Clim. Past, 5, 285–295, 2009
www.clim-past.net/5/285/2009/

Climate of the Past

Late Glacial and Holocene changes in vegetation cover and climate in southern Siberia derived from a 15 kyr long pollen record from Lake Kotokel

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Received: 21 October 2008 – Published in Clim. Past Discuss.: 14 January 2009
Revised: 5 June 2009 – Accepted: 20 June 2009 – Published: 1 July 2009

Abstract. In this study a radiocarbon-dated pollen record from Lake Kotokel (52°47′ N, 108°07′ E, 458 m a.s.l.) located in southern Siberia east of Lake Baikal was used to derive quantitative characteristics of regional vegetation and climate from about 15 kyr BP (1 kyr=1000 cal. yr) until today. Quantitative reconstruction of the late glacial vegetation and climate dynamics suggests that open steppe and tundra communities predominated in the study area prior to ca. 13.5 kyr BP and again during the Younger Dryas interval, between 12.8 and 11.6 kyr BP. The pollen-based climate reconstruction suggests lower-than-present mean January (∼−38°C) and July (∼12°C) temperatures and annual precipitation (∼270–300 mm) values during these time intervals. Boreal woodland replaced the primarily open landscape around Kotokel three times at about 14.8–14.7 kyr BP, during the Allerød Interstadial between 13.3–12.8 kyr BP and with the onset of the Holocene interglacial between 11.5 and 10.5 kyr BP, presumably in response to a noticeable increase in precipitation, and in July and January temperatures. The maximal spread of the boreal forest (taiga) communities in the region is associated with a warmer and wetter-than-present climate (T_w∼17–18°C, T_c∼−19°C, P_{ann}∼500–550 mm) that occurred ca. 10.8–7.3 kyr BP. During this time interval woody vegetation covered more than 50% of the area within a 21×21 km window around the lake. The pollen-based best modern analogue reconstruction suggests a decrease in woody cover percentages and in all climatic variables about 7–6.5 kyr BP. Our results demonstrate a gradual decrease in precipitation and mean January temperature towards their present-day values in the region around Lake Kotokel since that time.

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1 Introduction

The Lake Baikal region of northern Eurasia (Fig. 1) has experienced a boom of palaeoenvironmental studies during the past decade (e.g. Colman et al., 1996; BDP-Members, 1997, 1998, 2005; Grachev et al., 1997; Williams et al., 1997, 2001; Demske et al., 2005; Oberhänsli and Mackay, 2005; Tarasov et al., 2007a and references therein). A rising interest in Lake Baikal – the world's largest, deepest and oldest freshwater reservoir – is easy to understand. The lake bottom sediments contain detailed and well-preserved palaeoenvironmental archives, which provide an excellent opportunity for reconstructing the regional climate and environments (e.g. Bezrukova 1999; Bezrukova et al., 2005; Horiuchi et al., 2000; Khursevich et al., 2001; Prokopenko and Williams, 2004; Tarasov et al., 2005).

Objective reconstruction of the past climate is one of the priority tasks for scientists working in the field of past global changes and Earth's system modelling (PAGES: http://www.pages.unibe.ch/). Since the 1940s (e.g. Iversen, 1944) late Quaternary pollen records from the lake sediments have become a frequently used proxy providing palaeoclimatic information at local and large regional scales (e.g. Grichuk, 1969; Bartlein et al., 1984; Guiot et al., 1989; Nakagawa et

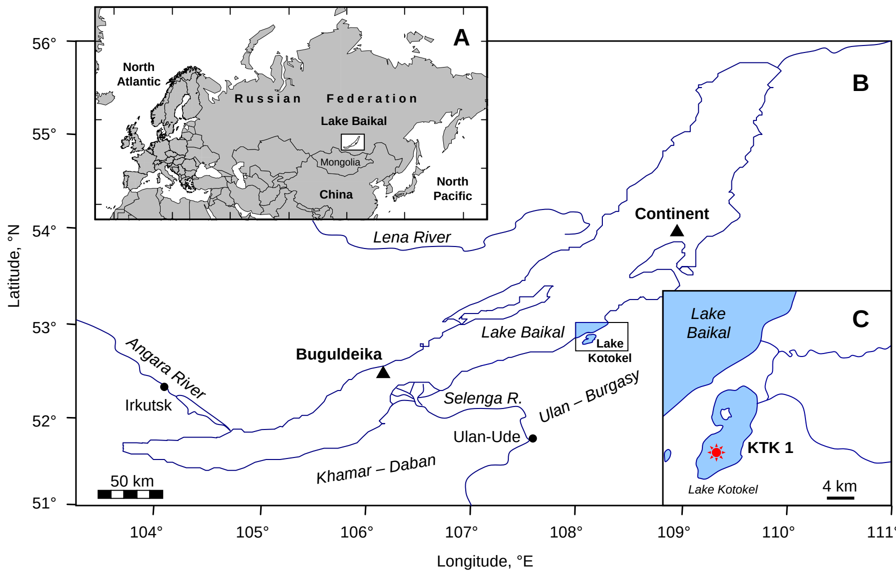

Fig. 1. Simplified maps of northern Eurasia **(A)**, the Lake Baikal region **(B)** and the Lake Kotokel (52°47′ N, 108°07′ E, 458 m a.s.l.) study area **(C)**, showing locations of the analysed core KTK1 (a star) and other sites with published quantitative palaeoclimatic records from the region (triangles).

al., 2002; Frenzel et al., 1992; Seppä and Birks, 2001, 2002; Tarasov et al., 2007a and references therein).

Despite a relatively high number of late glacial and Holocene pollen records generated for the Lake Baikal region, there have been very few attempts at their quantitative palaeoclimatic interpretation. The earlier pollen-based climate reconstructions were either solely qualitative (e.g. Khotinskii 1984; Bezrukova, 1999; Prentice and Jolly, 2000; Demske et al., 2005) or concerned with the "Holocene optimum" time slice (e.g. Frenzel et al., 1992; Tarasov et al., 1999). For the first time Holocene changes in annual precipitation (P_{ann}), mean temperature of the warmest (T_w) and coldest (T_c) month and moisture index (α) were reconstructed from continuous and adequately dated pollen records recovered from the underwater Buguldeika site (Fig. 1) in the southern part of Lake Baikal (Tarasov et al., 2007a). The latter results from Lake Baikal likely represent vegetation and climate dynamics in the relatively large region. However, pollen records from different parts of the lake and from surrounding coastal plains demonstrate spatial variations in the vegetation dynamics within the Lake Baikal region (e.g. Tarasov et al., 2002; Demske et al., 2005; Bezrukova et al., 2005), highlighting the need for more reconstructions from the region.

In this study we present the quantitative reconstruction of the temperature and precipitation variables derived from the Lake Kotokel pollen record collected in 2004 (Bezrukova et al., 2008). The lake is situated at the eastern shore of Lake Baikal (Fig. 1) and is representative for the middle part of the Lake Baikal region. The reconstructed climate from about 15 kyr BP (1 kyr=1000 cal. yr) to present is compared with the quantitative characteristics of vegetation around Kotokel, including dominant biome scores and woody cover percentages derived from the same pollen record. The regional environmental dynamics is then discussed together with the oxygen isotope records of the postglacial climate from the North Atlantic and North Pacific regions.

2 Regional setting

Kotokel (458 m a.s.l.) is a fresh-water lake occupying the western part of the intermountain depression located at the eastern coast of Lake Baikal (Fig. 1). A low-elevated mountain ridge (up to 729 m a.s.l.) separates the depression from Lake Baikal, and the Ulan-Burgasy Ridge (up to 2033 m a.s.l.) bounds it from the east (Galaziy, 1993). The lake has an area of about 67 km^2, a maximum length of about 15 km and maximum width of about 5 km. Its average water depth is 5–6 m and its maximum depth is about 15 m (see Tarasov et al., 1994 for more details and references).

The area has a continental climate with long cold winters and relatively short cool summers and large seasonal variations in temperature and precipitation (e.g. Alpat'ev et al., 1976; Galaziy, 1993). Around Kotokel the mean January temperature is about −20°C and decreases to below −26°C with increasing elevation. The mean July temperature is about 16°C, and annual precipitation sums vary from 400 mm in the coastal zone to above 500 mm in the upper elevation belt (Galaziy, 1993). Modern precipitation distribution has a well-pronounced summer maximum. July and

August are particularly wet. During these months westerly winds dominating through the year become weak, and south-eastern cyclones bring warm and wet Pacific air to the region and cause heavy rainfalls at the eastern branch of the Polar front (Bezrukova et al., 2008). The precipitation associated with the Atlantic air masses brought by the westerly winds is not abundant and mainly falls during autumn and spring. Dry, cold and sunny weather typically occurs in winter, when the whole region is controlled by the stationary Siberian Anticyclone.

Modern vegetation at the eastern coast of Lake Baikal and around Kotokel is mainly composed of boreal coniferous and deciduous forests. Swampy vegetation is common in the Selenga River delta and south of Kotokel Lake. Forests are composed of *Pinus sylvestris* (Scots pine), *Larix sibirica* (Siberian larch) and *Betula* (birch) species, with some admixture of *Populus tremula* (aspen) and shrubby alder *Alnus fruticosa* (Galaziy, 1993). Taiga forests composed of mainly boreal evergreen conifers (e.g. *Pinus sibirica* – Siberian pine, *Abies sibirica* – Siberian fir and *Picea obovata* – Siberian spruce) appear several kilometres eastward at the slopes of the Ulan-Burgasy Ridge. In the upper mountain belt open birch and larch forests coexist with *Pinus pumila* (shrubby pine) and alpine tundra vegetation (Molozhnikov, 1986; Galaziy, 1993).

3 Material and methods

3.1 Coring, core lithology and age determination

In the early 1960s the Lake Kotokel Holocene sediments were first studied for pollen and non-pollen microfossils (Korde, 1968; Vipper and Smirnov, 1979; Tarasov et al., 1994). In 1997 a near-shore Cheremushka peat bog was drilled (Takahara et al., 2000). The KTK1 sediment core (52°47′ N, 108°07′ E) was recovered in July 2004 (Bezrukova et al., 2008; Shichi et al., 2009). The coring was performed from a water depth of about 3.5 m in the southern part of the lake (Fig. 1C) using a Livingston piston core. A detailed pollen analysis was performed on the upper 900 cm of the KTK1 core, composed of the soft brownish black gyttja (0–810 cm) and slightly laminated gray clay (Bezrukova et al., 2008; Shichi et al., 2009).

Three radiocarbon dates (6070±60, 10 680±40 and 11 670±60 ^{14}C yr BP) were obtained from the brownish black gyttja unit (from 412–413 cm, 652–653 cm and 806–807 cm depth, respectively, Fig. 2) using the AMS facility at Nagoya University in Japan suggesting that the analysed 900 cm of sediments accumulated since about 15 kyr BP (see Bezrukova et al., 2008; Shichi et al., 2009). Radiocarbon years were converted to calendar years using the CalPal program available online (Danzeglocke et al., 2008). The resulting age-depth model represents a linear regression, suggesting a rather constant sedimentation rate of 0.59 mm/yr along the profile, in line with the undisturbed character of the sediment. This model was applied to the KTK1 pollen record and used to date reconstructed changes in vegetation and climate discussed in the text.

3.2 Pollen analysis

The KTK1 core material stored at the Institute of Geochemistry (Irkutsk) was sampled there for pollen analysis. In total 128 samples were taken as 1 cm slices, yielding an average temporal resolution of 118 years throughout the late glacial and Holocene period. Standard laboratory methods were used to extract pollen from the sediment samples, including HCl and KOH treatments, heavy-liquid separation and subsequent acetolysis (Berglund and Ralska-Jasiewiczowa, 1986). Pollen and spores mounted in glycerin were counted under the light microscope with ×400–1000 magnification. Identification of the pollen and spores was performed using regional pollen atlases and the reference collection (Bezrukova et al., 2008).

Samples were generally rich in pollen, and counting of 300 to 500 pollen grains per sample was easy to achieve (Fig. 2). However, the pollen content was lower (176–240 grains per sample) in the bottommost 3 samples. The quantitative climate reconstruction results from these samples need to be taken with caution.

The percentage diagram presented in Fig. 2 shows results of the pollen analysis from the KTK1 core. The diagram was constructed using the Tilia/Tilia-Graph/TGView software (Grimm, 1993, 2004). Percentages for individual terrestrial pollen taxa at each level were calculated from the total sum of AP and terrestrial NAP taken as 100%. Spore percentages for cryptogam plants were calculated in relation to the total sum of counted pollen and spores. To facilitate discussion of the pollen record, the pollen diagram was subdivided into local pollen zones (PZ) based on square-root-transformation of the percentage data and stratigraphically constrained cluster analysis by the method of incremental sum of squares (Grimm, 1987).

3.3 Pollen-based vegetation and climate reconstruction

The quantitative method of biome reconstruction (Prentice et al., 1996) adapted for reconstruction of vegetation in northern Eurasia (Tarasov et al., 1998) allows the objective assignment of pollen taxa to plant functional types (PFTs) and to biomes on the basis of the modern ecology, bioclimatic tolerance and geographical distribution of pollen producing plants. The method was successfully tested using an extensive surface pollen data set from northern Eurasia and used to reconstruct Last Glacial Maximum (LGM) and mid-Holocene vegetation at the hemispheric (e.g. Prentice and Jolly, 2000) and large regional (e.g. Tarasov et al., 2000) scales. In the Lake Baikal region the method was applied to the Eemian pollen record from Continent (Tarasov et al.,

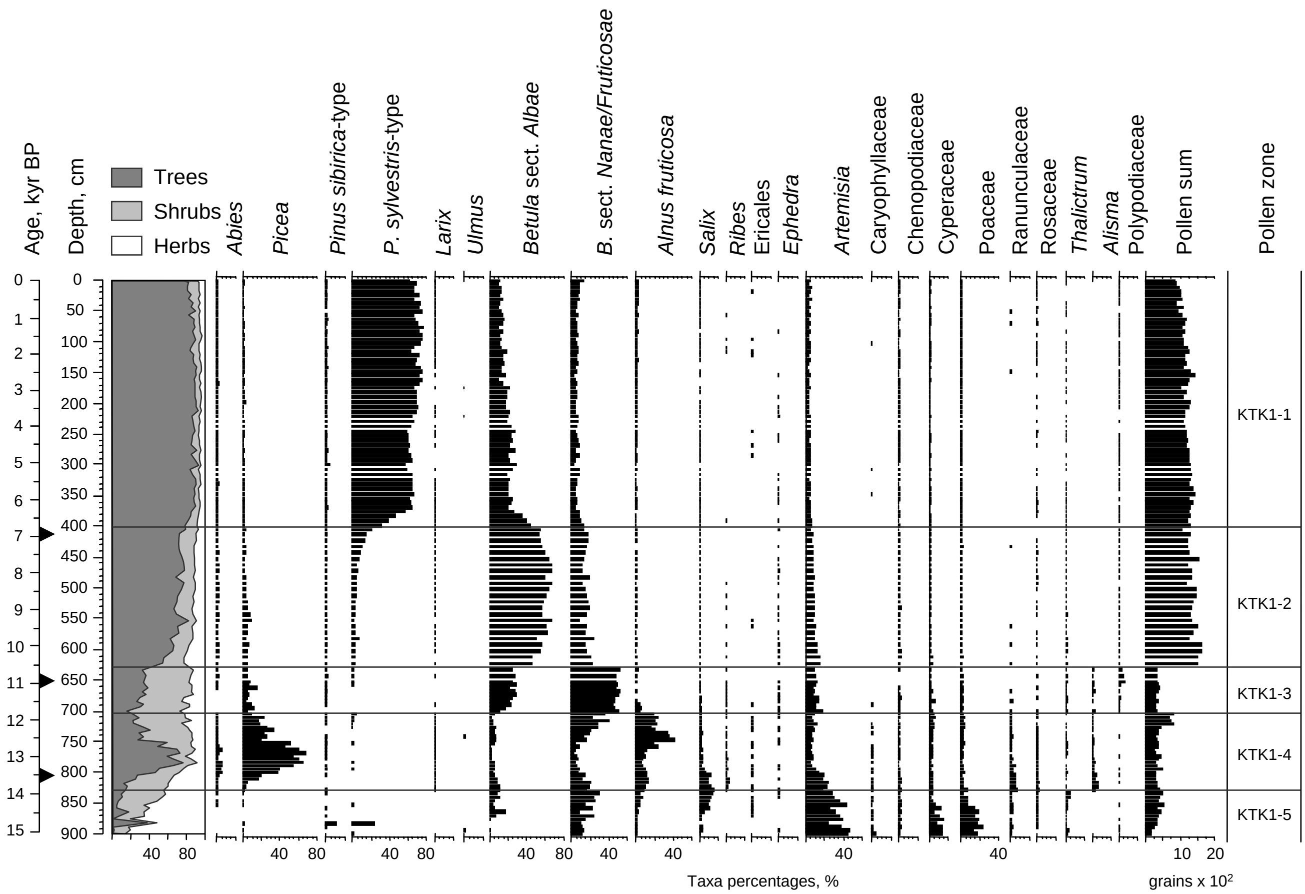

Fig. 2. Simplified pollen percentage diagram of the KTK1 core from Lake Kotokel. Pollen analyst E. Bezrukova. The arrows mark radiocarbon-dated gyttja levels: 6070±60 (Beta-207356, 412–413 cm), 10 720±40 (Beta-209 638, 652–653 cm) and 11 670±60 (Beta-207357, 806–807 cm) ^{14}C yr BP.

2005) and to the Holocene record from Buguldeika (Tarasov et al., 2007a). The modern analogue method and geographical distribution of the modern analogues with *Alnus fruticosa* pollen in Siberia were discussed in details by Tarasov et al. (2005). In the present study all identified terrestrial pollen taxa from the KTK1 record were assigned to the regional PFTs and biomes using the biome-PFT-taxon matrix published in the latter studies (see Tarasov et al., 2005, 2007a for further details).

The "biomisation" provides no quantitative information about vegetation composition or structure and can mask temporal variations in the internal structure and composition of biomes (Williams et al., 2004). To obtain this important information from the fossil pollen record we used a new approach for woody cover reconstruction (Tarasov et al., 2007b). The method combines extensive modern surface pollen and satellite-based Advanced Very High Resolution Radiometer (AVHRR) datasets from northern Eurasia (DeFries et al., 1999; Tarasov et al., 2007b) with the best modern analogue (BMA) approach (Overpeck et al., 1985; Guiot, 1990), allowing fossil pollen samples to be attributed to the vegetation characteristics associated with their closest modern pollen analogues. In this study the AVHRR-based estimates of woody cover percentages within a 21×21 km window around pollen sampling sites were attributed to the KTK1 pollen spectra (see Tarasov et al., 2007b for the method evaluation and design).

The BMA approach is frequently employed to infer past climates from fossil pollen assemblages (e.g. Guiot, 1990; Nakagawa et al., 2002). Recently it was used for the Lake Baikal region to reconstruct climate dynamics during the last and the recent interglacial (Tarasov et al., 2005, 2007a). In the present study we used the reference data set of 1173 modern pollen spectra from the large area of the former Soviet Union and Mongolia with all main bioclimatic regions well represented (see Tarasov et al., 2005 for details) to reconstruct changes in annual precipitation (P_{ann}) and mean temperatures in July (T_w) and January (T_c), respectively, warmest and coldest months. All selected climatic variables are important to explain the spatial distribution of the main vegetation types in northern Eurasia and are commonly derived from fossil records and simulated with climate models

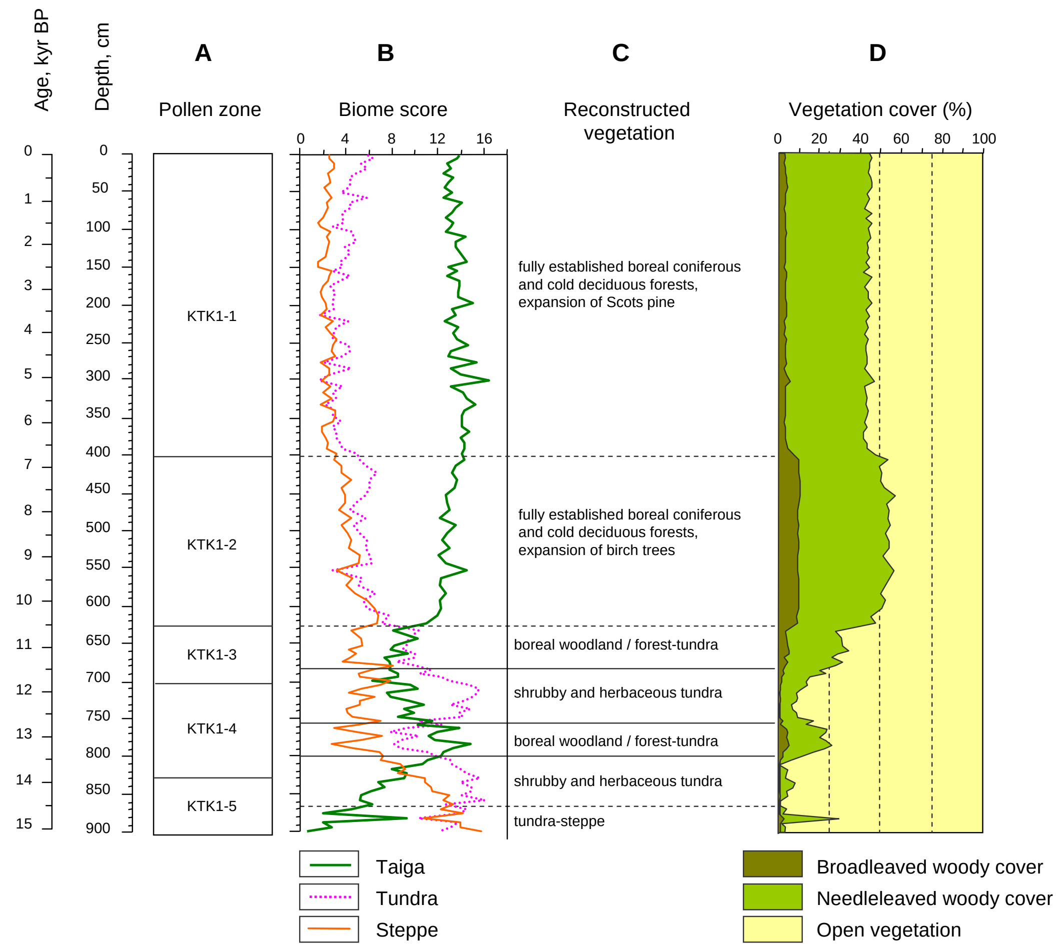

Fig. 3. Local pollen assemblages zones **(A)** and time series of individual vegetation types (biomes) dominating in the study area since 15 kyr BP **(B)**, along with the qualitative characteristics of vegetation **(C)**, and quantitative changes in woody cover percentages **(D)** derived from the KTK1 pollen record, plotted along the time axis.

(e.g. Kageyama et al., 2001; Battarbee et al., 2004). All terrestrial pollen taxa identified in the KTK1 record also appear in the list of 81 taxa presented in the reference pollen/climate data set. Modern climate values at each of the 1173 modern pollen sampling sites have been calculated from the high-resolution global climatology database that provides the 30-year average (1961–1990) of the monthly means of principal meteorological parameters on a 10 min grid (New et al., 2002).

4 Results

4.1 KTK1 pollen record and vegetation dynamics

Complete results of the pollen analysis and reconstructed vegetation and climate characteristics are available in the PANGAEA data information system (www.pangaea.de). The simplified pollen percentage diagram is shown in Fig. 2. The results of the pollen analysis used in this study, including conventional description of the pollen zones and their qualitative palaeoenvironmental interpretation, were presented by Bezrukova et al. (2008). To avoid repetitions with the latter publication, we concentrate in this chapter on the quantitative interpretation of the KTK pollen data in terms of the late glacial and Holocene vegetation (Fig. 3) and climate dynamics (Fig. 4).

The pollen assemblages prior to 14.5 kyr BP (lower part of PZ KTK1-5) are characterised by highest percentages of herbaceous pollen taxa (e.g. *Artemisia*, Poaceae and Cyperaceae) and low percentages of tree pollen taxa (Fig. 2), pointing to an open character of vegetation around the lake. Pollen of shrubby birches and willows is relatively abundant. Tundra and steppe biomes have the highest scores (Fig. 3B), suggesting that mainly these two vegetation types occupied the region about 15–14.5 kyr BP (Fig. 3C). The BMA reconstruction demonstrates very low woody cover percentages

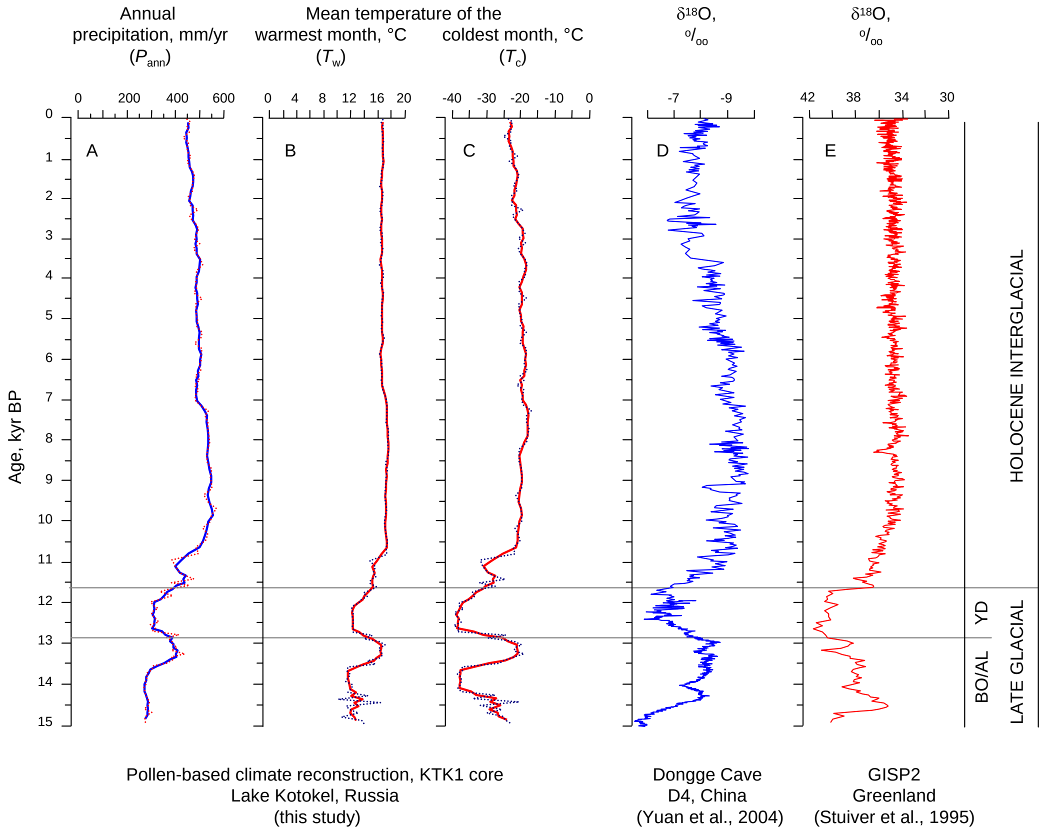

Fig. 4. Summary chart showing a comparison of three climatic variables **(A–C)**: annual precipitation (P_{ann}) and mean temperatures of the warmest (T_w) and coldest month (T_c) derived from the KTK1 pollen record (dashed lines indicate most probable values and smoothed lines are three-point moving averages shown for each reconstructed variable), along with oxygen isotope records from the stalagmite D4, Dongge Cave, China, as indicator of the Pacific (summer) monsoon intensity **(D)**, and from the GISP2 ice core, as indicator of the North Atlantic temperature change **(E)**, plotted along the time axis.

(Fig. 3D). However, woody cover rises to ca. 25% at one level dated to ca. 14.7–14.8 kyr BP, which is characterised by the relatively high amount of pine pollen.

Herbaceous pollen percentages decline and shrubby taxa (e.g. birch, alder, willow and heath) predominate in the pollen assemblages between 14.5 and 13.4 kyr BP (upper part of PZ KTK1-5 and lower part of PZ KTK1-4). The biome reconstruction demonstrates that the tundra scores became higher than those of the steppe and taiga, suggesting reduction of the cold steppe communities and spread of the shrub tundra communities in the region. Low amounts of arboreal pollen (Fig. 2) and low woody cover percentages (less than 10%) suggest that the landscape was open and scarce boreal trees could grow only in the locally favourable environments.

A sharp increase in spruce pollen percentages up to 54–68% is the characteristic feature of the pollen assemblages dated to ca. 13.3–12.8 kyr BP (middle part of PZ KTK1-4). The biome reconstruction shows that numerical scores of taiga biome become slightly higher than those of tundra (Fig. 3B), suggesting that the vegetation around Kotokel turned to boreal woodland or forest-steppe (Fig. 3C). Consistently, vegetation cover reconstruction demonstrates an increase in the total woody cover up to about 25% at that time (Fig. 3D).

Pollen of shrub alder and birch shrubs (both taxa are representative for the tundra and forest-tundra communities in northern Eurasia, e.g. Prentice et al., 1996; Tarasov et al., 1998, 2005) once more become a dominant component of the pollen assemblages between ca. 12.7 and 11.5 kyr BP (upper part of PZ KTK1-4 and lower part of PZ KTK1-3). This time interval is also noticeable for highest scores of tundra biome. However, numerical scores of taiga remain higher than those of steppe in contrast to the time period prior to 14.5 kyr BP. The reconstructed total woody cover is about 10%, suggesting that forests still occupied a limited area in the region.

After ca. 11.5 kyr BP pollen of boreal trees predominate in the pollen assemblages (Fig. 2). Results of the biome reconstruction demonstrate almost equally high scores for the tundra and taiga biomes (Fig. 3B), suggesting boreal woodland vegetation between 11.5 and 10.5 kyr BP (upper part of PZ KTK1-3). After about 10.5 kyr BP the taiga biome scores are noticeably higher than the scores of non-arboreal biomes, suggesting well-established boreal forest vegetation in the region. The pollen data show that birch tree pollen was relatively abundant in the pollen spectra between ca. 10.5 and 6.8 kyr BP (PZ KTK1-2) and that pine pollen went to first place after that time (PZ KTK1-1). This change in the pollen composition likely reflects change in the forest communities around the lake and spread of Scots pine in the study region after 7 kyr BP. The results of the vegetation cover reconstruction suggest that total woody cover increased to above 50% after 10.5 kyr BP and decreased to its present-day level of about 45% after 6.8 kyr BP.

4.2 Climate reconstruction

The results of the pollen-based quantitative climate reconstruction (Fig. 4A-C) suggest pronounced changes in the main climatic variables during the late glacial and Holocene, which can be summarised as follows. Prior to ca. 11.5 kyr BP climate conditions were rather unstable. The first relatively warm episode (T_w∼13°C, T_c∼−25°C) occurred about 14.5 kyr BP followed by the cold episode (T_w∼12°C, T_c∼−38°C) centered on ca. 14 kyr BP. The reconstructed precipitation sums were substantially lower than present (e.g. P_{ann}∼270 mm). The next warming occurred between 13.5 and 13 kyr BP. At that time both T_w and T_c reached modern levels, but P_{ann} remained slightly lower than present, e.g. ∼400 mm. The interval around 12.5–12 kyr BP was characterised by significantly lower-than-present temperatures and precipitation sums (e.g. T_w∼12°C, T_c ∼−38°C, P_{ann}∼300 mm). A shift towards warmer and wetter climate occurred after ca. 12 kyr BP. However, this gradual trend was interrupted by a smaller scale cold and dry oscillation dated to ca. 11.1 kyr BP. The onset of a warmer and wetter-than-present climate (T_w∼17–18°C, T_c∼−19°C, P_{ann}∼500–550 mm) occurred ca. 10.8–7.3 kyr BP. The climate reconstruction shows a decrease in all climatic variables about 7–6.5 kyr BP (Fig. 4A–C). The climate reconstruction suggests a subsequent gradual decrease in T_c, (Fig. 4C) and P_{ann}(Fig. 4A) towards present-day values in the region around Lake Kotokel. The T_w curve (Fig. 4B) does not show any significant changes after ca. 6.5 kyr BP.

5 Discussion

The recent study on the KTK1 core provides clear evidence for noticeable changes in the pollen assemblages and, thus, in the pollen-producing vegetation communities around Lake Kotokel during the late glacial and Holocene. The quantitative interpretation of the regional vegetation history (Fig. 3B, D) is in concordance with that based on the qualitative interpretation of the pollen record (Fig. 2; Bezrukova et al., 2008), but provides a more robust reconstruction of the regional vegetation dynamics.

The biomisation approach (Prentice et al., 1996) does not allow the reconstruction of transitional vegetation types (e.g. forest-steppe and tundra-steppe); this missing information can be obtained (Fig. 3C) by examining the relative values of the respective biome scores (e.g. Fig. 3B; Tarasov et al., 2000). Additional information concerning the spread of the woody vegetation communities is provided by the quantitative reconstruction of the vegetation cover (Fig. 3D). Our reconstruction supports the earlier idea (e.g. Grichuk, 1984; Tarasov et al., 2007b; Bezrukova et al., 2008) that the late glacial landscape in southern Siberia – although dominated by the cold and drought resistant steppe and tundra communities (e.g. up to 95% of the total vegetation cover) – was not completely free of boreal coniferous and deciduous trees. Recorded peaks in the arboreal pollen percentages (Fig. 2) and corresponding peaks in the taiga biome scores (Fig. 3B) and in the woody cover percentages (Fig. 3D) suggest that trees could quickly spread out of their glacial refugia, occupying up to ca. 25% of the area within the 21 km window at least two times during the late glacial interval, e.g. 14.8–14.7 kyr and 13.3–12.8 kyr BP. The latter afforestation phase around Kotokel falls within the Allerød (AL) Interstadial in line with other palaeobotanical records from northern Asia (see Andreev and Tarasov, 2007 for the overview) and from the Lake Baikal region (e.g. Demske et al., 2005; Bezrukova et al., 2008; Shichi et al., 2009). According to the applied age model the earlier short-term afforestation episode might be an analogue of the European Meiendorf or Bølling (e.g. Frenzel et al., 1992) in the middle Lake Baikal region. However, a more definitive conclusion cannot be adequately proved because of the uncertainty in the age model, which is based on extrapolation below the 13.6 kyr BP level. An attribution of the reconstructed increase in the woody cover around Kotokel about 14.8–14.7 kyr BP to the Meiendorf raises further question concerning the occurrence of the Bølling (BO) Interstadial in the region. The earlier publications presenting postglacial pollen records from the Lake Baikal region usually do not separate Bølling from Allerød (e.g. Bezrukova et al., 2005; Demske et al., 2005). The KTK1 pollen diagram (Fig. 2; Bezrukova et al., 2008) also does not provide clear evidence for their separation. The quantitative transformation of the pollen percentages using the AVHRR-pollen-based approach suggests a slight increase in the woody cover percentages about 14 kyr BP (Fig. 3D). The accuracy of the method tested with the pollen-based modern tree cover reconstructions and original AVHRR-based estimates match well in Siberia (Tarasov et al., 2007b), providing satisfactory estimates of percent variance explained and RMSE for both total woody cover (r^2=0.77, RMSE=11.69) and different woody-cover fractions, including broadleaved (r^2=0.66, RMSE=3.31) and needleleaved (r^2=0.79, RMSE=10.23) tree cover. However, the error bars are still relatively large to discuss such minor fluctuations in the vegetation cover.

The Younger Dryas (YD) Stadial is well recognised in the diatom and sedimentary records from Lake Baikal (e.g. Prokopenko et al., 1999; Morley et al., 2005). However, to date the pollen-based studies from the region have reported rather weak YD signals, suggesting that the YD cooling had little effect on regional vegetation and thus on the pollen assemblages (e.g. Bezrukova et al., 2005; Demske et al., 2005; Shichi et al., 2009). In the KTK1 pollen and vegetation records the YD event is well defined. Both the significant decrease in the woody cover percentages from ca. 25% during AL to below 10% around 12.4 kyr BP and the replacement of boreal woodland by shrubby tundra communities help to place this event within the ca. 12.8–11.6 kyr BP interval. Our reconstruction results also suggest that deterioration of the regional climate during YD was less pronounced in the vegetation records than during the earlier late glacial interval.

The onset of the Holocene interglacial conditions is marked in the KTK1 record by the increase in arboreal pollen percentages, return to boreal woodland vegetation and increase in woody cover to above 25% at 11.5 kyr BP. After that time boreal forest became a major feature of the landscape around Kotokel. However, it took about 1 kyr until forest coverage in the area reached a maximum (above 50%) between 10.5 and 7.5 kyr BP. Our pollen record shows a sharp increase in *Pinus-sylvestris* type percentages (8–32%) between 7.4 and 6.7 kyr BP, reflecting the spread of Scots pine in the region after 7 kyr BP. This feature is in good agreement with other pollen records from the Lake Baikal region and from the broader areas of Siberia (e.g. MacDonald et al., 2000; Bezrukova et al., 2005; Demske et al., 2005; Andreev and Tarasov, 2007). The reconstructed 10% decrease in woody cover percentages dated to ca. 7–6.5 kyr BP, indicating that the vegetation cover became similar to that observed today, can be explained by the partial degradation of the birch forest around Kotokel suggested by the KTK1 pollen record.

Our results point to distinct vegetation and environmental changes around Lake Kotokel since ca. 15 kyr BP, which can be related to the regional and global climate dynamics (Fig. 4). The first major spread of the boreal forest vegetation in the region at ca. 13.5 kyr BP was characterised by significant climate amelioration (e.g. increase in T_w, T_c and P_{ann}) associated with the BO/AL Interstadial (Fig. 4E). Similar changes in temperature and precipitation values were derived from the Buguldeika pollen record from southern Baikal (Tarasov et al., 2007a). However, already at ca. 12.5 kyr BP the BMA reconstruction suggests a decrease in T_w and T_c and in P_{ann} down to the pre-interstadial values (Fig. 4A–C) (Tarasov et al., 2007a; this study). This major climate deterioration is in line with the reconstructed shift in vegetation from boreal woodland to much more open tundra landscape. The cold and dry climate oscillation derived from the KTK1 pollen record is roughly synchronous with the YD Stadial seen in the oxygen isotope records from Greenland (e.g. Stuiver et al., 1995; Fig. 4E) and from China (e.g. Yuan et al., 2004; Fig. 4D).

The onset of a relatively warm and wet climate occurred after ca. 11.6 kyr BP, suggesting the start of Holocene interglacial conditions in line with the isotope records, indicating warming in the North Atlantic region and strengthening of the East Asian monsoon (Fig. 4). The most favourable conditions for the taiga growing with $T_w\sim$17–18°C, $T_c\sim-19$°C and $P_{\text{ann}}\sim$500–550 mm occurred ca. 10.8–7.3 kyr BP. In the Buguldeika record west of Kotokel the onset of the optimal conditions (e.g. $T_w\sim$16°C, $T_c\sim-21$°C, $P_{\text{ann}}\sim$480 mm) is reconstructed for the 9–7 kyr BP interval, i.e. 1.8 kyr later (Tarasov et al., 2007a). Further investigation is required to establish whether this delay in the onset of the reconstructed "climatic optimum" represents local phenomena or spatial variations in the regional climate or whether the results are influenced by other (non-climatic) factors, such as problems with the dating of the Baikal bottom sediments (e.g. Colman et al., 1996) and under-representation of some widely distributed woody taxa (e.g. larch) more pronounced in the pollen assemblages of the sediment cores recovered from larger lake. However, results of the recent study are consistent with the results derived from the Continent and Buguldeika pollen records (Fig. 1), suggesting that the most favourable climate conditions are typical for the first half of the Holocene, as well as the Eemian Interglacial.

About 7–6.5 kyr BP the climate reconstructions from the KTK1 and Buguldeika records demonstrate a decrease in temperature and precipitation in both records, but more pronounced in the Buguldeika record (Tarasov et al., 2007a). The reconstructed drop in $T_{c,}$ and P_{ann} values is particularly important for discussion of the regional changes in the vegetation cover (e.g. Demske et al., 2005; Shichi et al., 2009; Fig. 3 in this study). Comparison of the precipitation curve (Fig. 4A) derived from the KTK1 record with the δ^{18}O data from the Dongge cave (Fig. 4D) demonstrates similarity between the two records, suggesting that in the Lake Baikal region the Holocene precipitation and tree-cover dynamics may be linked to shifts in intensity of the Pacific monsoon. The Holocene changes in the thermal parameters derived from the KTK1 pollen assemblages are in agreement with the δ^{18}O data from Greenland. The late Holocene cooling trend, a characteristic feature of the Northern Hemisphere and particularly of the North Atlantic region (Wanner et al., 2008), is especially pronounced in the winter temperature curve. The KTK1 pollen data and pollen-based vegetation and climate reconstructions are available in the PANGAEA data information system http://doi.pangaea.de/10.1594/PANGAEA.718105.

Acknowledgements. This paper was written when Elena Bezrukova was a guest scientist at FU Berlin, funded by the German Research Foundation (DFG) via the project TA 540/1 "Comparison of climate and carbon cycle dynamics during late Quaternary interglacials using a spectrum of climate system models, ice-core and terrestrial archives". We thank O. N. Shestakova and RFBR Grant No. 09-05-00123-a; H. Takahara and the Russian-Japanese research team members, who took part in the coring campaign at

Lake Kotokel in 2004, supported by the grants RFBR 05-05-66942 and JSPS 16255009. We are very grateful to A. Beck, who carefully checked English grammar and spelling, and to D. Peteet, A. Andreev and H. Grobe for their comments and suggestions. The paper is dedicated to the memory of Dominique Jolly, who was among the pioneers introducing quantitative vegetation reconstruction methods in northern Eurasia.

Edited by: R. Bonnefille

Publication of this paper was granted by
EDD (Environnement, Développement Durable)
and INSU (Institut des Sciences de l'Univers) at CNRS.

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