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Structure and heterogeneity of the Cladocera taphocoenoses in lakes of the Sredny Island (Keretsky archipelago, Kandalaksha bay of the White Sea)

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Abstract. Surface sediments, which were selected from various depths in three lakes of the Sredny Island (Karelia, Russia), were analyzed for subfossil Cladocera assemblages. In total at least 30 taxa remains were identified in samples of surface sediments. Predominance of cold-water littoral and cosmopolitan taxa was noted according to biotypic characteristic. Eurybiont *Chydorus* cf. *sphaericus* and typical of wetlands, the phytophilous *Alonella nana,* were most common in Cladocera taphocoenoses. Spatial heterogeneity was noted in subfossil Cladocera assemblages from various depths. Pelagic taxa proportion increased just as littoral taxa proportion decreased towards the center of lake. Several species remains were only found in littoral surface sediments samples.

1 Introduction

High-latitude lakes aquatic ecosystems are especially heavily influenced by global climate change, therefore importance of determining the extent of this influence and its consequences constantly increases [1]. Planktonic invertebrates are good indicators of hydrological and hydrochemical characteristics in waterbodies, thus they can give us significant information about changes in aquatic ecosystems occurring under the influence of climate change [2-5]. Based on this, we have chosen zooplankton communities of the White Sea basin waterbodies as being of particular interest. Despite the fact that the White Sea is one of the most studied seas of Russia, information about the zooplankton communities of small lakes in its basin is still insufficient [6]. Paleolimnological analysis of

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bottom sediments can help us to study zooplankton communities from these lakes, since it is well known that uppermost sediments provide the most complete inventory of zooplankton taxa in a waterbody [2, 7, 10]. Cladocera (Crustacea: Branchiopoda) is particularly valuable paleoindicator group because their remains are especially well preserved in bottom sediments [9-11]. Chitinized parts of carapace, headshields, postabdomens, postabdominal claws and ephippia are most common in sediments and are easily identified to species and genera [8]. Chydoridae and Bosminidae families are usually well preserved in bottom sediments, on the other side, Holopedidae, Daphniidae, Sididae and Polyphemidae families are relatively rare [12, 13].

Cladocera taphocoenoses is poorly investigated at the bottom sediments of Karelia lakes. A. Ibragimova et al. [14, 15] studied bottom sediments of few lakes of Zaonezhsky Peninsula (Karelia), however taphocoenoses from the White Sea basin waterbodies are still uninvestigated. Besides taxonomical structure, intra-lake distribution of Cladocera remains in sediments is quite interesting. Intra-lake variation of Cladocera assemblages analysis can be used for more complete study of modern communities or for developing new methods for paleoecological analysis. Sedimentary Cladocera assemblages heterogeneity has been studied for quite some time [16-18] but it still draws attention. The study aims to explore the structure and the spatial heterogeneity of Cladocera taphocoenoses from three high-latitude lakes of Sredny Island.

2 Materials and methods

Studied lakes are located on the Sredny Island (Fig. 1), which is covered mostly by coniferous forests. There is a small bog [19] at the center of the island. The climate in the White Sea basin is temperate continental with marine influence. Winter is mild yet quite long, which is due to the predominance of air masses from the Atlantic. The mean July air temperatures is 14-15 °C. Excessive moisture was noted in this region [20].

Fig. 1. Map of the study area showing the location of the sampled lakes.

Surface sediment samples were collected in July 2023 from three Sredny Island lakes using ponar dredge or plastic bottle. Studied lakes had a small area (0.5-6.5 ha); we identified them as ultrafresh with TDS of 23-45 mg/L and water temperature of 20±3 °C. Water transparency fluctuated between 0.5 and 2.5 m; maximum depth ranged from 2.0 to

7.2 m in each lake. Surface sediment samples were selected in each lake with the aim of littoral and pelagic taphocenoses structure investigation; there were three points by each lake: the littoral zone close to the shore, the deepest point close to the center of lake and in between these points at equal distance. Sediment samples from the smallest lake were selected only by deepest point and littoral zone (Table 1).

Table 1. Some hydrological and limnological characteristics of lakes of the Sredny Island (Karelia, Russia)

Lake	Coordinates, N, E	Lake area, ha	Sampling depth, m			Water T, °C	Transparency, m	TDS, mg/L
Unnamed lake	66°17′17.08″N 33°38′28.28″E	0.6	1.0	1.8	2.0	18.8	0.5	0.45
Lake Maloye	66°17′16.97″N 33°39′51.12″E	0.4	1.0	-	2.5	23.8	1.0	0.25
Lake Bolshoye	66°17′06.26″N 33°40′05.78″E	6.4	0.6	4.8	7.2	17.2	2.45	0.23

Samples of surface sediments were dried in the open air. The analysis of Cladocera subfossil remains from sediments was performed using the methodology described by A. Korhola and M. Rautio [3]. Dry samples (0.4-3.0 g) were processed with 10% KOH, followed by heating at 75 °C for 40 min. Thereafter, KOH-sediment mixture was poured onto a 50 µm sieve and washed under running tap water. Chitinous remains of Cladocera were collected from sieve and transferred into a 10 ml tube, preserved with alcohol and colored with safranin solution. Subfossil remains of Cladocera were analyzed by Carl Zeiss Jena microscope, identified to species or genera using specialized qualifiers [21, 22] and counted. We counted one headshield, postabdomen, postabdominal claw, ephippium or two shell valves as one individual.

Several species diversity indexes (Shannon-Weaver, Simpson’s, Fischer’s alpha and Hill’s N2) were used for an analysis of the biodiversity of subfossil Cladocera communities. Pielou index was used for an evenness assessment yet similarity between Cladocera communities was measured using Jaccard coefficient and Czekanowski-Sorensen formula. The scale of Lubarsky was used in order to identify classes of the dominance. Assessment of biotypically different taxa frequency depending of the distance from shore was made using Generalized Linear Model (GLM). Statistical analyses implemented in the program PAST (PAleontological STatistics, v. 4.13) [23].

3 Results and discussion

According to the subfossil Cladocera analysis results, at least 30 taxa of Cladocera belonged to 9 families (Leptodoridae, Sididae, Daphniidae, Ilyocryptidae, Bosminidae, Eurycercidae, Chydoridae, Polyphemidae and Cercopagidae) were identified. 1686 individuals (213 ± 31 for each sample) in total were identified to generic assignment or species, and most of them belonged to littoral taxa (78.65%).

It is well known that surface sediment sample at center, most often selected in the deepest point of lake, is representative of the community for the entire lake [24-26]. According to this fact, we interpret Cladocera communities from deepest point of studied lakes as “generalized” community of entire lake. *Alonella nana* (20.39%), *Bosmina longirostris* (19.56%) and *Chydorus* cf. *sphaericus* (18.04%) species were the most frequent in taphocoenoses of the deepest points of Sredny Island lakes, moreover the last two taxa were found in each of the lakes. Accordingly, typically cold-water and eurybiont phytophilous taxa [23] were more frequent in studied Cladocera communities. The mean Jaccard (0.47) and Czekanowski-Sorensen (0.37) indices indicate a medium similarity degree of the studied communities. Intra-lake distribution of Cladocera remains was heterogeneous in studied lakes.

The unnamed lake, located on the territory of Kazan Federal University biological station (66°17′17.08″N; 33°38′28.28″E), had minimal water transparency (0.5 m) and high organic matter content. The littoral zone of this shallow lake was overgrown by macrophytes, notably *Carex sp*., *Menyanthes trifoliata* and *Calla palustris*. According to the Lubarsky scale the dominant of Cladocera community of the deepest point sample was eurybiont cosmopolitan *Ch.* cf. *sphaericus* (45.89%). Subdominant taxa were small phytophilous *Alona guttata* and *Coronatella rectangula* (17.75%), and secondary taxa was *B. longirostris* (13.85%). 18 species of Cladocera in total were identified in the lake. The Simpson's index (0.73) has reflected high dominance of one or two taxa, and Pielou index (0.64) characterized the structure of Cladocera community as sufficiently aligned. Predominance of littoral cosmopolitan taxa *C.* cf. *sphaericus* and *B. longirostris*, which are associated with high trophic status [27, 28], allows to classify the lake as polluted.

Sediment samples for intra-lake distribution of Cladocera remains analysis were collected of three points from the shore to the center at a distance of 25 m between each other. The highest Cladocera taxon richness (n=15) was found in the deepest point sediment sample, and the lowest was found in the sediment sample selected between deepest point and shore. The proportion of littoral taxa decreased just as proportion of pelagic taxa increased from shore to deepest point. The proportion of benthic *A. quadrangularus* also showed mild increasement towards to center (Fig. 2). Remains of *Sida crystallina*, which are usually attached to various substrates [29], and some other littoral taxa were noted only in littoral samples. *Simocephallus sp.* ephippium was once found here.

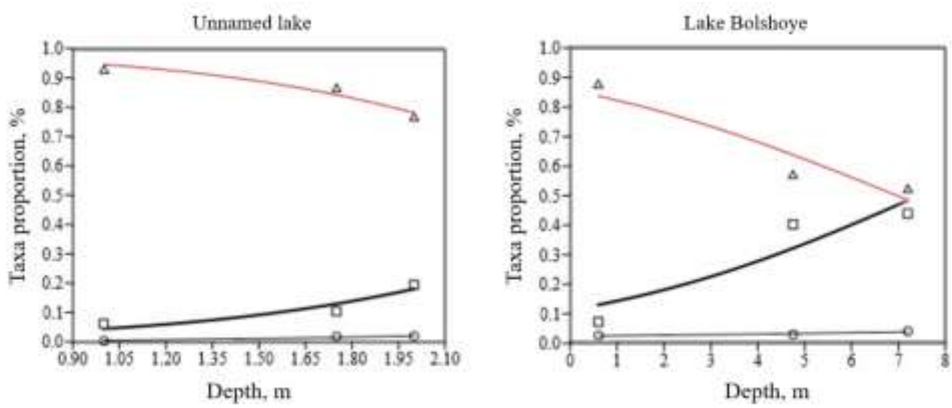

Fig 2. The curves of biotypic groups proportion changing in Unnamed lake and lake Bolshoye obtained using generalized linear model (GLM). Red line (triangle symbol) – littoral taxa; thick black line (square symbol) – pelagic taxa; thin black line (round symbol) – benthic taxa.

Lake Maloye, placed near Saint Petersburg State University marine biological station (66°17′16.97″N; 33°39′51.12″E), had the minimal area among studied waterbodies. In fact, this lake was a raised bog. Water in studied lake is characterized by a rich content of organic matter; sediments were composed of peat. Littoral zone was overgrown by sphagnum mosses. Except them, *Carex sp.* and *M. trifoliata* were abundant among macrophytes. Cladocera community from deepest part of lake characterized as mostly littoral, with subdominance of *A. nana* (27.03%), associated with oligotrophic wetland lakes. In total, 20 taxa of Cladocera were identified in lake Maloye taphocoenose. According to Lubarsky scale, species *Acroperus harpae* (13.96%) carnivorous *Polyphemus pediculus* (12.6%), *Ch.* cf. *sphaericus* (9.46%), *Biapertura affinis* (9.91%), *Daphnia longispina* (7.66%) and *A. guttata/Cor. rectangula* (4.66%) were secondary. Remains of *Ilyocryptus* sp., the benthic taxa, were also noted in sediments. This species not previously recorded for the Cladocera communities of Sredniy Island [6], but found in communities of other water bodies of the White Sea basin [20]. Simpson's and Pielou indices (Table 2) value reflecting moderate pollution of lake water.

Table 2. Diversity indices of cladoceran assemblages in lakes of the Sredny Island (Karelia, Russia)

Index	**Lake names and sediment sampling depth, m**								**Mean**
	Unnamed lake			**Lake Maloye**		**Lake Bolshoye**			
	1.00	1.75	2.00	1.00	2.50	0.60	4.75	7.20	
Number of taxa	13	9	15	14	20	16	13	16	14.50
Shannon-Weaver	1.33	1.20	1.78	1.91	2.31	1.95	1.38	1.78	1.64
Simpson's index	0.63	0.61	0.73	0.80	0.86	0.80	0.65	0.73	0.85
Fischer's alpha	3.22	1.96	3.91	3.16	4.97	4.15	3.08	4.02	5.82
Hill's N2	1.59	1.64	1.37	1.25	1.16	1.25	1.54	1.37	1.18
Pielou	0.52	0.55	0.64	0.75	0.78	0.70	0.54	0.63	0.64

Samples from Lake Maloye were collected at a distance of 25 m. Cladocera taphocoenosis, collected from littoral sediments, characterized by low taxonomically richness (n=14), with *Ch.* cf. *sphaericus* (31.05%) and *A. nana* (26.84%) subdominance. Proportion of littoral taxa was significantly higher here. Some pelagic taxa including *B. longirostris* and *Leptodora kindtii* weren't noted in littoral sediment sample at all. At the same time, small littoral species *A. guttata/Cor. rectangula, A. nana*, and also *P. pediculus* had a relatively equal abundance in both taphocoenoses.

Lake Bolshoye had a triangular shape, an area of 6.49 ha, and located on the southern side of the island (66°17′06.26″N; 33°40′05.78″E). The water had the highest transparency (2.45 m) and the lowest organic content. *Carex sp.*, *M. trifoliata*, *Nymphaea candida* and *Nuphar lutea* dominated among macrophytes and were found throughout the entire lake area. According to Lubarsky scale, the dominance of pelagic *B. longirostris* was noted in Cladocera community from 7.2 m depth (deepest point of lake). Subdominant taxa were *A. nana* (32.23%), and *A. quadrangularis* (4.03%) with *A. harpae* (4.76%) was secondary. High frequency of *A. nana* and *A. harpae* is typically for oligotrophic cold-water lakes with low pH, however, the dominancy of *B. longirostris* may reflect increasing trophic status, which is probably a consequence of the movement of organic matter from the raised bog located nearby. According to biodiversity and evenness indices value, we can to classify the lake as moderately polluted.

Table 3. Relative abundance of cladoceran taxa (%) from the studied lakes, habitat and zoogeographic characteristics

Taxa	**Lake Maloye**	**Lake Bolshoye**	**Unnam. lake**	**Habitat***	**Region***	**Occur-rence, %***
Leptodora kindtii	0.2	-	-	P	Pal	12.5
Sida crystallina	2.9	1.5	0.3	L	H	87.5
Diaphanosoma brachyurum	1.2	-	-	P	H	25.0

Ceriodaphnia sp.	-	-	0.2	P	H	12.5
Daphnia longispina	4.4	0.6	0.3	P	C	75
Daphnia pulex	-	0.1	0.7	P	C	37.5
Simocephalus sp.	-	-	0.2	L	C	12.5
Ilyocryptus sp.	0.2	-	-	B	C	12.5
Bosmina sp.	0.5	0.7	1.0	P	C	37.5
Bosmina (E.) longispina	-	2.7	0.8	P	C	50
Bosmina longirostris	0.7	28.2	10.3	P	C	87.5
Eurycercus sp.	-	0.7	-	L	H	12.5
Camptocercus rectirostris	0.2	-	-	L	H	12.5
Acroperus harpae	9.5	10.9	0.7	L	H	87.5
Biapertura affinis	1.2	0.6	1.2	L	C	87.5
Alona sp.	10.0	6.4	0.7	L	C	75.0
Alona quadrangularis	-	3.3	1.7	B	Pal	75.0
Alona intermedia/A. costata	-	-	2.0	L	Pal	12.5
Alona intermedia	1.9	0.3	0.2	L	Pal	37.5
Alona guttata/Coronatella rectangula	4.6	2.8	27.2	L	C	100.0
Alona guttata	-	0.1	-	L	C	12.5
Alona rustica	-	0.3	2.5	L	C	50.0
Coronatella rectangula	0.2	0.4	0.3	L	C	62.5
Graptoleberis testudinaria	2.4	-	-	L	C	25.0
Alonella nana	26.9	35.2	0.2	L	H	75.0
Alonella exigua	-	0.4	-	L	H	25.0
Alonella excisa	-	0.1	-	L	C	12.5
Pleuroxus sp.	-	0.1	-	L	C	12.5
Pleuroxus trigonellus	-	-	0.2	L	Pal	12.5
Chydorus cf. *sphaericus*	19.4	3.4	48.9	L	C	100.0
Pseudochydorus globosus	0.5	-	0.2	L	H	25.0
Polyphemus pediculus	12.4	0.9	0.5	L	H	62.5
Bythotrephes longimanus	0.5	-	-	P	Pal	12.5

*P = pelagic; L = littoral; B = benthic; Pal = Palearctic; H = Holarctic; C = Cosmopolite. Information about habitat preference and zoogeography was taken from Manuilova [30], Smirnov [31], Korovchinsky [22].

Three sediment samples collected from lake Bolshoye at a distance of 85 m between each other. The highest taxon richness (n=17) indicated in the Cladocera community from littoral sample collected close to the shore in *M. trifoliata* and *N. lutea* thickets. *A. nana* and *A. harpae* had the highest frequency here, but *A. harpae* proportion sharply decreased towards the center of the lake, while the proportion of *A. nana* stayed consistently high and reached its maximum (43.69%) at a distance of 85 m from the shore. At the same time, pelagic *B. longirostris* dominant of the center of lake, represented by only 0.5% of the community in the littoral zone. Species *Eurycercus sp.* and *Pleuroxus sp.* were found only in the littoral samples. Therefore, a gradual increasing of pelagic and benthic taxa with consistently high frequency of *A. nana* remains towards from shore to the center of the lake was found (Fig. 2).

4 Conclusion

The taxonomic structure of Cladocera taphocoenoses from surface bottom sediments is typically for shallow cold-water lakes, which are common in Karelia and northern Eurasia. However, each of the lake on Sredny Island had its own unique taxonomic structure, despite their close proximity and small area. Such differences can be explained by the hydrological and hydrochemical characteristics of the waterbodies, anthropogenic influence and the history of lakes formation. The heterogeneity of the intra-lake Cladocera remains distribution was noted, including a gradual change in the proportion of littoral and pelagic taxa from the shore to the center. Some taxa were found exclusively in littoral samples, suggesting that analysis of the spatial distribution of cladoceran remains in sediments may provide a more complete studying of taxonomic structure of the Cladocera communities.

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