======================= **GEOLOGY** =======================

Reconstructions of Paleoecological and Paleoclimatic Conditions of the Late Pleistocene and Holocene according to the Results of Chironomid Analysis of Sediments from Medvedevskoe Lake (Karelian Isthmus)

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Abstract—The use of chironomids (Diptera: Chironomidae) as indicators of changes in natural and climatic settings allows one to reconstruct paleoclimatic and paleoenvironmental conditions. Based on the results of lithological and chironomid analyses, the loss on ignition (LOI) values, as well as the results of radiocarbon dating (^{14}C AMS), new data on the paleoclimate in the Karelian Isthmus, in particular the quantitative reconstruction of the mean July temperature (T_{July}, °C) in the Late Pleistocene and Holocene and the evolution of the ecosystem of Medvedevskoe Lake have been obtained.

Climatic processes during the Late Pleistocene–Holocene transition in the area of the Karelian Isthmus have been previously studied in detail [1–5]; however, data on the paleoclimate in the Holocene in this region are scarce [6].

Deglaciation of the Karelian Isthmus occurred during the retreat of glaciers at the Luga and Neva stages of the Upper Valdai Glacial [4]. The central part of the Karelian Isthmus became open from ice before 13.6 ka and represented a hill (nunatak) above the glacier surface with small inland lakes [1], the study of which is of particular importance, since they are characterized most likely by continuous sedimentation in comparison with other areas of the Isthmus, which were repeatedly flooded by the waters of the Baltic Sea and Lake Ladoga [1].

Our study aimed to reconstruct the paleoecological and paleoclimatic conditions in the Karelian Isthmus during the Late Pleistocene and Holocene based on the data on the organic matter content and the results of biological analysis of bottom sediments from Medvedevskoe Lake. Chironomids (Diptera: Chironomidae) and statistical models based on extensive databases on ecological parameters and the taxonomic composition of chironomids of lakes of Northern Russia were used as an indicator group [7, 8].

In the spring periods of 2012 and 2014, two cores of bottom sediments (BS) were collected on Medvedevskoe Lake (60°31′51″ N, 29°53′57″ E, 102.2 m a. s. l., an area of 0.44 km², maximum depth of 4 m) (Fig. 1). The samples of sediments were analyzed using the loss on ignition (LOI) method to estimate the organic matter and carbonate content in lacustrine sediments (LOI, %) [9] and were dated using accelerator mass-spectrometry (^{14}C AMS). According to the radiocarbon data analysis and the LOI values, a BS composite column was compiled.

Chironomid analysis was performed following the standard procedure [10]. Reconstruction of the paleoecological conditions and the mean July air temperature (T_{July}) was performed using the Northern Russian chironomid-based data set and inference models [11]. Percentage stratigraphic diagram was made in C2 version 1.5 [12]. Cluster analysis and the principal com-

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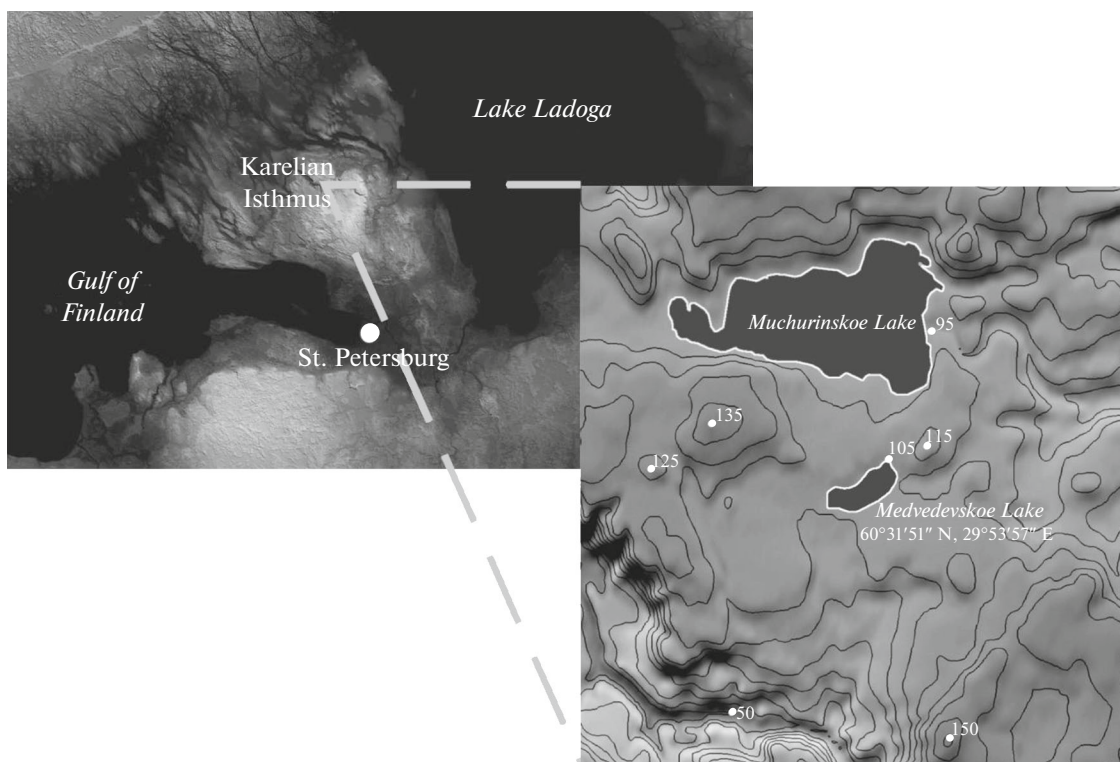*e-mail: lyudmilalsd@gmail.com*

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Fig. 1. The locality of Medvedevskoe Lake on the Karelian Isthmus.

ponent method (PCA) were performed using the PAST program software [13].

RESULTS

The bottom sediments of Medvedevskoe Lake are represented by Late Glacial gray sands, clays, and Holocene dark-brown organogenic silt. The age of sediment cores covers the Late Glacial and Holocene. The microscopic glass from the Vedde volcanic ash (12 ka) [5, 14] and traces of a meteorite impact that happened about 12.9 ka ago were identified [5]. Cluster analysis made it possible to distinguish four statistically significant zones, which are well correlated with the PCA 1 axis, reflecting variations in the taxa composition of chironomids.

Zone 1 (460–496 cm; 12.1–10.2 ka). LOI values are extremely low (median value 7.0%). Low-temperature taxa predominate (*Micropsectra insignilobus*-type, *Sergentia coracina*-type, *Heterotrissocladius maeaeri*-type 1, *Zalutschia* type B). Acidophilic (*S. coracina*-type, *H. maeaeri*-type 1, *Psectrocladius sordidellus*-type), or acidophobic (*M. insignilobus*-type) taxa are alternately dominated. *Smittia* a taxon associated with erosion processes, was found in the lower horizons.

The reconstructed T_{July} varied from 12 to 14 ± 1.1°C (mean value 13.0°C).

Zone II (420–460 cm; 10.2–8.5 ka). LOI values gradually increase (median value 23.7%); the species diversity increases, and the complex of dominant chironomid species changes. Oligotrophic *S. coracina*-type, *M. insignilobus*-type, and *H. maeaeri*-type 1 disappear. *Corynocera ambigua* dominates. There was the first occurrence of the *Microtendipes pedellus*-type, which is regarded as an indicator of moderate temperatures [10] and an increase in the number of phytophilic taxa (*Dicrotendipes nervosus*-type, *Zalutschia zalutschicola*, etc.). The *T* July temperature varied from 12.5 to 15.0 ± 1.1°C (mean value 13.8°C).

Zone III (340–420 cm; 8.5–3 ka). LOI values are maximal (median 72.7%). The number of *C. ambigua* decreases, while that of the *M. pedellus*-type and *D. nervosus*-type increases. The first occurrence of *Procladius* indicates an increase in trophicity and a decrease in the amount of dissolved oxygen [10]. After 4 ka there was a decrease in the amount of the thermophilic *M. pedellus*-type and *D. nervosus*-type and an increase in cold-water *Heterotanytarsus*. The temperature in July (T_{July}) varied from 13.7 to 15.2 ± 1.1°C (mean value 14.5°C).

Zone IV (260–340 cm; after 3 ka). The LOI values are high (median value 78.8%); in the upper horizon, a decrease to 42.8% was recorded. The fauna is characterized by a predominance of the thermophilic *D. nervosus*-type and the acidophilic *P. sordidellus*-type. In the middle of the zone, *Heterotanytarsus*,

Table 1. Reconstruction of natural and climatic settings on the Karelian Isthmus in the Late Pleistocene and Holocene

| Age, ka.	T_{july}, °C	Catchment	Soil cover	Vegetation	pH	Trophicity	Lake productivity	Taxa diversity	Dominants
0–3000	13.2–14.3	Overgrowing of coastal zone, coastal bog development	Developed soil cover	Boreal forests	Acidification	Mesotrophic	High	High	Moderate, mesotrophic
3000–8500	13.7–15.0				Acidification	Mesotrophic		High	Thermophilic, mesotrophic
8500–10200	12.5–15.2			Boreal forests with occurrence of pine, birch, elm, gray alder, hazel	Gradual pH change towards acidification, neutral–weak acid	Increase in trophicity		Increase	Moderate and mesotrophic
				Degradation			Degradation		
10200–12100	12.0–14.0	Overgrowing of coastal zone	Develomnent of soil cover	Birch-and-pine open woodland	pH change, alkaline–neutral	Oligotrophic	Rapid growth	Low	Cold-water oligotrophic
				Grass–dwarf shrub communities with sparse birch forest			Growth		
		Erosion processes	Permafrost	Tundra–steppe with grass–dwarf shrub communities					
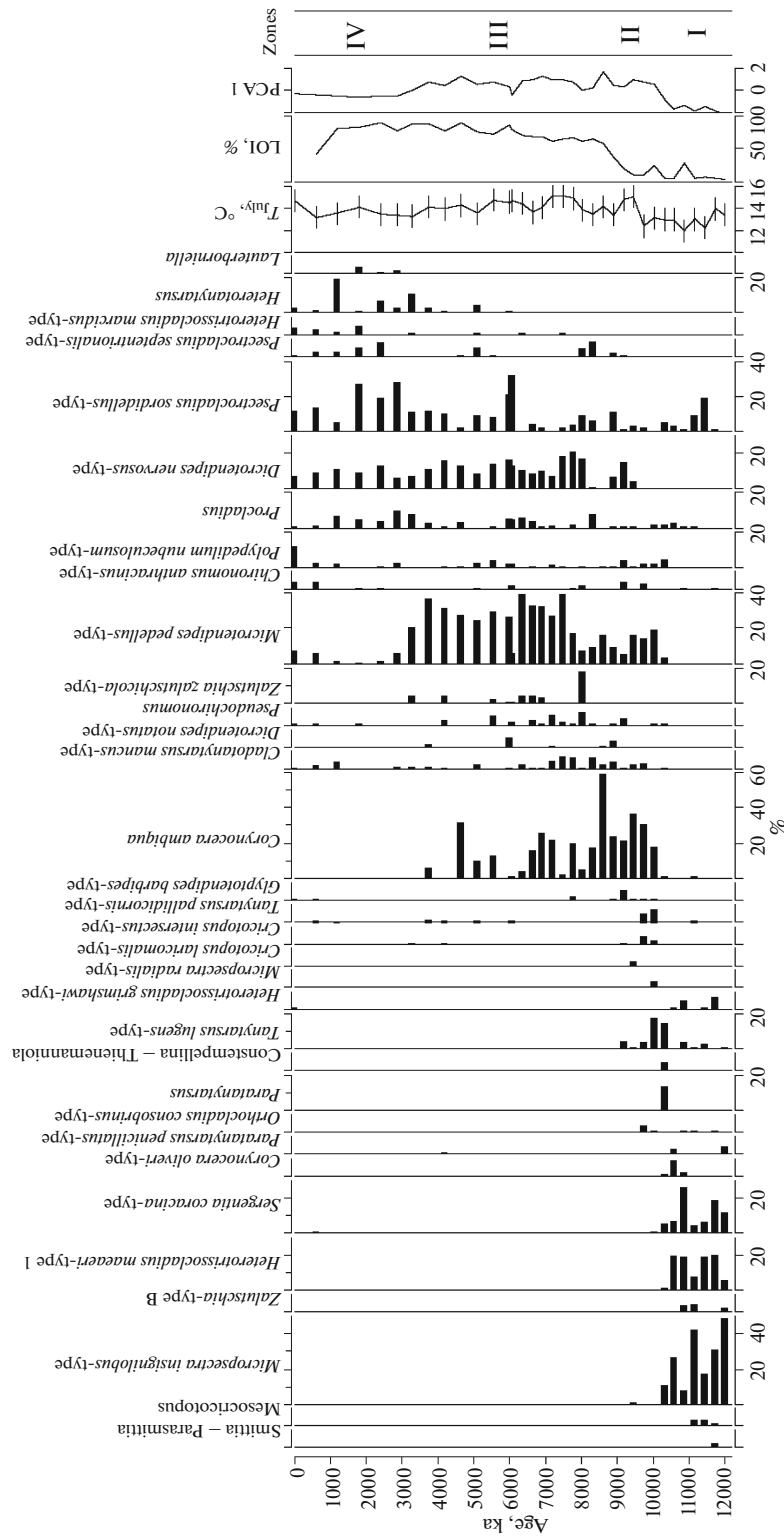
Fig. 2. Stratigraphic distribution of chironomid taxa in bottom sediments of Medvedevskoe Lake, LOI, %, and values of the PCA 1 axis.

associated with oligotrophic humic waters, was identified. T_{July} varied from 13.2 to 14.3 ± 1.1°C (mean value 13.6°C).

DISCUSSION

Prior to 12.65 ka, the climate in the Karelian Isthmus was arctic, cold, and dry. The central high represented an island washed by the cold waters of the Baltic glacial lake. Medvedevskoe Lake was shallow and was not clear of ice every year [1, 4].

During the Late Glacial-Holocene transition, the development of the lacustrine ecosystem started (Table 1) (12.1−10.2 ka). The predominance of cold-water taxa and the extremely low LOI values indicate that in this period the water reservoir remained oligotrophic under cool climatic conditions (Fig. 2). The occurrence of semi-aquatic taxa and the changes in acidophilic and acidophilic dominants indicate the instability of the lake level, which was dependent on the amount of precipitation and permafrost thaw, causing bogging of the coastal zone and the supply of humic acids from the catchment area [15].

After 10.2 ka significant changes in biological communities and a gradual increase in the content of organic carbon in bottom sediments ($C_{org} > 20\%$) occurred. Cryophilic taxa were replaced by inhabitants of waters with moderate and mesotrophic conditions. The climate became warmer; the surface runoff intensity decreased, and the lake trophicity increased.

The warm climatic conditions did not change throughout the entire period from 9 to 4 ka, which could be associated with the Holocene Climate Optimum. After 4 ka there was some cooling; at about 3000 ka, the climatic conditions became close to modern ones.

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