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The changes in the composition of Cladocera community in bottom sediments of Lake Maloye Shibrozero (Zaonezhsky Peninsula) as a consequence of shifts of environmental and climatic conditions

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Abstract. The study aims to explore the evolution of lakes of the boreal zone during the late- and postglacial time on the south-eastern periphery of the Fennoscandian crystalline shield since the last deglaciation. In order to reconstruct the past for virgin territories of the Zaonezhsky Peninsula current investigation on bottom sediments of Lake Maloye Shibrozero was conducted. Analyzes were performed using the new paleoindicator – subfossil remains of Cladocera (Cladocera, Branchiopoda). The 28 samples of bottom sediments were analyzed. It has been determined that discovered Cladocera remains belong to representatives of 6 families and 38 taxa. Species inhabiting Palaearctic zone are predominant in lake deposits; most of the identified subfossil remains are related to the pelagic species inhabiting the open part of the lake. According to the Lubarsky scale the dominant of Cladocera community is *Bosmina* (*Eubosmina*) cf. *longispina*. Secondary taxa are *Chydorus sphaericus*, *Bosmina coregoni*, *Alonella nana*, *Alona guadrangularis*, *A. affinis*, *Chydorus gibbus*. At a depth of 650-653 cm, a partial replacement of *Bosmina* (*Eubosmina*) cf. *longispina* by *Bosmina coregoni* takes place with a simultaneous increase in the significance of *Chydorus sphaericus*, which is used to be an indicator of eutrophication and increasing trophic status of the reservoir. *Changes in Cladocera community could be attributed to decreasing the level of periglacial lake, as a result of which the Lake Maloye Shibrozero became a small isolated lake with the trend to* trophic status *increasing.* Cold-water species were replaced by thermophilic ones with a further return to a cold-water fauna. In the upper layers of the column an increase of the number of phytophilous species is noted.

1. Introduction

The problem of climate change is of particular relevance in view of the real threat not only for the economic sector, but for the life and wellbeing of the population, preservation of the biological diversity and ecological balance. Numerous studies on climate and ecological conditions changes during the past, which were and are being conducted worldwide, allow us to create models of future climate change, therefore database of regional environmental reconstructions is to be constantly added and updated.

Bottom sediments of lakes are the archives, which layers contain the information about the environmental conditions of the past on regional and global scale with a resolution from the millennia and centuries to the year [1]. One of the methods of paleolimnology is paleoindication based on the analysis of qualitative and quantitative content of remains of animal (Chironomidae, Ostracoda, Cladocera) and plant organisms (spores and pollen, diatoms) of bottom sediments.

Zooplankton, such as Cladocera, is a key component of aquatic ecosystems [2, 3]. Its distribution in the lake is strongly related to abiotic and biotic factors [4]. Cladocera analysis, as the most recent paleoindicator, has already had time to prove to be a reliable and successful way to reconstruct past conditions [3, 5]. For studies related to global change biology, fossil assemblages and paleolimnological methods provide a unique and invaluable source of information through the long-term perspective of ecosystem dynamics that cannot be resolved by monitoring data, which usually consist of only few years or decades of monitoring [6-8]. Chitin structure of Cladocera exoskeleton (headshields, carapacse, postabdomens, postabdomenal claws, etc.) are saved in bottom sediments of lakes, generally in a good state of preservation that allows to identify them to species and on the basis of obtained data reconstruct changing conditions of the past [3, 9].

Regions that are remote from the direct anthropogenic influence are indicator-regions, that carry reliable information of the changes of the environmental and climatic conditions. The category of weakly disturbed areas include the Zaonezhsky Peninsula which is situated on the northern coast of Lake Onega.

Using the method of Cladocera paleoindication the study of Maloe Shibrozero Lake (figure 1) on the Zaonezhsky Peninsula was carried out. According to the glacial theory during the Quaternary period the territory of the Fennoscandian shield area of 1.7 million km^2 repeatedly was exposed to strong covering glaciations and was the center of the European continental glaciation with the ice thickness of 3.5-4 km [10]. The transition from cold and dry climate of the late Pleistocene to the warm and humid conditions of the Holocene led to the changes in the natural environment both in the catchment areas of lakes and aquatic ecosystems [1].

Figure 1. Location of Maloe Shibrozero Lake (The Republic of Karelia, Russia).

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The first fragmentary information about the rivers and lakes of the Karelia Republic was obtained in the 1920s and 1940s. In the early 1960-ies, the hydrographic studies of Zaonezhsky Peninsula was obtained by the water problem unit of the Karelian Branch of the USSR Academy of Sciences (now Northern Water Problems Institute, Karelian Research Centre of Russian Academy of Sciences) [11]. Introduction of a new method in paleoenvironmental and paleogeographic reconstructions provided additional information about the development of the aquatic ecosystems in post-glacial time and ecological and climatic situation of the region as a whole.

2. Material and methods

The Zaonezhsky Peninsula is located in the middle taiga subzone of the Karelia Republic, in the Northern Prionezhskiy geobotanical district, the vegetation of which is characterized by a great originality. Spruce forests take precedence over the pine [12].

The topography of the Peninsula is characterized by the presence of alternating long, narrow ridges and long, narrow depressions, presently occupied by lakes [13]. The western part of the Zaonezhye, where is Maloe Shibrozero Lake is located, is a typical area of selka tectonic denudation topography with its Quaternary period ice sheet structure. There is a system of ridges, oriented in the north-western direction, with a relative excess over the level of the lake up to 120 m [12].

Most of lake depressions of the Zaonezhye are formed by tectonic subsidence, glacial tectonics or other glacial processes. They differ considerably in their morphometric and hydrological indices. Water area of lakes varies from less than 0.01 to 30 km^2. Commonly the basins are highly elongated, sometimes dozens of kilometers long and no more than several hundred metres wide [11]. Extremely elongated lakes are relatively uncommon, occurring only in northern Scotland, northwestern England (Camberland Plateau) and northwestern Central Siberia (Putoran Plateau) [14].

The climate of Karelia has its own characteristics that distinguish it from other ecologically valuable areas of the Republic of Karelia. The average annual temperature in Zaonezhye is positive and amounts to 2.3 °C. The coldest month is February (average temperature is -10.2 °C - -11.0 °C), the warmest is July (average temperature is 15.8 °C -16.7 °C) [15].

On April of 2015, within the field works on the Zaonezhsky Peninsula, 6,15 m long of Maloe Shibrozero Lake sediment cores (N 62° 22.346', E 35° 12.660', 56.5m a.s.l., the area is 0.076 km^2, depth – 3.1 m) were recovered (figure 1), which once was a former part of Lake Onego. The expedition was carried out jointly with Northern Water Problems Institute, Karelian Research Centre of Russian Academy of Sciences (Petrozavodsk, Russia), Kazan (Volga region) Federal University (Kazan, Russia), Herzen State Pedagogical University of Russia (St.Petersburg, Russia) and University of Tartu (Estonia, Tartu).

Lithostratigraphic analysis of bottom sediments, analysis of ionic composition and gas mode were conducted. Samples for spore-pollen, diatoms, Chironomidae and Cladocera analysis were collected.

Water samples were taken from the surface, bottom and supernatant horizons. The component ratio of the ionic composition of the water classifies it as a hydrocarbonate group of magnesium, calcium. Supernatant water is characterized by a slight increase in the content of calcium, bicarbonates and pH (average in the lake - 6.81, in supernatant water - 7.45). According to these performances, the reservoir corresponds to moderate alkaline weak-acid neutral waters, supernatant water is classified as a moderate alkaline neutral weak-alkaline water. According to the results of the analysis, rising of the concentration of carbon dioxide, organic substances, ammonium ions, nitrates, iron, manganese and silicon from the surface to the bottom was observed. The content of nutrients indicates a mesotrophic status of the reservoir. There is a decline in the oxygen content with depth: 0.5 m -8.23 mg·L^{-1}, 1 m - $\frac{7}{26}$ mg·L^{-1}, 2 m - $\frac{5}{7}$ mg·L^{-1}, 2.5 m - 4.1 mg·L^{-1}.

According to the lithostratigraphical description the colour of brown organic homogeneous gyttja at a depth of 6.50 m from the surface of the lake turns greyer, indicating an increase of the content of mineral component in the sediments. At a depth of 6.75 the transition interval is noted - layered grey-brown silt with inclusion of plant remains (mosses), the thickness of the layers is different. Greybrownish clay gyttja occurring at a depth of 7.05 m, at a depth of 7.26 m turns to the dark grey silty-clay gyttja, and then at a depth of 7.50 m to grey layered sandy gyttja. Transitional zone, represented by streaky grey silt with black organic layers, is observed at a depth of 7.78 m. Sandy grey streaky clay with interlayers of hydrotroilite presented at depths of 7.82 – 8.01 m become more sandy moving down the column of bottom sediments– sandy layers reaches 4 cm in thickness. At the same depths the silt layers up to 4 cm are noted. At a depth of 9.40 m, the clay layers become lighter, layers become thinner. At depths of 9.70 – 9.95 m thin-bedded layer of pink clay is observed, which turns to the grey well-laminated clay.

Sand band between grey clays and overlying brown silts indicates the presence of a very sharp boundary between grey glaciolacustrine sediments and lacustrine Holocene sediments, that is the result of interruption of sedimentation due to a catastrophic drop in the water level of the Baltic Ice Lake at the boundary between the late Pleistocene and Holocene. A decrease in the level of lakes that are located within the catchment basin of the Baltic was caused by these changes [16].

The age of a pink banded clay horizon ("pink horizon"), which is used to be a stratigraphic marker of the Onego periglacial lake sediments and formed by diagenetic changes of sediments during the sharp fall of the Onega lake level, is about 11 300 years [17]. "Pink horizon" in Maloe Shibrozero Lake is noted at a depth below 970 cm from the lake surface.

The sample preparation and analysis of samples were carried out in the laboratory of "Paleoclimatology, paleoecology, paleomagnetism" of the Kazan Federal University. Samples were investigated under a light microscope Axiostar Plus Carl Zeiss at magnification x100-400. In each sample were identified at least 100 remains. Identification was carried out using specialized determinants of subfossil [18] and modern Cladocera [19]. Two half shells of the carapace were counted as an integral organism.

Analysis of changes in diversity of biotic groups is made using indices that determine the degree of species richness, diversity and dominance of Cladocera communities: index of Shannon-Weaver, index of uniformity of ecological groups of Pielou. The investigation included the values of saprobity index of Pantle and Buck. In order to identify classes of the dominance the scale of Lubarsky was used. Statistical and stratigraphic analyses implemented in the program C2 of S. Jaggens.

3. Results and discussion

According to the results of subfossil Cladocera analysis 3297 chitinous remains of Cladocera exoskeleton were detected and identified to generic assignment (*Eubosmina sp*., *Eurycercus sp*., *Pleuroxus sp*., *Simocephalus sp*., *Ceriodaphnia sp*.) and species. It was established that remains discovered in 28 bottom sediment samples belong to the representatives of 38 taxa and 6 families (Bosminidae, Chydoridae, Daphnidae, Polyphemidae, and Sididae, Leptodoridae).

Qualitatively species inhabiting the Palearctic (57.6 %) zoogeographic zones are dominated in Maloe Shibrozero Lake, the occurrence of species with cosmopolitan (22.17 %) and Holarctic (20.2 %) distribution is roughly equal. The majority of the identified remains are pelagic species inhabiting the open part of the reservoir (54.8 %). However, the high taxonomic diversity comes from species preferring overgrown, silt-covered or sandy areas.

According to the Lubarsky scale the dominant of Cladocera community is *Bosmina* (*Eubosmina*) cf. *longispina* (43.8 %). Among the secondary taxa are the following: *Chydorus sphaericus* (11.67 %), *Bosmina coregoni* (8.92 %), *Alonella nana* (5.7 %), *Alona guadrangularis* (5.61 %), *A. affinis* (5.06 %), *Chydorus gibbus* (3.88 %) (figure 2).

Bosmina (*Eubosmina*) cf. *longispina* might be present in the littoral zone, however, its volume in the pelagic zone, where *Bosmin*a forms a massive group, far exceeds the littoral zone, that taking the tanatocenosis of *Bosmina* for a pelagic group is fully justified. *Bosmina* have the age-related changes in the valves and the headshields form, which raises questions regarding their taxonomic status. Systematics of living *Bosmina* group remains far from clear and needs of major overhaul [20]. Fennoscandian *Bosmina* group was previously studied by Nillssen and Larsson [21]. They believed that the most common Fennoscandian *Bosmina* with the North Holarctic habitat should be called

Bosmina longispina (= *B. Obtusirostris* Sars, 1862, *B. lacustris* Sars, 1862). In their opinion it was the taxa which first moved to the postglacial water bodies. According to the early studies, the dominance of *Bosmina sp* has been noted in Lake Onega since the formation of thanatocenosis [20].

Bosmina (*Eubosmina*) cf. *longispina* is totally dominating in the lower layers of the column, reaching 82.76 %, that indicates a well-developed open part of the reservoir. There is a high species diversity with the dominance of the Northern species. At depths of 796-686 cm remains of *Camptocercus liljeborji* (*Schoedler, 1862*) are detected. The species is an inhabitant of the shallow ponds, small lakes, rivers, river basins littoral zone in which the species mostly occurs in areas covered with aquatic vegetation. *C. liljeborji* is found in Germany, Romania, Slovenia, Sweden and Northern part of European Russia [22]. The occurrence of the species suggests a decrease in the water temperature of the lake [23]. The remains of the *C. liljeborji* are not detected up to the column, above the depth of 686 cm, the species is completely replaced by *Camptocercus rectirostris*, associated with warm water [24, 25] and occurring in Maloe Shibrozero Lake at all stages of formation.

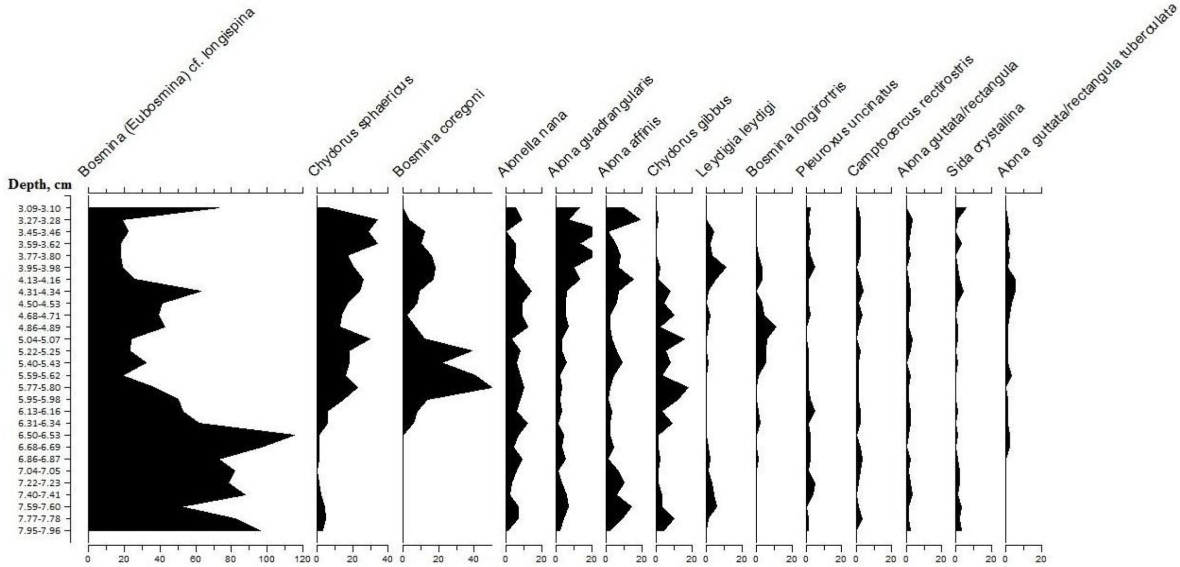

Figure 2. Relative abundances of the most common Cladocera taxa in the Maloe Shibrozero Lake.

The highest numbers of *Alonopsis elongata* remains are noted in the lower layers of the column. This species is typical for Northern and primarily Scandinavian countries [26]. The suggestion of cool climate was confirmed by the presence of the littoral species *Alona affinis*, *Alonella nana*, *Oxyurella tenuicaudis*, *Monospilus dispar* which can tolerate low temperatures [20, 27]. An increase in the numbers of individuals from the *Eubosmina*, along with simultaneous low percentage share of *B. longirostris* and littoral species, indicates low water fertility and temperature during this time [23].

The occurrence at this time of *Daphnia* species, particularly those from the *D. pulex* group, and *B. (E.) longispina*, typical for Northern (Scandinavian and Greenland) and mountain lakes, suggests that the lake was quite deep, and its waters were rather cool, with low trophic status [28, 29].

The representatives of the genus Pleuroxus (*P. uncinatus*, *P. trigonellus*, *P. laevis*) are found throughout the lake evolution, their relative abundance is 1.9%. The most numerous remains of the genus belong to *P. uncinatus* – inhabitant of the open littoral zone and silt-covered sand [20].

According to the results of the Cladocera analysis, the development of Alonella nana, which is one of the first invaders of the lake, occurred without sudden fluctuations in abundance. It is known that *Alonella nana* inhabits different types of Northern waters from oligo- dystrophic to eutrophic [20, 30, 31]. Phytophilous cold-water *Alona guttata/ rectangula* was also constantly present in the lake [27]. It is interesting to note that *Alona guttata/ rectangula* was found in all samples, whereas the closely related form *Alona guttata/ rectangula tuberculata* was found in samples above the depth of 686 cm.

The composition of subfossil Cladocera assemblages could have been the result of cool climate, with concurrent high water level of the lake.

Moving up the column, at the depths of 650-653 cm, a partial replacement of *Bosmina (Eubosmina)* cf. *longispina* by the larger taxa *Bosmina coregoni* takes place, at the same time an existence of another representative of the genus – *Bosmina longirostris*- is noted (figure 2). In accordance with Patalas [32] "subspecies" of *Bosmina coregoni* are common for lakes of different trophic status and can be present in oligotrophic and eutrophic water bodies [20]. Thus, in a number of lakes of Germany - Grosser Ploner See, Segeberger, and Schosee *Bosmina longispina* was replaced by *B. coregoni kessleri*, and then by *B. coregoni coregoni* with the eutrophication [33]. The decrease in the content of nutritious substances in the water is documented by a decrease in the frequency of *B. longirostris*, a species usually inhabiting fertile, shallow zones of lakes [34].

This observation is confirmed by the fact of simultaneous increase of importance of *Chydorus sphaericus*, which is an indicator of eutrophication, and cosmopolitan *Chydorus gibbus*- inhabitant of sandy-silty soils in the inshore zone of large water bodies found in sphagnum bogs [15]. The importance of phytophilous species (*Alona guadrangularis*, *A. guttata/ rectangula*, *A. affinis*, *A. costata*, *Alonella nana*, *A. exigua*, *A. excisa*) is increasing. According to a research conducted on Lake Charzykowskie [22], *Bosmina longirostris* prefers warm temperature and reducing its biomass under adverse conditions. Appearance of *B. longirostris* at the certain stage of the lake development may be considered as an improving of the environmental conditions and air temperatures rising.

Reducing the number of *Alonopsis elongata* above 686 cm depth may be associated with climate change in favor of higher temperatures and increasing the concentrations of Ca^{2+}. It is known that the species prefers acidic waters up to pH of 4.45 and with low Ca^{2+} concentrations of 0.4 and 2.2 mg dm^{-3} [35].

Above the depths of 413-416 cm, an increase in the number of *Alona affinis*, *Alona guadrangularis*, *Leydigia leydigi*, *L. acanthocercoides* remains is marked. Increasing biomass of *Alona affinis* may be associated with a decrease of temperature and increase of the overgrown part of the reservoir (the book Internet links, etc). It is known that members of the genus *Leydigia* appear or increase in numbers in biocenoses with eutrophication [3]. At the same time, the number of remains of *Bosmina coregoni* is decreasing above the depth of 468 cm, and the proportion of *Bosmina longirostris* is getting smaller to the point of extinction. This indirect evidence may indicate a decrease in the pelagic part of the lake and a cooling of the climate in the study region.

The average Shannon index in the Maloe Shibrozero Lake is 2.6 + 0.1, that allows to classify the lake as moderately polluted, which is consistent with the results of the hydrochemical analysis. The index values are in the range from 1.2 to 3.6. Index Pielou changes in the range from 0.23 to 0.69, with an average of 0.5, which characterizes the structure of Cladocera community as not sufficiently aligned. The saprobity index of the lake is 1.54, which determines the trophic status of the lake as β-mesosaprobic.

4. Conclusion

The study of the column of Maloe Shibrozero Lake bottom sediments using subfossil Cladocera analysis characterized changes that took place in the catchment area of the lake and in the region. It was established that the dominant of Cladocera community is *Bosmina (Eubosmina)* cf. *longispina*. The secondary species are *Chydorus sphaericus, Bosmina coregoni, Alonella nana, Alona guadrangularis, A. affinis, Chydorus gibbus*. The majority of the identified remains are pelagic species, but the high taxonomic richness of diversity is achieved by the taxa associated with specific substrates, primarily -overgrown areas. According to the results of Cladocera analysis the lake at the start of the foundation was a cold-water reservoir with a well-developed pelagic zone and was characterized by the presence of shallow areas and zones overgrown by macrophytes. With the development of Maloe Shibrozero the biomass of pelagic *Bosmina* group has decreased, trophic status has increased, as confirmed by the increase of the biomass of *Chydorus sphaericus*. *Changes in Cladocera community could be attributed to decreasing the level of periglacial lake, as a result of* *which the Lake Maloye Shibrozero became a small isolated lake with its own regime and processes.* These *factors can also be a consequence* of eutrophication. Moving up the column the presence of *Bosmina longirostris* is noted, which may be connected with the increase of air temperatures. Analysis of the upper part of the column of bottom sediments indicated an increasing of cold-water species that allows us to say that after some warming the weather got colder. The lake is moderately polluted and β-mesosaprobic, the structure of Cladocera community is not sufficiently aligned.

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