The history of vegetation and landscapes of the lake Ilchir basin for understanding the modern vegetation structure in the Okinsky plateau

E V Volchatova¹, E V Bezrukova¹, N V Kulagina², O V Levina¹, A A Shchetnikov³, E V Kerber¹, M A Krainov¹ and I A Filinov²

¹ Vinogradov Institute of Geochemistry SB RAS, Irkutsk, Russia
² Institute of the Earth’s Crust SB RAS, Irkutsk, Russia

E-mail: volchatova@igc.irk.ru

Abstract. The method of detailed sampling of sediments from Lake Ilchir allowed obtaining a high-resolution record of changes in the natural environment, which meets the world modern standards of temporal resolution in the studies of the Holocene environment. The data on the palynological analysis of bottom sediments from Lake Ilchir (51°58'26.0" N and 100°59'29.0" E) enable us to reconstruct the composition of vegetation and the structure of landscapes in the lake basin as well as to understand the process of its change in Middle-Late Holocene. The lake is located in the Republic of Buryatia and is the source of the Irkut River, which flows into the Angara River. The results obtained are unique for the regional Holocene environment, since they allow us to clarify the nature of changes in regional vegetation with an average time interval of 125 years. A reliable age model provides for intra- and interregional correlations of environmental changes that helps to understand the possible causes of changes in regional vegetation. Palynological records from inland regions are important for reconstructing the processes of past changes in landscapes, assessing the sensitivity of ecosystems in these regions to future climatic variations that affect the composition of vegetation and its change in time.

1. Introduction

The Sayan mountain system is located in Southern Siberia and Northern Mongolia. It extends eastward to Lake Baikal and is continued as the Altai mountain system in the west. In the study area, lakes of glacial origin predominate (figure 1). Pre-Cenozoic metamorphic and Neogene volcanic rocks overlain by remnants of Late Pleistocene terminal moraines prevail in the lake watershed.

The Ilchir graben is surrounded by high ridges, which determines a specific type of climatic regime [1]. The climate in this area is cold and is characterized by an average July temperature of +11°C and an average January temperature of -26°C. Minimum temperatures often fall below -40°C, and maximum summer temperatures can exceed +25 ° C. The average annual temperature does not exceed -6.6°C. The average annual precipitation is about 400 mm, of which only 10% falls during the cold season from October to March. The surface waters of Lake Ilchir can warm up to +15°C in July. From October to June, the lake is covered with ice [2].

Modern vegetation in the mountains of the Eastern Sayan has distinct high-altitude belts. Abies sibirica (fir), Picea obovata (spruce) and Pinus sibirica (Siberian pine) trees dominate mountain boreal forests at altitudes below 1000 m above sea level. Pinus sibirica and Larix sibirica predominate at 1000
and 1800/2000 m. Shrubs, including *Betula sect. Nanae*, *Alnus* and *Ericales* are common under the canopy of dark coniferous forests and in the subalpine zone above the tree line. Forests of *Pinus sylvestris* occupy warmer and drier habitats in the Eastern Sayan Mountains at low altitudes and in the foothill plains.

![Figure 1. Lake Ilchir location.](image1)

The vegetation of the watershed of Lake Ilchir is dominated by rare *Larix sibirica* (larch) stands with undergrowth of dwarf birch (*Betula sect. Nanae*), a ground cover of lichens (*Cladonia*) and mosses (figure 2). Macrophytes grow along the coastal part of the lake, including *Carex* (sedge) and *Potamogeton* spp. (cattail) [3].

![Figure 2. The landscape of Lake Ilchir, photo by the authors.](image2)

2. Models and methods
The Lake Ilchir bottom sediments were obtained through drilling in 2013. The length of the obtained core was 133 cm. The aim of the core study was to obtain spore-pollen spectra produced by modern and past plant taxa from the areas adjacent to the lake. Based on this core, we also intended to produce a description of the development of vegetation in the Okinskaya depression, in which Lake Ilchir is located.

2.1. Palynological analysis
For the extraction of pollen and spores under laboratory conditions, 1 cm³ of sediment was sampled and subjected to a standard treatment procedure using hydrofluoric acid and subsequent acetolysis [4]. In total, 67 samples were tested. The core was tested in laboratory conditions at the Institute of Geochemistry SB RAS, Irkutsk. The percentage of pollen taxa was calculated from the sum of all pollen grains, excluding spores of ferns and mosses. The spore percentage was determined from the sum of all
pollen and spore grains counted in each sample. Microparticles were counted on the same slides. The analysis results are presented in the pollen diagram (Figure 4).

Separate counting of coal particles of different dimensions was not carried out.

2.2. Chronological control
The age of the sediments in the core was determined through accelerator mass-spectrometry radiocarbon dating in Poznan (Poland). Five dates were obtained from depths of 5, 28, 61, 92, and 130 cm from the top of the core. The radiocarbon age of the dated levels was 8370 cal yr BP (before present) at a depth of 130 cm (core base) and 2200 cal yr BP in the upper part of the core, at a depth of 6 cm.

2.3. Analysis of the dynamics of light- and dark-coniferous tree pollen
The group of pollen of light coniferous trees includes pollen of *Pinus sylvestris* and *Larix*, and the group of pollen of dark coniferous trees includes pollen of *Pinus sibirica*, *Abies sibirica* and *Picea obovata* (Figure 3). Taking into account the different requirements of these trees to ecological, edaphic and climatic factors [5-7], it can be assumed that variations in the sums of these two groups may reflect the relative variability in the continentality of the climate (relative humidity and difference of the mean temperatures in the summer and winter seasons).

2.4. Statistical analysis
The upper part of the diagram (Figure 4) shows the composition of the surface spore-pollen spectra from the upper 1-cm soil layer around Lake Ilchir (standard), which serve as a basis for understanding the composition of the fossil spectra, and with which we compare the obtained fossil spectra, to draw correct conclusions about vegetation changes.

3. Results and discussion

3.1. Chronology
The radiocarbon age of the dated levels was 8370 BP at a depth of 130 cm (core base) and 2200 years ago for the upper part of the core, at a depth of 6 cm, respectively. The age of each cm of sediment was determined by calculating the average sedimentation rates between dated levels.

3.2. Palynostratigraphy
Based on statistical analysis, we distinguished three spore-pollen zones on the spore-pollen diagram, corresponding to three stages of vegetation development in the lake Ilchir basin.

The first, the most ancient stage (zone 3, Figure 4), lasted from ca. 8490 to almost 6000 cal yr BP and showed the widest development in the forest belt of the Eastern Sayan Siberian pine forests with fir, larch, Scots pine, and birch. Grass-forbs (timothy grass) meadow groups dominated the local vegetation. The climate was humid and moderately cold.

At the second stage (zone 2, Figure 4), 6000-3700 cal yr BP, there is a large amount of fir pollen, which indicates the onset of a milder climate with warmer winters and high snow, preventing the soil from freezing and supporting the development of fir forests in the high-mountainous zone of the Eastern Sayan. A high abundance of *Phleum* pollen may indicate an increase in the water level of Lake Ilchir.

At the third stage of vegetation in development in the lake basin (zone 1, Figure 4), 3700 cal yr BP to the present time, there is a decrease of fir and timothy, an increase in the pollen of sedges as well as of meadow-steppe herbs, which indicates an increase in the continentality of the climate (especially the cooling in winter seasons).

3.3. Pollen ratio of dark coniferous and light coniferous trees
Figure 3 clearly shows the change in the dynamics of the ratio of dark coniferous to light coniferous pollen. The pollen of light coniferous trees (*Pinus sylvestris* and *Larix*) dominates in the SPS (spore pollen specters) throughout the entire study period, several times exceeding the amount of pollen of dark
coniferous trees (Pinus sibirica, Abies sibirica and Picea obovata). The total values of both groups are very unstable; during the study period, there were frequent upward and downward changes in the amount of pollen. From ca. 3700 cal yr BP, there is a gradual decrease in the dark coniferous pollen. The pollen sum of light coniferous trees is constantly stable, showing only two periods of its significant decrease: ca. 5200 cal yr BP and in surface samples (standard). In the surface SPS, the sum of light coniferous tree pollen is slightly higher than in the studied core, whereas the sum of dark coniferous pollen, on the contrary, is much lower.

The pollen stratigraphic data obtained indicate the predominance of tree pollen, especially Pinus sibirica and Pinus sylvestris. In addition to representatives of the genus Pinus, the presence of Betula sect. Albae and Abies sibirica. Picea obovata pollen is found in small amounts in several samples.

However, knowing the composition of the vegetation in the immediate vicinity of the study object, when there is no dense forest vegetation near the lake (figure 2), it can be assumed that the pollen grains of these tree species are brought into Lake Ilchir with winds or water flows. In the immediate vicinity of the watershed, we recorded only the presence of small scattered stands from Larix, the pollen grains of which are found in small quantities in the studied samples.

In the pollen diagram (figure 4), until 3700 cal yr BP, the number of Abies sibirica pollen was higher than in the subsequent period. However, since the same period until 2000 cal yr BP (to the present), there is a sharp decrease in the presence of Abies sibirica, and it is almost absent in the SPS from surface samples. At the same time, there is an increase in the amount of Picea obovata pollen, which was absent in the interval of 130-95 cm (8370-5600 cal yr BP).
Figure 4. Spore-pollen diagram of bottom sediments from Lake Ilchir.
In comparison with the previous stage before ca. 1970 cal yr BP, the diagram also clearly shows an increase in the proportion of *Pinus sibirica* pollen in surface samples (standard) and a decrease in the proportion of *Abies sibirica* pollen in the same samples. This change may be due to a decrease in soil nutrient richness and an increase in permafrost, to which *Abies* is more susceptible than *Pinus sibirica*.

At the same time, the peak of *Betula sect. Albae* pollen is recorded in the diagram in the SPS of surface standard samples. This is likely due to birches ecology: it is not demanding on the richness of the soil easily forming stands on stony mountain slopes; they tolerate permafrost and spring frosts well. Due to properties of birch tree, it easily displaces trees that are more demanding to climatic conditions, gradually displacing coniferous forests, which, possibly, caused a decrease in the number of *Abies sibirica* in the surrounding landscape.

*Larix* pollen was detected in small amounts, which was virtually absent up to 105 cm of the core (earlier 6500 cal yr BP) and periodically appeared later. This is due to the pollen-producing peculiarities of this species: *Larix* pollen does not spread over long distances, settling close to producing trees; moreover, it is produced in small quantities. Larch is the only tree species from the entire spectrum of arboreal taxa growing in the immediate vicinity of Lake Ilchir, whose pollen was identified during the core research. Consequently, its pollen is a local component of the SPS.

Among the pollen of shrubs, *Betula sect. Nanae* pollen predominates, which was consistently observed in all samples, and recently this taxon is the main shrub species in the local landscape. The presence of *Duscheckia* (shrub alder) alder pollen is poorly manifested, but its pollen increases in the interval from 1 to 30 cm from the top of the core but decreases again in the surface samples. In the samples of the earlier stage, *Duscheckia* pollen is present in small amounts; sometimes, it is absent at all. Common features of shrubby birch and alder include light and moisture-loving, comparative cold resistance and indifference to soil fertility; none of these taxa tolerates stagnant moisture [8].

The largest part of the obtained spore-pollen spectra is the pollen of meadow herb. A wide range of taxa, among which the presence of noticeable pollen amounts for the genus *Artemisia*, *Poaceae*, *Cyperaceae*, *Phleum*, *Brassicaceae*, and *Chenopodiaceae* can be identified, represents this group. All five of the listed taxa prevailed in this area throughout the study period, except for the pollen of *Phleum*, which was nearly absent in the interval of 1-40 cm from the core top, i.e. in the past 3730 years. *Artemisia* and *Cyperaceae* grew throughout the studied time interval and stand out most clearly in comparison with other herbaceous taxa but less significant than *Phleum*.

*Poaceae*, *Chenopodiaceae* and *Ericales* are slightly less abundant. *Brassicaceae* was rather distinctly observed at earlier stages; however, in the surface samples, cabbages pollen is completely absent.

The presence of *Ephedra* pollen is poorly detected, most clearly appearing at the latest stage, in the past 3700 years.

Such species as *Athyrium*, *Rhododendron*, *Tulipa biebersteiniana*, *Lysichiton*, and *Rubiaceae* are occasionally present. Pollen of these taxa shows the irregular small occurrence and sometimes is absent for a long time or appear shortly as in the cases of *Lysichiton* and *Chenopodiaceae*.

Since ca. 4000 cal yr BP (50th centimeter of the core and upward), *Polygonum* pollen appears and is present nearly until 3000 cal yr BP (20th centimeter of the core). Later, the amount of *Polygonum* pollen began to decline again, and there was only a small peak in the surface samples.

Since ca. 3700 cal yr BP until now, pollen of such herbs as *Caryophyllaceae*, *Rosaceae*, *Thalictrum*, *Saxifragaceae*, *Asteraceae*, *Apiaceae*, and *Lamiaceae* appear. Of these, *Rosaceae*, *Caryophyllaceae*, *Saxifragaceae*, and *Lamiaceae* were not detected in the surface samples.

Data on the composition of local vegetation consisting mainly of shrubs and herbs suggest that this is the pollen of local plants.

After 3700 cal yr BP, there was a slight change in the species composition of the vegetation around Lake Ilchir. Some new taxa appeared, and some of the previously present ones disappeared. We assume that the cause for this change could be climate change and related change in soil moisture. In the surface samples, the taxa diversity significantly decreases, which suggests that the climate became colder, and permafrost appeared in the soils.
A significant content of spores of green mosses of the *Bryales* order and spores of ferns *Polypodiales* (ferns) in the past 3700 years may indicate an increase in soil moisture in the lake basin. The presence of *Sphagnum* spores, a typical mire moss, confirms high soil moisture.

During stages 2-3 (8490-3700 cal yr BP), a large number of micro-charcoal particles are observed, indicating frequent fires near Lake Ilchir, probably due to a denser vegetation cover than in the past 3700 years.

4. Conclusion

The application of the technique of detailed sampling of Lake Ilchir sedimentary section allowed us to obtain a high-resolution record of the changes in the natural environment that meets the modern world standards of temporal resolution in the studies of the natural environment in the Holocene.

The results obtained reveal that the vegetation in the Ilchir Lake basin developed gradually without abrupt changes in composition. Tundra and forest-tundra landscapes were dominated over the past 8490 years in the watershed of Lake Ilchir. The increasing role of fir during stages 2-3 most likely indicates the approach of the upper boundary of the forest belt to Lake Ilchir when the climate was warmer and more humid than the climate in the modern time. Subsequently, in the past 3700 years, the expansion of the spruce and larch in the lake basin correlates with a cooling in the Neoglacial period and indicates a reduction of forest landscapes in the Ilchir Lake watershed. During the long-term interval from 8490 cal yr BP and to ca. 3700 cal yr BP, probably, in the immediate vicinity, there were frequent fires that support the existence of rather dense vegetation that formed the basis for fire. After ca. 3730 cal yr BP, a sharp decrease in the number of micro-charcoal particles indicates that local fires have become insignificant most likely due to the retreat of the woody vegetation and an increase in soil moisture caused by low evaporation resulted from climate cooling.

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