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REGIONAL PROBLEMS OF ENVIRONMENTAL STUDIES AND NATURAL RESOURCES UTILIZATION

Vegetation of Central Transbaikalia in the Late Glacial Period and Holocene

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Abstract—Presented are the latest findings from investigating bottom sediments in Lake Arakhlei, containing continuous records of the vegetation evolution in the Beklemishevskaya depression and its mountain surroundings for the last 13 500 years.

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Keywords: lacustrine bottom sediments, palynological analysis, radiocarbon dating, Late Glacial period, Holocene.

INTRODUCTION

As a result of many years of investigations on the issue related to changes in natural environment and climate during the Late Glacial and the Holocene, based on data of palynological analysis, detailed evidence was obtained for the palaeogeography of Cisbaikalia [1–3] and Western Transbaikalia [4]. Such evidence is scarce for the territory of Central Transbaikalia (within Zabaikal'skii krai). Results from studying bottom sediments in Lake Tanga, for example, have been reported in [5], discussing the vegetation evolution in the western part of Chita oblast, beginning in the Early Holocene. The profile of floodplain deposits of the Ilya river, the left tributary of the Onon river, was instrumental in reconstructing the vegetation and climate of Southwestern Transbaikalia for the Mid- and Late Holocene [6].

In 2005, we obtained a palynological record from bottom sediments of Lake Arakhlei, characterizing changes in vegetation of the Beklemishevskaya depression for the last 1900 years [7]. This paper presents new findings from investigating the lake's bottom sediments; they contain a continuous record of the vegetation evolution for the depression, and for the mountains surrounding it for the last 13 500 years.

DESCRIPTION OF THE STUDY TERRITORY

Lake Arakhlei forms part of the system of Ivano-Arakhleiskie lakes which were granted the status of zakaznik and which are situated on the watershed of the Lena and Angara-Yenisei basins. The lake itself is 70 km west of the city of Chita, at an altitude of 965 m above the sea level, in a tectonic trough of the Meso-Cainozoic age − the Beklemishevskaya depression (Fig. 1.) According to the schematic map of physical-geographical regionalization, most of the study territory refers to the Vitim taiga-upland province. The natural uniqueness of the territory is determined by its location at the interface between the two physical-geographical regions: Baikal-Dzhugdzhur, and Southern-Siberian [8].

Lake Arakhlei is the deepest (the maximum depth 17 m, and the mean depth is 10.4 m) and the largest in the system of Ivano-Arakhleiskie lakes. The area of the lake's surface measures about 58 km^2. The river inflow constitutes 47.5 %, the other incoming water corresponds to atmospheric precipitation. Also, the output portion of the water balance is dominated by evaporation (80%), and only 20% is accounted for by the liquid runoff. This suggests a high sensitivity of the water balance and of the associated

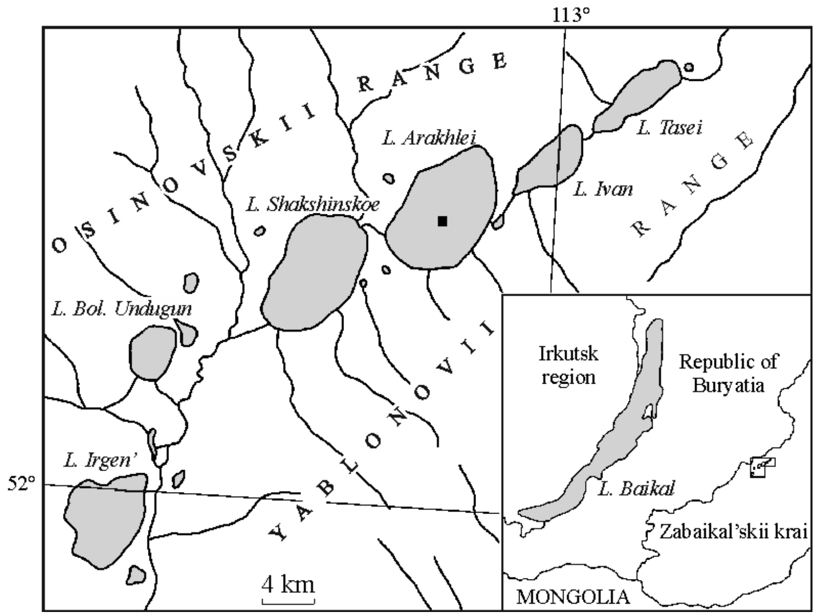

Fig. 1. Schematic map of the area of work.
The core sampling site is shown as a black square.

sedimentation to changes of climate.

The climate in the area of Lake Arakhlei is ultra-continental, with a difference of seasonal temperatures ranging from –19.3 ºC (October–March) to 12.7 ºC (April–September), which is due to mountain topography. The mean annual precipitation amount is 343 mm, and its main proportion (80–90%) corresponds to a warm period (July–August) [9]. North-westerly and westerly winds prevail.

An important characteristic of vegetation cover is the altitudinal zonality, and a clearly pronounced asymmetry of slopes. The southern slopes (Osinovskii Mountain Range) are steep and dry, whereas the northern slopes (Yablonovoi Mountains) are gentle and well humidified.

According to the schematic map of botanical-geographical regionalization of Baikalian Siberia, the territory under consideration belongs in the Eurasian coniferous-forest region, the East-Siberian subregion of light-coniferous forests [10]. The hollow is surrounded by mountain-taiga forests covering more than 40% of its territory. Larch forests of Gmelin larch are dominant. Very small areas are occupied by pine forests. Birch forests occur in the form of small along the hollow floor at the foot of the hillsides. Monodominant pine and birch forests occur only rarely, and they are characterized by some contribution from Gmelin larch. Spruce forms part of larch forests occasionally. The shores of the lakes are the home for mesoxerophilic steppes. Meadow-bog vegetation occurs in areas adjacent to the lakes, and to the river channels. Shrub vegetation of willow and shrub birch is common with gentle slopes and richer channels [11].

MATERIALS AND METHODS

A core of lacustrine deposits 166 cm in length, with an undisturbed sequence of layers, was sampled in 2007, using the piston core sampler, in the middle part of the lake (see Fig. 1) from a depth of 15 m at the point with the coordinates 52º 12' 44.2" N, 112º 53' 16.8" E. The sediment was represented by water-saturated, outwardly uniform, clay-organogenic silt black-green in color.

Samples for palynological analysis were collected at steps of 3 cm in the interval 0–40 cm, 5 cm – 40–135 cm, and 2 cm – 133–166 cm. The preparation of the samples, and the palynological analysis were carried out at the Geochemistry and ore Genesis Laboratory, Institute of Natural Resources, Ecology and Cryology, Siberian Branch, Russian Academy of Sciences, by using a standard technique [12] and with the aid of the Carl Zeiss Axiolab microscope with a 200X magnification. Concurrent with counting and determining spores and pollen, on these same slides we counted the remains of cenobiums of green algae of the genus of Pediastrum. A calculation of the percentage content of individual taxa in spectra used, as 100%, the total amount of pollen from ground plants without considering pollen from aquatic taxa, spores and algae, which were calculated from the total amount of pollen and spores as counted in the sample.

The age model for the sedimentary section of the deposits in Lake Arakhlei is based on three radiocarbon age datings using the method of accelerated mass spectroscopy (see Table). The deposits were dated for total organic matter at the Poznań Radiocarbon Laboratory (Poland). The values of direct radiocarbon

Results of ^{14}C dating of sediments from Lake Arakhlei, and sediment accumulate rate

Depth from core surface, cm	Values of calibrated age, calendar years	Accumulation rates, mm/year
14.5	2353.5	0.1
50.0	5087.0	0.12
144.0	13009.5	0.13

age were converted to calibration values with respect to the year 2005 using the IntCal_09, OxCal v. 4.1 software program [13]. The age of the layers as studied through palynological analysis was calculated by a method of linear interpolation having regard to the values of accumulation rates of deposits (see Table). Taking into consideration the sampling interval (averaging 4 cm) suggests the conclusion that the temporal resolution of the resulting palynological record is about 250 years. Below, throughout the text, all age estimates are given in the calibration chronology.

RESULTS AND DISCUSSION

On the spore-pollen diagram (Fig. 2), we identified seven palynozones which are characterized by a variation in total composition of spore-pollen spectra (SPS) and of their individual taxa.

Palynozone 7 (prior to ~13 500 years ago) Poaceae–Cyperaceae. The SPS are dominated by pollen from herbaceous plants: wormwoods, grass plants, and sedges. In the composition of pollen from woody plants were occur single grains of pollen from spruce, birch, Siberian stone pine, and pine. The SPS for this zone are characterized by high contents of redeposited Mesozoic and Neogene myospores.

Palynozone 6 (~13 500–12 850 years ago) Salix–Duschekia–Betula alba-type–Betula nana-type. The SPS showed an increase in abundance of pollen from willow and alder as well as pollen from birch of the two sections. There occurred a significant reduction in the number of redeposited myospores.

Palynozone 5 (~12 850–11 750 years ago) Larix–Betula nana-type–Betula alba-type. The SPS of the zone are dominated by pollen from dendriform birch, although content of pollen from shrub birch remains relatively high. The abundance of pollen from larch varies from 1 to 2.2%. The number of redeposited forms reduced to a few. There occur remains of algae of the genus of Pediastrum.

Palynozone 4 (~11 750–10 500 years ago) Larix–Betula alba-type. The SPS of the zone show an abundance of pollen from dendriform birch (up to 30–40%). The amount of pollen from spruce does not exceed 3–4%. In the SPS for the upper part of the palynozone, we determined pollen from fir and elm. The spectra for this zone showed the highest content of Pediastrum.

Palynozone 3 (~10 500–9000 years ago) Pinus sibirica–Abies–Larix–Picea. In the SPS of this zone, the amount of pollen from spruce (up to 20%) reached maximum values, from Siberian stone pine, it made up as much as 9–18%, and from larch, it approached 4%. The abundance of green algae decreased to unit values.

Palynozone 2 (~ 9000–6500 years ago) Betula alba-type–Larix. In the SPS of this zone, the content of pollen from dark-coniferous elements decreased to 1–2%, approaching their values in the surface sample.

Palynozone 1 (~ 6500 years ago – present) Pinus sylvestris–Larix. The SPS of this zone are characterized by a predominance (60–80%) of pollen from pine and larch.

Analysis of the data obtained was instrumental in examining the history of vegetation in the Beklemishevskaya depression over most of the Late Glacial and the entire Holocene, and in identifying several phases in its development. According to the principles of identifying and describing the pollen zones [14], the name of the zone is given according to the name of the species with maximum content of pollen and species of subordinate significance but characteristic for a given zone. In this case, the species, pollen from which is dominant in the SPS, occupies the last place in the name of the zone. Reconstructing the vegetation primarily takes into account information on the characteristics of pollen productivity from different plants, the dispersal of pollen by natural agents, and on the degree of its preservation in a fossil state; the description of the reconstructed plant groups is, in some cases, dominated by the taxon, pollen from which in the SPS was present in minor amounts. In this paper, the description of the pollen zones and interpretation of palynological data are carried out having regard to these methodological aspects of palynological analysis.

The high percentage content of pollen from grasses (see Fig. 2), especially from grass plants, sedges and wormwoods, gives evidence of the mosaic pattern of vegetation cover at the final stage of recent glaciation, earlier than 13 500 years ago (zone 7). The main areas along the lake's shore were occupied by waterlogged sedge-grass associations. A persistent presence of pollen from woody plants in the SPS is suggestive of the existence, on the watersheds, of open woodlands consisting of spruce and birch. Vegetation of this nature is characteristic for a cold climate with insufficient atmospheric humidification; on the other hand, it points to a high degree of soil moistening. This might be caused by a widespread occurrence of permafrost, and it is its thawing during summer seasons which provided the source for soil moisture sufficient for waterlogged plant associations, and erosion and destruction of older earth materials which were supplying to the lake's sediments myospores of Mesozoic ages.

Later, ~13 500–12 800 years ago (zone 6), along with spruce and larch, widespread encroachment of shrub birch and willow began. Most likely these woody

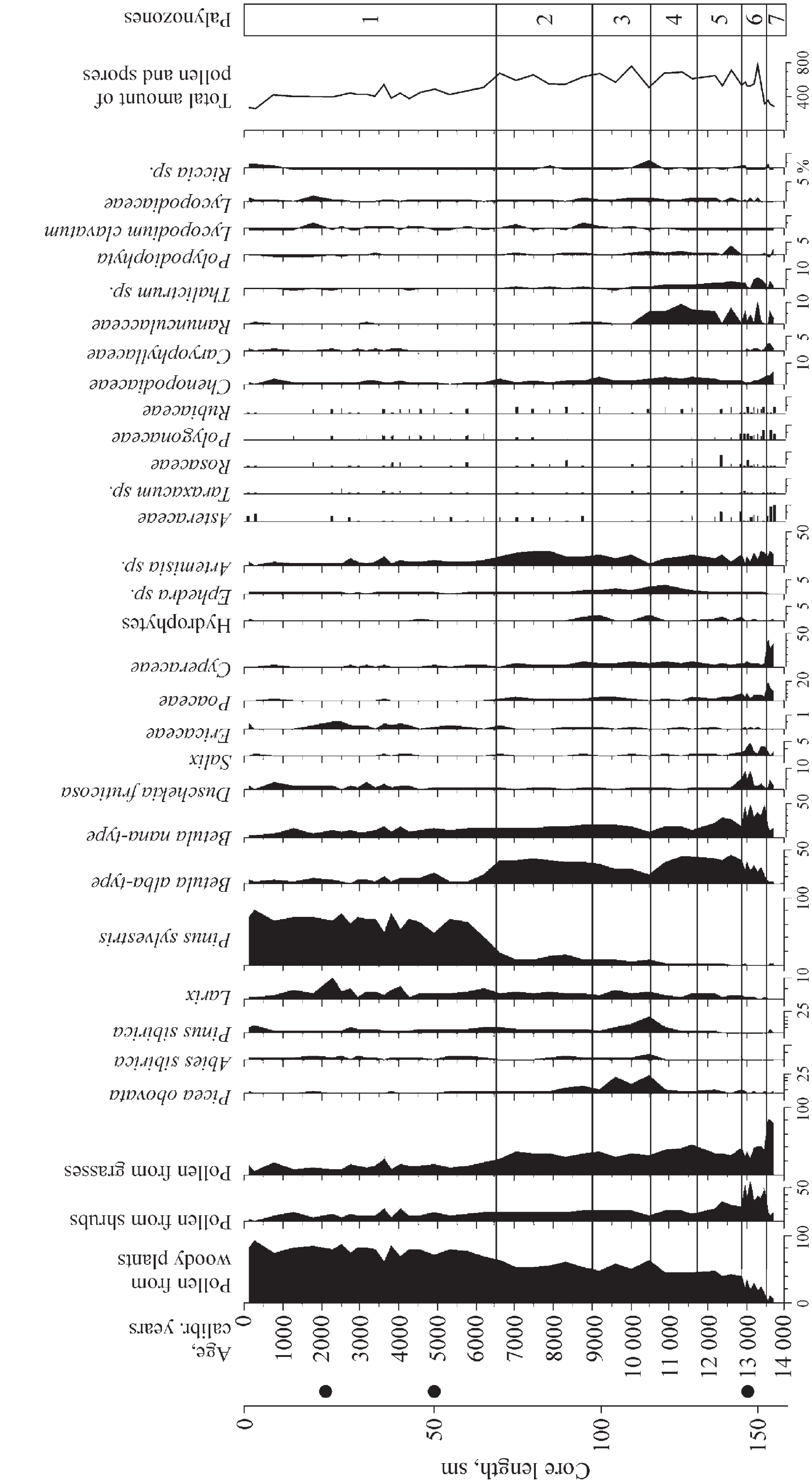

Fig. 2. Spore-pollen diagram of bottom sediments from Lake Arakhlei.
Dots correspond to the positions of levels as dated by the AMS ^{14}C method.

plants were forming areas of forest-tundras, while willow and shrub birch were producing shrub tundras. Emergence of Ephedra (joint-pine) in pollen spectra gives evidence of the occurrence of steppizated tracts. The climate continued cold and insufficiently wet. Chronologically, the deposits embedding SPS of zone 6 correspond to the time interval of climate bettering during the Allerød interstade [15].

A significant expansion of the forest associations consisting of dendriform birch and larch with the inclusion of spruce as well as with mesoxerophilic herbaceous communities (wormwood, and Ranunculaceae) came to be a characteristic feature of a next phase in the development of regional vegetation of the Beklemishevskaya depression, ~12 850–11 750 years ago (zone 5). A dramatic reduction in willow and alder associations is indicative of a decrease in wintertime atmospheric precipitation amounts, and an intensification of permafrost. On the chronological scale, this interval corresponds to the Late Dryas stadial [15]. The character of the reconstructed regional vegetation suggests that a worsening of climate at that time, which manifested itself globally [16, 17] and usually led to a reduction in forest vegetation, did not hamper in the Beklemishevskaya depression its progressive occurrence, although the climate was cold and insufficiently wet. It should be noted in this case that pollen from dendriform birch is dispersed by the wind over several tens of kilometers and is regarded as the indicator of regional vegetation [1, 18]. The content of pollen from larch in the SPS for this zone varies from 1 to 2.2%, while pollen from spruce varies from 5 to 6%. Even the presence of such a small amount of pollen from these woody plants is testimony to their considerable contribution to the vegetation composition nearby the profile. This inference is built upon the degree of representativeness of pollen from larch and spruce in regional SPS [19–20]. In addition to pollen from larch, it is though that the indicator of local vegetation is also provided by pollen from shrub birch, and of almost all grasses that are present in the SPS from deposits of that time [19, 20]. Consequently, over the course of the time interval similar to the Late Dryas, the composition of local vegetation nearby Lake Arakhlei was dominated by shrub and grass tundras with islands of forest-tundra vegetation consisting of larch and spruce. Birch groups were prevalent in the composition of regional vegetation. Comparison of the vegetation pattern of the Late Dryas in the Beklemishevskaya depression with Western Transbaikalia and Cisbaikalia shows that these regions were also dominated by forest-tundra associations with birch, spruce, larch, tundra groups of shrub birch, and by mesoxerophytic herbaceous associations. The difference lies in a more widespread occurrence of spruce forest-tundras in Western Transbaikalia and Cisbaikalia when compared with the Beklemishevskaya depression [17].

The period from ~11 750 to ~10 500 years ago saw a reduction in the areas occupied by shrub tundra groups of shrub birch (zone 4). There took place a decrease of the contribution from larch in the composition of woody vegetation. Mesoxerophitic herbaceous groups occurred nearby the lake. Dendriform birch became the main element of forest vegetation. The maximum of pollen from joint-pine can be used in reconstructing the expansion of areas occupied by semidesert-steppe vegetation. Such changes in the composition of vegetation give evidence of a short-lasting worsening of climate, and of a decline in available moisture for plants. On the other hand, a worsening of the conditions was taking place for woody vegetation within the Lake Okotel' watershed basin [21].

Onset of a moderately warm, wet climate in the Beklemishevskaya depression dates back to the time interval after ~10 500 years ago; it was marked by encroachment of woody vegetation dominated by larch, spruce and birch. High abundances of pollen from Siberian pine and fir give evidence of the most widespread (for the entire time interval (~10 500–9000 years ago) under investigation) occurrence of dark-coniferous forest vegetation in this area. Emergence of fir, the most sensitive element of woody vegetation of Siberia to changes in winter temperatures and to moisture content in soils and the air, serves as the indicator of the regional optimum of the Holocene. A warming of climate in the Beklemishevskaya depression at that period is also evidenced by an abundance in the lake of cenobiums of green algae of the genus Pediastrum. According to data reported by Vipper et al. [22], around 10 500 years ago, the wet, cold climate in Central Mongolia gave way to a warm, dry climate, which led to a shallowing of water bodies. The most widespread occurrence of dark-coniferous forests of spruce and fir with Siberian pine on the contiguous territory of Cisbaikalia also began 10 500–10 000 years ago [2, 22–24], signaling the onset of the most humid (for the Holocene) climate with a smoothed manifestation of seasonal contrasts (decreased continentality), and permafrost degradation. Completion of the maximum widespread distribution of dark-coniferous wet forest in the Beklemishevskaya depression occurred about 9000 years ago, although spruce continued to play a significant role nearly till 8000 years ago. On the territory of Cisbaikalia, the wet period of the Holocene with the most widespread distribution of spruce-fir forests came to a close later, 7000–6000 years ago [2, 25], whereas within the drainage basin of Lake Kokotel', spruce had degraded considerably more early — about 10 000 years ago [21], although somewhat increased abundance values of its pollen had been persisting till about 9000 years ago.

The composition of SPS from deposits that formed within the time interval from 9000–8000 to 6500 years ago suggests a worsening of the climatic conditions in the Beklemishevskaya depression. Furthermore, the areas of mesophilic dark-coniferous forests dwindled. Spruce, as is the case nowadays, had already existed in the form of an inclusion in the composition of larch forests. Regional vegetation came again to be dominated by larch and birch groups with a contribution from

Scots pine. Nearby Lake Arakhlei there could locally occur larch stands with mesoxerophytic forbs, while the lake's shore areas were occupied by waterlogged yernik groups.

About 6500 years ago there occurred a dramatic change in the composition of dominants of the forest complex in the Beklemishevskaya depression. Birch-larch forests were replaced by pine-larch forests (zone 1) of the contemporary pattern. Light-coniferous taiga vegetation of pine and larch began to play a dominant role. Rapid pine encroachment at that time has also been pointed out for the drainage basins of the other lakes in Transbaikalia [5]. The entire set of palynological data gives evidence for the transition of the climate of the Beklemishevskaya depression to a less wet and more continental climate. Encroachment of Scots pine onto a huge territory adjacent to Lake Baikal 7000–6000 years ago has been treated as a transitional period in the Holocene [2, 25]. By reconstructing the climate for the Lake Baikal and Hovsgol watersheds, it was shown that Scots pine encroachment began under conditions of rising mean winter and summer temperatures and, on the contrary, with a considerable decrease in the mean annual amount of atmospheric precipitation subsequent to 7000 years ago [24–26]. Consequently, the climate of the Beklemishevskaya depression also became considerably more arid, with sharply contrasting mean temperatures for summer and winter seasons. A strong reduction of larch forests around Lake Arakhlei during the last several hundred years could be the result of anthropogenic pressure on this territory.

CONCLUSIONS

A new palynological record from bottom sediments of Lake Arakhlei, dated by the method of acceleration mass spectrometry (^{14}C), was instrumental in re-constructing the dynamics of the climatic conditions, and of local and regional vegetation in the Beklemishevskaya depression and nearby the lake, and in identifying the main instants of its successional changes for the last more than 13 500 years.

Prior to 13 500 years ago, the vegetation cover of this territory had exhibited a mosaic pattern, a combination of wet waterlogged and steppizated groups under cold climate conditions with insufficient atmospheric humidification, and with high soil moisture content. This might have been associated with the occurrence of permafrost serving as the soil moisture in the summertime.

With a warming about 13 500–12 800 years ago, similar in time to the warm Allerød interstade, the study territory began to be colonized by woody and shrub vegetation, with larch and birch predominating. Spruce occupied very small areas, although its contribution was larger when compared with contemporary vegetation. Over the course of the time interval ~12 850–11 750 years ago, similar to the Late Dryas, the composition of local vegetation nearby Lake Arakhlei was dominated by open spaces of shrub and grass tundras, with the inclusion of larch and spruce. Birch groups were prevalent in the composition of regional vegetation. Comparison of the vegetation pattern of the Late Dryas in the Beklemishevskaya depression with Western Transbaikalia and Cisbaikalia shows that spruce forest tundras were of less widespread occurrence in the Beklemishevskaya depression.

In the Beklemishevskaya depression, a moderately warm, wet climate set in after ~ 10500 years ago, causing a widespread occurrence of vegetation consisting of larch, spruce and birch. Most likely the lake was becoming shallow and being overgrown with vegetation as evidenced by the development of colonies of Pediastrum algae. The vegetation composition exhibited a declining role of shrub birch, coupled with an enhancement in the contribution from dry-steppe herbaceous taxa – joint-pine, and wormwood. The most widespread occurrence of dark-coniferous forest vegetation of Siberian pine and spruce, with the possible inclusion of fir, corresponded to the period ~10 500–9000 years ago, implying the onset of a regional optimum with mild and snowy winter seasons, and with high moisture content in soils and the air. The end of the maximum occurrence of dark-coniferous wet forests in the Beklemishevskaya depression about 9000 years ago coincided with its completion in neighboring areas.

Change in the reconstructed vegetation composition dating back to 9000–8000 – 6500 years ago, when larch and birch groups with the inclusion of Scots pine came to be dominant, suggests a worsening of the climate in the Beklemishevskaya depression. About 6500 years ago there occurred a change in the composition of the dominants within the forest complex of the depression, from dark-coniferous to light-coniferous thus giving rise to the formation of the appearance of landscape similar to today's one. A leading part was played by pine and larch. The start of pine encroachment onto the study territory coincided with its widespread colonization of the entire Siberian region, the fact which allows a global change in the climatic system to be regarded as the chief cause for variability in the natural environment of the Beklemishevskaya depression.

The reconstructed changes in the natural environment of the Beklemishevskaya depression are generally in good agreement with its variations in neighboring areas of Central Asia. Further investigation into new sections to obtain more detailed records of changes in vegetation and climate, and a number of new determinations of absolute age will give an elucidating glimpse into the behavior of changes in the regional natural environment as well as the place of these changes in the global climatic system.

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