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Short Communication

Phytoplankton Community in Early Stages of Reservoir Development – a Case Study from the Newly Formed, Colored, and Episodic Lake of Mining-Subsidence Genesis

Wojciech Pęczuła[1]*, Agnieszka Szczurowska[2], Małgorzata Poniewozik[3]*****

[1]Department of Hydrobiology, University of Life Sciences in Lublin,
Dobrzańskiego 37, 20-262 Lublin, Poland
[2]Department of General Ecology, University of Life Sciences University in Lublin,
Akademicka 15, 20-950 Lublin, Poland
[3]Department of Botany and Hydrobiology, The John Paul II Catholic University of Lublin,
Konstantynów 1H, 20-708 Lublin, Poland

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Abstract

Mining activities affect a landscape in different ways, including by the formation of subsidence troughs, which after being inundated form wetlands and lakes. The development of new mining reservoirs may give a unique opportunity to study the early stages of colonization by various freshwater communities, including phytoplankton. Our paper presents the results of phycological research undertaken in newly formed subsidence reservoir near the coal mine "Bogdanka" (Polesie Lubelskie) a few months after its filling with water. The reservoir represented a unique, rare limnologic type due to the fact that it disappeared as a result of intended melioration works in the autumn of the same year. The study focused on morphometric measurements of the episodic reservoir, determination of general physicochemical parameters of water, and qualitative and quantitative structure of the phytoplankton community, was undertaken in five separated basins. A total of 80 algal taxa were determined. Most of them belonged to euglenoids (Euglenophyta-36) and green algae (Chlorophyta-26). Among euglenoids, most species were represented by *Trachelomonas* genus (14), while among green algae, most species were assigned to *Scenedesmus* genus (8). Several rare species were found, including: *Scenedesmus bacillaris* Gutw., *Dinobryon petiolatum* Willén, and *Trachelomonas botanica* Playfair. Green algae and euglenoids also had major contributions to the total phytoplankton abundance, which

*e-mail: wojciech.peczula@up.lublin.pl
**e-mail: agnieszka.szczurowska@up.lublin.pl
***e-mail: gonium@kul.pl

in all study sites did not exceed 2.2×10^6 ind.·dm^{-3}. This phytoplankton structure was probably influenced by the high water color related to particular and dissolved organic matter from pre-existing alder forests. Some differences in phytoplankton structure found among sampling sites were probably connected with habitat differentiation in terms of exposure to light.

Keywords: subsidence reservoir, phytoplankton, episodic lake, ecological succession

Introduction

Mining activities affect the landscape in different ways, among others, by a formation of subsidence troughs. The development of these forms below the water table leads to surface areas being inundated, resulting in the formation of wetlands and lakes, thus creating new recreational facilities, but also new freshwater "secondary" habitats, often of high biodiversity [1, 2]. Limnological studies covering artificial lakes created by mining activities are relatively rare and to date have tended to focus on hydrochemistry or freshwater biota determination in yet established reservoirs, such as open-cast flooded mines [3-8] or mining-subsidence reservoirs [9-12].

Habitat conditions in mining lakes are often extreme (low pH, high metal concentrations, high suspended and dissolved solids) and can serve as refuges for rare or invasive aquatic species [9, 12, 13]. Furthermore, the development of new mining reservoirs may give a unique opportunity to study the early stages of colonization by various freshwater communities [6, 14]. Although the topic seems to be attractive for researchers, to date no studies have been found in the limnological literature, which have focused on pioneering freshwater communities in newly formed mining-subsidence lakes.

One such reservoir appeared in spring 2010 as a result of land subsidence associated with coal mine activity in eastern Poland. Having the opportunity to study a unique, rare limnologic type of lake, we have carried out research covering its phytoplankton communities in the early stage of its colonization (first season after inundation). Because the lake disappeared (as a result of intended drainage) in the autumn of the same year, the studied object may also be defined as an episodic lake. According to Williams et al. [15], these are permanently dry lakes that may on occasion contain water. Biotic communities of this type of ecosystem are hardly identified due to the fact that they are often inaccessible and unpredictably filled with water [16, 17].

This paper will focus on determining the qualitative and quantitative structures of summer phytoplankton in this newly formed, mining-subsidence, and episodic reservoir against its morphometric features, as well as the physicochemical properties of its water.

Material and Methods

The studied subsidence reservoir appeared in spring 2010 as a result of land subsidence associated with the activity of the Bogdanka coal mine (Polesie Lubelskie, eastern Poland). Like most of such reservoirs, it had smooth embankments and the bottom was covered by soil and vegetation of the area. The lake arose near Kaniwola village, within a farm area, in an agricultural catchment (51º21' 49" N, 23º00' 55" E). Due to the nature of the flooded area, the reservoir was morphometrically and spatially diverse. Pre-existing woodlots and shrubs (consisting of alders and willows on peaty soils) divided the newly created reservoir into five pools of different depths, shape, and nature of the bottom (peaty forest soils, meadows, or arable lands).

Phycological research, physicochemical analysis of water, and morphometric measures were carried out in the beginning of July 2010 (one month after the establishment of the water table in the subsidence trough). Due to the episodic nature of the reservoir, research was performed only once without the opportunity for further studies. Due to the morphometric diversity of the reservoir, five sampling points were designated, which represented separate basins of different maximum depths, separated by one another with fragments of flooded forest stands:

1 – basin of 1.3 m depth situated near the farm
2 – basin of 1.1 m depth arisen as a result of arable field flooding
3 – basin of 1 m depth in the middle of the reservoir and separated with dense shrubs
4 – basin of 3 m depth formed in place of the earlier artificial fish pond
5 – the shallowest fragment (0.5 m), forming a basin adjacent to the main road (Fig. 1).

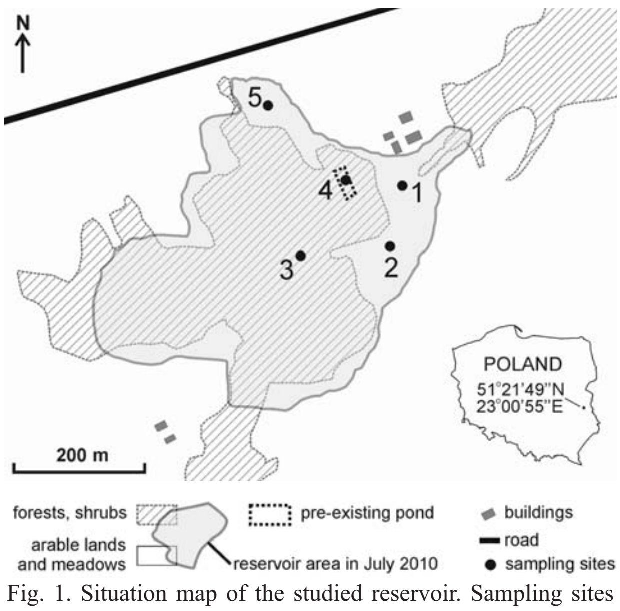

Fig. 1. Situation map of the studied reservoir. Sampling sites are indicated as 1-5 numbers.

Table 1. Physicochemical parameters of the water in five basins (sampling sites) in studied reservoir.

Physicochemical parameters	1	2	3	4	5
pH	6.6	6.6	6.6	6.5	6.3
EC [$\mu S \cdot cm^{-1}$]	199.0	202.6	204.6	198.7	182
O_2 [$mg \cdot dm^{-3}$]	5.1	5.2	5.6	2.9	3.5
Transparency [m]	0.4	0.3	0.5	0.4	0.3
Colour [mg $Pt \cdot dm^{-3}$]	163	174	160	164	159

Study sites differ one from another with exposure to the light: sites 3 and 4 were situated among trees, while the others were in an open area.

Due to the small depth, water samples for analysis were collected from the surface layer (0.5 m). Phytoplankton was sampled with the use of the Ruttner sampler (2 dm^3), then fixed with Lugol solution to further determine their numbers using an inverted microscope and the Utermöhl method [18]. Additional samples were taken with the plankton net (mesh size: 25 µm) for proper identification of species in live samples.

Samples for the analysis of water chemistry were taken simultaneously with phytoplankton samples, with the use of the Ruttner sampler (2 dm^3). Water transparency (with a standard 0.2 m diameter Secchi disc), temperature, oxygen content, pH and conductivity (with YSI 556 Multi Probe, MPS) were measured in the field. The concentration of chlorophyll-*a* was determined by the ethanol method [19] and water colour spectrophotometrically. Water colour was calculated according to Lean [20], using the formula:

$$\text{Water colour } [mgPt \cdot dm^{-3}] = 18.216 \times (A_{440} \times l \times 2.303) - 0.209$$

where: A_{440} – absorbency at 440 nm and l – optical length of a cuvette.

The lake bottom was dragged by hydrobiological anchor aiming to look for any submerged macrophytes. Morphometric measurements of the reservoir covered its surface area (with the use of GPS navigation device) and the depths of separated basins (with the use of cord probe).

In order to determine similarities among site-specific phytoplankton communities, cluster analysis was performed on the basis of species abundance. We also calculated Shannon's diversity index using algal taxa numbers. The analysis were performed using MVSP 3.1. software.

Results

Surface area of the reservoir was 17 ha and the depths of studied basins ranged from 0.5 to 3.0 m. Lake water was slightly acidic (pH 6.3-6.6), coloured (159-174 mg $Pt \cdot dm^{-3}$), and moderately mineralized (electrolytic conductivity: 182-204 $\mu S \cdot cm^{-1}$). Oxygen content was low (not exceeding 5.6 $mg \cdot dm^{-3}$) as well as water transparency, which ranged between 0.3 and 0.5 m (Table 1).

We found no submersed macrophytes within the lake. Some sparse vegetation developed only in places of pre-existing wetlands on the edges of the reservoir. The surface of the water also was covered by sparse populations of duckweed (*Lemna minor*), especially in sheltered places.

A qualitative analysis of summer phytoplankton showed 80 pro- and eukaryotic algal taxa belonging to seven taxonomical groups. Most identified taxa belonged to euglenoids (Euglenophyta-36) and green algae (Chlorophyta-26). Both groups accounted for almost 80% of all taxa. Among euglenoids, the largest number of species were represented by *Trachelomonas* genus (14), while among green algae, most species belonged to *Scenedesmus* genus (8). Other taxonomic groups were represented less frequently: 7 taxa were from Cyanoprokaryota, 6 taxa from Bacillariophyceae, and 3 taxa from Chrysophyceae. Only single species came from Cryptophyceae and Dinophyceae. Studied basins differed in the number of identified taxa. The highest number of phytoplankton species was recorded at two sampling points: near the farm (sampling site 1-38 taxa) and in the shallowest part of the reservoir (sampling site 5-39 taxa). The lowest number of taxa (28) was found at sampling point 3, which was isolated from the others by dense shrubs.

The taxonomic structure of phytoplankton communities at studied basins was similar. Euglenoids and green algae were dominant groups in terms of the number of identified taxa. Euglenoids prevailed at sampling sites 1-4, while green algae were the largest group at sampling site 5 (Fig. 2).

The most frequently identified Euglenophyceae that occurred at all basins were: *Lepocinclis acus* (O. F. Müller) B. Marin & Melkonian and three *Trachelomonas* species – *T. hispida* (Perty) F. Stein, *T. volvocina* Ehrenb., and *T. volvocinopsis* Svirenko. The most characteristic taxa for studied subsidence reservoir and identified at all sampling points were: *Dinobryon petiolatum* Willén and *Mallomonas* sp. (Chrysophyceae), *Cryptomonas* sp. (Cryptophyceae), *Peridinium* sp. (Dinophyceae), as well as *Monoraphidium arcuatum* (Korshikov) Hindák and *Desmodesmus communis* (E.Hegewald) E. Hegewald (Chlorophyta). Among identified algae, several rare species were found, i.e. *Scenedesmus bacillaris* Gutw., *Dinobryon petiolatum* Willén, *Trachelomonas botanica* Playfair, and *Stanieria* sp.

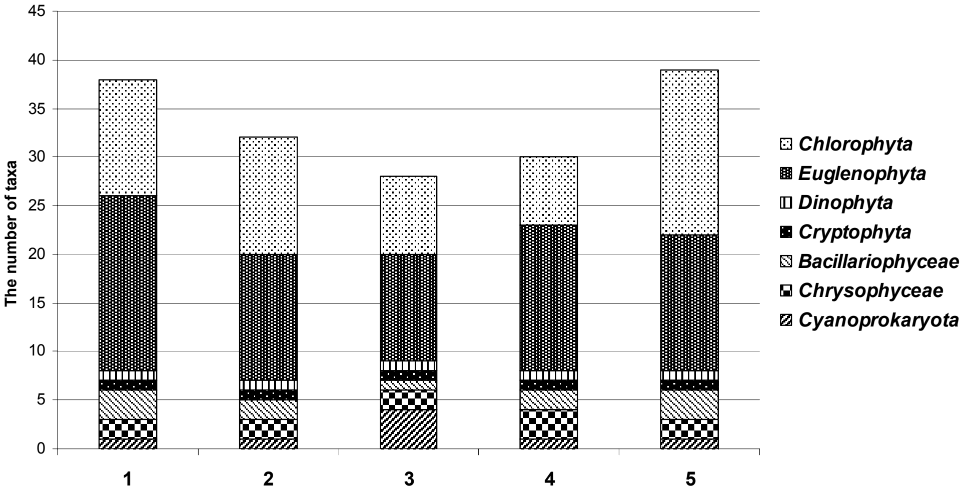

Fig. 2. Number of taxa of taxonomical groups of algae in studied reservoir.

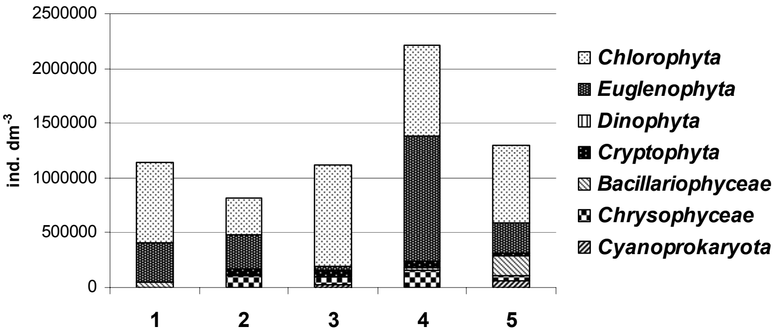

Fig. 3. The abundance of phytoplankton taxonomic groups in studied reservoir.

The total phytoplankton numbers ranged from 0.8×10^6 ind.·dm^{-3} at sampling site 2 to 2.2×10^6 ind.·dm^{-3} at the deepest sampling site, 4 (Fig. 3).

As in the case of the quality structure, green algae and euglenoids shared the highest proportion in total phytoplankton numbers. Both groups altogether made up from 76% (at site 5) up to 96% (at site 1) of the total numbers, but the structure of domination at the research points varied. At sampling site 3, green algae dominated, due to very high numbers of *Monoraphidium circinale* (Nygaard) Nygaard. At sites 1, 2, and 5 green algae dominance was not so significant, while at site 4, euglenoids showed the highest share of total phytoplankton abundance (Fig. 4).

A taxon that occurred at all study points in large numbers was *Desmodesmus communis* (Chlorophyta); this species made up from 6% to 30% of the total population at particular sampling sites. Among green algae the high abundance was shown by *Kirchneriella lunaris* (Kirchn.) Moeb. at sampling site 1 (17%), as well as *Monoraphidium arcuatum* and *M. circinale* at site 4 (28% together).

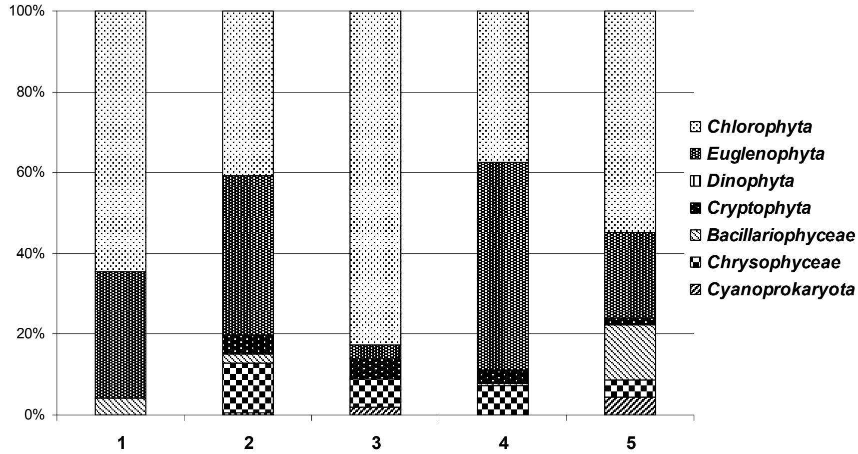

Fig. 4. The percentage share of the taxonomical phytoplankton groups in the total abundance in studied reservoir.

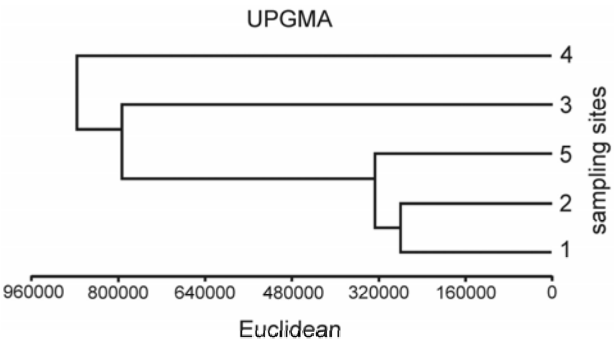

Fig. 5. Cluster Analysis dendrogram of phytoplankton communities in five studied basins within the reservoir.

Euglenophyta taxa present in large numbers were: *Lepocinclis acus*, *Trachelomonas hispida*, *T. volvocina*, and *T. volvocinopsis* at site 1; *Trachelomonas volvocinopsis* at site 2 (accounted 17%); and *Trachelomonas volvocina* and *T. volvocinopsis*, which together accounted for 41% of the total population, at site 4. Of other taxonomic groups, only diatom *Navicula* sp. was a subdominant at site 5.

The species diversity expressed with Shannon index was on an intermediate level within the range 2.2-2.5 at the majority of sampling sites. Lower value of the index (1.3) was recorded at site 3 (isolated by shrubs).

The cluster analysis carried out on the basis of the species numbers revealed that study sites located near the farm (1) together with sites 2 and 5, the bottom of which consisted of flooded arable lands, formed a single group on a dendrogram. Separateness of shady points isolated by trees can be noted as well (sites 3 and 4) (Fig. 5).

Values of chlorophyll-*a* concentrations ranged from 13.6 to 18.6 $\mu g \cdot dm^{-3}$. The highest values were determined at those sites where greens dominated. At sampling point 4 (with the highest total abundance) the lowest concentration of chlorophyll-*a* was recorded. At this point, however, euglenoids, mainly *Trachelomonas* genus, were the dominant group.

Discussion

Some prior studies have noted the importance of mining lakes in enhancing the biodiversity level of degraded landscape by creating secondary habitats for aquatic species [2, 10]. Little was found in the literature on the phytoplankton communities in mining lakes. Several studies concerned extremely acidic open-cast flooded mines, where specific low-biomass communities consisting mainly of small flagellates or diatoms had been described [8, 21-24]. However, after artificial neutralization of such habitats, the phytoplankton community may become more diverse, with diatoms, chrysophyceans, and blue greens predominating [25]. Phytoplankton communities in one of the studied sunken sulphur mines were also not abundant and were represented by a small number of species [3]. On the other hand, a study concerning clay-pit ponds showed that the total algal biomass may be very high (up to 143 µg chl-$a \cdot dm^{-3}$) and consist of diatoms, chlorophytes, and dinoflagellates [26]. Also, in one of the mining-subsidence reservoirs (situated near the studied one) very high phytoplankton biomass (458 µg·chl-*a*) with filamentous cyanobacteria and chlorococcal green domination was noted [27].

Although some research has been carried out in established mining lakes, no single study covers the phytoplankton communities in a subsidence reservoir in the early stages of its development. Thus, our results are hard to compare with results of other investigations. Nevertheless, some findings would be of general interest.

Phytoplankton was dominated by small algae – flagellates (Euglenophyta) and coccal (Chlorophyta) forms. Predominance of small planktonic forms is often noted in extreme habitats [28] or those in the early stage of succession [14], when R-strategists prevail [29]. The high diversity of euglenoids may be related to high values of water colour, which probably resulted from high loads of particulate and dissolved organic matter from flooded alder forests [30]. The dominance of euglenoids in plankton was found by Stevic et al. [31] in a floodplain lake during the autumn, when macrophytes started to decay and the availability of organic matter in the water was higher. Similar results were obtained by Solorzano et al. [32], who observed the highest species richness of *Trachelomonas* genus in a studied sub-urban reservoir during the dry season, when concentrations of organic matter, nitrogen, and phosphorus were the highest. An interesting succession pattern of phytoplankton functional groups was described by Naselli-Flores and Barone [33]. While studying temporal ponds in the Mediterranean region they pointed out that euglenoids appeared as a last group in seasonal sequence from the flooding to the drying phase. Nevertheless, our results showed that euglenoids may dominate phytoplankton also during early summer in the earlier stages of community development. Both the high diversity and the dominance of euglenoids in phytoplankton (mainly from *Trachelomonas* genus) were found by Poniewozik [34] in the subsidence reservoir with coloured water situated in the same region. The group had dominated the community during all the vegetation season. The high water colour in the studied reservoir might also influence light penetration to the water column, establishing poor light underwater climate [35]. This is favourable for mixotrophic flagellates, which may outcompete autotrophs in light or nutrient limitation conditions [36], and might be favourable for euglenoids, which are considered mixotrophic protists [37].

The structure of the phytoplankton community in the studied lake might be also influenced by the lack of macrophytes. Dense macrophyte structures – usually present in very shallow lakes or ponds – promote higher diversity of life forms, including metaphytic algae (like diatoms), which temporarily enrich phytoplankton communities [33]. However, some reports indicate that in shallow oxbow lakes with high macrophyte coverage euglenoids and metaphytic volvocalean species developed frequently [38].

Table 2. Morphometric features and physicochemical parameters of the water in three mine subsidence reservoirs in the Polesie region.

	Nadrybie West [27]	Nadrybie East [34]	Kaniwola*
Area (ha)	11.6	0.36	17.0
Max depth (m)	1.5	1.0	3.0
pH	7.3-10.2	6.7-9.8	6.3-6.6
EC ($\mu S \cdot cm^{-1}$)	319-537	620-1245	182-204
SD (m)	0.1-0.3	to the bottom	0.3-0.5
Land use before inundation	Arable fields, meadows	Willow shrubs on peaty soils, meadows	Alder forest, willow shrubs on peaty soils, meadows, arable fields

*the studied reservoir

The overall number of taxa identified in the whole lake was rather high (80) as compared to those noted in particular sampling sites (28-39), which resulted from the presence of many site-specific species. It may be an effect of the variability of habitat conditions, developed in particular basins, a phenomenon that occurs in shallow lakes [39]. The highest species richness (38-39 taxa) was noted in sites 1 and 5, situated in an open area on inundated arable lands. The lowest number of taxa was determined in site 3, the basin isolated from the others by trees and shrubs. This site was characterized also by the lowest species diversity (Shannon index = 1.3), which was related to the high level of dominance of *Monoraphidium circinale* green algae, a typical planktonic species often found in shallow lakes, wetlands, and ponds [40]. At another shaded site, 4, with the highest total phytoplankton abundance, the lowest concentration of chlorophyll-*a* was recorded, which was related to the predominance of species from the *Trachelomonas* genus. The chlorophyll-*a* content in many euglenoid species is relatively low [41]. The peculiarity of two shaded sites (3 and 4) was confirmed by Cluster Analysis, where they form separated group from open sites.

There are two other mine subsidence reservoirs in the studied area. Unfortunately, the only available data on phytoplankton covers the time period of ca. 10 years after these reservoirs developed, so the comparison with the studied lake is limited. In one lake with comparable morphometric features, but with different water chemistry (Table 2), cyanobacterial blooms occurred with the domination of *Anabaena spiroides* and *Rhabdoderma lineare* [27]. In the second, very small lake phytoplankton was dominated by euglenoids with the high share of *Trachelomonas* species [34]. The key difference between those reservoirs lies, among others, in the land use before their inundation: arable fields and meadows prevailed in the first one, while willow shrubs on peaty soils in the second one (which one was similar to the studied lake).

Conclusions

In the newly formed mine subsidence reservoir in the early stage of the ecosystem development we have found the domination of euglenoids and chlorophytes in the summer phytoplankton, which had relatively low biomass. After the comparison with other mine subsidence lakes situated in the studied area we can hypothesize that the phytoplankton structure in a studied lake might mainly relate to specific habitat conditions. The presence of alder forests and willow shrubs on inundated areas might shape the structure of phytoplankton communities by the load of particulate and dissolved organic matter. However, with a small sample size (one lake studied during one season), caution must be applied, as the findings might not be transferable to other mining-subsidence lakes. Further research, including an enhanced number of reservoirs, would be of great help in our understanding of these ecosystems' structure and functions, as well as the mechanisms of phytoplankton succession.

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