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Evaluation of the Effect of Heavy Metals on the Plankton in the Technogenic Water Reservoir

R. E. ROMANOV[1], N. I. ERMOLAEVA[2] and S. B. BORTNIKOVA[3]

[1]*Central Siberian Botanical Garden, Siberian Branch of the Russian Academy of Sciences, Ul. Zolotodolinskaya 101, Novosibirsk 630090 (Russia)*

E-mail: romanov_r_e@ngs.ru

[2]*Institute for Water and Environmental Problems, Siberian Branch of the Russian Academy of Sciences, Morskoy Pr. 2, Novosibirsk 630090 (Russia)*

[3]*Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of the Russian Academy of Sciences, Pr. Koptyuga 3, Novosibirsk 630090 (Russia)*

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Abstract

For water reservoirs of the system of Belovo settling tank (Kemerovo Region, Russia) as example, the species composition, structure and abundance of phyto- and zooplankton of the technogenic water reservoir formed by acidic ore drainage water are characterized. According to the chemical composition, the water of these water bodies may be related to a special technogenic type never occurring under natural conditions. The species diversity and composition of the plankton depict the features of the chemical composition of water and allow us to consider these water objects as extremal localities.

Key words: technogenic water reservoir, acidic ore drainage water, phytoplankton, zooplankton

INTRODUCTION

Human activities serve as one of the system-forming factors for technogenic water reservoirs and water flows – peculiar ecosystems that often possess extremal conditions for living organisms in the environment. Typical technogenic water objects are formed in the regions with extensive mining and processing of mineral resources. Development of mining industry in the Kuznetsk basin caused not only substantial transformation of the ecosystems of water bodies and water flows of the Tom River basin but also resulted in the appearance of new water ecosystems formed by acid mine drainage. In these water bodies, the formation of the communities of living organisms is possible, so that their investigation is urgent not only for revealing the regularities of their expansion to new habitats with extremal environmental conditions but also for evaluation of the changes of the latter as a result of vital activity of hydrobionts. The data obtained may serve as the informational basis for the development of the methods of biological purification and reclamation of these anthropogenic objects.

The goal of the present work was to characterize the composition and abundance of plankton in a technogenic water body formed by acid mine drainage from the dump of processed polymetallic ores.

EXPERIMENTAL

Description of the object

The dump is situated at the territory of the Belovo Zinc Plant JSC (Belovo sity, Kemerovo Region, Russia) (Fig. 1).

The plant started to operate in the 30es of the past century and until 1990 stably manufactured up to 10 thousand t of zinc and occa-

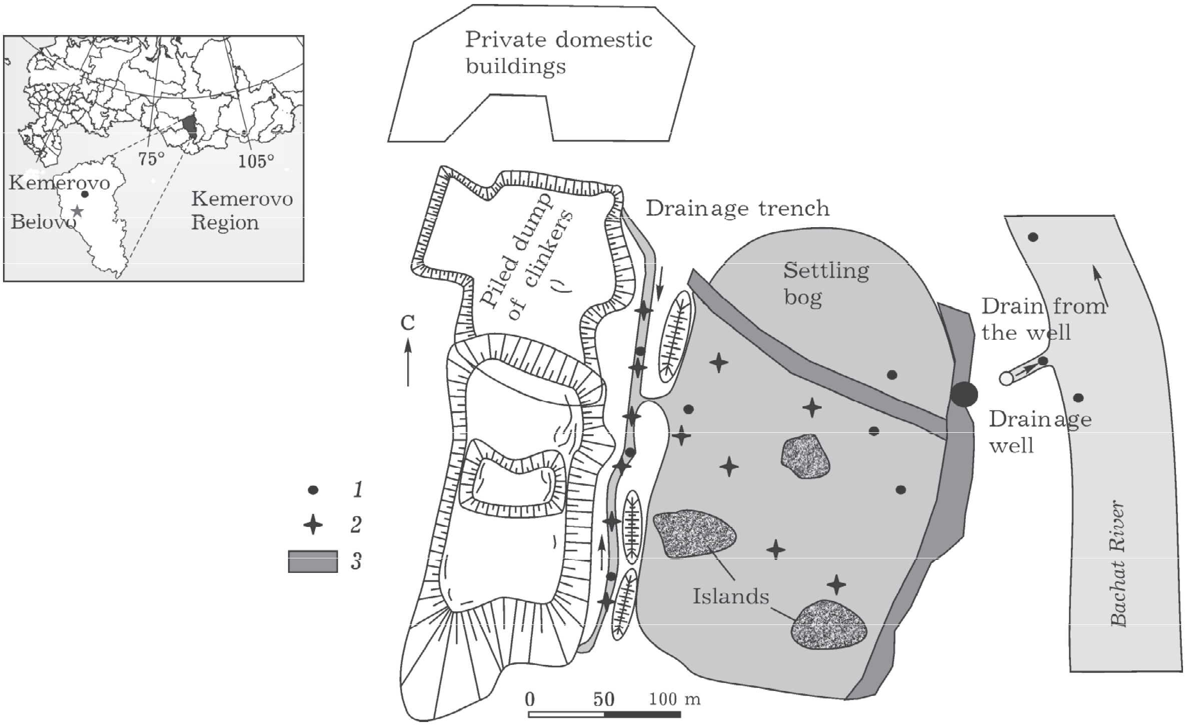

Fig. 1. Geographical position and sampling scheme for the Belovo settling bog: *1* – water samples, *2* – samples of bottom sediments, *3* – dump.

sionally up to 30 thousand t H_2SO_4. The production was focused on processing blende concentrate from the Salair Lead-Zinc Concentration Plant (Kemerovo Region). After depletion of the raw material basis of Salair deposits, the plant was working with the raw material transported from Kazakhstan deposits. Due to the low quality of ore, fine mutual growth of sulphide minerals, complications connected with concentrating, the blende concentrate contained a large amount of extrinsic elements (Cu, Pb, Cd, As, Sb *etc.*) that were disposed in the wastes. The plant ceased its operation from the middle 90es of the past century. About 1 million t of wastes in the form of slag and ash containing a substantial amount of residual sulphuric acid remained stored at the territory of the plant. The wastes are piled as a dump 15 m high with a flat top and steep slopes (about 45°). Visually, the clinker is a coarse-grained sand (the fraction >4 mm accounts for 50–65 %) of typical slag. Its major part is represented by silicate glass with the inclusions of feldspar, olivine, spinel, alloys and a small amount of residual sulphides [11]. Due to the large amount of ingrown sulphides is blende from ore concentrate, the clinkers are characterized by the high metal content (Table 1). In addition, coke dust, which is added during the technological process, is present in the dump at a level of 15–25 %. Specific features of this dump are spoil fires in several places due to self-ignition of the free coke dust. The intensity of chemical weathering processes in the clinkers is evidenced by the appearance of abundant secondary miner-

TABLE 1

Averaged chemical composition of clinker from the Belovo Zinc Plant

Components	Content, %	Components	Content, g/t
SiO_2	15–25	Cd	2–400
Al_2O_3	3–5	As	100–500
CaO	4–6	Sb	500–1000
MgO	0.3–0.6	Ag	150–250
Fe	3–22	In	13
S	0.5–1.5	Te	2
C	10–25	Ga	36
Zn	0.7–14	Ge	8
Cu	0.3–8.5	Au	<4
Pb	0.03–0.7	Se	Traces

als on the dump surface; draining water in the bypass channel is intensely blue coloured, while bottom sediments and littoral deposits at the boggy neighbouring territory are white, blue and greenish.

The western boundary of the dump is limited by the bog into which the drainage water flows (see Fig. 1). Water from the bog enters the drainage well and then flows into the Bachat River. There is a settlement at a distance of 100–300 m from the dump, which became as essential argument in favour of evaluation of the toxicity of the dump and its effect on the environment.

Materials and methods

Water and bottom sediments of the drainage system (bypass and bog settling tank) were studied during several years (1999–2008). Samples were collected during summer and autumn, except for 2008 when the samples of solutions were taken in winter from under ice through holes drilled in ice. Water was sampled in polyethylene containers that were rinsed with the same water at the sampling site three times before sampling. The solutions were filtered; pH values were measured (with the help of the portable of HANNA Instruments HI 9025C). The accuracy of measurements was ±0.01 pH. Bottom sediments (hydrogenous flocks) were sampled in polyethylene bags, then dried at the sampling site and abraded under laboratory conditions. To compare water composition, a background reference was chosen: water from the Gavrilovskiy water basin situated in the same region at a distance of 40 km from Belovo.

The solutions were analyzed by means of ICP-AES. The metrological characteristics of atomic emission spectroscopy correspond to GOST P 61309–99 [2]. Relative error within the concentration range did not exceed 10 %. The concentration of sulphate ions in solutions was measured using the standard turbidimetric procedure [3]. Determination of the concentrations of chlorides in the samples was carried out by means of titration [4]. Bottom sediments were analyzed by means of XPA-SR [5].

The samples of phytoplankton were collected in June 2008 from the surface water layer, concentrated using direct filtration through membrane filters with pore diameter 055–0.65 mm, fixed with formalin, bringing its concentration to 2–4 %. The samples were treated in non-fixed and fixed states. The abundance of phytoplankton was determined using countable volumetric procedure with the help of Fuchs–Rosenthal chamber (volume: 3.2 mm^3). In parallel, the number of cells and individuals – sole cells, temporary aggregates, colonies, coenobia, filaments, trichomes *etc.* without taking into account the number of cells comprising them.

Zooplankton samples were collected in February–March, June–July and October 2008 by filtering 300–350 L of water through Apstein plankton net made of caprone sieve No. 64. The samples were fixed with 4 % formalin [6, 7]. To identify the taxonomic composition and to calculate the number of organisms, zooplankton samples were analyzed in Bogorov chamber [7].

RESULTS AND DISCUSSION

Water in the drainage brook that flows from under the dump relates to the type of highly mineralized metal-containing solutions (Table 2). During the years 1999–2008, substantial changes in the state of the dump occurred: combustion processes stopped, the temperature of drainage flows decreased, their composition somewhat changed. It is important to note that the tests in 2008 in winter revealed extremely high concentrations of many chemical elements. The solutions relate to the sulphate class; the leading part in the cation composition is played by zinc and copper (more than a half of the total amount of cations):

$$M_{18}\frac{SO_4\,98\,Cl\,2}{(Zn+Cu)\,54Mg\,21Na\,12Ca\,8Al\,4}\,pH\,4.47$$

This kind of water can be distinguished as a separate technogenic type that does not occur under natural conditions. The concentrations of many microelements (Co, Ni, Cd, As, Se, and Be) achieve high values exceeding the background levels by six orders of magnitude for some elements.

In the summer phytoplankton of water reservoirs from the system of Belovo sediment

TABLE 2

Chemical composition of the solutions in the settling tank and drainage trench, February, 2008, μg/dm^3

Components	Background	Settling tank					Drainage trench
		Northern part		Southern part			
pH	7.9	6.5	7.4	4.6	4.5	4.3	4
Cl^-	45	160	180	250	200	220	420
SO_4^{2-}	110	1800	2000	7100	10 500	27 000	12 900
NO_3^-	0.4	2.5	3.2	4.4	2.5	3.2	15
HCO_3^-	240	220	270	50	40	35	25
Na^+	5.7	510	200	210	500	1300	550
K^+	0.78	70	18	20	69	170	73
Ca^{2+}	44	380	220	320	410	440	620
Mg^{2+}	8	430	150	170	450	1180	520
Fe	0.029	0.11	0.24	0.23	0.1	4.0	0.55
Al	<0.1	11	<0.1	<0.1	12	260	32
Mn	0.006	31	4.6	2.2	32	110	39
Zn	0.01	4100	41	26	990	3200	11 000
Cu	0.003	4100	1.1	0.55	930	7300	12 000
Co	<0.1	8.6	0.66	0.70	9.3	31	13
Ni	0.096	6	0.46	0.37	6.1	20	9
Pb	0.009	1.3	0.013	0.008	1.5	3.5	1.5
Cd	0.020	8.4	0.31	0.13	5.4	14	26
Sr	0.24	2.6	2.5	2.7	2.7	1.1	1.8
Ag	0.78	82	1.4	1.6	9.6	31	350
Sn	2.9	29	0.26	<0.01	<0.01	<0.01	110
Sb	22	34	0.7	1.4	5.1	8.4	33
As	28	<0.05	<0.05	<0.05	<0.05	650	<0.05
Se	<0.01	100	0.0	22.0	110.0	360	190
Be	<0.0002	5.0	<0.001	<0.001	5.4	28	8.6

collector, or settling tank, 14 species of algae and cyanobacteria were revealed (Table 3), including one aerophilic species identified on the basis of the empty shell. In addition, phototrophic eukaryote cells were detected; their identification even to a level of section or order turned out to be impossible due to the absence of clearly pronounced morphological indices or low number. Green algae are represented by the largest number of species. The minimal species variety was discovered in the drainage trench and in the sediment collector near the mouth of the trench; it was increasing in the direction from the trench mouth. *Chlamydomonas acidophila* and non-identified flagellates (here and below – *Chrysophyceae* and *Cryptophyta*) were detected in all the regions under study. Abnormal forms were not observed.

The abundance of phytoplankton in the settling tank was maximal near the mouth of the drainage trench (Fig. 2); it sharply decreased in the direction from the mouth, and then increased slightly. The part of settling tank that is the most remote one from the mouth of the drainage trench did not differ much from the drainage trench in the number of phytoplankton, the biomass of which was, quite contrary,

TABLE 3

Taxonomic composition of phytoplankton in water reservoirs of the system of Belovo settling tank in June 2008

Taxons (section, class, species)	Drainage trench	Regions of settling tank[в] No. 1	No. 2	No. 3
Cyanoprokaryota, Cyanophyta				
Hormogoniophyceae gen. sp. status *pseudanabaenoideus*[a]	–	–	+	–
Chlorophyta				
Chlamydomonas acidophila Negoro sensu Fott 1956	+	+	+	+
Chlorophyceae или *Trebouxiophyceae* gen. sp.	–	–	–	+
Pseudoschroederia robusta (Korsch.) Hegew. et E. Schnepf (*Schroederia robusta* Korsch.)	–	–	+	–
cf. *Stichococcus bacillaris* Näg. (cf. *S. minor* Näg. s. str.)	–	–	+	–
Ulothrix sp.[б]	–	–	–	+
Streptophyta, Charophyta				
Klebsormidium subtile (Kütz.) Tracanna ex Tell (*Ulothrix subtilis* Kütz. s. l.)	+	+	–	–
Koliella cf. *sigmoidea* Hind.	–	–	–	+
Heterokontophyta				
Стоматоцисты *Chrysophyceae* gen. sp.	–	–	–	*
Bacillariophyta				
Achnanthes s. l. sp.	–	–	+	–
Bacillariophyceae gen. sp.	–	–	–	*
Hantzschia amphioxys (Ehr.) Grun. in Cl. et Grun.	**	–	–	–
Cryptophyta				
Cryptophyta gen. sp.	–	–	+	–
Non-identified flagellates				
(Chrysophyceae or Cryptophyta)	+	+	+	+
Total number of species, varieties and forms vegetating simultaneously	3	3	7	7

Note. + Presence of the species, *shell with protoplast residue, **empty testa.

[a] The stage of development of cyanobacteria hormogone is named according to [8].

[b] More precise definition is necessary, this may be the representatives of *Klebsormidium* genus (Streptophyta).

[c] Regions of settling tank are listed in the order of increasing distance from the mouth of the drainage trench.

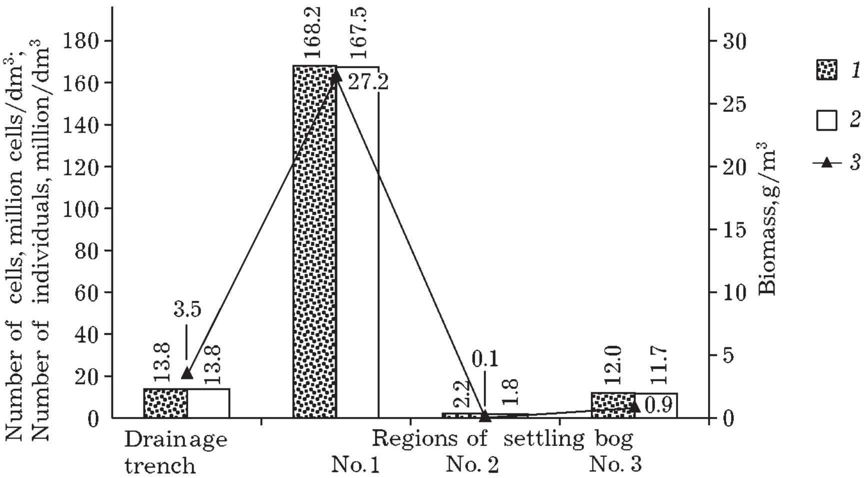

Fig. 2. Phytoplankton abundance in water reservoirs of the system of Belovo settling bog in June 2008:
1 – number of cells, *2* – number of individuals, *3* – biomass.

substantially lower. These points to the prevalence of relatively small celled forms.

Green algae comprise a basis of the plankton of drainage trench and the adjacent region of the settling tank. With an increase in the distance from the mouth, their number decreases but the number of non-identified flagellates increases substantially. In the plankton of the drainage trench and the adjacent region of the settling tank, absolutely predominant species are *Chlamydomonas acidophila* (approximately 100 % of phytoplankton abundance). For region No. 2, the most numerous species were *C. acidophila* (48 % of the number of cells, 58 % of the number of individuals, 27 % of the biomass), non-identified flagellates (20, 23 and 48 %, respectively), cf. *Stichococcus bacillaris* (14, 14 and 11 %, respectively) and cyanobacteria (15 % of the number of cells); for region No. 3 – non-identified flagellates (42, 43, 83 %, respectively), *Koleilla* cf. *sigmoidea* (51 % of the number of cells, 50 % of the number of individuals).

Zooplankton was not detected in the drainage trench and in the brook; its separate representatives were observed only in the settling bog. Seven zooplankton species were detected in winter samples: Cladocera *Bosmina longirostris* O. F. Mull.; Rotatoria – *Filinia longiseta longiseta* (Ehrb.), *Keratella quadrata* (O. F. Mull.), *Keratella cochlearis* (Gosse), *Br. angularis angularis* (Gosse), *Brachyonus quadridentatus*, *Testudinella patina*. Among the detected zooplankton organisms, 90 % bear morphological deformations, which sometimes brought substantial complications into species determination. The shells of the major part of rotifers were deformed. It is possible that the high concentrations of heavy metals cause genetic mutations because almost all the individuals of one or another species were transformed in the identical manner. It is interesting that similar mutations were detected in the representatives of zooplankton in the brook at the territory of the assumed development of the polymetallic ore deposit Karakul (Kosh-Agach District, Republic of Altay, 2007). In winter samples, the total number of zooplankton did not exceed 730 specimens/m^3, with the biomass of 0.36 mg/m^3, while in the background water bodies (the Ob River, the floodplain lakes of the Ob) these parameters were 1200–3700 specimens/m^3 and 2.72–65.00 mg/m^3. Rotifers dominated in samples (620 sp./m^3, 0.24 mg/m^3).

Zooplankton was completely absent from the samples collected in summer and in autumn. An increase in water temperature and acceleration of metabolism in zooplankton organisms was likely to lead to the accumulation of the lethal dose of toxic substances for all the studied groups of rotifers and crustaceans from the water of the settling tank [9].

It is known [10] that 51 species and one variety of algae and cyanobacteria were detected in water reservoirs with low pH values acidified with ore drainage water. According to the molecular genetic data, the appearance of some taxons under these environmental conditions is most likely due to colonization of these habitats by local populations from circumneutral conditions (pH ~ 7) rather than expansion from water bodies that are similar in conditions but are situated at a substantial distance [10].

One of the most abundant species of summer phytoplankton in water reservoirs of the lakes in the system of the Belovo settlement – *C. acidophila* – was likely to be detected in the water bodies of West Siberia for the first time. The shape of the front edge of a cell differs in different images of this species [11–13]. The cells of *C. acidophila* in water bodies of the Belovo settlement system are slightly sharpened from the front and narrowly rounded at the top; the front edge is slightly tapered.

This species was detected at pH 1.0–3.3 in a volcanic lake, in solfatara mud [12], in volcanic ponds in tundra [14], in small artificial water bodies in dimples after peat extraction (for example, *C. applanata* var. *acidophila* Fott) [11], in the lake affected by acid ore drainage water formed during mining [10]. In general, this species is usually detected in extremely acidic environment [15–17]; it survives low pH values, high concentrations of heavy metals [18] and poor illumination [19].

A 100 % occurrence and most frequent dominance of *Chlamydomonas* spp. and *Ochromonas* spp. [14] were observed in the plankton of lakes formed at the sites of open-pit mining of brown coal deposits characterized by low pH (average pH ≤ 3), high electric conductance and high Fe, Al, Mn content. Non-identified representatives of flagellates detected in the Belovo settlement may be the representatives of the indicated genera.

Low species diversity of algae and cyanobacteria, simple structure of communities discovered in water reservoirs of the Belovo settlement system are typical features of extremal habitats [20], including low pH values [14, 17]. Water ecosystems with low pH values can be characterized as relatively simple ones where monocultures of phototrophic acid-stable flagellates from the green algae section can develop [17].

On the basis of the biomass of phytoplankton at the region of the Belovo settlement near the mouth of the drainage trench, this region corresponds to polytrophic class, the drainage trench corresponds to eutrophic one, region No. 2 – to oligotrophic one, region No. 3 – to the mesotrophic class [21]. However, the use of generally accepted signs of trophic classes appears to be incorrect in this environment [22].

Changes of the composition of phytoplankton may depict, on the one hand, a complex gradient of environmental conditions with an increase in the distance from the drainage trench. On the other hand, taking into account the flow-through character of the system of Belovo settlement, we may consider this inhomogeneity as different stages of succession of the community transported with the habitat in which the conditions change.

The hydrochemical mode determines the species composition and structure of phytoplankton communities in the lakes that are formed at the sites of open-pit mining of brown coal, while the trophic status identified on the basis of the concentrations of biogenic elements determines the value of its biomass [22]. The low primary productivity under these conditions may be due to the high heavy metal content or low concentration of dissolved phosphates but not due to the acid reaction of the medium. Under these conditions, the productivity of algae also may be determined by the level of insolation and the spectral composition of sunlight penetrating into water layers, as well as by the concentrations of H_2S and CO_2 [23]. Nevertheless, the productive potential of water with low pH can be high in rare cases [22], though in general it is very low [24]. Under these conditions, the formation of the chemical precipitate at the bottom can exclude the development of benthos forms [23] but not metaphyton ones.

On the other hand, algae and cyanobacteria can alter in different ways the environmental conditions of acid ore drainage water [23]. In spite of their presence, in such an environment, the direct contribution of these organisms into the improvement of water quality is likely to be small. One of the most important consequences of the development of algae and cyanobacteria may be extracellular organic substances that serve as the source of carbon for the populations of sulphate-reducing bacteria: in turn, their vital activity causes an increase in pH value [23].

Zooplankton in the bog settling tank develops exclusively during the ice period and is represented by the forms that occur in fresh water reservoirs of West Siberia all year round. The reason of this phenomenon can be connected with the specific features of zooplankton vital activities. The dormant ova of rotifers and Cladocera are surrounded by a dense shell protecting them from unfavourable external action, both thermal and chemical. Copepods are devoid of such an advantage and thus they are permanently affected by toxic metals. During summer, when water temperature is higher, the rate and intensity of metabolism in zooplankton organisms increase [25, 26]. The high concentrations of heavy metals turn out to be sublethal at first, causing bisexual reproduction and the appearance of dormant ova, and then lethal for zooplankton organisms. So, in summer the whole zooplankton community of the Belovo bog is in the state of diapause, or waiting through unfavourable conditions. With a decrease in temperature, the level of metabolism decreases; rotifers and Cladocera (most probably represented already by two sexes) burst out of the dormant ova and have enough time to produce a new generation of zooplankton. As a result, winter zooplankton in the Belovo bog is represented only by rotifers and Cladocera. Copepods that normally survive the diapause as copepodites of the II and III stages were not detected in the community.

CONCLUSION

Water of the Belovo settling tank (Kemerovo Region, Russia) can be related on the basis of its chemical composition to a special technogenic type that does not occur under natural conditions. The species diversity and composition of phytoplankton depict the features of the chemical composition of water in the reservoirs of the Belovo settling tank system. Low species diversity and mass development of one or few species of algae and cyanobacteria is typical for different types of extremal habitats in which the species that turn out to be beyond competition are able to achieve mass development. Zooplankton is almost non-developed because high metal concentrations in combination with low pH values cause lethal action on zooplankton organisms; at low temperature the lethal action is somewhat compensated by a decrease in metabolism. As a result, the organisms developing to a limited extent include only rotifers and Cladocera that are able to live waiting through the most unfavourable period at the stage of ova that are indifferent to external toxic action.

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