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Factors influencing the fauna of pit lakes in the Cheremkhovo district (Irkutsk region, Russia)

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Abstract

Recently, the global scientific community has shown interest in studying pit lake ecosystems. This interest is driven by a number of factors, including the significant role of pit lakes in enhancing regional biodiversity and providing ecosystem services. The Irkutsk region contains a large number of pit lakes. This study compares aquatic organism groups and the hydrochemical and physicochemical parameters of two pit lakes in the Cheremkhovo district. Thus, using the example of two lakes, three stages of colonization of pit lakes by macrophytes and aquatic invertebrates can be identified. These stages differ in both the level of development and organization of macrophyte communities and aquatic invertebrate communities. The obtained data demonstrate that even under common geological and geographical conditions, the formation of hydrobiocenoses in pit lakes can occur according to different scenarios. The results of the study show that the presence of a forest on the site of a future pit lake contributes to stabilization, a reduction in acidity, and the formation of a fully functioning aquatic ecosystem within less than 40 years. At the same time, the nearby lake, around which vegetation is still sparse, has a low pH (3.05), and the most favorable conditions are created by thickets of moss (*Warnstorfia exannulata*).

Keywords
Artificial lakes, acidity, zooplankton, abiotic factors, biotic factors, hyperoxic conditions

Introduction

Pit lakes are bodies of water formed in pits following mining operations. These lakes are typically filled by the influx of groundwater or surface water (Søndergaard et al. 2018; Lund et al. 2020; Bernasconi et al. 2022; Lund and Blanchette 2023). The study of pit lakes has previously been often ignored by the scientific community (Blanchette et al. 2020; Bernasconi et al. 2022; Lund and Blanchette 2023). However, these lakes are subject to the same chemical and environmental processes as natural lakes (Lund and Blanchette 2023).

The studies of pit lakes conducted to date have mainly focused on the study of physicochemical, geological, hydrological and limnological parameters, which was primarily associated with the design of quarries (Castendyk et al. 2015; Blanchette and Lund 2016). Published research has typically been published in highly focused conference proceedings or technical reports (Blanchette and Lund 2016), and only now are pit lakes beginning to attract the attention of the scientific community for the biological and ecological aspects of their functioning.

The most interesting of these aspects are the following. Firstly, in the early stages of their existence, such lakes represent an aquatic "desert" (Blanchette and Lund 2016). In this regard, the processes of colonization of these lakes by communities of aquatic organisms and succession are of interest (Bernasconi et al. 2022). Secondly, as a type of artificial reservoir, pit lakes are capable of increasing biodiversity in certain areas (Starzak et al. 2025), which is achieved through the formation of new habitats not previously found in these areas. In addition, these lakes increase the local habitat area of many species, thereby improving species resilience and regional biodiversity (Deacon et al. 2018; Zamora-Marín et al. 2021). Thirdly, pit lakes often belong to extreme ecosystems with high salinity, low acidity, and high levels of certain elements. Given this, they can harbor unique plant, animal, and microbial taxa (Bernasconi et al. 2022). Finally, another aspect worthy of attention is the search for methods and approaches to remediate these ecosystems (Castendyk et al. 2015). Remediation of pit lakes will contribute to increasing the quantity and quality of the ecosystem services they provide (Meyerhoff et al. 2019; Weber 2020).

The Irkutsk region is rich in lake ecosystems of various types (Korytny 2017). Along with natural lakes, the region also contains a significant number of pit lakes. Their study (similar to global practice) has not received significant attention. This study is the first of its kind to comprehensively understand the communities of organisms and how they function in a given area. The aim of this study is to investigate the aquatic communities of two lakes located in the Cheremkhovo district of the Irkutsk region. Both lakes formed in the 1990s and were associated with the coal mining industry. One of the lakes, popularly known as the "Cheremkhovskie Maldives," is actively used for spontaneous recreation thanks to its picturesque turquoise waters and sandy shores.

Materials and methods

Both lakes are located in the Cheremkhovo district of the Irkutsk region (Russia). The shortest distance between the lakes is less than 100 m (Figs 1–2). Lake No. 1 "Cheremkhovskie Maldives" (Fig. 3) (53°07'00.5"N 102°57'49.9"E) is an elongated pit. One side of this pit is actively overgrown with trees and shrubs, as well as higher aquatic vegetation. Moreover, on this same side, from the water's edge to approximately the middle of the lake, thickets of moss descend into the water. The second side of this pit (compared to the first) is almost devoid of vegetation. Lake No. 2 (53°07'03.4"N 102°57'50.6"E) is also an elongated pit. However, compared to the first lake, both sides of the pit are heavily overgrown with vegetation (Fig. 4).

In this study, zooplankton and zoobenthos samples were collected in both lakes (September 24, 2024), as well as environmental physicochemical parameters were measured and samples were collected for hydrochemical analysis. Macrophyte samples were also collected for determination.

Quantitative zooplankton samples were collected by filtering water from the lakes through a hydrobiological net (mesh diameter: 100 μm). Three quantitative samples, each containing 50 liters, were collected from each lake. A number of qualitative samples were also collected. Since quantitative benthic samples were not possible, only qualitative samples were collected.

Physicochemical parameters were recorded, including temperature (T), pH, electrical conductivity (EC), total dissolved solids (TDS), oxidation-reduction potential (ORP), salinity, and dissolved oxygen concentration (DO). The oxygen saturation percentage (M) was calculated in the laboratory. Hydrochemical analysis of the water was conducted at the V.B. Sochava Institute of Geography, Siberian Branch of the Russian Academy of Sciences, using standard methods.

Statistical processing of quantitative zooplankton data was performed using the Pearson chi-square test. The nonparametric Mann-Whitney test was used to compare physicochemical environmental parameters and hydrochemical analysis data. Qualitative composition in plankton samples was compared using multidimensional scaling. Data were normalized using the presence/absence method (1/0). If a taxon was present, it was assigned a value of 1; if absent, it was assigned a value of 0. The Bray-Curtis distance was used to calculate distances between points. Coefficients of variation (CV) were additionally calculated to represent dissolved oxygen concentration data.

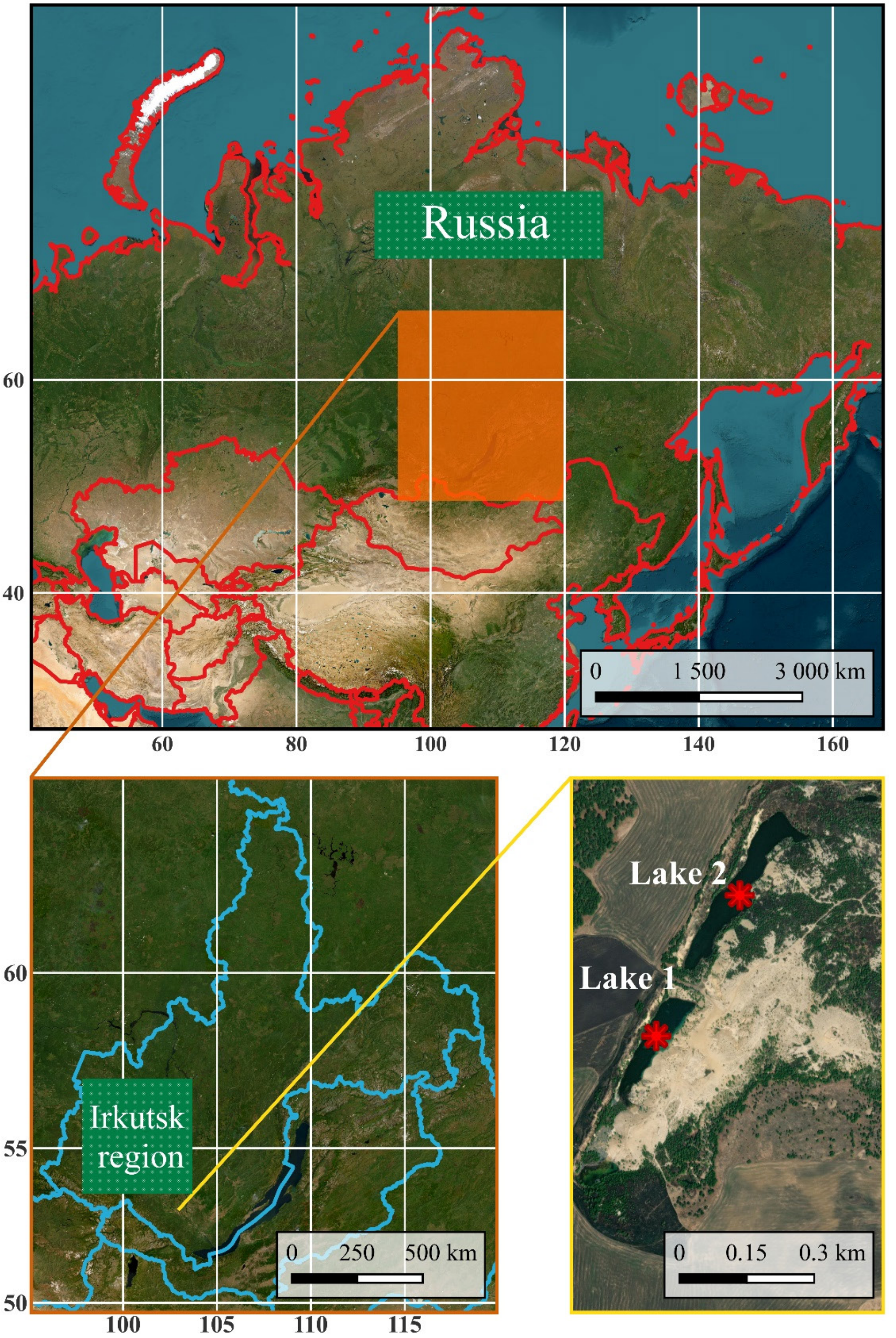

Figure 1. Map showing the location of two pit lakes in the Cheremkhovo district of the Irkutsk region (Russia) (an ESRI satellite was used as a baseline).

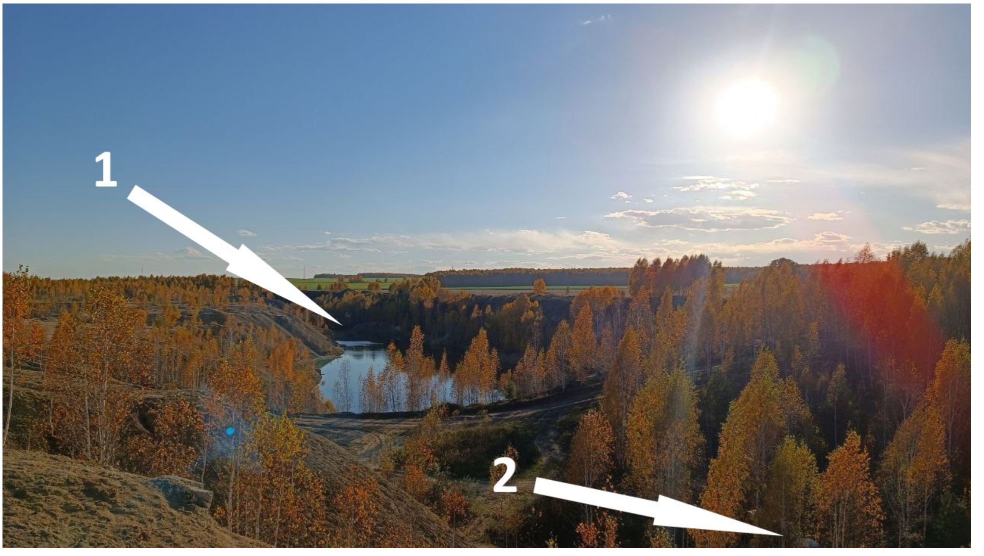

Figure 2. The location of the studied lakes relative to each other: **1** – lake No. 1 ("Cheremkhovskie Maldives"), **2** – lake No. 2.

Results

A comparison of hydrochemical analysis data showed that the chemical composition of the water in the lakes differs significantly (W = 33, *p*-value = 0.04). Hydrochemical analysis data showed a complete (or almost complete) absence of hydrocarbonates in the water (Table 1) and a fairly high sulfate anion value. The values of the physicochemical parameters (Table 2) in this case merely supplement the hydrochemical analysis data. However, there are no significant differences in the physicochemical parameters (W = 16, *p*-value = 0.06). It is worth noting that for technical reasons it was not possible to measure the concentration of dissolved oxygen in Lake No. 1, however, in Lake No. 2 at the sampling point this parameter was measured twice (at the surface of the water and at the bottom above the leaf litter). In the first case, the concentration of dissolved oxygen was 9.178 ± 0.009 mg/l (CV - 0.15%), while the percentage of water saturation with oxygen was 111.82%. In the second case, the concentration of dissolved oxygen was equal to 6.054 ± 0.001 mg/l (CV - 0.04%), while the percentage of water saturation with oxygen was equal to 64.68%. According to scientific data, hyperoxic conditions are quite common in pit lakes (as in this case) (Blanchette and Lund 2021). High oxygen saturation can be observed both at the surface and at the bottom. However, hypoxic conditions are also found near the bottom of such lakes (Blanchette and Lund 2021).

Processing of quantitative plankton samples showed that in lake No. 1, only 3 groups of organisms (Cladocera, Hydrachnidia and Diptera) are noted in the plankton community (including random planktonic organisms) (Table 3). At the same time, 8 groups of organisms were noted in the planktonic (random-planktonic) community of Lake No. 2. Representatives of Cyclopoida occupied a dominant position (3687 ± 2187 ind./m^3), and Cladocera were subdominant (1173 ± 764 ind./m^3). Visible differences in the community composition are also confirmed statistically (X-squared = 3174.6, df = 8, p-value < 2.2×10^{-16}).

Figure 3. Lake No. 1 "Cheremkhovskie Maldives": **1** – general view, **2** – general view from above (moss thickets are visible on one side of the lake), **3** – the shore of the lake from the unovergrown side, **4** – sediments from the unovergrown side.

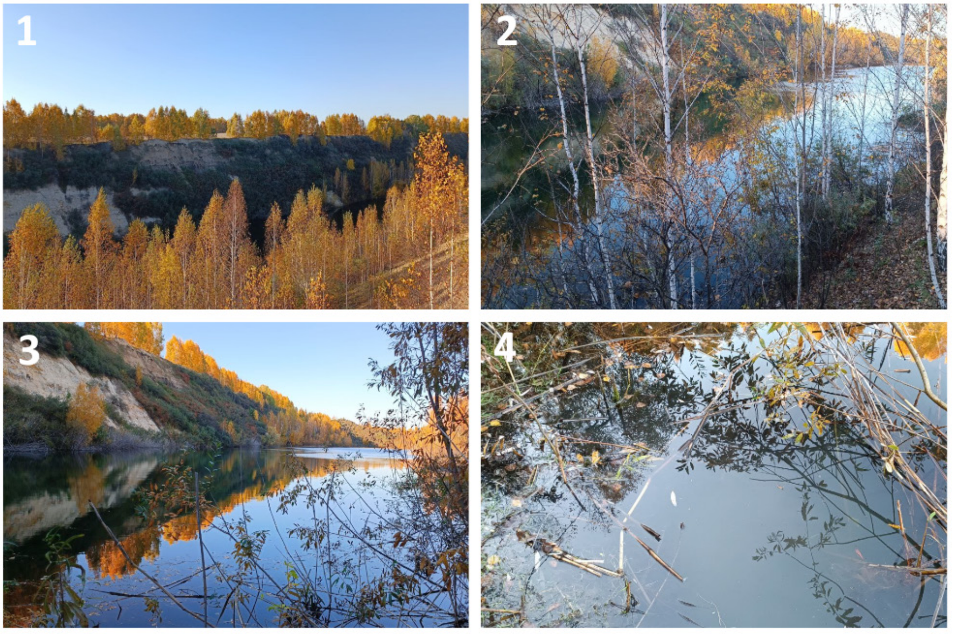

Figure 4. Lake No. 2: **1** – general view of the pit, **2–3** – general view of the lake, **4** – at the lake's edge.

Table 1. Hydrochemical analysis of pit lakes of the Cheremkhovo district (September 24, 2024), mg/l

Sampling location	HCO_3^-	SO_4^{2-}	Cl^-	NH_4^+	NO_2^-	NO_3^-	PO_4^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
Lake No. 1 "Cheremkhovskie Maldives"	< 13.7	900	8.5	0.49	0.015	0.38	0.01	192	81.6	14	7.6
Lake No. 2	68.3	1102	21.3	0.28	0.005	0.47	0.05	316	113	15.4	6.8

Table 2. Physicochemical parameters of pit lakes of the Cheremkhovo district (September 24, 2024)

Location of measurements	T, °C	pH	EC, µS/cm	TDS, mg/l	ORP, mV	Salinity, ‰	DO, mg/l	M, %
Lake No. 1 "Cheremkhovskie Maldives"	15.2	3.05	3084	1204	464	< 0.1	–	–
Lake No. 2	19.9 / 13.8	7.60	3864	1608	180	0.4	9.178 / 6.054	111.82 / 64.68

Table 3. The number of representatives of different groups of aquatic organisms in the planktonic and random-planktonic communities of the studied lakes, ind./m^3

Groups of aquatic organisms	Lakes	
	No. 1	No. 2
Cyclopoida	0	3687±2187
Calanoida	0	560±53
Nauplius	0	7±7
Cladocera	7±7	1173±764
Ostracoda	0	593±453
Oligochaeta	0	420±360
Chironomidae	0	307±207
Hydrachnida	80±53	80±42
Other Diptera	20±20	0
Heteroptera	0	220±31

Processing of qualitative samples confirms the quantitative data. All three qualitative plankton samples collected in Lake No. 1 demonstrate low diversity of aquatic organism groups (Fig. 5: 1A-1C) compared to Lake No. 2 (Fig. 5: 1D). It's worthwhile to dwell in more detail on the sampling locations for qualitative samples. 1A corresponds to the quantitative plankton sampling location. 1B is a plankton sample collected from a boat across the lake, and 1C is a sample collected in the moss (*Warnstorfia exannulata* (Schimp.) Loeske) thickets, which occupy up to half the lake bottom on one side (Fig. 3.2). The percentage of organisms in these thickets is similar to that in the first two qualitative samples. However, in natural numbers, the number of aquatic organisms in the moss thickets is quite high (the sample contained 282 organisms), while in the first two samples the number of organisms does not exceed 20 individuals. This circumstance, however, was taken into account when comparing the data using the multidimensional scaling method, where this sample corresponds to point "1C" (Fig. 6). Returning to the obtained data, it is worth noting that the low diversity of organism groups in Lake No. 1 compared to Lake No. 2 is also confirmed by the ratio of organisms in the benthic samples (Fig. 5: 2A-2B).

It is also worth mentioning that the following macrophyte species were noted for Lake No. 2: *Myriophyllum sibiricum* Komarov, *Potamogeton perfoliatus* L., *Drepanocladus afuncus* (Hedw.) Warnst., and *Bryum* sp. Representatives of two genera of diatoms (*Pinnularia* sp., *Stauroneis* sp.) were also found.

In this study, all encountered representatives of the following groups were identified to the genus or species level: Cladocera, Cyclopoida, Heteroptera, Coleoptera, and Odonata (Table 4). Only one species from the Cladocera group, *Bosmina* (*Bosmina*) *longirostris* (O.F.Müller, 1776), was found in Lake No. 1. However, this species was absent from samples from Lake No. 2. In addition to Cladocera, we were able to Factors influencing the fauna of pit lakes in the Cheremkhovo district (Irkutsk region, Russia) 9 identify 6 taxa from the Cyclopoida group (one taxon only up to genus level), 6 species from the Heteroptera group, 3 taxa from the Coleoptera group (all 3 only up to genus level), and two species from the Odonata group.

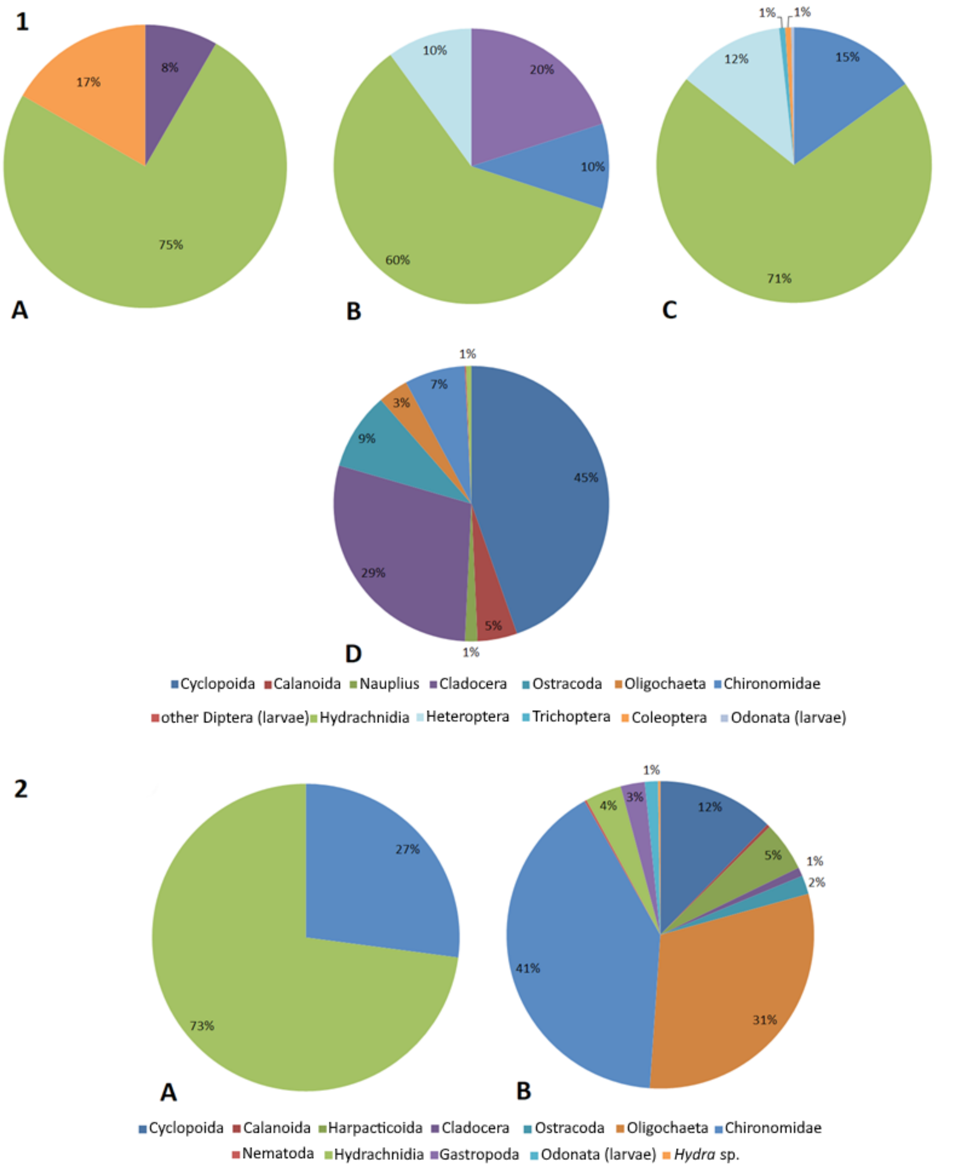

Figure 5. The ratio of groups of aquatic organisms: 1A, 1B, 1C – qualitative plankton samples from lake No. 1, 1D – qualitative plankton sample from lake No. 2; 2A – qualitative benthic sample from lake No. 1, 2B – qualitative benthic sample from lake No. 2.

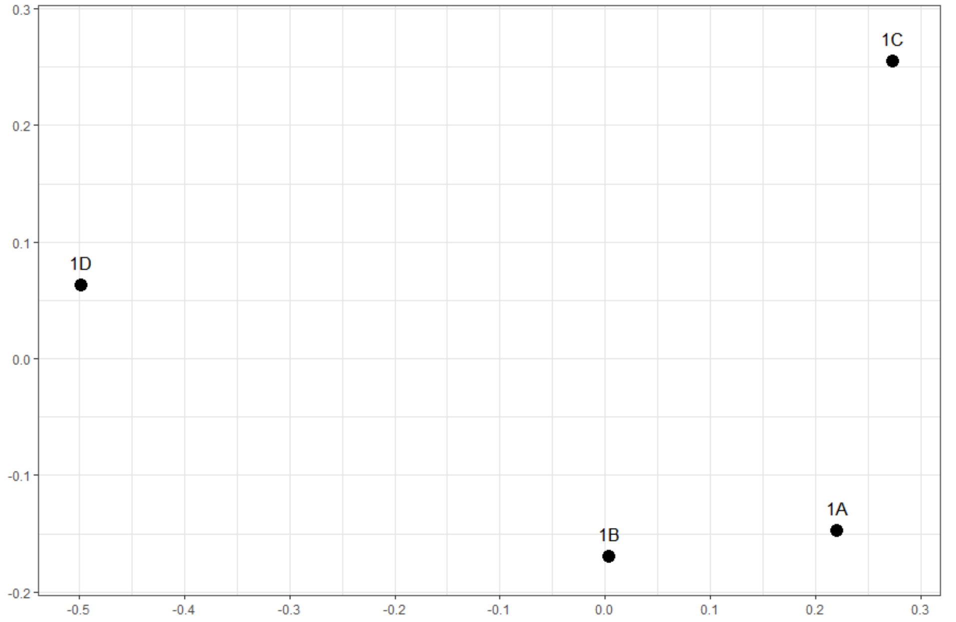

Figure 6. Comparison of the qualitative composition of organisms in plankton samples using the multidimensional scaling method (the Bray-Curtis distance was used): 1A, 1B, 1C – qualitative plankton samples from lake No. 1, 1D – qualitative plankton sample from lake No. 2.

Table 4. Diversity of representatives of some groups of aquatic organisms in the studied lakes, identified to the genus or species level

No.	Taxon name	Lake No. 1	Lake No. 2
	Cladocera		
1	*Alonella excisa* (Fischer, 1854)	–	+
2	*Bosmina* (*Bosmina*) *longirostris* (O.F.Müller, 1776)	+	–
3	*Chydorus* cf. *sphaericus* (O.F.Müller, 1776)	–	++
4	*Pleuroxus aduncus* (Jurine, 1820)	–	+
5	*Prendalona guttata* (Sars, 1862) Sinev, Sousa & Elmoor-Loureiro, 2018	–	+
6	*Simocephalus vetulus* (O.F.Müller, 1776)	–	+
	Cyclopoida		
7	*Eucyclops serrulatus* (Fisher, 1851)	–	++
8	*Mesocyclops* sp.	–	+
9	*Acantocyclops venustus* (Normanet Scott, 1906)	–	+
10	*Megacyclops viridis* (Jurine, 1820)	–	++

No.	Taxon name	Lake No. 1	Lake No. 2
11	*Ectocyclops phaleratus* (Koch, 1838)	–	+
	Heteroptera		
12	*Hesperocorixa linnaei* (Fieber, 1848)	++	–
13	*Hesperocorixa sahlbergi* (Fieber, 1848)	++	–
14	*Corixa dentipes* Thomson, 1869	+	–
15	*Microvelia buenoi* Drake, 1920	–	++
16	*Microvelia reticulata* (Burmeister, 1835)	–	++
17	*Nepa cinerea* L, 1758	+	–
	Coleoptera		
18	*Georissus* sp. Latreille, 1809	+	–
19	*Hygrobia* sp. Latreille, 1804	+	–
20	*Haliplus* sp. Latreille, 1802	+	–
	Odonata		
21	*Anaciaeschna isosceles* Müller,1767	–	+
22	*Libellula quadrimaculata* (L., 1758)	+	–

Discussion

The low pH, absence of bicarbonates, and high sulfate anion are explained by the presence of acid-forming minerals (e.g., pyrite). Crystals of this mineral were found in close proximity to the sampling site (Fig. 7).

Iron sulfide oxidizes to form sulfate ions (SO_4^{2-}) and hydrogen ions (H^+), which acidify the water:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

In the acidic conditions of the lake (which is formed under the influence of sulfuric acid), hydrocarbonates are completely broken down into CO_2 and H_2O.

At the same time, in Lake No. 2 (apparently), some changes have already occurred since the formation of the pit and its filling with water. These changes were influenced by the plant communities around Lake No. 2. Plants with strong root systems are known to promote the accumulation of organic matter and the development of microorganisms, which, in turn, leads to the stabilization and reduction of the acidity of the environment (Tostche et al. 2003). However, in this case, stabilization occurred in only one of the lakes. This prompted us to analyze satellite images of the area. Analysis of the satellite images (Fig. 8) shows that the site of Lake No. 2 (where environmental conditions stabilized) was forested before the excavation and filling of the pit (there was no forest at the site of Lake No. 1). The presence of forest on the site of Lake No. 2 created a number of preconditions for the rapid stabilization of the newly created aquatic ecosystem. Firstly, it appears that the partially remaining root system in the soil after the trees were felled prevented erosion of the steep banks of the pit. Secondly, this same root system contributed to the rapid restoration of the forest in this area. Third, forest restoration led to a rapid accumulation of organic matter (for example, due to leaf litter), which, combined with the colonization of the reservoir by macrophytes, led to the environmental conditions we are currently observing. Fourth, the presence of forest in this area before the excavation of the pit meant that the area contained more organic matter than the surrounding cropland (Polláková et al. 2016).

Figure 7. Conglomerate with pyrite inclusions from the sampling site.

In contrast, Lake No. 1, "Cheremkhovskie Maldives," is located on formerly cultivated land with potentially low organic matter levels. Forest has now encroached on one of the lake's shores. Satellite images (Fig. 8) show that this process near Lake No. 1 began significantly later than near Lake No. 2. The side of the pit (Lake No. 1) opposite the forest is currently undergoing erosion, and the runoff water that erodes this side of the quarry continues to acidify the water. This is likely the cause of the asymmetry that has developed on the lake bed, with a bare bottom on one side and a bottom covered with reeds (*Phragmites australis* (Cav.) Trin. ex. Steudel) and moss (*W. exannulata*) on the other. Of course, regarding this lake, it can be hypothesized that there was no forest in this area initially due to the presence of a high concentration of mineral compounds (pyrite) and soil acidification. This could have led to the formation of an initially more aggressive environment, which persists to this day, creating unfavorable conditions and preventing successful plant establishment. However, at this time, we cannot confirm or refute this.

Figure 8. Dynamics of overgrowing of the territory near the pits with trees and shrubs: **1** – arable land at the site of lake No. 1 (L1) and forest at the site of lake No. 2 (L2) (Source: EarthExplorer), **2** – lakes No. 1 and No. 2 (Source: Google Earth), **3–4** – overgrowing of the territory around the lakes (Source: Google Earth).

Currently, three successive stages of ecosystem development can be observed in these two lakes. These stages demonstrate the development of macrophyte and aquatic invertebrate communities. The first stage is observed in Lake No. 1 on the eroded slope of the pit. The environmental conditions created here are likely similar to those during the initial period of this ecosystem's existence. The lake bottom on this side is devoid of macrophytes. Aquatic organisms include aquatic beetles, aquatic mites, bugs, Diptera, and Cladocera (Fig. 5; Table 4). Diptera larvae could have migrated here from the moss beds on the opposite side of the lake, for example, during nocturnal vertical migrations. The few representatives of Cladocera (species *B. longirostris*) found here are either more adapted to an acidic environment (Imant and Novoselov 2021) or were found here by chance (possibly even as a result of being carried by migratory birds). This is confirmed by the fact that we did not encounter other individuals of this species in either the qualitative sample 1C (which exhibits the greatest diversity) from this lake or in the quantitative and qualitative samples from Lake No. 2. Furthermore, we did not encounter other representatives of typically planktonic organisms in this lake (No. 1).

The second stage can be observed in Lake No. 1 on the slope overgrown with trees and shrubs. Macrophytes along the shore include reeds (*P. australis*), and the bottom up to the middle of the lake is overgrown with moss (*W. exannulata*). The moss thickets create favorable habitats (Więcek et al. 2013; Zheleznova et al. 2019) for several species of aquatic bugs and various amphibiotic insect larvae, in addition to aquatic beetles. Due to the presence of these organisms, a high percentage of aquatic mites is also observed in the community.

The third stage is represented by a fully formed ecosystem and is observed in Lake No. 2. A complex of macrophyte species is observed here. Aquatic organisms are represented by a number of groups, including both benthic invertebrates and typically planktonic organisms (Fig. 5; Tables 3, 4).

Thus, to summarize, we see that the first two stages are evident in the example of the same lake. The acidic environment prevents the development of a typical planktonic community in the lake (Holopainen 1991; Lin et al. 2025), but it allows the penetration of organisms that are quite well adapted to it due to certain adaptations (physiological regulation and protective features of the exoskeleton) (Bell and Nebeker 1969; Cooper 1994). Moreover, the second stage demonstrates that it is the *W. exannulata* thickets (which, incidentally, is an indicator of acidic ecosystems) that create conditions suitable for the colonization of aquatic bugs and amphibious insects. In turn, water mites (which are also indicators of an acidic environment (Więcek et al. 2013) thrive in this ecosystem. It is known that mite eggs (compared to adults and nymphs) are the most resistant to acidic conditions (Edwards 2004), but it is possible that in this case, the host abundance is more important than the pH of the environment. The third stage is evident in Lake No. 2, where the extreme factor is no longer pH, but rather high oxygen saturation of the water (due to the influence of the macrophyte community, most likely mosses). High oxygen concentrations are preferred by some Copepoda (Dinh et al. 2020), as clearly demonstrated in this study. This high concentration likely corresponds not to the entire lake, but to specific areas where Cyclops aggregations are observed due to hyperoxic conditions (Dinh et al. 2020).

Conclusions

The differences in the taxonomic diversity of aquatic organisms between the two pit lakes, despite their common origin and close geographic location, are due to a combination of abiotic, biotic, and anthropogenic factors. The key limiting factor in the first lake is its acidic environment (pH 3.05). The transformation of this environment in Lake No. 2 was significantly influenced by phytocommunities (both those previously located (and quickly restored) at the site of the future quarry, and those forming for the first time in this place).

The data obtained clearly illustrate the initial and subsequent stages of the natural colonization of anthropogenic water bodies by aquatic organisms. The uniqueness of this situation lies in the possibility of directly comparing two alternative ecosystem development trajectories under practically identical conditions, but with different initial environmental states. Additionally, it's worth noting that these two lakes demonstrate the gradual colonization of pit lakes by flora and fauna. Taking into account the above, it is advisable to continue monitoring the development of these lakes. Subsequent monitoring will not only allow us to document the further dynamics of successional processes but also identify specific mechanisms and timeframes for neutralizing extreme conditions and forming stable biocenoses in anthropogenic water bodies. This is fundamental for forecasting and managing restoration processes in disturbed areas.

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