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Reconstruction of Holocene environmental conditions based on the complex studies of Lake Shnitkino sediments (Tver Region, Russia)

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ABSTRACT. The presented study aims to investigate the paleoenvironmental conditions of Lake Shnitkino in Tver Region (northwestern European Russia). Two sediment cores from the lake bottom were obtained and analyzed using lithological and paleobotanic methods. The Holocene landscape and climatic characteristics of the lake basin are reconstructed. Four stages of lake evolution were inferred: 1) Younger Dryas/Preboreal transition, 2) Boreal, 3) Middle-Late Holocene, and 4) Recent time.

Keywords: limnology, lithostratigraphy, pollen analysis, bioindicators, Late Glacial/Holocene transition

1. Introduction

This work aims to reconstruct the Holocene limnologic features of Lake Shnitkino. Landscape dynamics and climatic conditions influenced the reservoir conditions and its catchment area on a regional scale. Locally the lake is strongly connected with the fluvial system. Lake Shnitkino is located in northwestern European Russia in the upper reaches of the Zapadnaya Dvina (Daugava) River. The Toropa River – a right tributary of Daugava – flows through Lake Shnitkino from the north to the south. The paleoenvironmental changes of the studied area were investigated during geoarchaeological research near the medieval site Shnitkino.

2. Materials and methods

Key site and regional settings. Lake Shnitkino is 4 km long and up to 0.8 km in width. The maximum depth of the lake is 2m. The lake has many small tributaries and the main tributary is the Toropa River. The lake is acting as a local basis for the Toropa River, causing the accumulation within its inflow into the lake. The surroundings of the river-lake system are the Late Pleistocene hilly plains with kames, and swampy meltwater depressions.

The fieldwork was performed in 2020 and analytical work during 2020-2022. The fieldwork included lake-bottom sediment coring using an Eijkelkamp manual auger. Sediment core profiling with a lithostratigraphic description of eight cores was made and representative cores 20770 and 20769 were sampled for lithological (grain size, loss on ignition, and magnetic susceptibility analyses), pollen analysis, and the study of the biological composition of sediments. The core 20770 is 8.5m long. It is located in the central part of the northern Shnitkino lake basin and is composed fully of massive or laminated lacustrine sediments. The core 2069 is 5m long. It is located closer to the shoreline and composed of lacustrine and alluvial deposits.

The grain size analysis (GS) was carried out with laser diffractometry using a Malvern Mastersizer 3000 instrument. The particle size distribution was calculated based on the Fraunhofer diffraction model (Konert and Vandenberghe, 1997). Concentrations of organic matter and CO_2 from carbonates were determined by loss on ignition (LOI) followed the procedure by Heiri et al. (2001). Magnetic susceptibility (MS) was measured by a portable susceptimeter ZHinstruments SM-30 for the stratigraphic analysis of deposits. This characteristic depends on the concentrations and occurrence of magnetic particles. All the lithological methods were applied to deposits of the core 20770 to a depth of 0-6.5 m, each 10 cm.

Pollen analysis was carried out for 16 samples from the core 20770. Separation with heavy liquid (2.25 g cm–3) was used for pollen extraction from sediments. Calculation of pollen percentages was based on the total terrestrial pollen and spores sum.

Analysis of the composition of aquatic plant and animal organisms accompanied by their ecological analysis was applied for the reconstruction of lake and

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mire environments using the technique developed by N.V. Korde (1960). Analysis of bioindicators was made for two samples from the core 20769, but it can be correlated with the data on the core 20770. Sample 9 from the depth of 3.1-3.2 m and sample 10 from the depth of 3.25–3.35 m in core 20769 bracket a clear stratigraphic boundary at 3.21 m between silt and sapropel (gyttja). This boundary is also well defined in the core 20770 at a depth of 5.5 m.

3. Results and discussion

The results of lithological analysis of sediments from the core 20770 allow identifying some features of sedimentation and landscape dynamics. Moreover, analytical results agree with the beds identified in the description.

Coarse silt (0.01-0.05 mm) is a modal fraction of sediments, it dominates in all samples, except for the first. The proportion of fine silt and clay (0.005-0.01 mm) tends to increase with a depth. Two clear boundaries, marked by a change in granulometric composition, are 1) the transition from silt to sapropel at 5.5 m and 2) the coarsening of sapropel composition at 4.45 m.

The coarsening of the grain composition over geological time indicates either a decrease in the depth of the lake or a more active supply of the sandy component with runoff. This input may be the result of a restructuring of the meandering channels of the Toropa River or anthropogenic activities in the watershed that stimulate erosion.

The value of LOI 550°C varies in the range of 3.3-44%, with a maximum at 2.2 m depth in sapropel, and a minimum at 6.45 m depth in silt. That indicates the most organic-rich beds in the upper part of the core. The value of LOI 950°C changes in the range of 0.6-16.7%, with a maximum at 5.55 m depth in the roof of the silty layer, and a minimum at 1.45 m depth in sapropel. Loss on ignition also emphasizes only the boundary at 5.5 m noted above.

Magnetic susceptibility (MS) varies in the range of 0.035-0.138*10^{-3} SI and generally decreases upwards. The saturation with magnetic minerals is higher in silt.

The results obtained for core 20770 indicate changes in sedimentation, as well as granulometric, chemical, and magnetic properties of sediments, sharply occurred at 5.5 and 4.45 m depths. The boundary at 5.5 m can be interpreted as a transition from mineragenic to organogenic sedimentation, which occurred at the turn of the Pleistocene and Holocene in lakes of the European part of Russia. Within the northwestern Russian Plain, predominantly mineragenic sedimentation often continued at the beginning of the Holocene, and a rapid change to the organogenic accumulation occurred after 10 cal. kyr BP (approximately at the Preboreal/Boreal boundary) both in large relict and small lakes (Subetto, 2009).

The results of pollen analysis of samples from the core 20770 confirm the correlation of the lacustrine silt layer at a depth of 6.5-5.5 m with the end of the Late Glacial (or the Younger Dryas). The pollen spectra here demonstrate all the characteristic features of this interval: Non-Arboreal Pollen (NAP) makes up to 20% of the spectra, it contains a noticeable proportion of *Artemisia* and Chenopodiaceae pollen and a great variety of meadow plants. Simultaneous findings of pollen from the typical xerophyte *Ephedra*, heliophyte *Helianthemum*, and spores of such a cryophilic plant as *Selaginella selaginoides* are also indicative. Arboreal Pollen (AP) is represented by boreal tree species (*Betula sect. Albae, Pinus, Picea, Salix*) and microthermal shrubs (*Betula nana, Alnaster fruticosus*, etc.). Among aquatic plants, only the hardiest ones were noted, such as *Potamogeton, Myriophyllum*, and *Ceratophyllum* (leave spines).

The layer at a depth of 5.5-4.5 m is quite comparable in terms of pollen composition with the Boreal layers in this region. AP increases to almost 90% of the spectra and is represented mainly by birch and pine pollen. The amount of spruce pollen drops sharply, and pollen of broad-leaved species of oak forests appears (*Ulmus, Quercus, Tilia, Fraxinus*), as well as pollen of shrubs characteristic of the undergrowth in such forests: *Corylus, Lonicera*, etc. The proportion of spores of Polypodiaceae ferns is increasing; pollen of more heat-loving aquatic plants, such as *Nuphar, Hydrocharis*, occur here.

In the organic-rich sediment at a depth of 4.5-0.75 m, the composition of pollen spectra reflects further warming, probably accompanied by some decrease in climate continentality. The share of pollen of broad-leaved species increases, pollen of *Acer, Carpinus, Myrica* is noted; the proportion of alder and hazel pollen increases. The composition of aquatic plants becomes richer: pollen of *Nymphaea alba, N. candida, Trapa natans* is registered.

The pollen spectra of the upper 0.75 m of the sediment are close to those described above, however, there are some signs of anthropogenic impact: pollen of Cerealia and herbaceous plants, which can be considered weeds, appear: *Plantago, Rumex, Cannabis*. The share of NAP slightly increases, along with that of pine pollen, which may be associated with the cutting down of broad-leaved forests.

Analyses of biological composition confirmed quite different limnological and ecological conditions within sapropel at 3.10-3.20 m (sample 9) and silt at 3.25-3.35 m (sample 10) from the core 20769. In the first stage, the lake was much shallower, the water was rich in carbonates and contained less nutrients, as indicated by the abundance of the calcite-loricated alga *Phacotus lenticularis* and Ostracod shells. In the second stage, the water depth and the productivity of the lake increased, possibly as a result of the inflow enriched with nutrients, which is indicated by a greater diversity of algae and higher plant remains in sediment.

Combining all the proxies (GS, LOI, MS, pollen, bioindicators) we can distinguish four lithostratigraphic units corresponding to the main stages of Lake Shnitkino evolution in the Holocene: 1) Younger Dryas/Preboreal transition, 2) Boreal, 3) Middle-Late Holocene, 4) Recent time.

4. Conclusions

Based on all the data obtained we can reconstruct the landscape and climate dynamics of the lake Shnitkino basin. Four lithostratigraphic divisions with different granulometric, chemical, pollen, and biological composition are inferred. 1) Younger Dryas/Preboreal transition, 2) Boreal, 3) Middle-Late Holocene, 4) Recent time.

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Conflict of interest

The authors declare no conflict of interest.

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