birks, 1983; Lang, 1994) comes from Bakaly and is 2000 years old (Table 7). Nevertheless, earlier single pollen finds of *Juglans* (e.g. Bakaly) may actually derive from single trees that were present in Kyrgyzstan more than 2000 years ago. As for the other sites, the presence of *J. regia* is documented only around 1000 cal. yr BP or even later. At Nishneye and Verkhneye Ozero the expansion of this tree and the build-up of the populations leading to the walnut-fruit forest occurred only after 900 and 650 cal. yr BP, respectively (1050 AD and 1300 AD). At Ak Terek and Ortok the establishment of forests of *J. regia* seems markedly younger (300 cal. yr BP, 1650 AD). In agreement with the fact that Kosh Sas and Bakaly are sites at the upper modern altitudinal limit of *J. regia*, our paleobotanical record shows that the species never formed larger forests there. To conclude, independently from the question whether the tree is native or not in Kyrgyzstan, we can state with almost absolute certitude that the *Juglans* forests and ecosystems of Kyrgyzstan are surprisingly young at all sites we investigated. Moreover, in the light of our results it is most likely that they are of anthropogenic origin.

An existing local legend about the origin of the walnut-fruit forests in the valley of Arslan-Bop, where the two sites Nishneye- and Verkhneye Ozero are located, is another indicator for the active anthropogenic role in the formation of these forests. According to this legend, which is still told by the people in Arslan-Bop today, the *Juglans* forests in the valley as well as other forest types dominated by fruit-bearing woody species have been established under the leadership of Arslan-Bop, the legendary founder of the Uzbek village that bears his name. Arslan-Bop is said to have been a much respected scholar and leader of great strength who lived around the turn of the 11th to the 12th century and died in 1120 AD (CBT Arslan-Bop, 2003). Interestingly, these dates of his lifetime roughly coincide with the increase of walnut trees and the formation of *Juglans* stands in the valley according to the palynological findings from the Nishneye- and Verkhneye Ozero (1050 AD and 1300 AD). Thus, this
legend is in agreement with the conclusion of our investigations. This is an interesting example of agreement of scientific data, in form of the palynological findings, and local history based on legends.

**Earliest traces of *Juglans regia* and its possible origin**

*Juglans regia* is considered a relict species of the Tertiary (Renault-Miskovsky, 1984) and to be native of the mountain ranges of central Asia extending from Xinjiang province of western China, parts of Kazakhstan, Uzbekistan, and southern Kyrgyzstan in Central Asia, and the mountains of Nepal, Tibet, northern India, and Pakistan, west through Afghanistan, Turkmenia, and Iran to portions of Azerbaijan, Armenia, Georgia, and eastern Turkey (McGranahan and Leslie, 1991). Today the species is also found throughout southern and western Europe, although it is more frequent in south-central and southeastern Europe (Huntley and Birks, 1983). Moreover, it is also cultivated in North, Central, and South America, Australia, New Zealand, South Africa, and Japan (McGranahan and Leslie, 1991). The location of the refugia and the spread of the species is still a debated subject. In Europe the earliest consistent Holocene records are from the Balkans and Italy at 6000 cal. yr BP, and by 5000 cal. yr BP moderate pollen values occurred in the northern Balkans and Italy (Huntley and Birks, 1983; P. Kaltenrieder, personal communication). Subsequently the area of consistent occurrences expanded especially in the Balkans, so that by 2000 cal. yr BP *J. regia* occurred throughout the western Balkans and extended west to southern France (Huntley and Birks, 1983). By 1000 cal. yr BP its range in the eastern Balkans increased, but the most dramatic expansion was in western France and reached high pollen values in northwestern Italy. Nevertheless, Renault-Miskovsky (1984) gives an overview of several locations in France, England, Belgium, The Netherlands, and Spain where pollen and macro-remains of *Juglans* occur from the late Tertiary onwards throughout the Quaternary.
Palynological data from the Carihuela Cave (Granada, southeastern Spain) suggest the presence of walnut in that region throughout the early and middle stages of the last glaciation, indicating the native character of the species in that area (Carrion and Sánchez, 1992). However, in most cases the first appearances of *Juglans* pollen in Europe occurs around 1500-2500 cal. yr BP and is contemporaneous with the establishment of the Greek and Roman civilizations (Huntley and Birks, 1983; Schaarschmidt, 1999) e.g. on the Dalmatian coast (Beug, 1966) and in the Crimea (Cordova and Lehmann, 2003). Palynological investigations in southwestern Bulgaria (Tonkov et al., 2002) show stray pollen grains of *Juglans regia* around 7200 cal. yr BP. Higher pollen values are only found from 2000 cal. yr BP onwards. Some authors have suggested that it was introduced from the east (Beug, 1962), i.e. from the Caucasus region and the Near East through the Balkans (Filipovitch, 1977, Bottema, 1980), whereas others propose that it is native in parts of Greece, Bulgaria, Romania, Yugoslavia, and Albania (Jalas and Suominen, 1976). Gerasimidis and Athanasiadis (1995) report from Greece that *Juglans* pollen appears at a time of human interference at Voras, Paiko, and Lailias together with *Castanea*, but that it is found earlier in the Rhodopes Mountains probably pointing to the existence of a natural population of walnut in that region. In Turkey *Juglans regia* was likely planted by early farmers (van Zeist et al., 1975; Bottema and Woldring, 1984; Eastwood et al., 1999; Wick et al., 2003) although stray grains of *Juglans* are found in some diagrams during earlier periods. In the Zeribar region in Iran *Juglans* appears only about 2000-2500 years before present (van Zeist and Bottema, 1977), whereas, in the Ghab Valley in Syria the pollen of *Juglans* is found scantily during the last Glacial and later during the Holocene (Niklewski and van Zeist, 1970). Yet, another study in the Ghab Valley proposes that *Juglans* occurred only around 5000 cal. yr BP and that very early human impact can be detected as early as 9000 cal. yr BP (Yasuda et al., 2000). Nevertheless, it has to be noted that this record covers only the past 15,000 years. The pollen sequences of two peat bogs in Kashmir (Butapathri bog I, and II) show that *Juglans* appears from 17,000 cal. yr BP,
and from 10,000 cal. yr BP onwards, respectively; in Butapathri bog I the pollen of *Juglans* is constantly present but never attains more than around 5%, whereas in Butapathri bog II it attains 30% at a depth of 150 cm (Dodia et al., 1983). Schlütz and Zech (2004) found in a site in the Gorkha Himalaya (Central Nepal) pollen of the *Juglans regia*-type in the Late Glacial disappearing with the onset of the Holocene. However, the pollen is only clearly determinable at a generic level, and it can include species other than *J. regia*.

The situation is much clearer in the rare cases where macrofossils such as fossil nuts have been found. Schaarschmidt (1999) reports findings of fossil nuts in southern Germany dating to the La Tène period (i.e. before the arrival of the Greeks and Romans) that were named *Juglans germanica*, being much harder and smaller than today’s walnuts. Likewise, in Hebei, China, a small carbonised walnut shell has been recovered and dated 7300 years old, interpreted as being a natural form of *Juglans regia*, not yet gone through the long series of breeding procedures (Xi, 1990). Interestingly, the Kyrgyz walnuts also vary greatly with respect to fruit size and hardness of the shell and have therefore formerly been subdivided into different varieties and subspecies by some authors (Granahan and Leslie, 1991). In this light, it is conceivable that the modern form that produces large fruits is not a natural species at all but rather an ancient cultivar, descending from a small-fruited form such as those macrofossils found in Germany or China.

**Conclusions**

As with other old and widespread cultivated plants it is not easy to reconstruct the original distribution and determine the borders of the past natural ranges (Hegi, 1981). Many reports are found concerning the earliest fossil pollen and nut finds of *Juglans regia*, and the conclusions that various authors draw are somewhat contradictory. Taken together these finds suggest that *J. regia* possibly survived the last glaciations in several refugia; as the
compilation of the data shows most likely southern Europe, the Near East, and the Himalaya. Yet for Kyrgyzstan the results of our palynological investigation demonstrate that the occurrence of walnut is relatively young, i.e. 2000 years old. Moreover, as its pollen co-occurs with indicators of human interference (e.g. Plantago lanceolata-type) the tree was very likely introduced by humans, although sub-spontaneous spread is not excluded as the trees grow and reproduce vigorously on the mountain slopes north of the Fergana Valley. Stray grains of Juglans found around 6000 cal. yr BP most likely point to earlier presence of single trees in Kyrgyzstan, whose origin is uncertain; either natural or introduced along some travelling routes, possibly from the Himalayas.

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**Table 1** ¹⁴C dates from Nishneye Ozero

<table>
<thead>
<tr>
<th>Lab. No.</th>
<th>Depth</th>
<th>Material</th>
<th>¹⁴C dates</th>
<th>cal. BP 95% confidence limits *</th>
<th>Age in Diagram cal. yr BP (BP = 1950)</th>
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<td></td>
<td>(cm)</td>
<td></td>
<td>years BP conv. uncal.</td>
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<tr>
<td>Poz-6502</td>
<td>63.5-65.5</td>
<td>periderm, leaves, roots</td>
<td>125.8 ± 1</td>
<td>23-264</td>
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<tr>
<td>Poz-6504</td>
<td>175.5-177.5</td>
<td>Leaves, periderm, seed fragment</td>
<td>1060 ± 30</td>
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<td>Poz-6505</td>
<td>262.5-263.5</td>
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<td>1220 ± 40</td>
<td>1058-1265</td>
<td>1149</td>
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<tr>
<td>Poz-6506</td>
<td>367.5-368.5</td>
<td>wood, periderm, bud</td>
<td>1655 ± 30</td>
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<tr>
<td>6492</td>
<td>441.5-443.5</td>
<td>periderm</td>
<td>1790 ± 35</td>
<td>1614-1820</td>
<td>1719</td>
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* Calibration of radiocarbon dates: Calib 5.01 (Stuiver & Reimer 1993)

**Table 2** ¹⁴C dates from Verkhneye Ozero

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<td>(cm)</td>
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<td>Poz-6507</td>
<td>65.5-66.5</td>
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<td>Poz-6490</td>
<td>91.5-103.5</td>
<td>charcoal, insect remains</td>
<td>1250 ± 30</td>
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<td>Poz-6508</td>
<td>251.5-252.5</td>
<td>twig</td>
<td>1885 ± 30 †</td>
<td>1731-1889 †</td>
<td>1834 †</td>
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<tr>
<td>Poz-6509</td>
<td>289.5-291.5</td>
<td>periderm</td>
<td>1600 ± 30</td>
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* Calibration of radiocarbon dates: Calib 5.01 (Stuiver & Reimer 1993)

† Rejected date
### Table 3 $^{14}$C dates of Ak Terek

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<th>$^{14}$C dates y ears BP</th>
<th>cal. BP 95% confidence limits</th>
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<td>Poz-16252</td>
<td>232-234</td>
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<td>Poz-16253</td>
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* Calibration of radiocarbon dates: Calib 5.01 (Stuiver & Reimer 1993)

### Table 4 $^{14}$C dates of Ortok

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<th>Depth (cm)</th>
<th>Material</th>
<th>$^{14}$C dates y ears BP</th>
<th>cal. BP 95% confidence limits</th>
<th>Age in Diagram cal. yr BP (BP = 1950)</th>
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</thead>
<tbody>
<tr>
<td>Poz-14765</td>
<td>196-198</td>
<td>wood with periderm</td>
<td>635 ± 30</td>
<td>553-665</td>
<td>599</td>
</tr>
<tr>
<td>Poz-14766</td>
<td>249.5-251.5</td>
<td>wood</td>
<td>830 ± 30</td>
<td>686-789</td>
<td>736</td>
</tr>
<tr>
<td>Poz-14768</td>
<td>566-569</td>
<td>twigs</td>
<td>980 ± 30</td>
<td>796-956</td>
<td>876</td>
</tr>
</tbody>
</table>

* Calibration of radiocarbon dates: Calib 5.01 (Stuiver & Reimer 1993)

### Table 5 $^{14}$C dates of Kosh Sas

<table>
<thead>
<tr>
<th>Lab. No.</th>
<th>Depth (cm)</th>
<th>Material</th>
<th>$^{14}$C dates y ears BP</th>
<th>cal. BP 95% confidence limits</th>
<th>Age in Diagram cal. yr BP (BP = 1950)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poz-16264</td>
<td>296.5-298.5</td>
<td>charcoal</td>
<td>3625 ± 35</td>
<td>3841-4077</td>
<td>3937</td>
</tr>
</tbody>
</table>

* Calibration of radiocarbon dates: Calib 5.01 (Stuiver & Reimer 1993)
Table 6: $^{14}$C dates of Bakaly

<table>
<thead>
<tr>
<th>Lab. No.</th>
<th>Depth (cm)</th>
<th>Material</th>
<th>$^{14}$C dates</th>
<th>cal. BP 95% confidence limits</th>
<th>Age in Diagram cal. yr BP (BP = 1950)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poz-16317</td>
<td>142.5-144.5</td>
<td>root fragment, periderm</td>
<td>1145 ± 30</td>
<td>973-1169</td>
<td>1047</td>
</tr>
<tr>
<td>Poz-16258</td>
<td>296.5-298.5</td>
<td>root periderm</td>
<td>3050 ± 40</td>
<td>3084-3367</td>
<td>3274</td>
</tr>
<tr>
<td>Poz-16259</td>
<td>622.5-628.5</td>
<td>bud, wood, seedcoat</td>
<td>5600 ± 40</td>
<td>6299-6461</td>
<td>6370</td>
</tr>
<tr>
<td>Poz-16260</td>
<td>1025.5-1030.5</td>
<td>periderm</td>
<td>5900 ± 40</td>
<td>6638-6842</td>
<td>6720</td>
</tr>
</tbody>
</table>

* Calibration of radiocarbon dates: Calib 5.01 (Stuiver & Reimer 1993)

Table 7: timing of the occurrence of a continuous curve respectively the expansion of *Juglans regia* at six different sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Start of sedimentary record (cal. BP)</th>
<th>continuous curve [cal. BP] (AD)</th>
<th>expansion [cal. BP] (AD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nishnaye Ozero</td>
<td>1560</td>
<td>[1100] (850)</td>
<td>[900] (1050)</td>
</tr>
<tr>
<td>Verkhneye Ozero</td>
<td>1600</td>
<td>[1050] (900)</td>
<td>[650] (1300)</td>
</tr>
<tr>
<td>Ak Terek</td>
<td>7500</td>
<td>[800] (1150)</td>
<td>[300] (1650)</td>
</tr>
<tr>
<td>Ortok</td>
<td>850</td>
<td>[700] (1250)</td>
<td>[300] (1650)</td>
</tr>
<tr>
<td>Kosh Sas</td>
<td>3700</td>
<td>[900] (1050)</td>
<td>[-] (-)</td>
</tr>
<tr>
<td>Bakaly</td>
<td>6800</td>
<td>[2000] (50 BC)</td>
<td>[-] (-)</td>
</tr>
</tbody>
</table>
Figure captions

Fig. 1: Map showing the location of the study sites: 1) Nishneye Ozero; 2) Verkhneye Ozero; 3) Ak Terek; 4) Ortok; 5) Kosh Sas; 6) Bakaly

Fig. 2: Depth-age model of Nishneye Ozero

Fig. 3: Depth-age model of Verkhneye Ozero

Fig. 4: Depth-age model of Ak Terek

Fig. 5: Depth-age model of Ortok

Fig. 6: Depth-age model of Kosh Sas

Fig. 7: Depth-age model of Bakaly

Fig. 8: Pollen percentage of selected pollen types and microscopic charcoal diagram of Nishneye Ozero. Empty curves show x10 exaggeration

Fig. 9: Pollen percentage of selected pollen types and microscopic charcoal diagram of Verkhneye Ozero

Fig. 10: Pollen percentage of selected pollen types and microscopic charcoal diagram of Ak Terek

Fig. 11: Pollen percentage of selected pollen types and microscopic charcoal diagram of Ortok

Fig. 12: Pollen percentage of selected pollen types and microscopic charcoal diagram of Kosh Sas

Fig. 13: Pollen percentage of selected pollen types and microscopic charcoal diagram of Bakaly
Fig. 1

Fig. 2 Nishneye
Fig. 3 Verkhneye

Fig. 4 Ak Terek
Fig. 5 Ortok

Fig. 6 Kosh Sas
Fig. 7 Bakaly
Nishneeye Ozero, Kyrgyzstan: 1371 m a.s.l.
Corine (2003): W. Tinner, W. Tanner
Analysis: R. Beer, IPS, Bern

Fig. 8
Verkhneye Ozero, Kyrgyzstan: 1440 m a.s.l.
Coring (2003): W. Tinner, W. Tanner
Analysis: R. Beer, IPS, Bern

Fig. 9
Fig. 10
Fig. 11
Fig. 12
Fig. 13
Palaeoecological investigations in the juniper forest region of southern Kyrgyzstan (Alay Range, Central Asia).

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Abstract

Analyses of pollen, microscopic charcoal, and chironomids in the sediment of the small sub-alpine lake Kichikol (Alay Range, Kyrgyzstan) provide new data to reconstruct the vegetational and lacustrine history during the past 6400 years. The pollen data suggest that *Juniperus* spp. (*Juniperus zeravshanchica* Kom., *J. semiglobosa* Rgl., and *J. turcestanica* Kom.) were the dominant trees in this region from the beginning of our record. From 5100-4000 cal. yr BP dense *Juniperus* forest was present around the lake. Around 4000 cal. yr BP the forest retreated and was probably restricted to north-facing slopes, as is the case today. Changes in the hydrology of Kichikol are inferred from sediment properties, pollen of aquatic plants, and remains of aquatic invertebrates. The lacustrine development of Kichikol suggests a step-wise increase in humidity during the mid and late Holocene, with major shifts recorded at 5000 and 4000 cal. yr BP. At the beginning of the record Kichikol was a very shallow possibly temporary pond. An initial rise in water-table is registered at ca. 5000 cal. yr BP, followed by a second rise to near present levels at ca. 4000 cal. yr BP. These hydrological shifts could be related to an increase of westerly moisture transport from the Mediterranean region as a consequence of a late-Holocene weakening of the Central Asian High and Indian monsoon systems. Moderate human impact in the region is recorded after 2100 cal. yr BP, as indicated by pollen of *Plantago lanceolata*-type and a slight increase of charcoal accumulation rates. Considering the general course of climate as well as human impact we conclude that the present forests composition is natural or quasi natural.

**Key words:** *Juniperus*, pollen, natural vegetation, chironomids, lake-level changes, Holocene, Kyrgyzstan, Central Asia
Introduction

Most of the forests of Kyrgyzstan occur on mountain slopes, and they are both varied and rich in commercially valuable tree species (Musuraliev, 1998). In the continental regions of Central Asia vertical gradients of temperature and precipitation limit the growth of forest to a narrow band. The upper limit of tree growth is controlled primarily by temperature, whereas the lower limit is restricted by precipitation (Miehe et al., 1996). Kyrgyzstan lies at a latitude of ~40° N, where insolation on the south-exposed slopes is very strong. Therefore, forests are mostly found on slopes of northern aspect (Walter, 1974) and in gullies (Cermak et al., 2005). Insolation plays also a crucial role in snow melting, which occurs differentially according to exposition. North-facing slopes retain more humidity in spring and early summer, i.e. early in the vegetation season (Esper, 2000). In the dry conditions of the Alay Range, southwest Kyrgyzstan, forests of Juniperus zeravschanica, J. semiglobosa, and J. turcestanica occur at an altitude of 1800-3200 m a.s.l. on north-facing slopes (Kosmynin, 1998; Musuraliev, 1998). Most of the forests consist of open patches, where the juniper trees are often 10 meters apart. They are usually less than 20 m tall, and many of them have several stems. The crown is composed of a bundle of small branches that may be dead or stripped of bark. On rocky slopes, the trees develop large root systems as anchors in the slumping bedrock (Esper, 2000). The juniper trees are reported to have been cleared from the valleys and gentle slopes and remain only on steep slopes (Kosmynin, 1998). Over the last 25 years, areas under Juniperus forest have decreased. The degradation of mountain vegetation is accompanied by the progressive drying of the slopes and desertification. Inspection of separate areas has shown that livestock pressure on pastures exceed the carrying capacity by 5-10 times and more (Kosmynin, 1998), and problems arise from over-exploitation of the region of Juniperus forests by grazing cattle.

Little is known about the Holocene vegetation and fire history of this poorly studied region of juniper forests and the effects of changing climate and human impact on the
environment. The main aim of this investigation is to fill this gap. We reconstruct the mid and late Holocene vegetation history, fire history, lacustrine development, and human activity on a millennial scale for a site in the Alay Range by means of pollen, microscopic charcoal, and chironomid analyses.

**Material and Methods**

**Study area**

Kichikol (2541 m a.s.l.; N 39°59’, E 73°33’) is a large lake of 10 ha located in the Alay Range in southwest Kyrgyzstan (Fig 1). It has neither a major inlet nor an outlet. The region is characterized by a highly continental climate without precipitation from the Arabian Sea and with marked seasonal variation (Esper *et al.*, 2002). A strong vertical gradient in temperature and precipitation exists in the region of the Alay Range, which is part of the Pamiro-Alay mountain system, with semiarid conditions in the valleys and a non-linear increase of precipitation with increasing altitude (Böhner, 1996; Esper, 2000). Gultcha (1542 m a.s.l.; N 40°19’, E 73°26’), the nearest climatic station, is a mid-elevation site. Mean January and July temperatures are -6.5 and 19.5°C and mean annual temperature is 7.7 °C. Mean annual precipitation is 520 mm. The nearest climatic station at a comparable altitude is located at Kyzyl-Djar (2230 m a.s.l.; N 40°19’, E 74°15’), where mean January and July temperature are -14.9 and 15.7 °C and mean annual temperature is 2.8 °C. Mean annual precipitation is 347 mm (Administration of the hydrometeorological agency, 1966; 1969). At present the forest around the lake consists of stands of *Juniperus semiglobosa*, which grow up to 3000 m a.s.l. and *J. turkestanica* that reaches up to 3500 m a.s.l. The forest is restricted to steep north-facing slopes. Patches of pastures and meadows are interspersed within the forest and cover the south-facing slopes. These pastures are heavily grazed by sheep and cattle during summer months.
Coring

One short sediment core (KI4) was taken with a Perspex-tube piston corer near the centre of the lake at 10.8 m water depth. Water depths of 20 meters and more were recorded at other points. For older sediment two parallel long cores (KI1 and KI2) were taken with a modified Streif-Livingstone piston corer (Merkt and Streif, 1970) at 10.2 m water depth. The cores were correlated by a number of distinct sediment layers in the lower part, but above 217 cm the marl had no distinct lithological markers, so no correlation could be achieved for this section. Therefore, only the core KI2 was sampled from 260 cm upwards. For interpretation of the records the long (66-294 cm) and the short cores (6.5-60.5 cm) were combined according to their depth.

Dating

AMS (Accelerated Mass Spectrometry) $^{14}$C ages were obtained at the University of Poznan for four samples of terrestrial plant macrofossils from the sediments (Table 1). The $^{14}$C dates were converted to calibrated ages (cal. years BP) with the program Calib version 5.0.1 (Stuiver and Reimer 1993). The age-depth models were based on linear interpolation of the median values of calibrated $^{14}$C dates (Fig. 2).

Pollen and microscopic charcoal analysis

Pollen preparation followed standard procedures (Moore et al. 1991). Lycopodium tablets (Stockmarr, 1971) were added to sub-samples of 1 cm$^3$ for estimating pollen concentrations (grains cm$^{-3}$) and accumulation rates (grains cm$^{-2}$ yr$^{-1}$). Pollen types were identified with pollen keys (Moore et al., 1991; Beug, 2004), pollen atlases (Reille, 1992; 1998), and the reference collection of the Institute of Plant Sciences, University of Bern. A minimum of 600 pollen grains, excluding aquatic pollen and spores, were counted at each depth except for levels where pollen concentrations were extremely low. Stomata were identified following
Identification of non-pollen objects in the pollen slides followed van Hoeve and Hendrikse (1998). The pollen diagram was subdivided into local pollen assemblage zones (LPAZ) by use of the zonation method of optimal partitioning (Birks and Gordon, 1985) as implemented in the program ZONE, version 1.2, written by Steve Juggins. To determine the number of statistically significant zones in diagrams, we used the program BSTICK (Bennett, 1996).

Microscopic charcoal particles, i.e. black, completely opaque, and angular fragments (Clark, 1988) longer than 10 μm (or area > 75μm²) were counted in pollen slides following Tinner and Hu (2003) and Finsinger and Tinner (2005). Charcoal particle concentration (particles cm⁻³) and influx (particles cm⁻² yr⁻¹) were estimated by the same approach as for pollen (Stockmarr 1971). Charcoal area influx (mm² cm⁻² year⁻¹) was estimated from a regression established for Lago di Origlio, southern Switzerland (Tinner and Hu, 2003).

**Chironomid analysis**

Samples used for chironomid analysis were separated with a 100μm mesh sieve, and the sieve residue was examined at 30-40x magnification under a dissecting microscope. Chironomids and other invertebrate remains were isolated from the samples and mounted on microscope slides with Euparal mounting medium. Chironomids were identified at 100-400x magnification with a compound microscope and identification keys by Wiederholm (1983), Schmid (1993), Heiri et al. (2004), and Brooks et al. (in press). Remains of Sciaridae larvae were identified with Heiri and Lotter (in press), and the remains of mites, *Chaoborus* mandibles, and Ceratopogonid head capsules were based on illustrations in Frey (1964), Solhøy (2001), and Walker (2001). The mandibles of Amphipoda were identified by comparing the fossil remains with mounted modern amphipod specimens collected near the Uithof, Utrecht, The Netherlands. Besides these invertebrate remains the oogonia of Characeae (Haas, 1994) were mounted and enumerated.
Results

Chronology and lithology

The chronology is based on radiocarbon dates of terrestrial plant material (Table 1). One date (2740 ± 35 yr. BP, 87 cm depth) appeared clearly too old and was therefore rejected. Linear interpolation among the remaining three dates and the core top were used to develop an age-depth relationship (Fig. 2). The sediment consisted of lake marl down to 217 cm (0-4000 yr cal. BP), of marl with peat from 217 to 267 cm (4000-5500 yr cal. BP) with a band of peat at 250-257 cm (5000-5200 cal. yr BP). The basal sediments oldest part (267-294 cm; 5500-6400 yr cal. BP) are silt (Fig. 3).

Pollen and charcoal

A total of 75 pollen samples were analysed. Pollen percentage, concentration, and influx values are comparable, and we therefore use the percentage (Fig. 3) and influx (Fig. 4) results for discussion. The charcoal stratigraphy is discussed with the four zones that have proven to be statistically significant and can be summarized as follows.

LPAZ KK1 (6300-5500 cal. yr BP):

The pollen of arboreal taxa reaches 20% and is dominated by Juniperus. Betula is represented by low pollen percentages only. Pollen of Chenopodiaceae and Poaceae each reaches 20%, whereas Artemisia attains 15%. High pollen abundances of Ephedra distachya, E. fragilis, and Cichorioideae are found as well. The pollen of Cyperaceae and the zygospores of Spirogyra show high values, followed by a decreasing trend. Charcoal shows stable influx values around 100 particles cm$^{-2}$ year$^{-1}$ (0.045 mm$^2$ cm$^{-2}$ year$^{-1}$).
LPAZ KK2 (5500-5100 cal. yr BP):

Pollen of *Juniperus* still reaches 20%. *Artemisia* increases to 30% in this zone, while the pollen of Chenopodiaceae decreases. The pollen of Poaceae attains values around 15%, and *Potamogeton natans*-type occurs with slightly higher abundances in this zone. *Spirogyra* shows a peak at the end of the zone. Charcoal influx values fluctuate around 100 particles cm$^{-2}$ year$^{-1}$.

LPAZ KK3 (5100-4000 cal. yr BP):

Arboreal pollen is dominated by *Juniperus*, which shows relatively stable high values of 40-45% and intermittently reaches 60%. The pollen of *Betula* attains slightly higher values in this zone, while *Hippophaë rhamnoides* and *Salix* show a small peak at the beginning of the zone. *Juniperus*, *Betula*, and *Hippophaë rhamnoides* all show comparatively high pollen percentages above 5100 cal. yr BP. A continuously increasing trend is registered for pollen of *Artemisia*, reaching 30% at around 4600 cal. yr BP. Chenopodiaceae pollen shows stable values around 8%, while the Poaceae stabilizes at 5%. *Potamogeton natan*-type, *Spirogyra* zygospores, and microfossil n.i. “Smilax” are all present in this zone and then disappear. Charcoal concentration and influx show a marked peak at the beginning of this zone and then decrease.

LPAZ KK4 (4000-90 cal. yr BP):

The pollen of arboreal taxa shows a marked decrease at 4000 cal. yr BP. *Juniperus* remains the dominant arboreal taxon but shows a marked decline from 45 to 25%. Pollen of *Betula* declines to very low values. Pollen of *Juglans regia* is found above 1930 cal. yr BP and *Morus alba*-type pollen from 1400 cal. yr BP. Pollen of *Artemisia* shows an increase and then keeps mean values of approx. 40%, pollen of Chenopodiaceae is present with an abundance of 10-15%, and Poaceae attains constant values around 10%, whereas Cerealia-type pollen
increases to 3% at the beginning of this zone. *Plantago lanceolata*-type is present from 2200 cal. yr BP onwards. Charcoal influx shows an increasing trend after 2500 cal yr BP and reaches values of 150-300 particles cm$^{-2}$ year$^{-1}$ (0.065-0.125 mm$^2$ cm$^{-2}$ year$^{-1}$).

**Chironomids**

A total of 21 samples were analyzed (Fig. 5). The abundance of fossil chironomids in large sections of the Kichikol record was too low for reliably calculating percentages. Therefore we confine our discussion to concentration changes of the chironomid and other invertebrate fossils.

At 283-293 cm sediment depth, in the lowest two samples of the profile, no chironomid remains were found, although comparatively large volumes of sediment were analysed. The only identifiable fragments isolated from these samples were the remains of mites and the head capsule of a sciarid larva. At 267 cm, a single chironomid head capsule belonging to the terrestrial to semi-terrestrial chironomid genus *Smittia* was found. However, in the same sample a mandible belonging to the crustacean order Amphipoda suggests at least temporary lacustrine environments at the coring site. In the next horizon fossils of a number of lacustrine chironomids, such as *Psectrocladius sordidellus*-type, *Heterotrissocladius marcidus*-type, and *Procladius* were found in low abundances. Furthermore, a few specimens of chironomids typical for terrestrial and semi-terrestrial habitats were isolated from this sample, together with a comparatively large number of sciarid head capsules and mites. Between 246 and 222 cm chironomid concentrations reached high values of ca. 60-180 chironomid head capsules per cm$^3$ of sediment. Chironomid taxa present in this section of the record include *Psectrocladius sordidellus*-type, *Zavrelimyia* type A, *Heterotrissocladius marcidus*-type, *Corynoneura edwardsi*-type, *Polypedilum nubeculosum*-type, *Chironomus anthracinus*-type, *Procladius* and *Tanytarsus lactescens*-type. Mite remains are found abundantly during this period. Between 246 and 236 cm ceratopogonid head capsules of the
Dashyelea-type are present, and between 232 and 210 cm the sediments contain significant concentrations of Characeae oogonia. Between 222 and 210 cm sediment depth the concentrations of chironomid head capsules decrease abruptly and the only chironomid taxa found consistently in the upper two meters of sediment are Chironomus anthracinus-type and Heterotrissocladius marcidus-type. The abundance of mite remains decreases at the same time as chironomid concentrations decrease. Between 222 and 180 cm phantom midge mandibles belonging to Chaoborus flavicans-type are found. In the upper 180 cm of the record remains of both of C. flavicans and Characeae are largely absent.

Discussion

Terrestrial vegetation changes and fire history

Juniperus is a prolific pollen producer but its pollen is poorly dispersed. In consequence, the occurrence of pollen is a reliable indication of local presence of the trees. Values > 5% occur consistently in areas where Juniperus is abundant in the regional vegetation (Huntley and Birks, 1983; Burga and Perret, 1998). Moreover, Juniperus stomata corroborate the finds of pollen and indicate local presence of the tree. The pollen record suggests open scrubland or woods dominated by Juniperus between 6300 and 5500 cal. yr BP. Regionally dry steppe vegetation with Chenopodiaceae and Ephedra spp. dominated the landscape. Poaceae indicate grasslands and possibly also the marsh vegetation belt along the sedimentary basin, whereas Cyperaceae were most likely forming wetland communities (Fig. 3). The pollen data suggests the persistence of open Juniperus woods and a shift from the dry steppe vegetation that was characteristic in the previous period to a moister steppe dominated by Artemisia during the period 5500-5100 cal. yr BP. For the subsequent period, 5100-4000 cal. yr BP, the pollen record suggests the presence of dense Juniperus forests, and the local occurrence of the
tree is unambiguously testified by regular finds of stomata (Fig. 3). The steppe and meadow vegetation was probably restricted to sites unsuitable for forest growth, such as the drier lowlands. The sediment properties and the pollen of water plants imply a low water level with stagnant shallow water. It is likely that due to the low water level Juniperus stands could grow closer to the coring point and thus deliver more pollen into the sediment than is the case during later parts of the record. In fact, this pollen zone (KK-3) coincides with the presence of peat deposits, suggesting a conversion from a temporary with influx of silt to permanent shallow pond or shore with marginal peat and then to stratified lake (marl) at the coring spot. According to the pollen data, a major change occurred when forests diminished and steppe vegetation expanded at the beginning of LPAZ KK-4 (4000-90 cal. yr BP). Given the altitude of Kichikol, far above the uppermost limit of thermophilous trees, the pollen of Juglans regia and Morus alba-type may have originated from extra-regional vegetation in the lowlands, probably from cultivated fruit-tree orchards.

Pollen types do not show a reaction to the peak of charcoal at the depth of 254 cm (5100 cal. yr BP), nor does the increasing trend of charcoal influx seem to influence the pollen types from 2300 cal. yr BP onwards. Spatial comparisons of charcoal records are often difficult because different methods (e.g. pollen slides, thin sections, sieving, combustion/digestion, or spectrographic analysis) have been used in previous studies (Tinner and Hu, 2003). Here we compare our results with data where similar techniques have been applied. Compared with influx area of charcoal found in Alaskan sediments (e.g. Lost Lake: maximum: 3.256 mm² cm⁻² year⁻¹; average: 0.804 mm² cm⁻² year⁻¹; Grizzly Lake: maximum: 27.053 mm² cm⁻² year⁻¹; average: 7.705 mm² cm⁻² year⁻¹; Tinner et al., 2006), the accumulation rates found at Kichikol (maximum: 0.125 mm² cm⁻² year⁻¹; average 0.053 mm² cm⁻² year⁻¹) are very low. Similar low accumulation rates with low fire frequencies are found in eastern Canada (e.g. Lac Yelle, Lac Spearman, and Lac J’Arrive: Carcailllet and Richard, 2000). In Europe (e.g. Soppensee and Lobsigensee, on the Swiss Plateau) such low
accumulation rates (not exceeding 1-3 mm$^2$ cm$^{-2}$ year$^{-1}$) are found only during the Palaeolithic and the Mesolithic periods, pointing to a low occurrence of natural or quasi-natural fires during these times (Tinner et al., 2005). We conclude that natural fires played a minor role in shaping the vegetation of southern Kyrgyzstan during the past 6400 years.

**Changes in limnic conditions**

Before ca. 5400 cal. yr BP lacustrine chironomid remains are absent from Kichikol (Fig. 5). Invertebrates isolated from this part of the sediment sequence include fossils of mites and sciarid larvae, both taxa that are common in terrestrial habitats (Solhøy 2001; Heiri and Lotter, in press). Chironomids colonize most freshwater habitats, and the total absence of the remains of chironomid larvae suggests that the coring site may not have been permanently inundated during this period. Zygospores of *Spirogyra* are abundant in the sediments during this episode (Fig. 3). This genus of filamentous green algae belonging to the Zygnemataceae is common in stagnant shallow water, where it occurs in high amounts (van Hoeve and Hendrikse, 1998). Van Geel (2001) indicates that zygospores are usually formed in very shallow water and are resistant to desiccation. The high abundance of *Spirogyra* zygospores is therefore consistent with the presence of a temporary pond at Kichikol before ca. 5400 cal. yr BP. The conspicuous presence of Poaceae and Cyperaceae in this part of the sequence may be a consequence of marsh vegetation around the lake. At ca. 5450 cal. yr BP the first chironomid head capsule of the genus *Smittia*, was isolated from the sediments. This genus consists mainly of terrestrial species that can be found in habitats such as damp soils or rotting vegetation. The first truly aquatic chironomids are registered at ca. 5160 cal. yr BP. Chironomids such as *Tanytarsus lactescens*-type, *Psicrocladius sordidellus*-type, *Procladius*, or *Heterotrissocladius marcidus*-type are all considered to be typical for lacustrine environments and are restricted to open standing or flowing water. However, in the same assemblage the abundance of terrestrial midge remains, e.g. *Smittia* and *Pseudosmittia*,

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is still comparatively high, and a number of fossils of the terrestrial sciarid larvae were found in this sample (Fig. 5). Between 5200-5000 cal. yr BP peaty sediments were deposited at Kichikol. However, the presence of truly aquatic chironomids and the presence of a mandible belonging to the Amphipoda (Crustacea) indicate that Kichikol was already a permanent water body at this stage of its existence. We therefore infer that the peat may have derived from subaquatic higher plants or mosses. From 5000-4000 cal. yr BP the sediment properties and the pollen of water plants such as *Potamogeton natans*-type, *Sparganium*-type, *Spirogyra* zygosporres, and microfossil n.i. “Smilax” suggests a low water-level with shallow and stagnant water, microfossil n.i. “Smilax” indicating eutrophic fresh water (van Hoeve and Hendrikse, 1998). Chironomid remains are common in this part of the sequence, and assemblages are dominated by taxa typical for shallow lacustrine systems and littoral regions in lakes, such as *Polypedilum nubeculosum*-type, *Psectrocladius sordidellus*-type *Corynoneura edwardsi*-type, and *Tanytarsus lactescens*-type (Heiri, 2001). In this part of the record the statoblasts of Bryozoa (Francis, 2001), amphipod mandibles, and the head capsules of ceratopogonids were found in the record, confirming that Kichikol was a shallow but permanent pond or lake at this time. At ca. 4400 cal. yr BP the abundance of *Chironomus anthracinus*-type, *Ch. plumosus*-type, and *Procladius* increases, taxa that are often found in but not restricted to deeper lakes. At the same time the abundance of ceratopogonid head capsules decreases. Ceratopogonidae are usually considered typical for shallow waters and semi-terrestrial habitats (e.g. Szadziewski et al., 1997; Ilyashuk et al., 2005), and hence their reduced abundance suggests a deepening of the lake. At the same time a marked increase in the abundance of Characeae oogonia is registered in the sediments. At ca. 4000 cal. yr BP there is a sharp lithologic change from lake marl with peat to marl, and many of the indicators of shallow stagnant water disappear. Chironomid concentrations decrease abruptly, and for the rest of the sequence *Chironomus anthracinus*-type remains the most dominant chironomid, together with *Heterotrissocladius marcidus*-type. Both taxa are known to
colonize the sublittoral and profundal of stratified lakes. The low overall abundance of chironomids and the dominance of *Ch. anthracinus*-type suggest that Kikichol was a reasonably deep stratified lake with at least seasonally anoxic conditions near the coring site. In the uppermost part of the sequence chironomid assemblages show no further marked changes suggesting that the lake reached the modern level ca. 4000 cal. yr BP.

**Changes in climate as inferred from vegetation and rising lake level**

In the present vegetation of the Alay Range Juniperus trees are only found on north-facing slopes. As seen in Fig. 3, an abundance of 25% of Juniperus pollen seems to reflect this situation. A major shift in the vegetation composition is found in the Kichikol record around 5100 cal. yr BP, when steppe elements, i.e. Chenopodiaceae, Poaceae, Artemisia, and Ephedra diminished and gave way to Juniperus. As Beer *et al.* (in review) have shown, 65-80% Juniperus pollen in surface samples of moss cushions can reflect dense juniper stands. In LPAZ KK-3 (Fig. 3) Juniperus is present at pollen percentages up to 60%, and Juniperus stomata are found. From this we infer that forest stands of *Juniperus semiglobosa* and *J. turkestanica* expanded around the lake most probably also on south-facing slopes, and perhaps stands grew closer to the coring point for the time period from 5100-4000 cal. yr BP. An abrupt decrease of Juniperus is recorded around 4000 cal. yr BP. The expansion and decrease of Juniperus trees was accompanied by lake-level fluctuations. From 6400-5000 cal. yr BP the sediment properties, the signal of the aquatic pollen (i.e. Spirogyra, microfossil n.i. “Smilax, Potamogeton natans*-type, and Sparganium*-type), and invertebrate remains indicate a shallow water table up to 10 m or more lower than today (Fig. 3, 5). A first rise in lake level is registered at ca. 5000 cal. yr BP, followed by a second rise to levels near the present at ca. 4000 cal. yr BP. The results for Kichikol suggest that before 5000 cal. yr BP climate may have been too dry for the local development of rather dense juniper forests, as indicated by
the low water-level. Coinciding with the second lake-level rise the pollen of *Juniperus* declined. This shift is not easily explained but it may simply reflect harsher environmental conditions as a result of the general mid and late Holocene climatic development. In fact palaeo-treeline studies suggest a marked cooling trend in the Northern Hemisphere after 5000 cal yr BP that persisted until today. This cooling trend was estimated to have been of amplitude of 2.5-7.0° C in Northern Asia (Kremenetski et al., 1998; MacDonald et al., 2000; Tinner, 2006). Such a distinct climatic deterioration could have affected juniper growth in the forests on the northern slope around our high-altitudinal site (2541 m a.s.l., ca. 400 m below the uppermost limit of present forests of *Juniperus semiglobosa*). Alternatively, lower pollen values of *Juniperus* may have resulted from rising lake-levels that induced a retreat of the trees upslope on drier soils. In this case the decreasing pollen abundances would reflect the larger size of the water body and the related increased distance of the juniper stands from the coring spot.

A major reorganization of climate and precipitation patterns over Central Asia during the mid- to late Holocene is reported from a range of sources. Rickets *et al.* (2001) report progressively dryer climate at Lake Issyk-Kul, a large inland lake in northern Kyrgyzstan, during the younger Holocene, with a distinct shift towards more arid conditions between 4000 and 5000 cal. yr BP. Similarly, a progressive trend to more aridity is indicated for many parts of West and Central China (An *et al.*, 2000) and for Pakistan (von Rad *et al.*, 1999). Furthermore, the so-called Lyavlyakanskiy pluvial epoch is reported for the Central Asian desert regions for the time between 8000 and 4000 ^14^C yr B.P., characterized by the formation of soils, considerable flooding, and the appearance of lakes (Khotinskiy, 1984; Lioubimtseva *et al.*, 2005). These changes in humidity are generally interpreted as being a consequence of a weaker Southeast Asian or Indian monsoon. In contrast to these reports the lacustrine development of Kichikol suggests a step-wise increase in humidity with major changes recorded at 5000 and 4000 cal. yr BP. With respect to monsoon winds the Alay Range is
located on the leeward side of the major Central Asian mountain ranges. At present the region receives a large part of its annual precipitation in winter via eastward propagation of mid-latitude cyclones from the Mediterranean region (Syed et al., 2006). Possibly the development of this westerly moisture transport during the late Holocene is associated with a weakening of the Southeast Asian and Indian monsoon system. A reinforcement of westerly air masses may have led to the increasing water levels at Kichikol. The timing of the second lake-level rise is conspicuous, as it agrees reasonably well with reported droughts in the Middle East at approx. 4200 cal. yr BP that supposedly led to the demise of the Akkadian and early Indian civilisations (Staubwasser et al., 2003; Cullen et al., 2000).

Esper et al. (2002; 2003) investigated the variation of the frequency of climatically forced extreme years and the magnitude on decadal to centennial timescale in the mountains of southern Tien Shan (Kyrgyzstan) and northwest Karakorum (Pakistan) since AD 618 on the basis of dendrological methods. The authors found above-average growth conditions until AD 1139 followed by reduced growth below the long-term average since AD 1140. Later, in the twentieth century growing conditions exceeding the long-term average but with lower amplitude compared to the conditions around AD 1000. These changes correspond to the Medieval Warm Period, the Little Ice Age, and the period of warming since about the middle of the nineteenth century, as reported in a number of northern hemisphere palaeoclimate records (e.g. Crowley, 2000; Hu, et al., 2001). None of this variation, however, is recorded in the pollen data or in the chironomid record of Kichikol.

Vegetation and human impact

In the 2nd millennium B.C. during the period immediately preceding the emergence of the Scythian and Saka tribes, the vast expanse of the Eurasian steppe zone was inhabited by Bronze Age peoples of diverse origins. These peoples had rather complex economies, being
engaged in hunting, river fishing, and gathering. Domestic animals were raised, and in some places agriculture was practiced using primitive irrigation systems (Bashilov and Yablonsky, 1995). In modern scientific literature, the term Saka designates the Iranian-speaking cattle breeding tribes who inhabited the steppe regions of Central Asia and Eastern Turkestan in the 1st millennium B.C. (Yablonsky, 1995a). Objects from a destroyed Saka kurgan dating to the 8th to 6th centuries B.C. were found on the shore of Lake Issyk-Kul, northern Kyrgyzstan. Many sites dating to the Saka period from the 5th and 3rd centuries B.C. have been discovered in the valleys surrounding the Fergana valley (Yablonsky, 1995b). We would therefore expect that early human impact could be visible in the pollen diagram from ca. 2800 cal. yr BP onwards. However, pollen and charcoal particles suggest that human impact was very low at the high altitudinal site of Kichikol. Cerealia-type pollen shows a continuous curve with values around 3% from 4000 cal. yr BP onwards. As has been discussed elsewhere (van Zeist et al., 1975; van Zeist and Bottema, 1977), in the Eurasian East wild grasses produce Cerealia-type pollen, and therefore it cannot be interpreted as an anthropogenic indicator in steppe vegetation regions. Plantago lanceolata-type is commonly referred to as the classic anthropogenic indicator in Central, Western, Eastern, and Northern Europe (i.e. indicator of pasture land), and from its presence the extent of pasturing can be estimated (Behre, 1981). Its adventive behaviour and the strong association with Neolithic agriculture in non-Mediterranean Europe suggest that the origin of Plantago lanceolata is located in the Near East or in the Mediterranean region. Liu et al. (1999) report that Plantago-type can hardly be regarded as an indicator of human interference in semi-arid and arid areas. Based on our new record Plantago lanceolata-type clearly seems to be an indicator of human activities in Kyrgyzstan, as its pollen is completely missing in the older parts of the sediment, and it appears only around 2100 cal. yr BP in the sediment of Kichikol, at a time when human settlements are indicated by archaeological finds and the cultivation of crop trees such as
*Juglans regia* and *Morus alba*-type in the lowlands of the region for which long-distance pollen is found.

The Kichikol paleo records suggest that climatic conditions during the past 4000 years were rather stable and that they permitted the growth of forests in the study area. In the present vegetation of Kichikol, *Juniperus* trees are found only on north-facing slopes. As shown by the top pollen samples of the lake core (Fig.3), 25% of *Juniperus* pollen seems to reflect this situation. Given the fact that such values are typical for the past 4000 years and that human impact was rather low at this marginal site, it is likely that the restriction of forests to northern slopes reflects natural conditions. On the basis of the paleobotanical record, the general course of climate as well as the history of human impact in the Kichikol area, we also conclude that the present forest composition around Kichikol can be considered as natural or quasi-natural.

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Table 1

Radiocarbon dates from Kichiköl, Kyrgyzstan

<table>
<thead>
<tr>
<th>Lab. No.</th>
<th>Depth (cm)</th>
<th>Material</th>
<th>$^{14}$C dates</th>
<th>cal. BP 95% confidence limits *</th>
<th>Age in Diagram cal. yr BP (BP = 1950)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poz-6533</td>
<td>84.5-87.5</td>
<td>twigs, wood, periderm</td>
<td>2740 ± 35†</td>
<td>2761 – 2923†</td>
<td>2829†</td>
</tr>
<tr>
<td>Poz-6494</td>
<td>153.5-155.5</td>
<td>twig</td>
<td>2140 ± 30</td>
<td>2004 – 2178</td>
<td>2128</td>
</tr>
<tr>
<td>Poz-6495</td>
<td>239.5-241.5</td>
<td>periderm, root</td>
<td>4230 ± 50</td>
<td>4584 – 4869</td>
<td>4747</td>
</tr>
<tr>
<td>Poz-6483</td>
<td>267.5-269.5</td>
<td>twig, periderm</td>
<td>4740 ± 40</td>
<td>5326 – 5586</td>
<td>5493</td>
</tr>
</tbody>
</table>

* Calibration of radiocarbon dates: Calib 5.01 (Stuiver & Reimer 1993)

† Rejected date
Figure captions

**Fig. 1:** Map showing the location of the study site

**Fig. 2:** Depth-age model of Kichikol

**Fig. 3:** Pollen percentage and microscopic charcoal diagram from Kichikol. Empty curves show 10x exaggerations.

**Fig. 4:** Pollen influx diagram from Kichikol. Empty curves show 10x exaggeration

**Fig. 5:** Chironomid and other invertebrate and algal remains in the sediments of Kichikol. Except where indicated otherwise abundances are given as counts per cm$^3$ of sediment.
Kichikol, Kyrgyzstan: 2554 m a.s.l.
Analysis: R. Beer, IPS, Bern

Fig. 3
Fig. 4
Fig. 5
4000 years of vegetation and fire history in the spruce forests of northern Kyrgyzstan (Kungey Alatau, Central Asia).

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Abstract

Analyses of pollen, macrofossils, and microscopic charcoal in the sediment of a small sub-alpine lake (Karakol, Kyrgyzstan) provide new data to reconstruct the vegetation history of the Kungey Alatau spruce forest during the late-Holocene, i.e. the past 4000 years. The pollen data suggest that *Picea schrenkiana* F. et M. was the dominant tree in this region from the beginning of the record. The pollen record of strong die-backs of the forests, along with lithographical evidence, point to possible climatic deterioration around 3800 cal. yr BP and between 3350 and 2520 cal. yr BP, although stable climatic conditions, for this region for the past 3000 to 4000 years are reported in previous studies. From 2500 to 190 cal BP high pollen values of *Picea schrenkiana* suggest rather closed and dense forests under the environmental conditions of that time. A strong decline of spruce forests occurred with the onset of modern human activities in the region from 190 cal. yr BP. These results show that the present forests are anthropogenically reduced and represent only half of the potential natural extent. As *Picea schrenkiana* is an endemic species of the western Tien Shan, it is most likely that its refugium was bound to this region. However, our palaeoecological record is too young to address this hypothesis thoroughly.

Key words: *Picea schrenkiana*, pollen, natural vegetation, Kyrgyzstan, Central Asia
Introduction

Kyrgyzstan is one of the countries in Central Asia with little forest cover; only 4.2% of the land surface (Musuraliev 1998). In wide areas of the Kyrgyzstan lowlands and mountains steppes, subalpine, and alpine meadows dominate the landscapes (Gottschling 2005). Non-linear vertical gradients of temperature and precipitation (Böhner 1996; Esper 2000) confine forest growth to a narrow band or patches on mountain slopes (Miehe et al. 1996). The upper limit of tree growth is primarily controlled by temperature, and the lower limit by precipitation (Miehe et al. 1996). The natural range of *Picea schrenkiana*, an endemic species of the area, is confined to the mountains north of the Naryn (Kyrgyzstan) and extends out to the ranges of the Chinese Tien Shan as far as Bogda Shan (Xinjiang) (Farjon 1990). In the region of Lake Issyk-Kul the spruce forests occur between 2000 to 2900 m a.s.l. on north-facing slopes (Gottschling 2006). The trees grow 40-50 m tall and have a straight columnar habit. They grow on various mountain soils, usually in rocky places with seepage water from snowmelt (Farjon 1990). During the Second World War great areas of the forests were cleared for fuel supply. After termination of the war the remaining forests have been protected and could recover to a certain degree. Although, logging of trees was forbidden, the forests were heavily grazed, so natural regeneration was constrained. It has been hypothesized that the present forest cover is only half of its natural potential (Gan 1982). However, in the absence of paleobotanical investigations such statements are elusive. Even though the extent of spruce forests is rather low, they have an important capacity for water retention and they inhibit erosion and landslides (Gottschling 2006).

Because of the concern for the forests in Kyrgyzstan, the Kyrgyz-Swiss Forestry Support Programme (KIRFOR), a project of Intercooperation (Switzerland) was started in 1995 with the aim to develop modern forestry management tools, to promote productive activities in forest management by private sectors, and to support adequate education and research in forest management. Started in 2003, a common research project by KIRFOR and
the paleoecological group of the Institute of Plant Sciences (IPS) of the University of Bern was set up to reconstruct the Holocene vegetation and fire history of the different forest types in Kyrgyzstan, for almost nothing is known about them at present. In the context of this project special attention is paid to human impact and the natural potential of these forests. Through the record presented in this study we reconstruct the late-Holocene vegetation history, fire history, and human activity on a millennial scale for a site in the spruce forests of the Kungey Alatau by means of pollen, macrofossils, lithostratigraphy, and microscopic charcoal.

**Material and Methods**

**Study area**

Karakol (N 42°50’, E 77°23’) is a subalpine lake located at 2353 m a.s.l. on the north-facing slope of the Kungey Alatau in the Biosphere Reserve Issyk-Kul. It has a surface of 5 ha and has an outlet at its eastern border. *Picea schrenkiana* forms dense forests on north-, east-, and west-facing slopes in this area. Pastures and meadows extend around the lake. Atmospheric circulation over the Issyk-Kul region is controlled by the Siberian High Pressure Cell and the Southwest Indian Low. During winter months the southwest branch of the Siberian High extends south into the Tien Shan, bringing cold dry air from Mongolia into the region. During summer months, frontal cyclonic circulation develops when cold air masses from the north occlude cyclones from the southwest, generating precipitation. This circulation pattern brings maximum, albeit minor, precipitation to the Issyk-Kul region during the summer months and driest conditions during the winter months (Dando 1987; Aizen et al. 1995; Ricketts et al. 2001). The nearest climatic station at a comparable altitude for our site of investigation is located at Naryn (N 41°43’, E 76°00’, 2039 m a.s.l.), where mean January and
July temperature is -15.8 and 17.3 °C, mean annual temperature is 3.65 °C and mean annual precipitation 285.5 mm (World Climate 2006).

Coring

One short core (KA4) was taken with a Plexiglass-tube piston corer near the centre of the lake (N 42°50’20”, E 77°23’33”) at 3.18 m water depth. For deeper sediment two parallel long cores (KA1 and KA2) were taken with a modified Streif-Livingstone piston corer (Merkt and Streif 1970). The cores were correlated by distinct sediment layers. KA1 was used as the main core, as it had fewer gravel.

Dating

AMS (Accelerated Mass Spectrometry) $^{14}$C ages were obtained from six terrestrial plant macrofossils from the sediments (Table 1) at the University of Poznan. The $^{14}$C dates were converted to calibrated ages (yr cal. BP) with the program Calib version 5.0.1 (Stuiver and Reimer 1993). The depth-age model was based on linear interpolation of the median values of calibrated $^{14}$C dates (Fig.2).

Pollen and microscopic-charcoal analysis

Pollen preparation followed standard procedures (Moore et al. 1991). Lycopodium tablets (Stockmarr 1971) were added to sub-samples of 1 cm$^3$ for estimating pollen concentrations (grains cm$^{-3}$) and accumulation rates (grains cm$^{-2}$ yr$^{-1}$). Pollen types were identified with pollen keys (Moore et al. 1991; Beug 2004), pollen atlases (Reille 1992; 1998), and the reference collection of the Institute of Plant Sciences of the University of Bern. A minimum of 600 pollen grains, excluding aquatic pollen and spores, were counted at each level except at levels where pollen concentrations were extremely low. The identification of non-pollen objects in the pollen slides followed van Hoeve and Hendrikse (1998) and for spores of
ascomycetes van Geel and Aptroot (2006). The pollen diagram was subdivided into local pollen assemblage zones (LPAZ) by the zonation method of optimal partitioning (Birks and Gordon 1985) as implemented in the program ZONE, version 1.2, written by Steve Juggins. To determine the number of statistically significant zones in diagrams, we used the program BSTICK (Bennett 1996).

Microscopic charcoal particles, i.e. black, completely opaque, and angular fragments (Clark 1988) longer than 10 μm (or area > 75μm²), were counted in pollen slides following Tinner and Hu (2003) and Finsinger and Tinner (2005). Charcoal number concentration (particles cm⁻³) and influx (particles cm⁻² yr⁻¹) were estimated by using the same approach as for pollen (Stockmarr 1971). Charcoal area influx was estimated from the regression proposed for Lago di Origlio (Southern Switzerland) by Tinner and Hu (2003).

Results and interpretation

Chronology and lithology

The chronology is based on six radiocarbon dates of terrestrial plant material (Table 1). All dates were accepted for the depth-age model (Fig. 2). The sediments of Karakol show rather strong changes between gyttja, silt, sand, and gravel (Table 2). However, only fine material (gyttja and silt) was sub-sampled for pollen and charcoal analyses.

Pollen and charcoal

A total of 73 pollen samples were analysed. Pollen percentage, concentration, and influx values are comparable, and we therefore use the percentage (Fig. 3) and influx (Fig. 4) results for further discussion. The charcoal stratigraphy is discussed together with pollen within the eight zones that have proven to be statistically significant.
KA-1: 276-274 cm; 3870-3850 cal. yr BP: closed sub-alpine forests of *Picea schrenkiana*

High percentage values (up to 40%) of arboreal pollen dominated by *Picea schrenkiana* characterize this oldest zone. Many *Picea* stomata and several *Picea* needles were found in the sediment at the base of the core. Pollen of *Betula*-type, *Alnus incana*-type, and *Fraxinus* are present in only very low percentages. The pollen of herbaceous taxa accounts for 60-70% of the pollen sum and is mainly represented by steppe elements (e.g. *Artemisia*, Chenopodiaceae, and Poaceae). A minor peak of Cichorioideae reaches 5%.

Pollen data suggest the presence of rather closed forests of *Picea schrenkiana* around the lake during this period. *Picea* was admixed with some trees of *Betula*, *Alnus*, and *Fraxinus*. Steppes and meadow vegetation were probably restricted to the drier lowlands.

KA-2: 274-214 cm; 3850-3640 cal. yr BP: Opening of *Picea schrenkiana* forest, expansion of meadow and steppe vegetation

At the onset of this zone pollen and stomata of *Picea* decline. After a minimum at a depth of 260 cm (ca. 3800 cal. yr BP) the values increase to 20%. A marked rise of pollen of *Salix* begins at 274 cm (ca. 3850 cal. yr BP). Pollen of *Salix* subsequently increases and reaches a maximum of 12% at 260 cm (ca. 3800 cal. yr BP), when different pollen types of Rosaceae show minor peaks as well. After this maximum *Salix* pollen shows a declining trend throughout the rest of the KA-2. The increase of *Salix* pollen is accompanied by a rise of *Artemisia* (30%) and Poaceae (25%). Pollen of Chenopodiaceae remains stable at 10%, and Cyperaceae shows one, very marked peak at 260 cm. Pollen of *Ranunculus aquatilis* has distinct peaks at 224 and 216 cm. *Botrychium*-type spores show an increasing trend from 268 cm onwards and reach comparatively high values at 224 cm (3700 cal. yr BP). Rather high charcoal concentrations and accumulation rates occur throughout this pollen zone. Influx values occur around 3000 and 2000 particles cm\(^{-2}\) yr\(^{-1}\) (1.08-0.74 mm\(^{-2}\) cm yr\(^{-1}\)). The
sediments of the core are characterized by the conspicuous presence of sand and gravel between 250 and 232 cm.

According to the pollen record the spruce forests first opened around 3800 cal. yr BP, possibly induced by climatic or environmental changes. Natural forest fires likely played an important role in the ecology of the forests. The expansion of *Salix* and enhanced presence of different types of Rosaceae as well as the pollen of Cyperaceae possibly reflect a larger belt of pioneer and shore vegetation around the lake as a response to the opening of the forests. Increased erosional input (sand and gravel layer) may have directly resulted from forest openings. *Ranunculus aquatilis* was probably growing in shallow and possibly eutrophic water with low calcareous content.

KA-3: 214-209 cm; 3640-3615 cal. yr BP: **grassland and open Picea schrenkiana forests**

This zone shows a marked peak of pollen of Poaceae, at 60% and a peak of Cichorioideae, at 10%. Spores of *Podospora* and other Sordariales are present. A peak of charcoal at 211 cm (ca. 2630 cal. yr BP) reaching an accumulation rate of 2000 part. cm$^{-2}$ yr$^{-1}$ (0.74 mm$^2$ cm$^{-2}$ yr$^{-1}$) coincides with a decline of all arboreal and shrub taxa and is accompanied by a minimum of *Artemisia* and Chenopodiaceae.

The pollen record suggests a forest opening possibly caused by fire, for charcoal reaches a rather high influx of 2000 part. cm$^{-2}$ yr$^{-1}$ (0.74 mm$^2$ cm$^{-2}$ yr$^{-1}$). It is possible that parts of the steppe vegetation burnt as well, allowing grasslands to become dominant during this time period of 25 years.

KA-4: 209-152 cm; 3615-3350 cal. yr BP: **meadows and steppe vegetation and woods of Picea schrenkiana**

The arboreal pollen shows a positive trend due mainly to the increase of *Picea* pollen, which reaches 25% at the top of the zone. Poaceae pollen decreases, while Chenopodiaceae and
Cichorioideae show rather constant values of about 12 and 8%. *Artemisia* pollen reaches minimum values throughout the zone (15%). *Podospora* and other spores of the Sordariales show high values throughout this zone and a peak at 180 cm (3450 cal. yr BP). A last peak of charcoal (1500 part. cm$^{-2}$ yr$^{-1}$, 0.56 mm$^2$ cm$^{-2}$ yr$^{-1}$), which has no corresponding pollen change, occurs at 184 cm (3500 cal. yr BP).

Our pollen data suggest that forest expanded during the 250 years of this zone. Meadow plants included Cichorioideae and Poaceae. The increase of fire frequency around 3500 yr cal. BP could originate from patches of vegetation burning beyond the pollen catchments, so that vegetational responses were not recorded in our pollen data.

KA-5: 152-124 cm; 3350-2800 cal. yr BP: *Picea schrenkiana* forests and steppe vegetation

The pollen of *Picea* shows a series of sharp stepwise declines at 152, 140, and 128 cm (3350, 3150, and 2900 cal. yr BP). After 146 cm (3200 cal. yr BP) no *Picea* stomata are found till the end of KA1-7. The series of declines of *Picea* pollen corresponds to peaks of *Artemisia* and Chenopodiaceae reaching 25 and 15%. *Salix* pollen is represented with low but constant values, and *Botrychium*-type spores show high values from 150 cm onwards. All pollen curves show quickly changing values, whereas accumulation rates of pollen show a steep stepwise decrease during this zone. Charcoal influx is rather low and shows a declining trend in this zone (1000 part. cm$^{-2}$ yr$^{-1}$, 0.39 mm$^2$ cm$^{-2}$ yr$^{-1}$).

The series of *Picea* pollen declines probably reflect marked diebacks of *Picea* forests. Steppe vegetation and meadows possibly expanded on open patches where *Picea* collapsed. The lack of plants indicative of human impact (e.g. *Plantago lanceolata*-type) points to climatic or environmental changes as primary driving factors. Interestingly, fires (as inferred from charcoal influx) seemed to play a less significant role, although more fuel (dead biomass from the dieback of the forests) was present locally.
KA-6: 124-110 cm, 2800-2500 cal. yr BP: *Picea schrenkiana and steppe vegetation*

Marked declines of *Picea* are recorded at 122 and 112 cm (2800 and 2520 cal. yr BP). Small but distinctive peaks of *Juniperus*-type pollen occur at the same levels, and a peak of Cichoroideae is recorded at about 2800 cal. BP (120 cm). Accumulation rates of all pollen types reach minimal values towards the younger zone border of KA-6. Charcoal influx shows lowest values during this zone (100 part. cm$^{-2}$ yr$^{-1}$, 0.04 mm$^2$ cm$^{-2}$ yr$^{-1}$).

The series of declines of *Picea* continues and reaches its apex at the end of KA6; probably reflecting further marked diebacks of *Picea* stands which peaked at 2800-2600 cal. yr BP. Forest fires seemed to have played a minor role during this time period.

KA-7: 110-51 cm, 2500-190 cal. yr BP: **closed forests of Picea schrenkiana**

This long-lasting zone is characterized by high percentages of pollen of *Picea*, though only one single *Picea* stomate was found at 62 cm. Pollen of *Picea* decreases briefly at 76 cm (1300 cal. yr BP) and 68 cm (1100 cal. yr BP). However, pollen of *Artemisia* and Chenopodiaceae shows rather constant values of 20 and 10%, and Poaceae pollen decreases from 20 to 10%. A first small peak of pollen of *Plantago lanceolata*-type is found at 78 cm, only briefly before *Picea* pollen decrease for the first time in this zone. From 70 cm onwards spores of the Sordariales occur again together with higher frequencies of *Botrychium*-type spores. Very low accumulation rates of charcoal (100 part. cm$^{-2}$ yr$^{-1}$, 0.04 mm$^2$ cm$^{-2}$ yr$^{-1}$) are found in this zone. Between 114 and 80 cm, the accumulation rates of all pollen types reach maximal values with a strong decline around 80 cm.

The pollen record suggests an expansion of *Picea*, which was able to form rather dense forests around the lake between 2500 and 190 cal. yr BP. We assume that this period is representative for rather natural vegetation under the environmental conditions of that time. The occurrence of *Plantago lanceolata*-type coincided with the appearance of dung spores as well as an expansion of *Botrychium*. It is likely that at least some of the transient changes
around 1000 cal. yr BP were induced by moderate human impact in the region. Interestingly, fires seemed to have played a minor role throughout the 2310 years covered by this zone.

KA-8: 51-0.5 cm 190 cal. yr BP to present: meadow and steppe vegetation and woods of *Picea schrenkiana*

Pollen of *Picea schrenkiana* declines sharply from 35 to 10% at the beginning of this zone. Other arboreal pollen such as *Betula*-type and *Morus alba*-type occurs with slightly higher values than before. From 36 cm (ca. 100 cal. yr BP) onwards, single pollen grains of *Juglans regia* are recorded. Pollen of *Juniperus*-type shows an increasing trend and reaches 12% at 20 cm. A sharp increase in pollen of *Artemisia* coincides with a decrease of *Picea*. Conspicuous values of *Plantago lanceolata*-type and *Urtica* occur at 51-42 cm (200-100 cal. yr BP). Spores of dung fungi are found throughout the zone. A remarkable peak of pollen of *Rumex obtusifolius*-type occurs at 26 cm (60 cal. yr BP). High concentration and influx values of charcoal are found in this zone (e.g. up to 4000 part. cm$^{-2}$ yr$^{-1}$, 1.41 mm$^2$ cm$^{-2}$ yr$^{-1}$).

Pollen of the wetland plants Cyperaceae and *Ranunculus aquatilis* decreases markedly at the beginning of the zone, while the pollen of other water plants (e.g. *Myriophyllum*-type, *Potamogeton natans*-type) increases.

During this period a strong shift in the vegetation composition occurred. As the collapse of *Picea* forests coincided with the appearance of human indicators (e.g. *Plantago lanceolata*-type, *Urtica, Rumex obtusifolius*-type), it is likely that human impact contributed to the disruption of spruce forests ca. 200 years ago. Our data (i.e. sedimentary change, pollen of Cyperaceae, and pollen of aquatic plants) point to a rise in lake-level during the past 200 years.
**Discussion**

The pollen and charcoal record reaches back to 4000 cal. yr BP and documents important vegetation and fire-history changes during the late Holocene. *Picea schrenkiana* was the dominant tree species in the forests over the entire period as implied by pollen, stomata, and macrofossils (needles) found at the base of the record. As suggested by the relatively high percentages of spruce pollen (Beer et al. accepted), the trees most likely formed rather closed stands around the lake at the beginning of our record. An interesting question arises where the endemic tree survived the last glaciation. Unfortunately it can not be addressed thoroughly by our pollen record, as it is too young. However, our record unambiguously documents the natural presence of the tree since the beginning of the sediment record. The glaciers on the mountain ranges surrounding Lake Issyk-Kul extended nearly to the present lake shore during the last glaciation (Grosswald et al. 1994). Given the fact, that the present range of *Picea schrenkiana* is confined to the western part of the Tien Shan (Farjon 1990), it is most likely that the refugia were bound to our region, and that the tree survived locally in ice-free and sheltered spots in the lowlands of the Tien Shan mountain system.

**Climate and vegetation dynamics**

Climatic changes implied by changes in trace elements and stable-isotope composition of ostracodes from Lake Issyk-Kul have recently been reconstructed by Rickletts et al. (2001). A major transition from relatively humid to more arid conditions occurred between 6900 and 4900 cal. BP. For the remainder of the record relatively stable conditions analogous to the modern situation are inferred. Similarly, a progressive trend to more aridity is indicated for many parts of West and Central China (An et al. 2000) and for Pakistan (von Rad et al. 1999) from ca. 4000 cal. yr BP onwards. Relatively high temperatures are reported from 6000 to 4500 cal. yr BP for Central Asia (Christian 1998). A sharp decrease in temperatures to rather
low values occurred between 4500 and 4050 cal. yr BP, reverting to higher values again between 4050 and 3100 cal. yr BP. Stable temperatures comparable to modern values are reported from 3100 cal. yr BP to present.

Our new high-mountain record documents changing frequencies of pollen of *Picea schrenkiana* and conspicuous sediment changes (i.e. layers of silt, sand, and gravel, suggesting high erosional input into the lake) throughout the past 4000 years. The series of *Picea* declines around 3800 cal. yr BP and between 3300 and 2500 cal. yr BP, with an apex at 2800-2600 cal. BP, may point to climatic or environmental shifts (e.g. change in precipitation or cooling). As the decline of *Picea* is accompanied by increases of *Artemisia*, cooling rather than aridity is implied (El-Moslimany, 1990). This interpretation is supported by the strong increase of Cichorioideae at 2800-2600 cal. yr BP, which was probably due to the expansion of local alpine meadows. Global cooling around 2800 cal. BP (850 BC) has been suggested by many authors (e.g. Denton and Karlen 1973; van Geel et al. 1996, 1999; Bond et al. 1997; 2001). The cooling event was probably induced by a decrease of solar activity as reflected in the $^{14}$C-residual curve (Stuiver and Braziunas 1971). Another similar episode is reported around 2400 cal. BP (450 BC; Bond et al. 1997, 2001). At Lake Bakaly, a site located in the mixed forests of the Sary Chelek region in the Chatkal Range (Kyrgyzstan), a conspicuous expansion of *Juniperus* started at 2800 cal BP and was followed by the expansion of *Abies* (with pollen lacking prior to 2500 cal. BP (Beer et al. submitted). In the Sary Chelek region, *Abies* may have benefited from increased moisture availability as a result of lower temperatures. Our new evidence of climatic change at around 2800-2600 cal. yr BP is in contrast with the reported stable climatic conditions reconstructed for Central Asia during the late Holocene. However, the question remains elusive till further investigations are carried out in this region, especially at high-altitudinal sites, which are particularly sensitive to climatic changes (e.g. Tinner and Theurillat, 2003).
Vegetation history and human impact

Prehistoric traces of Neolithic human activities ascribed to the Hissar cultures, whose remains have been found along the mountain rim from the Amu Darya to Lake Issyq-Kul (ca. 30 km down slope from our site) are dated from the 7th to the 5th millennia BC (Christian 1998). Most sites appear to have been seasonal camps of hunters following hoofed animals. Until the second half of the fourth millennium, southern Central Asia remained firmly within the village world of the early Neolithic. Objects from a destroyed Saka kurgan on the shore of Lake Issyq-Kul date back to the 8th to 6th centuries B.C., and many sites dating to the Saka period from the 5th and 3rd centuries B.C. have been discovered in the valleys surrounding the Fergana valley (Yablonsky 1995). We would therefore expect that early human impact could be visible in the pollen diagram at least from 2800 cal. yr BP. The sharp stepwise declines of *Picea schrenkiana* between 3300 and 2500 cal. yr BP point to forest openings (Fig. 3). Yet, as a clear indicator of human impact, i.e. *Plantago lanceolata*-type (Beer et al. submitted) is missing in our pollen record, we prefer to relate the die-back of the forest to climatic deteriorations that occurred during this time period. The earliest finds of pollen of *Plantago lanceolata*-type are recorded around 1600 cal. yr BP. We therefore assume that tribes of steppe nomads lived in the lowlands of Lake Issyq-Kul, but that their impact on the high-altitudinal spruce forests was marginal. It is conceivable that the steppe-forest ecosystem of the western Tien Shan was adapted to grazing by wild (e.g. wild sheep, ibex) and domesticated animals and that an interrelation between the animals and the plant cover formed a dynamic equilibrium (Gottschling 2006). The regular finds of the spores of ascomycetes growing on dung (i.e. *Podospora*, Sordariales; van Geel and Aptroot 2006) throughout the sedimentary stratigraphy likely point to a constant degree of grazing in the region, but it is difficult to assess whether this was natural or pastoral grazing.

A sharp decline of *Picea schrenkiana* is recorded in the uppermost zone (KA-8: 190 cal. yr BP to present, Fig. 3). Several historical events are reported for this time period that
could have caused the strong die-back of the forests recorded in the pollen record. By the 1820s the influence of the Kokand khanate (Uzbek tribe) began to extend into the Tien Shan. To enforce its power and protect the caravan routes from China to the Caucasus and Russia, Kokand people built a string of fortresses, one of which was Pishpek, located in the modern Bishkek (Stewart 2002). The disruption of *Picea* forests may thus be related to logging of trees for construction or intensification of agriculture as related to a certain economic wealth. In 1860s the Russians launched an attack on the Bishkek fortress. It took seven days and several tons of gunpowder to destroy the structure. Extraordinarily the Russians then returned to their military base at Verniy (Almaty), and the Kokand khanate rebuilt the fort (Stewart 2002). The Kokand khanate came to an end in the year 1877. From this time on the Russians were involved in the history of today’s Kyrgyzstan (Stewart 2002), and their influence may have led to an intensification of agriculture and partly industrialisation. In fact forests did not recover from the openings that had occurred at around 1800 AD.

Later on, it is reported that during the Second World War great areas of the spruce forests were logged for fuel supply (Gottschling 2006). After termination of the war the remaining forests have been protected and could recover to a certain degree. Although, logging of trees was forbidden, open patches of the forests were heavily grazed and therefore natural regeneration was constrained. Maximal numbers of grazing animals were achieved in the late 1980es, when the number of sheep alone increased fivefold (from 360,000 in 1989 to 1.9 million in 1991) in the Issyk-Kul region. Degradation of pastures and lacking forest regeneration became an issue of concern (Gottschling 2006). It is supposed that the potential natural forest area would double under natural conditions (Gan 1982). Our palaeoecological data support this assumption, as it shows a sharp decrease of *Picea* pollen values as well as an increase of pollen indicative of human impact (e.g. *Plantago lanceolata*-type, *Urtica dioica*-type) 190 years ago with the onset of historically reported increase in strong human impact in this region. The conspicuous increase of charcoal concentration and accumulation rates at the
same time imply that forest fires became more important and were possibly induced anthropogenically.

Taken together our results suggest that *Picea* forests in this area are natural and have a millennial history. It is likely that under undisturbed conditions they would expand and invade meadows that were created for agricultural purposes only ca. 200 years ago.

**Acknowledgments**

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the Early Iron Age. Zinat Press, Berkeley, pp 201 – 239
Table 1: Radiocarbon dates from Karakol, Kyrgyzstan

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<th>Lab. No.</th>
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<th>Material</th>
<th>(^{14}\text{C dates} )</th>
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<th>Age in Diagram cal. yr BP (BP = 1950)</th>
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<td>Poz-6477</td>
<td>51-53</td>
<td>4 bud fragments</td>
<td>130 ± 30</td>
<td>-3 – 275</td>
<td>128</td>
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<tr>
<td>Poz-6478</td>
<td>79.5-87.5</td>
<td>charcoal (needle)</td>
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<td>1817 – 1947</td>
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<td>wood</td>
<td>3110 ± 35</td>
<td>3224 – 3436</td>
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<td>Poz-6479</td>
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<td><em>Picea</em> cone scale</td>
<td>3445 ± 35</td>
<td>3619 – 3831</td>
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* Calibration of radiocarbon dates: Calib 5.01 (Stuiver & Reimer 1993)

Table 2: Lithographical layers of the sediment of Karakol

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<td>150 – 154 cm</td>
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<td>251 – 270 cm</td>
<td>sand</td>
</tr>
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<td>270 – 276 cm</td>
<td>gyttja</td>
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</table>
Figure captions

Fig. 1: Map showing the location of the study site

Fig. 2: Depth-age model of Karakol

Fig. 3: Pollen percentage and microscopic charcoal diagram from Karakol. Empty curves show 10x exaggerations.

Fig. 4: Pollen influx diagram from Karakol. Empty curves show 10x exaggeration
Fig. 1:

![Map of Kyrgyzstan and Kazakhstan](image1)

Fig. 2:

![Graph showing depth and age](image2)
Karakol, Kyrgyzstan: 2353 m a.s.l.

Coring: W. Tinner, W. Tanner
Analysis: R. Beer, IPS, Bern

Fig. 3
Fig. 4
Summary

Climate variability, human impact, invasions, and wildfires may drive important ecosystem changes. Most records used to assess environmental changes are based on short-term ecological data or satellite imagery spanning only a few decades. Paleoecological records can be used to provide a longer temporal perspective, which may help to address specific conservation and management issues such as long-term aspects of forest stability and diversity, land use, biological invasions, or wildfire disturbance. Especially the use of paleoenvironmental records can reduce much of the uncertainty surrounding the question of what is “natural” and thereby start to provide important guidance for long-term management and conservation.

In this PhD study the vegetation and fire history of the different forest types (i.e. *Juglans* forests in the southwest of Kyrgyzstan, *Juniperus* forests in the south, and *Picea schrenkiana* forests in the northeast) was reconstructed with the aim to know more about the history and natural state of the forests, their natural potential extent, and their resilience or vulnerability to changing climate and human impact.

In a first step surface pollen deposition at five sites (Kichikol, Karakol, Nishneye, Verkhneye Ozero, and Bakaly) in four different forest types (*Juniperus*, *Picea*, *Juglans*, and mixed forests) in Kyrgyzstan have been investigated to assess the relationship between modern vegetation and pollen composition. Our results indicate that *Juniperus* spp. is under-represented in the pollen deposition, *Picea schrenkiana* pollen reflects the vegetation cover accurately in the moss polsters but is under-represented in the lake surface samples of Lake Karakol, *Juglans regia* produces average pollen but is under-represented in the pollen rain, whereas *Acer* and tree species of Rosaceae (e.g. *Prunus*-type and *Sorbus*-type) are strongly under-represented in the pollen spectra. Although arboreal pollen (AP) and non-arboreal pollen (NAP) percentages give only an approximation of the percentage of forest or open land, we can state that one implication of the results presented in this paper is that, in contrast to other investigated areas in the temperate forest zones in Europe and North America, forests are under-represented in the Kyrgyz sites in respect to pollen representation. Considering the biogeographical setting of our study area, our results imply that isolated forests in steppic environments, which are predominant over wide areas in Eurasia and North America, are not easy to trace by pollen records alone.

In a second step sedimentary archives of six lakes and two peat bogs were analysed: Analysis of pollen and charcoal of the sediment of four lakes and two peat bogs in the region of the walnut fruit forests provide new data to infer the vegetation and fire history of these forests during the last 7000 years. Our results suggest that before the onset of intensive land-use forests or woods in the modern *Juglans* belt were co-dominated by *Juniperus*, *Betula*, *Fraxinus*, Rosaceae trees, and probably *Acer*. A special focus was put on the vegetation history of *Juglans regia*, as it has been suggested that the walnut fruit forests of Kyrgyzstan might be natural and represent the original distribution of this tree. Our results suggest that the Kyrgyz forests of *Juglans regia* are at the most 2000 years old, and most of them even only about 1000 years old. The strong connection of the expansion of *Juglans regia* with pollen indicative of human activities (e.g. *Plantago lanceolata*) strongly points to the anthropogenic origin of these forests, which is in agreement with old orally transmitted legends in Kyrgyzstan. As with other old and widespread cultivated plants it is not easy to reconstruct the original distribution and determine the borders of the past natural ranges. A review of paleoecological data points to refugia in southern Europe, Syria, and the Himalaya, where *Juglans* possibly outlived the last glaciation.

Analyses of pollen, microscopic charcoal, and chironomids in the sediment of the small sub-alpine lake Kichikol (Alay Range, Kyrgyzstan) in a region of *Juniperus* forests
provide new data to reconstruct the vegetational and lacustrine history during the past 6400 years. The pollen data suggest that *Juniperus* spp. (*Juniperus zeravschanica* Kom., *J. semiglobosa* Rgl., and *J. turcestanica* Kom.) were the dominant trees in this region from the beginning of our record. From 5100-4000 cal. yr BP dense *Juniperus* forest was present around the lake. Around 4000 cal. yr BP the forest retreated and was probably restricted to north-facing slopes, as is the case today. Changes in the hydrology of Kichikol are inferred from sediment properties, pollen of aquatic plants, and remains of aquatic invertebrates. The lacustrine development of Kichikol suggests a step-wise increase in humidity during the mid and late Holocene, with major shifts recorded at 5000 and 4000 cal. yr BP. At the beginning of the record Kichikol was a very shallow possibly temporary pond. An initial rise in water-table is registered at ca. 5000 cal. yr BP, followed by a second rise to near-present levels at ca. 4000 cal. yr BP. These hydrological shifts could be related to an increase of westerly moisture transport from the Mediterranean region as a consequence of a late-Holocene weakening of the Central Asian High and Indian monsoon systems. Moderate human impact in the region is recorded after 2100 cal. yr BP, as indicated by pollen of *Plantago lanceolata*-type and a slight increase of charcoal accumulation rates. Considering the general course of climate as well as human impact we conclude that the present forests composition is natural or quasi natural.

Analyses of pollen, macrofossils, and microscopic charcoal in the sediment of a small sub-alpine lake (Karakol, Kyrgyzstan) provide new data to reconstruct the vegetation history of the Kungey Alatau spruce forest during the late Holocene, i.e. the past 4000 years. The pollen data suggest that *Picea schrenkiana* was the dominant tree in this region from the beginning of our record. Strong die-backs of the forests, as indicated by the pollen record and lithographical evidence, possibly point to climatic deterioration around 3800 cal. yr BP and between 3350 and 2520 cal. yr BP. Forest die-back peaked at 2800-2600 cal. yr BP, when climate changed at a global scale, shifting to cooler conditions in Eurasia and North America. From 2500 to 190 cal BP high pollen values of *Picea schrenkiana* suggest rather closed and dense forests under the environmental conditions of that time. A strong decline of spruce forests is recorded with the onset of modern human activities in the region from 190 cal. yr BP. These results show that the present forests are anthropogenically reduced and represent only half of the potential natural extent.
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2000 Volkshochschule Bern
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