Russian Arctic lakes as climatic archives: pollen-based reconstructions of the Late Quaternary climate

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Introduction

During past ten years Russian Arctic has been open for the international research teams and paleolimnological research in this region benefited a lot from such cooperation. Recent results of interdisciplinary studies of lake sediments include analysis of different biological, sedimentological and geochemical proxies and geomorphological evidences to reconstruct hydrological and climatic conditions (e.g. Laing et al., 1999; MacDonald et al., 2000; Pisaric et al., 2001; Porinchu and Cwynar 2002; Schwamborn et al., 2002; Andreev et al., 2003,). These publications provide substantial contribution to the existing summaries (e.g. Tarasov et al., 1996) of the scarce sedimentary records from the Arctic lakes obtained by the scientists from the former USSR. In this paper we present examples of Russian-German research cooperation in the Russian Arctic, namely from the Polar Ural, Taymyr Peninsula and Lena River Delta. These results led to the creation of new Late Quaternary climatic records derived from pollen spectra analyzed in the lake sediments (Andreev et al., 2003, in press).

Methods of climate reconstruction using pollen data

Pollen assemblages reflect not only climatically-induced vegetation changes, but are also influenced by other factors, e.g. long-distance transport, redeposition, pollen preservation etc. However, pollen records from the Arctic have been used to derive quantitative climate characteristics by different non-statistical and statistical approaches. Prentice et al. (1992) demonstrated that Arctic tundra and boreal vegetation in northern Russia is mainly controlled by annual sum of mean daily temperatures above 5 °C, so-called growing degree days (*GDD5*). This "bioclimatic" variable correlates well with "conventional" climate variable of mean July temperature (T_{VII}), which is often reconstructed from pollen and other biological records.

A qualitative climate interpretation of the fossil pollen records has been refined with the help of quantitative methods. The standard best modern analogues (BMA) method (Guiot, 1990) uses a chord distance (Euclidean metric between two points in the *n*-dimension space defined by the square root of the pollen percentages) to calculate the similarity between each fossil pollen spectrum and the reference modern data. In the present study the reference modern pollen data set is that compiled by Tarasov et al., (1998; 2002) from northern Eurasia. It includes 1110 surface spectra former Soviet Union and Mongolia for which taxa percentages were calculated based on the terrestrial pollen sum. The same taxa were selected in the fossil pollen records. For each analyzed fossil spectrum 10 modern spectra which have the smallest chord distance were considered as the best modern analogues following Guiot (1990). Modern climate variables at the pollen sampling sites have been calculated from the updated version of Leemans and Cramer (1991) climate database. PPPBase software (Guiot and Goeury, 1996) facilitates the calculations. In the best modern analogues method the error bars for the reconstructed values are defined by the climate variability among the chosen number of analogues. However, the small error bars that can be obtained in this way are often underestimated, especially when analogues are situated close to each other.

The information-statistical (IS) method (Klimanov 1984) is based on the statistically found correlation between more than 800 recent pollen spectra from 220 different sites across northern Eurasia and modern climate characteristics (Klimaticheskiy Atlas SSSR, 1960) at sampling sites. Relative abundance of spores, arboreal and non-arboreal pollen, as well as relative abundance of 14 tree and shrub pollen taxa considered for the climate reconstruction. Treatment of the modern pollen and climate data by the information analyses resulted in the preparation of tables that revealed the correlation of recent pollen data and the four climatic variables. The main statistical errors for the reconstruction of T_{VII} are ±0.6 °C (Klimanov, 1984).

Results

Lyadhej-To Lake (68° 15 'N, 65° 45 'E, 150 m), Polar Ural

Lyadhej-To Lake is situated at the NW rim of the Polar Urals. It has an area of 4 km^2 and a maximum water depth of 26 m. The modern climate is continental with severe winters with T_I -16 - 24 °C and short summers with T_{VII} of 6 - 8 °C. Lake Lyadhej-To is ice-covered 8 - 9 months and becomes ice-free by June. The vegetation in the lake catchment is dominated by grass and low shrub tundra. Lacustrine sedimentation in the 11.9-m-long core taken at the 26-m water depth started about 10,950 cal BP. The age-depth model is created on the basis of 17 ^{14}C-AMS dates on picked plant remains and 3 dates on dispersed organic carbon in bulk till samples.

Pollen assemblages at ca 10,950-10,700 cal BP are dominated by Pre-Quaternary spores and redeposited Pinaceae pollen, pointing to a high input of terrestrial material. The rare Cyperaceae pollen and *Equisetum* spores suggest sparse, treeless vegetation and severe climate conditions in the catchment area. Between ca 10,700-8500 cal BP pollen spectra are dominated by *Betula* pollen. The pollen concentration is highest through the whole record. This may reflects a northward shift of the tree line and the warmest conditions during the Holocene. Decrease in *Betula* pollen content and increase in herbaceous pollen content registered in the pollen assemblages suggest cooling after ca 8500 cal yr BP. The cooling continues after ca 7500 cal BP, marked by the ongoing decrease of tree birch pollen and the simultaneous increase of dwarf birch pollen. A low pollen concentration in the upper part of the record together with the low concentration of arboreal pollen and pollen of *Alnus fruticosa* suggests a southward migration of the tree line and establishment of tundra vegetation associated with rather cold climate around the lake after ca 6000 cal BP.

The climate was reconstructed from the pollen spectra of the upper 6.5-m part of the core. The lower part of the record with high content of redeposited pollen and spores has been excluded from the quantitative analysis. Results are in agreement with the qualitative interpretation of the Holocene climate around the lake. Reconstructed values of T_{VII} suggest warmer than present summers between 10,500 and 7500 cal yr BP. In the area first well-recognized cooling occurred ca 7000 cal yr BP, second - ca 5500 - 3500 cal yr BP and third - after 1000 cal yr BP. Bearing in mind possible errors of the reconstruction, we suggest that T_{VII} could reach 12 – 13 °C during the early Holocene climatic optimum. During the colder intervals mean July temperatures likely were between 7 and 10 °C.

Levinson-Lessing Lake (74° 28 'N, 98° 38 'E, 47 m), northern Taymyr Peninsula

Levinson-Lessing (74° 28 'N, 98° 38 'E) is the deepest (110 m) lake of the region. It is 15 km long and 1 - 2 km wide. The modern climate is continental with severe winters and short summers with T_{VII} of only 5 - 7 °C. The vegetation varies from mountain desert to moss-forb and sedge-forb tundra. Willow shrubs are sparsely distributed. Pollen data from the 22.1-m long core taken in the central part of the lake at the 108-m depth reflect environmental changes on the northern Taymyr since ca 32,000 yr BP (Andreev et al., 2003). Pollen spectra suggest that scarce steppe-like vegetation dominated on the northern Taymyr between ca 32,000 yr BP and the onset of the Holocene (ca 11,500 cal yr BP). Tundra-like vegetation grew in wetter places. The late Glacial pollen records reflect climate signals which may be correlated with the Bölling and Allerød warm events, while the climate deterioration about 12,000 cal yr BP with the Younger Dryas. Late Glacial/Holocene transition is characterized by a change from the herb-dominated vegetation to shrubby tundra with dwarf *Betula* and *Salix*. *Alnus fruticosa* grew in the area between ca 10,150 and 9500 cal yr BP. It disappeared from the vegetation after ca 4500 cal yr BP. *Betula* sect. *Nanae* communities, broadly distributed in the area during the Early and Middle Holocene also almost disappeared after ca 3500 cal yr PB. Since then vegetation became similar to modern-day herbaceous tundra. Climate reconstructions suggest that T_{VII} might have been about 1 - 3.5 °C below modern values ca 32,000-29,000 and 25,000-20,000 yr BP and slight climate amelioration with T_{VII} being 0.5 - 2 °C above modern values occurred ca 27,000 - 26,000 yr BP. During the maximum stage of the Late Sartan glaciation (ca 21,000 cal yr BP) reconstructed T_{VII} could be up to 3.5 °C below modern values. During relatively warm intervals likely associated with Bölling and Allerød T_{VII} might have been up to 1 - 2 °C higher than today. During the cold Younger Dryas-like interval T_{VII} might have been up to 2 °C below modern values. The first Holocene warming is associated with the early Preboreal time, ca 11,000 yr BP. Generally much warmer than present summers are reconstructed between 11,000 and 6000 cal yr BP, when T_{VII} anomalies varied from +2 to +4.5 ºC. However, the maximum temperature rise occurred at the beginning and at the end of this interval. Reconstructions suggest that T_{VII} fluctuated between -2 to 2 ºC around present-day values during last 6000 years.

Nikolay Lake (73° 20 'N, 124° 12 'E), Lena River Delta

Nikolay Lake, which is the largest lake in the delta area, consists of five sub-basins, and is about 8 km wide from west to east, and ca 6 km long from north to south. Approximately 70 % of the basin is less than 2 m deep. A maximum water depth of 30 m was recorded in one sub-basin. Present day T_{VII} are around 5 °C and T_I are – 30 °C. The area belongs to the northern tundra zone, where moss-grass-low shrub tundra dominates the vegetation. Pollen records collected in the central part of the largest lake subbasins from the water depth of 14 m were used to reconstruct vegetation and climate. A total of 13 samples were radiocarbon dated and used to establish the age-depth model. Shrubby *Alnus fruticosa* and *Betula exilis* tundra existed during 10,300 - 4800 cal. yr BP, and gradually disappeared after that time. Climate reconstruction suggests that summers during ca 10,300 9200 cal. yr BP were up to 2 - 3 °C warmer than nowadays. T_{VII} relatively warm during 9200 - 6000 cal. yr BP, and became rather unstable between ca 5800 - 3700 cal. yr BP. Both qualitative interpretation of pollen data and quantitative reconstruction imply that summer temperatures and vegetation became similar to modern-day conditions after ca 3600 cal. yr BP.

Conclusions

Two different statistical techniques (e.g. BMA and IS methods) being applied to the Late Quaternary pollen spectra from Arctic Russia show comparable results in reconstruction of changes in the mean July temperature – an important climatic characteristic, controlling modern distribution patterns in the Arctic area. The differences are relatively small compared to the statistical errors of the reconstructions. The time of maximum warmth at the sites from the Polar Ural, northern Taymyr Peninsula and the lower Lena River Delta took place during the Early and Middle Holocene.

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