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Article

Ecological status of recently formed quarry-origin water bodies: a case study of the Nivy and Ushakovo quarries, Kaliningrad Region

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Abstract. This paper presents the results of an assessment of the current ecological status of two young flooded quarry lakes located in the Kaliningrad Region, near the settlements of Nivy and Ushakovo. The findings indicate that the ecosystems of both water bodies are at the early stages of succession and are still undergoing active formation. While dissolved oxygen and nutrient concentrations were highly similar across two water bodies, the permanganate index was significantly higher in the Ushakovo quarry lake. Phytoplankton, zooplankton, and zoobenthos communities in both lakes were composed of widely distributed species, though taxonomic similarity between the two water bodies remained low. The Ushakovo quarry supported aquatic communities with higher species diversity, a more complex, and more even structure, with a wider range of trophic groups. A comprehensive analysis of hydrochemical and hydrobiological parameters suggests that the water quality in both quarry lakes is currently transitional between clean and moderately polluted.

Keywords: man-made water body, hydrochemistry, aquatic ecosystem, phytoplankton, zooplankton, zoobenthos

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Научная статья

Экологическое состояние молодых водоемов карьерного происхождения (на примере карьеров у поселков Нивы и Ушаково, Калининградская область)

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Аннотация. Приводятся результаты исследования современного экологического состояния двух молодых обводненных карьеров Калининградской области возле поселков Нивы и Ушаково. Отбор гидрохимических и гидробиологических проб проводился в весенне-летний период 2023 г. Установлено, что экосистемы исследуемых водоемов находятся на ранних этапах сукцессионного ряда и продолжают свое формирование. Содержание растворенного кислорода и биогенных элементов в обоих карьерах сходное, величина перманганатной окисляемости выше в обводненном карьере возле пос. Ушаково. Сообщества фитопланктона, зоопланктона и зообентоса карьеров представлены широко распространенными видами, однако видовое сходство между водоемами низкое. В карьере Ушаково наблюдаются сообщества гидробионтов, характеризующиеся более высоким видовым разнообразием, более сложной и более выровненной структурой, в которой представлено большее количество трофических групп. Анализ комплекса гидрохимических и гидробиологических показателей позволяет оценить качество вод рассматриваемых карьеров как переходное от чистого к умеренно-загрязненному.

Ключевые слова: техногенный водоем, гидрохимия, водная экосистема, фитопланктон, зоопланктон, зообентос

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Introduction

In recent decades, the global prevalence of anthropogenic water bodies – created primarily as a result of mineral extraction, including sand and gravel – has increased significantly. These water bodies are typically characterized by isolation, considerable depth, and specific hydrological and hydrochemical conditions that distinguish them from natural lakes and ponds (Mironova et al., 2022; Seelen et al., 2021a). In the Kaliningrad Region, as in many other regions, the demand for sand and gravel materials remains high. Mining activities have intensified; currently, 18 sand and gravel deposits and 29 construction sand deposits are under active development in the region¹. Many exhausted quarries have since flooded, resulting in the formation of surface water bodies, often referred to as «flooded quarries» (Vypkhanova et al., 2014). Such water bodies are frequently used for recreational purposes, angling, and, in some cases, aquaculture (Seelen et al., 2021a, b; Søndergaard et al., 2018). Despite their widespread occurrence, ecosystem processes and successional dynamics in flooded quarries remain insufficiently studied, especially when considering regional climatic and geological conditions alongside global environmental change (Blanchette and Lund, 2016; Seelen et al., 2021a).

Quarry lakes and other artificial water bodies can hold substantial ecological value by supporting regional biodiversity, providing unique ecosystem services, and facilitating the restoration of lost wetland functions. For instance, in the Po River basin (Italy) and across Western Europe, such water bodies are increasingly integrated into landscape rehabilitation schemes and targeted for ecological improvement (Ghirardi et al., 2023; Seelen et al., 2021a, b). Conversely, studies conducted in Eastern Europe and Russia emphasise the necessity of accounting for highly localized hydrological, hydrochemical, and biological dynamics, alongside the compounding effects of anthropogenic pressures and climate change on successional patterns (Domnin et al., 2023; Shelyuk and Astakhova, 2021; Sienkiewicz and Gąsiorowski, 2016).

Deciphering the developmental trajectories of young anthropogenic ecosystems is crucial for several key reasons: assessing their capacity to sustain regional biodiversity (Tropek et al., 2010); designing robust management and restoration strategies, including the mitigation of eutrophication and the preservation of favourable hydrochemical regimes (Napiórkowska-Krzebietke et al., 2023; Sienkiewicz and Gąsiorowski, 2016); predicting ecosystem responses to climate change and human impact (Seelen et al., 2021a, 2021b); and securing their sustainable deployment for recreation, aquaculture, and water supply (Domnin et al., 2023; Lund and Blanchette, 2023; Seelen et al., 2021a, b).

A comprehensive study of young quarry lakes is particularly urgent in the Kaliningrad Region, where specific interactions with brackish marine and underground aquifers can drastically alter water mineralisation and overall ecological status (Domnin et al., 2023). Investigations from other Russian territories (e.g., Leningrad Region, Western Siberia) and globally (Poland, Germany, China, USA) indicate that their young age, minimal catchment areas, lack of developed littoral zones, and distinct hydrochemical characteristics create unique templates for ecological succession (Dmitrakova et al., 2018; Sienkiewicz and Gąsiorowski, 2016; Stephan and Hubbart, 2022; Sumina and Koptseva, 2019; Xu et

¹ Natural resources. Government of Kaliningrad Oblast. Web-page. URL: <https://gov39.ru/press/region/prirodnye-resursy/> (accessed: 23.04.2026).

al., 2020). Despite their relatively small surface areas, these newly established technogenic ecosystems contribute disproportionately to regional biodiversity due to their environmental heterogeneity and isolated positions (De Meester et al., 2005).

The primary aim of this study was to conduct a comprehensive assessment of the ecological status of two young quarry lakes in the Kaliningrad Region at their initial stages of development, integrating hydrochemical and hydrobiological indicators. This approach aims to elucidate the early stages of ecosystem assembly and identify the key factors limiting biodiversity development.

Materials and methods

The research focuses on two former sand-and-gravel extraction pits located in the western Kaliningrad Region (Fig. 1). Both water bodies are recently formed, not later than five years ago. Sand extraction at the quarry near Nivy settlement (hereafter, Nivy quarry) occurred between 2014 and 2020, with the basin filling completely with water by 2022 (Moiseenko and Tsupikova, 2023). Excavation at the Ushakovo settlement quarry (hereafter, Ushakovo quarry) commenced in 2017, and the pit was subsequently filled by groundwater in 2020. Currently, the Ushakovo quarry lake is used for the cage culture of juvenile coregonids (Moiseenko et al., 2023). The surrounding landscape is characterised by a monotonous, flat relief, comprising morainic plains with brown forest and podzolic-gleyic/gley podzolic soils at elevations of approximately 9 m above sea level (a.s.l.) in the vicinity of the Niva quarry; and flat lake and lowland peatland plains with sod-podzolic and alluvial soils at elevations no higher than 2 m a.s.l. near the Ushakovo quarry.

Morphometric parameters for both flooded quarries were calculated by mapping the lake contours onto high-resolution satellite imagery using various web-based cartographic platforms to ensure adequate image quality across the Kaliningrad Region.

Field sampling was conducted during the spring-summer season of 2023 at three stations systematically distributed across the northern, central, and southern sectors of each water body to capture spatial heterogeneity in ecosystem structure and taxonomic diversity of aquatic life. The coordinates of each sampling station are detailed in Table 1.

Surface runoff into the studied water bodies was estimated using standard hydrological water-balance methodologies².

Hydrochemical samples were analysed in the hydrochemical laboratory of Kaliningrad State Technical University (KSTU) using standard volumetric and colorimetric techniques³. The following parameters were measured: dissolved oxygen, permanganate index, and key inorganic nutrients (ammonium nitrogen, nitrites, and total phosphorus). These analytes were selected as primary indicators of trophic state and anthropogenic impact in freshwater ecosystems.

Phytoplankton, zooplankton, and zoobenthos samples were collected concurrently with hydrochemical parameters from a boat. In the Nivy quarry, sampling spanned the entire growing season (May–August), whereas the Ushakovo quarry was sampled only during the summer. During the field campaign, the Nivy quarry exhibited a continuous rise in water level, pointing to highly unstable hydrological conditions; the water level in the Ushakovo quarry remained stable.

Phytoplankton samples were collected from the photic zone, fixed with Lugol's solution containing formalin and glacial acetic acid, and subsequently concentrated via direct filtration. Zooplankton samples were collected by total vertical hauls using a Jeday plankton net (mesh size 99 µm) and preserved in 40% formalin to a final concentration of 2–4%. Zoobenthos samples were gathered in the littoral zones using a standard benthic hand-frame (cutting edge 0.24 m) with a fixed drag length to ensure equal sampling areas. Benthic samples were fixed with 4% formaldehyde.

Laboratory processing of the biological materials was conducted at the Water Ecology Laboratory of KSTU following standardized protocols (Krylov et al., 2024). Taxonomic identification and enumeration of organisms were performed under a Motic-Z171 stereomicroscope (Motic China Group Co., China) and a Motic-BA310 laboratory light microscope (Motic China Group Co., China) using regional and specialised taxonomic keys (Alekseev and Tsalolikhin, 2010, 2016; Beliakova et al., 2006; Medvedeva and Nikulina, 2014). Phytoplankton diversity was assessed at the genus level and below.

² Recommendations for the calculation of systems for collection, conveyance, and treatment of surface runoff from residential areas and industrial sites, and for determining the conditions for its discharge into water bodies, 2025. Ministry of Construction and Housing and Communal Services of the Russian Federation, Moscow, Russia, 146 p.

³ Characteristics of pollutants from Section "II. For Water Bodies" of the "List of Pollutants Subject to State Regulation Measures in the Field of Environmental Protection", 2016. Ural Research Institute «Ecology», Ekaterinburg, Russia, 296 p.



Fig. 1. Location of the quarry lakes near Nivy and Ushakovo settlements.

Table 1. Coordinates of the sampling stations in the studied quarry lakes.

Coordinates	Water body	
	Nivy quarry	Ushakovo quarry
Station 1 (North)	N 54.76677 E 20.05174	N 54.67534 E 20.81644
Station 2 (Centre)	N 54.76513 E 20.05299	N 54.67429 E 20.81524
Station 3 (South)	N 54.76345 E 20.05425	N 54.67323 E 20.81332

Phytoplankton and zooplankton abundance (N) was determined using counting chambers. Phytoplankton biomass (B) was calculated using the volumetric-geometric approximation method. The cell size structure of the phytoplankton was evaluated using the abundance-to-biomass ratio (N/B). Zooplankton biomass was calculated using established length-weight regression equations (Krylov et al., 2024). Zoobenthos abundance was determined by direct counts, and biomass was measured using an analytical balance (AND HR-250AZG, A&D Co. LTD, Japan). Species dominance was assessed using the Palia-Kovnacki index (Shitikov et al., 2003); species with an index value greater than 10 were classified as dominant.

Community taxonomic similarity was computed using the Sørensen-Czekanowski index (Sørensen, 1948). Species diversity was estimated using the Shannon-Wiener index based on abundance data (Shannon, 1949).

The trophic status of the quarries was determined using Andronikova's classification system (Andronikova, 1996). Water quality was assessed hydrochemically in compliance with GOST 17.1.2.04-77⁴. Biological water quality assessment was based on the Mischke phytoplankton scale (Mischke et al., 2002), the Pantle-Buck saprobity index modified by Sladeczek, Balushkina's chironomid index, and the oligochaete index (Krylov et al., 2024; Shitikov et al., 2003). The food resource capacity of the water bodies was evaluated according to the GosNIORKH fishery classification (Pidgaiko et al., 1968).

Results

The studied flooded quarries, sharing similar technogenic origin and geomorphological features, exhibit comparable morphometric characteristics. However, their basin shapes differ slightly: the Nyva quarry is generally more circular but features a highly indented shoreline. Furthermore, its water volume exceeds that of the Ushakovo quarry by over 1.7 times (Table 2).

The steep underwater slopes and minimal littoral zones characteristic of these quarry basins promote strong summer thermal stratification, which is typically more pronounced than in natural lakes of comparable size (Suhovilo and Romanchuk, 2018). Deeper systems are capable of undergoing complete vertical mixing during spring and autumn turnovers, which dramatically shapes water quality. A depth range of 10–15 m is considered optimal for the development of distinct thermal layers and reduces the system's susceptibility to rapid cultural eutrophication (Szatylowicz et al., 2015).

Reflecting their artificial origin, both quarries have catchment areas that are disproportionately small compared to their lake surface areas (Fig. 2). The annual surface runoff from the catchments⁵ is estimated at $17.1 \times 10^3 \text{ m}^3$ for the Nivy quarry and $25.4 \times 10^3 \text{ m}^3$ for the Ushakovo quarry. Consequently, combined surface runoff and direct precipitation onto the lake surfaces account for only 8 and 13% of the total water volume in the Nivy and Ushakovo quarries, respectively. This indicates that meteoric water cannot account for the rapid filling of the pits; instead, both systems are predominantly fed by groundwater aquifers. In the Ushakovo quarry, this is facilitated by its low-lying topographic position. In the Nivy quarry, a sub-surface freshwater spring of unknown origin was discovered near the south-eastern shore at a depth of less than 0.5 m, likely originating from abandoned agricultural tile drainage systems.

Under current municipal zoning and land-use registers, neither water body is officially designated as a protected surface water object, and no riparian buffer zones⁶ have been established. At present, the catchment of the Nivy quarry is managed under the state forestry fund, with active reforestation plots surrounding the lake.

According to the Public Cadastral Map of the Kaliningrad Region⁷, the Ushakovo quarry catchment lies within a combined industrial and agricultural zone. The surrounding landscape is heavily drained by a dense network of reclamation channels, and several drainage pumping stations operate nearby on the right bank of the Pregolya River.

⁴ GOST 17.1.2.04-77. Nature Protection. Hydrosphere. State indices and rules for taxation of fishery water bodies.

⁵ Recommendations for the calculation of systems for collection, conveyance, and treatment of surface runoff from residential areas and industrial sites, and for determining the conditions for its discharge into water bodies, 2015. Ministry of Construction and Housing and Communal Services of the Russian Federation, Moscow, Russia, 146 p.

⁶ Rules of land use and development of municipalities. Ministry of Urban Planning Policy of the Kaliningrad Region. Web page. URL: <https://mingrad.gov39.ru/activity/pzz/#kld> (accessed: 22.04.2026).

⁷ Public cadastral map. Federal Service for State Registration, Cadastre and Cartography. URL: <https://pkk.rosreestr.ru/> (accessed: 22.04.2026).

Table 2. Morphometric characteristics of the Nivy and Ushakovo quarry lakes.

Parameter	Water body	
	Nivy quarry	Ushakovo quarry
Surface area, ha	12.6	10.9
Shoreline length, km	1.87	3.14
Maximum Length, km	0.55	0.25
Mean width, km	0.27	0.22
Maximum width, km	0.29	0.25
Maximum depth, m	~12	15
Water volume, million m ³	≤1.51	0.86
Basin shape	Ellipsoid	Paraboloid
Shoreline development index	1.9	1.3
Catchment area, ha	2.7	4.9

Because all water samples were collected from the surface layer, the values of most hydrochemical variables were highly uniform across all sampling stations within each lake, with the notable exception of the permanganate index. Water transparency was consistently high (2–3 m Secchi depth), and oxygen conditions were highly favourable, with dissolved oxygen saturation hovering near 100% throughout the growing season. However, the concentration of labile organic matter differed markedly: according to Alekin's classification (Alekin, 1970), the permanganate index was graded as «very low» in the Nivy quarry, but “moderate” in the Ushakovo quarry. The elevated level of labile organic matter in the Ushakovo quarry is directly attributable to the metabolic outputs and feed inputs from the active cage-aquaculture farm.

With the exception of phosphate phosphorus in the Nivy quarry, concentrations of dissolved oxygen, nutrients, and BOD₅ did not exceed the maximum permissible concentrations (MPCs) established for fishery water bodies by the Ministry of Agriculture⁸. The elevated BOD₅ and phosphate levels in the Nivy quarry likely stem from agricultural runoff entering the lake via the surrounding drainage network.

In general, based on hydrochemical water qualities parameters, both quarry lakes can be classified as oligosaprobic (Table 3).

The algal flora of the two reservoirs exhibited clear qualitative and quantitative differences, with the Nivy quarry supporting a much poorer community. A total of 45 phytoplankton taxa spanning eight phyla were identified in the Ushakovo quarry, compared to 32 taxa from seven phyla in the Nivy quarry. In both lakes, Chlorophyta (green algae) and Bacillariophyta (diatoms) were the most species-rich groups. Cryptophyta, Chrysophyta, and Streptophyta were minor components in the Ushakovo quarry. In the Nivy quarry, Euglenophyta and Cryptophyta were moderately diverse, whereas Cyanoprokaryota (cyanobacteria) and Dinophyta exhibited very low species richness (Table 4).

The quantitative development of phytoplankton showed pronounced spatial heterogeneity. In the Ushakovo quarry, both abundance and biomass decreased systematically with increasing station depth

⁸ Ministry of Agriculture of the Russian Federation (2016) Order No. 552 of 13 December 2016 on the approval of water quality standards for water bodies of fishery significance, including standards for maximum permissible concentrations of harmful substances in the waters of water bodies of fishery significance (as amended up to 22 August 2023).

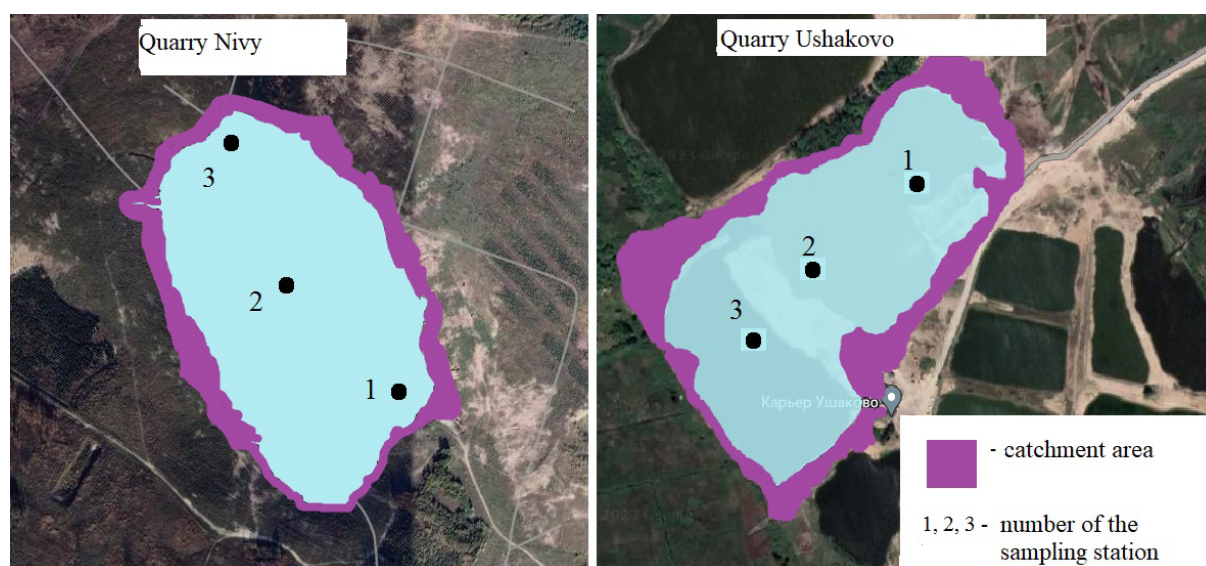


Fig. 2. Catchment areas of the quarry lakes.

(Fig. 3). Cyanobacteria dominated numerically at all stations and in terms of biomass at Stations 1 and 2, accounting for an average of 86% of total abundance and 39% of total biomass. This community was dominated by *Dolichospermum planctonicum* (Brunnthal) Wacklin, L. Hoffmann & Komárek, a species known to form dense summer blooms in both lentic and lotic systems (Gorokhova, 2018; Kulizin, 2023). Dinophyta and Euglenophyta also contributed significantly to total biomass (jointly over 40%). This aligns with literature showing that under stable, stratified, warm water conditions, heavy-celled diatoms are often outcompeted by motile, large-celled dinoflagellates and flagellated euglenoids (Gorokhova, 2017; Trifonova, 1990).

In the Ushakovo quarry, moderate positive correlations were observed between ammonium nitrogen, BOD_5 , and phytoplankton biomass across stations ($r = 0.35$ – 0.47), whereas a strong correlation was found between dissolved oxygen and biomass ($r = 0.63$). Other hydrochemical-biological correlations were weak or negligible.

In the Nivy quarry, the relationship between phytoplankton metrics and station depth was less pronounced. Phytoplankton abundance remained relatively stable across seasons (averaging 0.6–0.9 million cells/L), with narrow biomass fluctuations (1.1–1.2 mg/L), representing a moderate level of algal development according to Pidgaiko's classification (Pidgaiko, 1969). However, spatial differences were visible: peak abundance and biomass shifted seasonally, occurring in the shallow north-eastern sector in spring and near the south-western shore in summer. In both seasons, green algae dominated the highly productive stations (averaging 79% of total abundance). In contrast to the Ushakovo quarry, cyanobacteria represented only 6–9% of the community. Strong positive correlations were observed between dissolved oxygen and phytoplankton biomass in both the Ushakovo ($r = 0.57$) and Nivy ($r = 0.73$) quarries. Furthermore, in spring, Nivy's phytoplankton biomass correlated very strongly with BOD_5 and the permanganate ($r > 0.7$), though this relationship decoupled in summer, suggesting that other environmental drivers become limiting later in the season.

A total of 22 zooplankton species were identified across both systems (Table 5), including seven cladocerans (Cladocera), five copepods (Copepoda), nine rotifers (Rotifera), and one conchostracan (Conchostraca). Within the Cladocera, the family Chydoridae was the most diverse; Brachionidae dominated the Rotifera, and Cyclopidae dominated the Copepoda. All identified species are typical for water bodies of the Kaliningrad Region (Shibaeva et al., 2013, 2018). Approximately 63% of the species are cosmopolitans, 26% are restricted to the Palaearctic, and 11% are Holarctic. Due to the steep underwater slopes and narrow littoral zones, macrophytes are very sparse in both quarries, forcing the assembly of a predominantly pelagic, non-predatory zooplankton community.

The Ushakovo zooplankton community comprised 17 species (Table 5), dominated by rotifers (8 species). Cladocerans and copepods were slightly less diverse. The cladocerans *Bosmina longirostris* and *Chydorus sphaericus*, the copepods *Diacyclops bicuspidatus*, *Eudiaptomus gracilis*,

Table 3. Saprobiological classification of the Nivy and Ushakovo quarry lakes based on GOST 17.1.2.04-77⁹.

Parameter	Water body			
	Nivy quarry		Ushakovo quarry	
Permanganate index, mgO/L	1.25 ±	Xenosaprobic	5.75 ±	Xenosaprobic
Dissolved oxygen, %	100 ±	Oligosaprobic	100 ±	Oligosaprobic
Nitrites, mg/L	0.001	Xenosaprobic	0.001	Xenosaprobic
Phosphates, mgP/L	0.20 ±	α-mesosaprobic	0.025 ±	Oligosaprobic
Ammonium, mgN/L	0.4 ±	β-mesosaprobic	0.20 ±	β-mesosaprobic
BOD ₅ , mgO ₂ /L	3.5 ±	α-mesosaprobic	2.5 ±	β-mesosaprobic

Table 4. Taxonomic structure of the phytoplankton communities in the studied quarry lakes.

Phylum	Water body			
	Nivy quarry		Ushakovo quarry	
	Number of taxa	Share, %	Number of taxa	Share, %
Bacillariophyta	11	34.38	6	13.33
Chlorophyta	7	21.88	17	37.78
Chrysophyta	0	0.00	1	2.22
Cryptophyta	3	9.38	4	8.89
Cyanoprokaryota	2	6.25	6	13.33
Dinophyta	2	6.25	5	11.11
Euglenophyta	5	15.63	5	11.11
Streptophyta	2	6.25	1	2.22
Total	32	100	45	100

⁹ GOST 17.1.2.04-77. Nature Protection. Hydrosphere. State indices and rules for taxation of fishery water bodies.

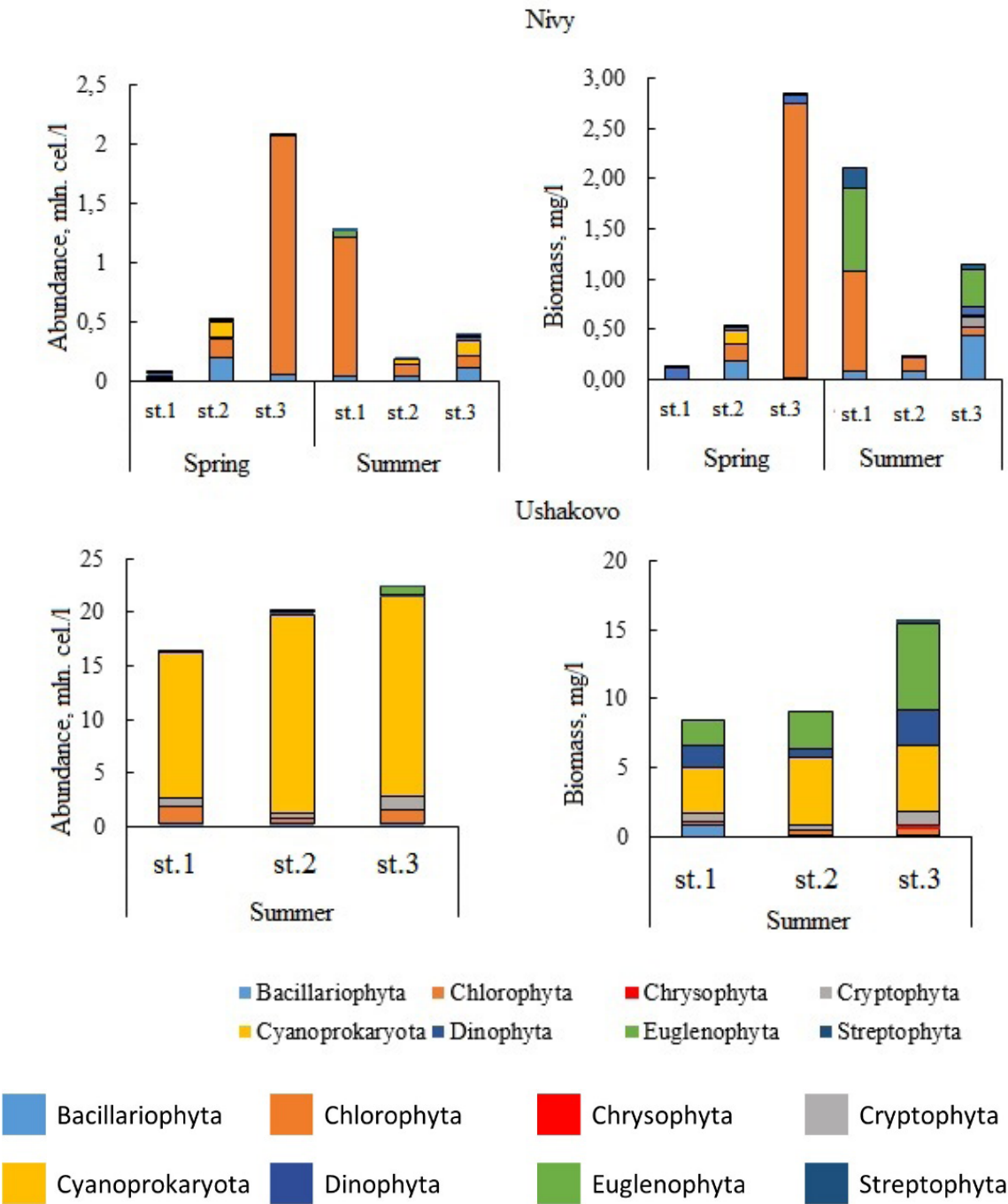


Fig. 3. The abundance and biomass of phytoplankton in the water-flooded quarries.

Table 5. Zooplankton species composition and saprobity indicator values in the studied quarry lakes.

Group	Taxon	Water body		Saprobity indicator value (Kolkwitz and Marsson, 1902)
		Nivy quarry	Ushakovo quarry	
Cladocera	<i>Biapertura affinis</i> (Leydig, 1860)		+	o-β
	<i>Bosmina longirostris</i> (Müller, 1785)	+	+	o-β
	<i>Coronatella rectangula</i> (Sars, 1862)	+		o-β
	<i>Chydorus sphaericus</i> (Müller, 1785)		+	β-o
	<i>Daphnia longispina</i> (Müller, 1776)	+		β
	<i>Leptodora kindtii</i> (Focke, 1844)		+	β-o
	<i>Monoculus aduncus</i> (Jurine, 1820)		+	o-β
	Subtotal Cladocera	3	5	
Copepoda	<i>Cyclops</i> sp.	+		–
	<i>Diacyclops bicuspidatus</i> (Claus, 1857)		+	o
	<i>Eudiaptomus gracilis</i> (Sars, 1863)	+	+	o-β
	<i>Mesocyclops leuckarti</i> (Claus, 1857)	+		o-β
	<i>Thermocyclops oithonoides</i> (Sars, 1863)	+	+	o
	Subtotal Copepoda	4	3	
Rotifera	<i>Asplanhna priodonta</i> (Gosse, 1850)		+	β
	<i>Brachionus quadridentatus</i> (Hermann, 1783)	+		β
	<i>Euchlanis dilatata</i> (Ehrenberg, 1832)		+	β-o
	<i>Filinia teminalis</i> (Plate, 1886)		+	–
	<i>Kellicottia longispina</i> (Kellicott, 1879)	+	+	o-β
	<i>Keratella cochlearis</i> (Gosse, 1851)		+	o-β
	<i>K. quadrata</i> (Müller, 1785)	+	+	β-o
	<i>Polyarthra major</i> (Burckhardt 1900)		+	o-β
	<i>Trichocerca</i> sp.		+	β-o
	Subtotal Rotifera	3	8	
Others	<i>Conchostraca</i> sp.		+	–
Total		10	17	

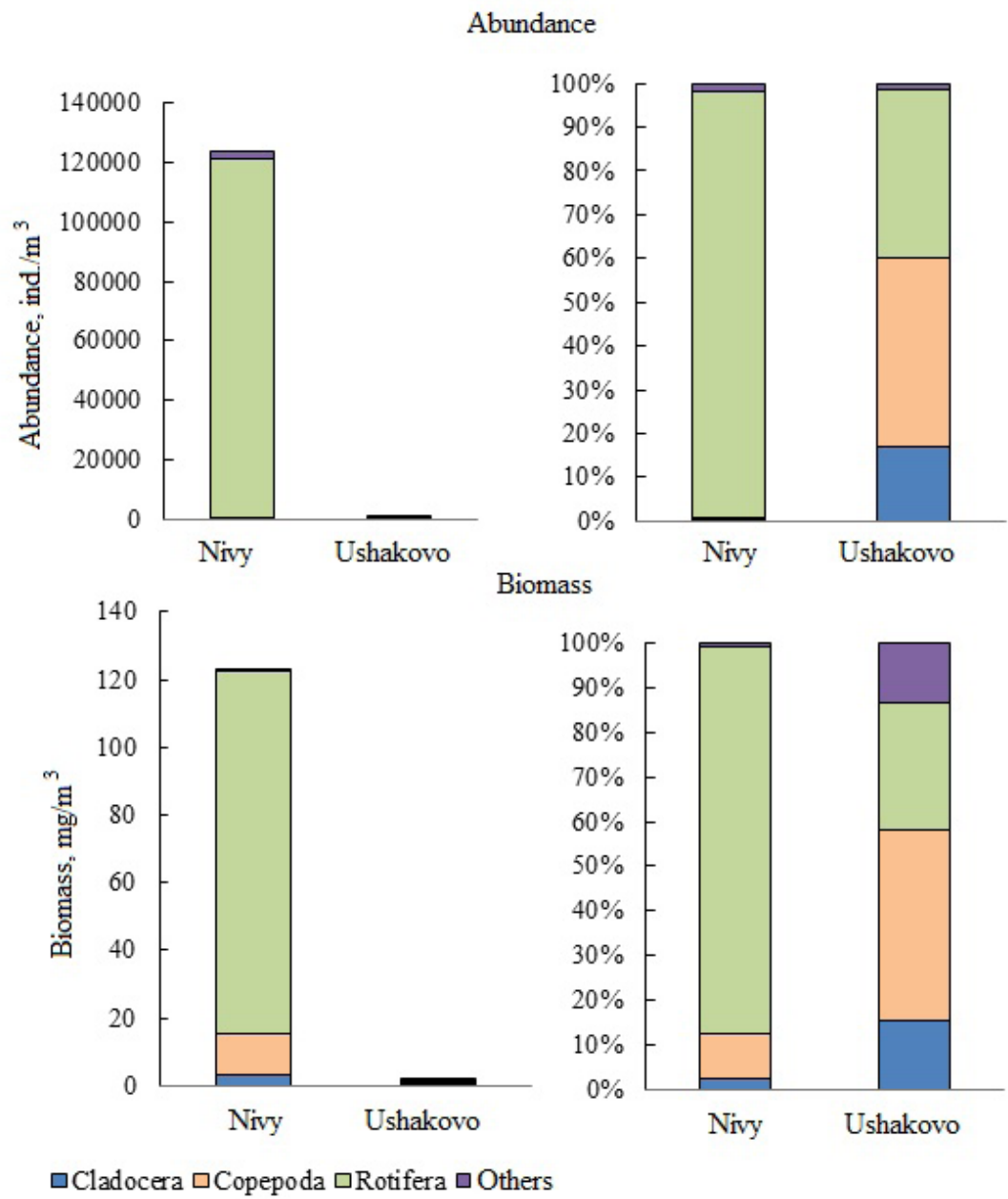


Fig. 4. The abundance and biomass zooplankton in the water-flooded quarries.

and *Thermocyclops oithonoides*, and the rotifers *Asplanchna priodonta*, *Filinia terminalis*, and *Keratella cochlearis* occurred at all stations.

In contrast, the Nivy quarry supported a significantly impoverished zooplankton community featuring just 10 species: four copepods, three cladocerans, and three rotifers (Table 5), dominated by small-bodied taxa. The rotifer *Brachionus quadridentatus* was recorded at all stations in both spring and summer. *Bosmina longirostris* and *Keratella cochlearis* were less frequent, occurring in 60% of samples.

The taxonomic similarity between the zooplankton communities of the two quarries was very low, with a Sørensen-Czekanowski index of just 0.27, sharing only five species. In the Ushakovo quarry, copepods and rotifers dominated both zooplankton abundance and biomass. This copepod-dominated structure is highly typical for small natural lakes in the Kaliningrad Region (Shibaeva et al., 2018). Copepod nauplii and copepodites dominated numerically, while *A. priodonta* and *F. terminalis* were the most abundant rotifers. The bulk of the biomass was made up of the large calanoid *E. gracilis* and the large rotifer *A. priodonta*. Trophically, the community was dominated by microconsumers (collectors), predators, and primary filters.

In the Nivy quarry, the zooplankton community was extremely skewed: 99% of total abundance was comprised of a single rotifer species, *Brachionus quadridentatus* (Fig. 4), with all other taxa combined accounting for below 1%. This extreme monodominance (more than 90% abundance share) was persistent across all stations in both spring and summer. *B. quadridentatus* also dominated total biomass, though minor contributions were made by the larger *E. gracilis* and *D. longispina*.

Several authors suggest that mass developments of the genus *Brachionus* indicate eutrophic conditions (Andronikova, 1996; Derevenskaya et al., 2019). However, *B. quadridentatus* is a highly eurytopic, small-bodied r-strategist characterised by rapid reproduction and a short life cycle. Trophically, *Brachionus* species feed by filtering suspended phytoplankton, bacteria, and fine detritus. In the Nivy quarry, the phytoplankton community is dominated by green algae, which are highly digestible food sources for *B. quadridentatus* (Heerkloß and Hlawa, 1995). This abundant food supply, combined with a lack of invertebrate predators, facilitated rapid population growth. Furthermore, such monodominance is a classic feature of newly established water bodies or ecosystems undergoing early recovery following ecological rehabilitation (Derevenskaya, 2025).

A total of 23 macrozoobenthos taxa (resolved to genus or species) were recorded across both sites. These are all widely distributed Palaearctic taxa common to the Baltic region. The highest diversity was found among chironomid larvae (11 taxa; Table 6), reflecting patterns seen in other local waters (Masyutkina et al., 2014; Shibaeva et al., 2018).

The Sørensen-Czekanowski index for macrozoobenthos was exceptionally low (0.08), indicating almost complete faunal dissimilarity. The only shared taxon was the corixid water boatman *Sigara* sp.

In the Ushakovo quarry, 15 benthic taxa were identified, including chironomids, alderflies, gastropods, oligochaetes, leeches, aquatic beetles, and hemipterans. This diverse assemblage contains both amphibious insects and obligate aquatic organisms, indicating at least temporary hydrological connectivity with nearby drainage channels. Additionally, some species (such as leeches) were likely co-introduced alongside fish stocking events.

The zoobenthic community of the Nyva quarry is depauperate (comprising just 9 taxa) and predominantly consists of amphibious elements, including larvae of chironomids, odonates, trichopterans, plecopterans, and aquatic heteropterans. This reflects both the short ecological lifespan and hydrological isolation of the Nivy basin from adjacent water bodies.

In terms of abundance, the Ushakovo benthos was dominated by chironomids, dytiscids, gastropods, and oligochaetes, with *Polypedilum nubeculosum*, *Radix auricularia*, and larval Dytiscidae being the most abundant taxa. Benthic biomass was heavily dominated by the large gastropods *R. auricularia* and *Lymnaea stagnalis*. In the Nivy quarry, the corixid *Sigara* sp. and the chironomid *Procladius choreus* dominated both abundance and biomass (Fig. 5).

The dominant species complex by biomass is composed of *Sigara* sp., *Sialis lutaria*, and nymphs of *Cordulia aenea*.

Table 6. Taxonomic composition of the macrozoobenthos in the Nivy and Ushakovo quarry lakes.

Group	Taxon	Water body		Saprobity indicator value (Kolkwitz and Marsson, 1902)
		Nivy quarry	Ushakovo quarry	
Chironomidae	<i>Chironomus plumosus</i> (L., 1758)	+		p
	<i>Chironomus</i> sp.		+	α-p
	<i>Cladotanytarsus mancus</i> (Walk., 1856)		+	–
	<i>Corynoneura</i> sp.	+		–
	<i>Cricotopus</i> sp.		+	–
	<i>Cryptochironomus defectus</i> (Kief., 1913)		+	α
	<i>Endochironomus albipennis</i> (Meig., 1830)		+	β
	<i>Polypedilum convictum</i> (Walk., 1856)	+		β-α
	<i>P. nubeculosum</i> (Meig., 1804)		+	β-α
	<i>Procladius choreus</i> (Meig., 1804)	+		β-α
	<i>Tanytarsus</i> sp.	+		–
Crustacea	<i>Asellus aquaticus</i> (L., 1758)		+	α
Hirudinea	<i>Piscicola geometra</i> (L., 1758)		+	β
Mollusca	<i>Radix auricularia</i> (L., 1758)		+	β-α
	<i>Lymnaea stagnalis</i> (L., 1758)		+	β
Odonata	<i>Cordulia aenea</i> (L., 1758)	+		–
Oligochaeta	<i>Limnodrilus hoffmeisteri</i> (Clap., 1862)		+	α-p
	<i>Ophidonais serpentina</i> (Müller, 1773)		+	–
Trichoptera	<i>Ecnomus tenellus</i> (Rambur, 1842)	+		–
Others	<i>Dytiscidae</i> (иммаго)		+	–
	<i>Dytiscidae</i> (личинка)		+	–
	<i>Sialis lutaria</i> (L., 1758)	+		β-α
	<i>Sigara</i> sp.	+	+	β
Total	23	9	15	

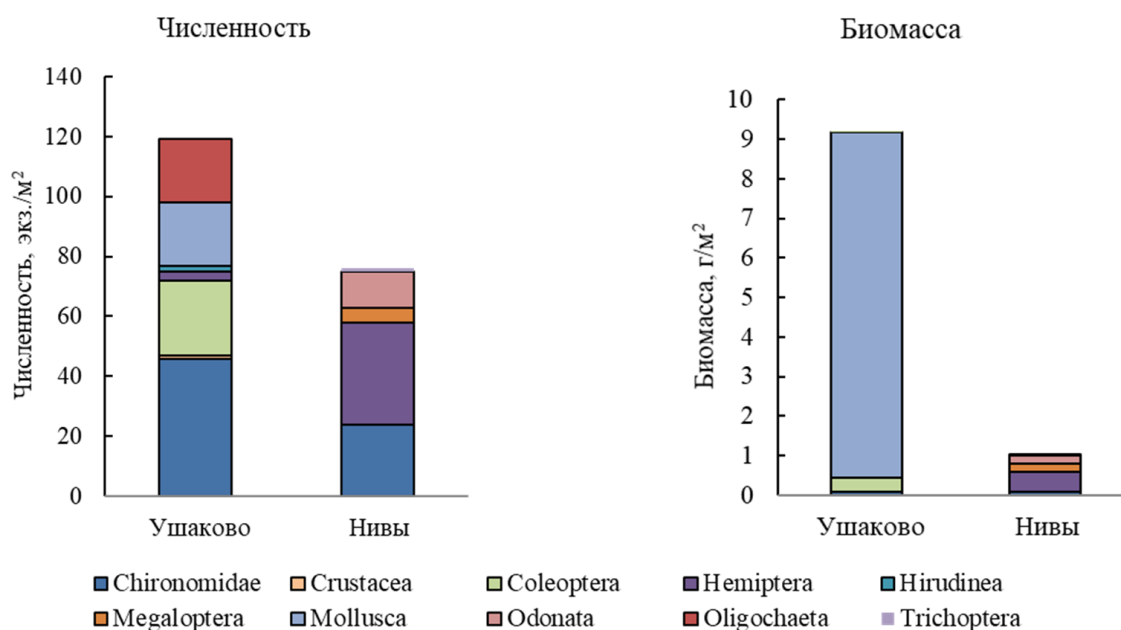


Fig. 5. The abundance and biomass of zoobenthos in the water-flooded quarries.

Discussion

The shared origin of the studied water bodies as flooded sand-gravel quarries explains their similar morphometric and partially overlapping hydrochemical characteristics. Both water bodies exhibit poorly developed macrophyte communities. Although both phytoplankton, zooplankton, and zoobenthic communities comprise widespread species, but they differ substantially in taxonomic composition, abundance, and structural organization.

Recently formed water bodies with unestablished ecosystems typically feature monodominant communities composed of species most resilient to extreme environmental conditions. For zooplankton, this niche is commonly filled by rotifers of the family Brachionidae (De Meester et al., 2005; Tavernini et al., 2009), as is characteristic of the Nyva quarry as well. Additionally, factors directly affecting the likelihood of individuals or species reaching a given habitat include the abundance of source habitats, and regional biodiversity characteristics (De Meester et al., 2005). The Ushakovo quarry exhibits several key differences from the Nyva quarry that shape its ecological characteristics: its intermittent hydrological connection to the Pregolya River; the active stocking of fish and consequent introduction of hitchhiking organisms; and its longer ecological age (flooded two years earlier than Nivy). These factors likely underlie the distinct differences in aquatic biodiversity observed between the two flooded quarries.

Phytoplankton, possessing rapid generation times, respond almost instantaneously to environmental fluctuations (Devyatkin, 1983; Sakharova and Korneva, 2018). Consequently, spatial and temporal variations among stations in both studied water bodies were much more pronounced in the phytoplankton than in the slow-responding zooplankton and zoobenthos.

To compare community structure, we employed the Shannon-Wiener index, which accounts for both species richness and evenness. Average Shannon diversity was consistently higher in the Ushakovo quarry for both phytoplankton and zooplankton, indicating a more balanced and mature community structure (Table 7). In contrast, very low Shannon values are typical for eutrophic water bodies.

Phytoplankton biomass is a highly informative and widely adopted proxy for assessing the productivity of aquatic ecosystems. It forms the basis of quantitative indicator system that enables the most trophic classification of water bodies. The phytoplankton biomass recorded in the Ushakovo quarry reflects a moderately high level of algal development and a tendency towards summer blooms, with trophic indices pointing to a eutrophic state. This is corroborated by its size structure - characterised by a high abundance-to-biomass ratio indicating small-celled dominance (Korneva et al., 2021) – and its evaluation as «moderate/satisfactory» according to the Mischke ecological scale (Mischke et al., 2002). Conversely, the low phytoplankton biomass and associated indices in the Nivy quarry were

Table 7. Indices reflecting the trophic status and ecological condition of water bodies based on structural-functional parameters of phytoplankton, zooplankton, and zoobenthos communities. N - abundance; B – biomass.

Parameter		Water body	
		Nivy quarry	Ushakovo quarry
Phytoplankton	Trophic status (by abundance)	Oligotrophic	Mesotrophic
	Trophic status (by biomass)	Mesotrophic	Eutrophic
	Ecological status (Mischke scale)	Goog	Satisfactory
	Saprobity index	2.0	1.9
	Milius trophic index	Oligo-mesotrophic	Eutrophic
Zooplankton	Shannon diversity	2.01	2.19
	Zooplankton/phytoplankton biomass ratio	0.200	0.001
	Nclad/Ncoop	0.52 (oligotrophic)	0.40 (oligotrophic)
	Bclad/Bcop	0.28 (oligotrophic)	0.35 (oligotrophic)
	Bcrusr/Brot	0.132	2.02
Zoobenthos	Mean individual weight, mg	0.00097 (eutrophic-hypereutrophic)	0.020 (oligo-mesotrophic)
	Trophic status (by biomass)	Oligotrophic	Oligotrophic
	Food supply category (fishery scale)	Very poor	Very poor
	Mäemets index (E)	0.64 (Oligotrophic)	5 (hypereutrophic)
	Saprobity index	1.55 (β-mesosaprobic)	1.46 (oligosaprobic)
Zoobenthos	Shannon diversity	0.35	3.29
	Saprobity index	1.99 (β-mesosaprobic)	2.21 (β-mesosaprobic)
	Shannon diversity	1.39	2.02
	Balushkina's chironomid index	4.84 (moderately polluted)	1.5 (moderately polluted)
	Oligochaete index	–	17 (clean)
Zoobenthos	Food supply category (fishery scale)	Very poor	Very poor

typical of underdeveloped phytoplankton communities (Kitaev, 2007; Oksiyuk and Stolberg, 1986; Pidgaiko, 1969).

This contrast is further supported by the zooplankton-to-phytoplankton biomass ratio (Derevenskaya et al., 2012; Zhdanova et al., 2024). In oligotrophic systems, zooplankton biomass often exceeds phytoplankton biomass, reflecting highly efficient top-down control and indicating a balanced, undisturbed ecosystem through efficient grazing. During eutrophication, this ratio typically inverts as grazing efficiency falls and energy is diverted into detrital pathways. Consequently, the diet of zooplankton shifts markedly toward bacteria and detritus, reducing their reliance on phytoplankton. In the Nivy quarry, zooplankton communities are dominated by herbivorous grazers. In the Ushakovo quarry, the addition of specialized invertebrate predators, including obligate carnivores, indicates a more complex, multi-tiered food web. However, in both quarries, phytoplankton biomass greatly exceeded zooplankton biomass (Table 7). We suggest this is not a sign of advanced cultural eutrophication, but rather reflects a deficit in zooplankton biomass, potentially driven by intense fish predation and the early, unestablished stage of ecological succession in both water bodies. Absolute zooplankton biomass at both sites was extremely low (less than 0.5 g/m³), which is highly characteristic of oligotrophic waters.

Phytoplankton community structure suggests a transitional trophic state in both quarry lakes. The Nivy quarry is oligo-mesotrophic, characterised by a high share of green algae and diatoms and very low cyanobacterial abundance. Conversely, in the Ushakovo quarry, cyanobacteria dominated heavily, keeping diatom and green algae shares low, which is typical of mesotrophic-eutrophic systems.

The Mäemets faunal index (E), which relies on specific oligotrophic and eutrophic indicator species (Andronikova, 1996), yielded conflicting results. For the Ushakovo quarry, the complete absence of oligotrophic indicators combined with the presence of eutrophic indicators resulted in a «hypereutrophic» designation. In the Nivy quarry, the index indicated an oligotrophic state, though some eutrophic indicators were present. Out of the 22 zooplankton species recorded in both quarry lakes, only six serve as valid indicators under the Mäemets index. In our view, the Mäemets index is highly unreliable when applied to such young, newly filled systems (1–3 years old), as they have not yet reached a stable, climax community state. Furthermore, short-term, survey-based monitoring campaigns naturally miss rare or seasonally transient taxa in these water bodies.

Future successional shifts in trophic status can be tracked using the macro-taxonomic biomass ratio ($B_{\text{crust}}/B_{\text{rot}}$), which systematically declines as lakes eutrophy. In this study, higher $B_{\text{crust}}/B_{\text{rot}}$ values were observed in the Ushakovo quarry.

Trophic shifts are also reflected in zooplankton size structure. Eutrophication generally drives a shift from large-bodied to small-bodied species. The zooplankton in the Nivy quarry is dominated by the small-bodied rotifer *B. quadridentatus*; although larger cladocerans (*D. longispina*) and copepods (*E. gracilis*) are also present, their abundances are negligible. Consequently, the mean individual zooplankton weight in Nivy was extremely low (below 0.001 mg), a pattern typical of eutrophic-hypereutrophic waters (Andronikova, 1996; Aubakirova et al., 2021; Haberman and Haldina, 2014). Conversely, the Ushakovo zooplankton community includes both small-bodied species (*K. longispina*, *P. major*) and large-bodied taxa (such as the rotifer *A. priodonta*, the cladoceran *L. kindtii*, and the copepod *E. gracilis*). This results in a higher mean individual weight (0.020 mg), which is typical of oligotrophic-mesotrophic waters.

From a fisheries perspective, both aquatic ecosystems are classified as “very poor” in terms of food supply (zooplankton and zoobenthos biomass), representing a major limiting factor for fish productivity.

An additional criterion for assessing trophic status in water bodies is the presence and proportional abundance of trophic indicator taxa within plankton communities. In terms of organic pollution, the dominance of β -mesosaprobic indicator species in the phytoplankton communities suggests moderate levels of pollution. In the Ushakovo quarry, oligosaprobic species dominated, indicating clean water. In the Nivy quarry, the share of β -mesosaprobic species was slightly higher, indicating moderate pollution. Overall, both systems fall into a transitional zone between oligosaprobic and β -mesosaprobic classes.

The benthic fauna at both sites consisted primarily of β -mesosaprobic and α -mesosaprobic species, with the former being slightly more abundant, indicating moderately polluted conditions in two studied quarry lakes. Because benthic organisms inhabit the sediment-water interface where organic matter naturally accumulates, saprobity indices calculated from zoobenthos were slightly higher than those derived from pelagic zooplankton (Bezmaternykh, 2007).

Chironomid larvae were present in both quarries, and their high taxonomic diversity allowed water quality assessment using Balushkina's chironomid index. Although the index was slightly higher in the Nivy quarry, both systems fell within the “moderately polluted” range.

Oligochaetes were useful indicators only in the Ushakovo quarry, as they were entirely absent from the Nivy samples. In Ushakovo, oligochaetes accounted for approximately 17% of benthic abundance, which is indicative of clean water conditions.

Conclusion

Both of the studied quarry lakes are characterised by small catchments, groundwater-dominated hydrology, and depths exceeding 10 m that support strong summer thermal stratification. The lakes exhibit high water transparency (2–3 m Secchi depth) and highly favourable, near-saturated oxygen conditions. Inorganic nutrient concentrations and BOD₅ values are low and do not exceed fishery limits. Based on hydrochemical metrics, both quarries can be classified as oligosaprobic (clean waters). However, biological quality indicators based on zooplankton and zoobenthos classify quarry water quality as transitional shifting from clean to moderately polluted, while phytoplankton indicators suggest greater contamination.

The aquatic communities (phytoplankton, zooplankton, and zoobenthos) at both sites are dominated by widespread, cosmopolitan species, but they share very low taxonomic similarity. The Nivy quarry supports a species-poor community compared to the Ushakovo quarry, which exhibits higher species richness, greater evenness, and a more complex trophic web. This contrast is driven by Ushakovo's longer ecological lifespan, its intermittent hydrological connections with other water bodies, and active fish stocking. The Nivy benthos consists entirely of amphibious insect larvae, whereas Ushakovo supports several obligate aquatic species. In terms of zoobenthic and zooplanktonic biomass, the food resource capacity of both water bodies is classified as «very poor».

The ecosystems of these recently formed quarry lakes are at the early successional stages and are still in the process of assembly. Zooplankton community structure indicates a predominantly oligotrophic status for both quarry lakes.

In the Nivy quarry, green algae dominated phytoplankton abundance and biomass, whereas cyanobacteria dominated in the Ushakovo quarry. The spatial and temporal heterogeneity of the phytoplankton and the cyanobacterial dominance in the Ushakovo quarry are likely driven by the elevated nutrient loading associated with cage-aquaculture operations. In the Ushakovo quarry, peak phytoplankton abundance and biomass occurred in relatively shallow areas with gentler slopes. In the Nivy quarry, despite slightly higher nutrient concentrations, phytoplankton abundance and biomass remained low.

In the Nivy zooplankton, the rotifer *Brachionus quadridentatus* exhibited persistent, massive dominance across all stations. In the Ushakovo quarry, the zooplankton community was more balanced, dominated by copepods and rotifers.

Thus, recently formed quarry lakes in the Kaliningrad Region are characterised by high water transparency, poor macrophyte development, and high dissolved oxygen levels accompanied by active biochemical oxygen demand. To accurately assess the trophic status of such water bodies is best achieved via zooplankton and zoobenthos biomass metrics, as in the early stages of succession, taxonomic composition is often dominated by highly tolerant species. This phenomenon is a result of the unique hydrochemical properties of the groundwater (specifically, highly mineralised, magnesium-calcium hydrocarbonate waters) that initially fills these deep basins. Phytoplankton communities are highly dynamic in space and time, making them less reliable for water quality assessments based on single, short-term sampling surveys.

Finally, aquaculture in flooded quarries can indirectly alter the species composition, enrich plankton communities and increase taxonomic diversity by complexifying the food web. In the Ushakovo quarry, this was reflected in an increased share of predatory zooplankton and a corresponding strengthening of detrital energy pathways.

References

- Alekin, O.A., 1970. Osnovy gidrokhimii [Fundamentals of hydrochemistry]. Gidrometeoizdat, Leningrad, USSR, 443 p. (In Russian).
- Andronikova, I.N., 1996. Strukturno-funkcional'naya organizatsiya zooplanktona ozernykh ekosistem raznykh troficheskikh tipov [Structural and functional organization of zooplankton in lake ecosystems of various trophic types]. Nauka, Saint-Petersburg, SSSR, 189 p. (In Russian).

- Aubakirova, M., Krupa, E., Mazhibayeva, Z., Isbekov, K., Assylbekova, S., 2021. The role of external factors in the variability of the structure of the zooplankton community of small lakes (south-east Kazakhstan). *Water* **13** (7), 1–20. <https://doi.org/10.3390/w13070962>
- Beliakova, R.N., Voloshko, L.N., Gavrilova, O.V. Gogorev, R.M., Makarova, I.V., Okolodkov, Yu.B., Rundina, L.A., 2006. Vodorosli, vyzyvaiushhie «cvetenie» vodoemov na Severo-zapade Rossii [Algae causing «blooming» of water bodies in Northwestern Russia]. KMK Scientific Press Ltd, Moscow, Russia, 369 p. (In Russian).
- Bezmaternykh, D.M., 2007. Zoobentos kak indikator ekologicheskogo sostoiianiia vodnykh ekosistem Zapadnoi Sibiri [Zoobenthos as an indicator of the ecological status of aquatic ecosystems in Western Siberia]. State Public Scientific and Technical Library of the Siberian Branch of the Russian Academy of Sciences, Institute of Water and Environmental Problems, Novosibirsk, Russia, 87 p. (In Russian).
- Blanchette, M., Lund, M., 2016. Pit lakes are a global legacy of mining: an integrated approach to achieving sustainable ecosystems and value for communities. *Current Opinion in Environmental Sustainability* **23**, 28–34. <https://doi.org/10.1016/J.COSUST.2016.11.012>
- De Meester, L., Declerck, S., Stoks, R., Louette, G., Van De Meutter, F. et al., 2005. Ponds and pools as model systems in conservation biology, ecology and evolutionary biology. *Aquatic Conservation* **15**, 715–725.
- Derevenskaya, O.Yu., 2025. Changes in zooplankton in Kazan reservoirs after the implementation of ecorehabilitation measures]. *Ecosystem Transformation* **8** (1), 161–184. <https://doi.org/10.23859/estr-230515>
- Derevenskaya, O.Yu., Palagushkina, O.V., Mingazova, N.M., 2012. Troficheskie vzaimootnosheniia fito- i zooplanktona v karstovykh ozerakh [Trophic relationships of phyto- and zooplankton in karst lakes]. *Teoreticheskaya i prikladnaya ekologiya [Theoretical and Applied Ecology]* **3**, 84–89. (In Russian).
- Derevenskaya, O.Yu., Mingazova, N.M., Unkovskaya, E.N., 2019. Izmenenie struktury soobshchestv zooplanktona v processe eutrofirovaniia ozer Srednego Povolzh'ia [Changes in the structure of zooplankton communities during the eutrophication of lakes in the Middle Volga region]. *Ekosistemy [Ecosystems]* **20**, 92–104. (In Russian).
- Deviatkin, V.G., 1983. Sostav i produktivnost' fitoplanktona v pribrezhnoi zone Rybinskogo vodohranilishcha [Phytoplankton composition and productivity in the coastal zone of the Rybinsk reservoir]. In: Monajkov, A.V. (ed.), *Presnovodnye gidrobionty i ikh biologiya [Freshwater aquatic organisms and their biology]*. Nauka, Leningrad, USSR, 52–70. (In Russian).
- Dmitrakova, Y., Rodina, O., Alekseev, I., Polyakov, V., Petrova, A. et al., 2018. Restoration of soil-vegetation cover and soil microbial community at the Pechurki limestone quarry (Leningrad region, Russia). *Soil Science Annual* **69**, 272–286. <https://doi.org/10.2478/ssa-2018-0028>
- Domnin, D.A., Mikhnevich, G.S., Vershinin, D.S., Karmanov, K.V., Gmyria, E.I., 2023. Usloviia vzaimodeistviia morskikh i presnykh vod v sisteme pribrezhnykh obvodnennykh kar'erov lugo-Vostochnoi Baltiki [Conditions of interaction between marine and fresh waters in the system of coastal flooded quarries in the South-Eastern Baltic Sea]. *Uchenye zapiski Kazanskogo universiteta. Seriya Estestvennye nauki [Scientific Notes of Kazan University. Series Natural Sciences]* **165** (3), 467–485. (In Russian). <https://doi.org/10.26907/2542-064X.2023.3.467-485>
- Ghirardi, N., Bresciani, M., Pinardi, M., Nizzoli, D., Viaroli, P., 2023. Pit lakes from gravel and sand quarrying in the Po River basin: An opportunity for riverscape rehabilitation and ecosystem services improvement. *Ecological Engineering* **196**, 107103. <https://doi.org/10.1016/j.ecoleng.2023.107103>

- Gorokhova, O.G., 2017. Vodorosli planktona malykh vodoemov iuga lesostepnogo Povolzh'ia (Kolichestvennaia kharakteristika fitoplanktona) [Algae of plankton of small reservoirs in the south of the forest-steppe Volga region (Quantitative characteristics of phytoplankton)]. *Izvestiia Samarskogo nauchnogo tsentra Rossiiskoi akademii nauk [IProceedings of the Samara Scientific Center of the Russian Academy of Sciences]* 19 (5), 192–199. (In Russian).
- Gorokhova, O.G., 2018. Sostav massovykh vidov i struktura al'gotsenozov pri «tsvetenii» vody v malykh vodoemakh iuga lesostepnogo Povolzh'ia [The composition of mass species and the structure of algocenoses during the «flowering» of water in small reservoirs in the south of the forest-steppe Volga region]. *Uchenye zapiski Kazanskogo universiteta. Seriya Estestvennye nauki [Scientific Notes of Kazan University. Series Natural Sciences]* 160 (2), 276–291. (In Russian).
- Haberman, J., Haldna, M., 2014. Indices of zooplankton community as valuable tools in assessing the trophic state and water quality of eutrophic lakes: long term study of Lake Vörtsjärv. *Journal of Limnology* 73 (2), 263–273. <https://doi.org/10.4081/jlimnol.2014.828>
- Heerkloß, R., Hlawa, S., 1995. Feeding biology of two brachionid rotifers: *Brachionus quadridentatus* and *Brachionus plicatilis*. *Hydrobiologia* 313, 219–221. <https://doi.org/10.1007/BF00025954>
- Haberman, J., Haldna, M., 2014. Indices of zooplankton community as valuable tools in assessing the trophic state and water quality of eutrophic lakes: long term study of Lake Vörtsjärv. *Journal of Limnology* 73 (2), 263–273. <https://doi.org/10.4081/jlimnol.2014.828>
- Heerkloß, R., Hlawa, S., 1995. Feeding biology of two brachionid rotifers: *Brachionus quadridentatus* and *Brachionus plicatilis*. *Hydrobiologia* 313, 219–221. <https://doi.org/10.1007/BF00025954>
- Kitaev, S.P., 2007. Osnovy limnologii dlia gidrobiontov i ihtologov [Fundamentals of limnology for aquatic biologists and ichthyologists]. Karelian Scientific Center RAS, Petrozavodsk, Russia, 395 p. (In Russian).
- Kolkwitz, R., Marsson, M., 1902. Grundsätze für die biologische Beurteilung des Wassers nach seiner Flora und Fauna. *Mitteilungen der Königlichen Prüfanstalt für Wasserversorgung und Abwasserbeseitigung* 1, 33–72. (In German).
- Korneva, L.G., Mitropol'skaia, I.V., Makarenkova, N.N., Tsvetkov, A.I., 2021. Struktura i dinamika fitoplanktona bol'shikh melkovodnykh zarastaiushchikh ozer (Vozhe i Lacha, Vologodskaiia i Arhangel'skaia oblasti, Rossiia) [The structure and dynamics of phytoplankton of large shallow overgrown lakes (Vozha and Lacha, Vologda and Arkhangelsk regions, Russia)]. *Trudy IBVV RAN [Proceedings of the Institute for Biology of Inland Waters RAS]* 94 (97), 17–29. (In Russian).
- Krylov, A.V., Berezina, N.A., Voronin, L.V., Baryshev, I.A., Bezmaternykh, D.M., Gerasimova, A.A., 2024. Metody gidrobiologicheskikh issledovaniy vnutrennih vod [Methods of hydrobiological studies of inland waters]. Filigran', Yaroslavl', Russia, 592 p. (In Russian).
- Kulizin, P.V., 2023. Sostav, struktura i sukcessiia fitoplanktona vodotokov Yuga taezhnoi zony v predelakh vodosbora Srednei Volgi. [Composition, structure and succession of phytoplankton in the streams of the Southern taiga zone within the catchment area of the Middle Volga]. PhD in Biology thesis abstract. Nizhnii Novgorod, Russia, 251 p. (In Russian).
- Lund, M., Blanchette, M., 2023. Closing pit lakes as aquatic ecosystems: Risk, reality, and future uses. *Wiley Interdisciplinary Reviews: Water* 10 (4), e1648. <https://doi.org/10.1002/wat2.1648>
- Masiutkina, E.A., Shibaeva, M.N., Matveeva, E.P., 2014. Komary-zvontsy sem. Chironomidae kak pokazatel' kachestva vody malykh vodoemov Kaliningradskoi [Chironomidae as a representative of the family of small water bodies of the Kaliningrad region]. *Izvestiia KGTU [Proceedings of the Kaliningrad State Technical University]* 32, 54–62. (In Russian).

- Medvedeva, L.A., Nikulina, T.V., 2014. Katalog presnovodnykh vodoroslei iuga Dal'nego Vostoka Rossii [Catalog of freshwater algae of the Southern Far East of Russia]. Dalnauka, Vladivostok, Russia, 271 p. (In Russian).
- Mironova, N., Mateyuk, O., Biletska, H., Shevchenko, S., Kazimirova, L. et al., 2022. Parametric assessment of macrophytes ecological niches in solving problems of sand quarry lakes phytomelioration. *Journal of Human, Earth, and Future* 3 (4), 215–224. <https://doi.org/10.28991/hef-2022-03-04-02>
- Mischke, U., Nixdorf, B., Hoehn, E., Riedmüller, U., 2002. Möglichkeiten zur Bewertung von Seen anhand des Phytoplanktons. Aktueller Stand in Deutschland. In: Deneke, R., Nixdorf, B. (eds.), *Implementierung der EU-Wasserrahmenrichtlinie in Deutschland: Ausgewählte Bewertungsmethoden und Defizite. Aktuelle Reihe*. Eigenverlag der BTU, Cottbus, Germany, 25–37. (In German).
- Moiseenko, V.V., Tsupikova, N.A., 2023. Rybovodno-ekologicheskaya kharakteristika obvodnennogo kar'era voze p. Nivy (Kaliningradskaia oblast') [Fish farming and ecological characteristics of a flooded quarry near the village of Niva (Kaliningrad region)]. *Sbornik statei II mezhdunarodnoi nauchno-prakticheskoi konferentsii «Aktual'nye ekologicheskie problemy i ekologicheskaya bezopasnost' v sovremennykh usloviakh» [Current environmental problems and environmental safety in modern conditions: Collection of articles of the second scientific and practical international conference]*, Saratov, 21.10.2025. Saratov, Russia, 292–300. (In Russian).
- Moiseenko, V.V., Tsupikova, N.A., Shibaev, S.V. 2023. Izuchenie ekologicheskogo sostoiianiia obvodnennogo kar'era voze p. Ushakovo [Study of the Ecological State of the Flooded Quarry near Ushakovo]. *Materialy XI Mezhdunarodnogo Baltiiskogo morskogo foruma, Baltiiskii morskoi forum [Proceedings of the XI International Baltic Maritime Forum]*, Kaliningrad, 25–30.09.2023. Kaliningrad, Russia, 192–198. (In Russian).
- Napiórkowska-Krzebietke, A., Skrzypczak, A., Kicińska, A., 2023. Abiotic–biotic interrelations in the context of stabilized ecological potential of post-mining waters. *Water* 15 (19), 3328. <https://doi.org/10.3390/w15193328>
- Oksiuk, O.P., Stol'berg F.V., 1986. Upravlenie kachestvom vody v kanalakh [Water quality management in canals]. Naukova dumka, Kiev, USSR, 176 p. (In Russian).
- Opredelitel' zooplanktona i zoobentosa presnykh vod Evropeiskoi Rossii. T. 1. Zooplankton [Key of zooplankton and zoobenthos in freshwater of European Russia. Vol. 1. Zooplankton], 2010. Alekseev, V.R., Tsalolikhin, S.Ya. (eds.). KMK Scientific Press Ltd, Moscow, Russia, 495 p. (In Russian).
- Opredelitel' zooplanktona i zoobentosa presnykh vod Evropeiskoi Rossii. T. 2. Zoobentos [Key of zooplankton and zoobenthos in freshwater of European Russia. Vol. 2. Zoobenthos], 2016. Alekseev, V.R., Tsalolikhin, S.Ya. (eds.). KMK Scientific Press Ltd, Moscow, Russia, 457 p. (In Russian).
- Pidgaiko, M.L., 1969. Pribrezhnyi zooplankton v usloviakh «tsveteniia» vody v Kremenchugskom vodohranilishche [Coastal zooplankton in the conditions of «blooming» water in the Kremenchug reservoir]. *Gidrobiologicheskii zhurnal [Hydrobiological Journal]* 26 (5), 26–32. (In Russian).
- Pidgaiko, M.L., Aleksandrov, B.M., Ioffe, C.I., Maksimova, L.P., Petrov, V.V., Savateeva, E.B., Salazkin, A.A., 1968. Kratkaia biologo-produktsionnaia kharakteristika vodoemov Severo-Zapada SSSR [Brief biological and productive characteristics of reservoirs in the Northwest of the USSR]. *Izvestiia GosNIORH [Proceedings of State Research Institute of Lake and River Fisheries]* 67, 205–228. (In Russian).
- Sakharova, E.G., Korneva L.G., 2018. Fitoplankton litorali i pelagiali Rybinskogo vodohranilishcha v gody s raznymi temperaturnym i urovennym rezhimami [Phytoplankton of the littoral and pelagial of the Rybinsk reservoir in years with different temperature and level regimes]. *Biologiya vnutrennikh vod [Biology of Inland Waters]* 1, 11–18. (In Russian). <https://doi.org/10.7868/S0320965218010023>

- Seelen, L., Teurlincx, S., Armstrong, M., Lürling, M., Van Donk, E., De Senerpont Domis, L., 2021a. Serving many masters at once: a framework for assessing ecosystem services delivered by quarry lakes. *Inland Waters* **12**, 121–137. <https://doi.org/10.1080/20442041.2021.1944765>
- Seelen, L., Teurlincx, S., Bruinsma, J., Huijsmans, T., Van Donk, E., Lürling, M., De Senerpont Domis, L., 2021b. The value of novel ecosystems: Disclosing the ecological quality of quarry lakes. *The Science Of the Total Environment* **769**, 1–9. <https://doi.org/10.1016/j.scitotenv.2020.144294>
- Shannon, C.E., 1949. The mathematical theory of communication. *University of Illinois Press*, Urbana, USA, 117 p.
- Shelyuk, Y.S., Astahova, L.Y., 2021. Phytoplankton succession in the anthropogenic and climate ecological transformation of freshwater ecosystems. *Biosystems Diversity* **29** (2), 119–128.
- Shibaeva, M.N., Masiutkina, E.A., Matveeva, E.P., Okhapkina, A.A., 2013. Vidovoe raznoobrazie zooplanktona kak pokazatel' ekologicheskogo sostoianiia vodoemov Kaliningradskoi oblasti [The species diversity of zooplankton as an indicator of the ecological status of reservoirs in the Kaliningrad region]. *Izvestiia Kaliningradskogo gosudarstvennogo tekhnicheskogo universiteta [Proceedings of the Kaliningrad State Technical University]* **28**, 153–163. (In Russian).
- Shibaeva, M.N., Masyutkina, E.A., Shibaev, S.V., 2018. Hydrobiological characteristics of water bodies in the Kaliningrad Region. *The Handbook of Environmental Chemistry* **65**, 285–316. https://doi.org/10.1007/698_2017_99
- Shitikov, V.K., Rozenberg, G.S., Zinchenko, T.D., 2003. Kolichestvennaia gidroekologiya: metody sistemnoi identifikatsii [Quantitative hydroecology: methods of system identification]. Institute of Ecology of the Volga Basin RAS, Togliatti, Russia, 463 p. (In Russian).
- Sienkiewicz, E., Gąsiorowski, M., 2016. The evolution of a mining lake – From acidity to natural neutralization. *The Science Of the Total Environment* **557-558**, 343–354. <https://doi.org/10.1016/j.scitotenv.2016.03.088>
- Søndergaard, M., Lauridsen, T.L., Johansson, L.S., Jeppesen, E., 2018. Gravel pit lakes in Denmark: chemical and biological state. *The Science Of the Total Environment* **612** (9), 17.
- Sorensen, T., 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analysis of the vegetation on Danish commons. *Det Kongelige Danske Videnskabernes Selskab Biologiske Skrifter* **5** (4), 1–34.
- Stephan, K., Hubbart, J., 2022. Plant community, soil and microclimate attributes after 70 Years of natural recovery of an abandoned limestone quarry. *Land* **12** (1), 117. <https://doi.org/10.3390/land12010117>
- Suhovilo, N.Yu., Romanchuk A.I., 2018. Termodinamicheskie i gidrohimicheskie osobennosti mal'kh ozer i melovykh kar'ernykh vodoemov Belarusi i Pol'shi [Thermodynamic and hydrochemical features of small lakes and chalk quarries in Belarus and Poland]. *Materialy VI Mezhdunarodnoi konferentsii «Aktual'nye voprosy nauk o Zemle v kontseptsii ustoychivogo razvitiia Belarusi i sopredel'nykh gosudarstv» [Materials of the VI International conference «Current issues of Earth sciences in the concept of sustainable development of Belarus and adjacent states»]*. Gomel', Belarus', 42–47. (In Russian).
- Sumina, O., Koptseva E., 2019. Vegetation monitoring on quarries in the Russian Far North as a basis for creating models and analyzing trends of landscape processes. Current trends in landscape research. In: Mueller, L., Eulenstein, F. (eds.), *Innovations in landscape research*. Springer Nature, Cham, Germany, 559–578. https://doi.org/10.1007/978-3-030-30069-2_25
- Szatyłowicz, E., Matulewicz, D., Skoczko, I., 2015. Assessment of susceptibility to degradation by Schindler factor of selected reservoirs in Podlaskie. *Journal of Ecological Engineering* **16** (4), 81–88.

- Tavernini, S., Viaroli, P., Rossetti, G., 2009. Zooplankton community structure and inter-annual dynamics in two sand-pit lakes with different dredging impact. *International Review of Hydrobiology* 94 (3), 290–307. <https://doi.org/10.1002/iroh.200811124>
- Trifonova, I.S., 1990. Ekologiya i sukcesiya ozernogo fitoplanktona [Ecology and succession of lake phytoplankton]. Nauka, Leningrad, USSR, 184 p. (In Russian).
- Tropek, R., Kadlec, T., Karešová, P., Spitzer, L., Kočárek, P. et al., 2010. Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropods and plants. *Journal of Applied Ecology* 47, 139–147. <https://doi.org/10.1111/J.1365-2664.2009.01746.X>
- Vypkhanova, G.V., Ershova, I.V., Shpakovskiy, Yu.G., Agafonov, V.B., 2014. Prirodoupravlennoye zakonodatel'stvo v usloviyakh modernizatsii ekonomiki Rossii: sovremennyye problemy [Natural resource legislation in the context of modernization of the Russian economy: Modern problems]. Norma: INFRA-M, Moscow, Russia, 160 p. (In Russian).
- Xu, J., Yin, P., Hu, W., Fu, L., Zhao, H., 2020. Assessing the ecological regime and spatial spillover effects of a reclaimed mining subsided lake: A case study of the Pan'an Lake wetland in Xuzhou. *PLoS ONE* 15 (8). <https://doi.org/10.1371/journal.pone.0238243>
- Zhdanova, S.M., Prianichnikova, E.G., Semenova, A.S., Sidelev, S.I., Beliakov, E.A., Sokolova, A.S., 2024. Phytoplankton, zooplankton, and macrozoobenthos of some small lakes (Yaroslavl region, Russia). *Ecosystem Transformation* 7 (1), 85–119. <https://doi.org/10.23859/estr-220802>

Список литературы

- Алекин, О.А., 1970. Основы гидрохимии. Гидрометеиздат, Ленинград, СССР, 443 с.
- Андроникова, И.Н., 1996. Структурно-функциональная организация зоопланктона озерных экосистем разных трофических типов. Наука, Санкт-Петербург, СССР, 189 с.
- Белякова, Р.Н., Волошко, Л.Н., Гаврилова, О.В., Гогорев, Р.М., Макарова, И.В., Околотков, Ю.Б., Рундина, Л.А., 2006. Водоросли, вызывающие «цветение» водоемов Северо-Запада России. Товарищество научных изданий КМК, Москва, Россия, 369 с.
- Безматерных, Д.М., 2007. Зообентос как индикатор экологического состояния водных экосистем Западной Сибири. Государственная публичная научно-техническая библиотека Сибирского отделения РАН, Институт водных и экологических проблем, Новосибирск, Россия, 87 с.
- Выпханова, Г.В., Ершова, И.В., Шпаковский, Ю.Г., Агафонов, В.Б., 2014. Природоресурсное законодательство в условиях модернизации экономики России: современные проблемы. Норма: НИЦ ИНФРА-М, Москва, Россия, 160 с.
- Горохова, О.Г., 2017. Водоросли планктона малых водоемов юга лесостепного Поволжья (Количественная характеристика фитопланктона). *Известия Самарского научного центра Российской академии наук* 19 (5), 192–199.
- Горохова, О.Г., 2018. Состав массовых видов и структура альгоценозов при «цветении» воды в малых водоемах юга лесостепного Поволжья. *Ученые записки Казанского университета. Серия Естественные науки* 160 (2), 276–291.
- Девяткин, В.Г., 1983. Состав и продуктивность фитопланктона в прибрежной зоне Рыбинского водохранилища. В: Монаков, А.В. (ред.), *Пресноводные гидробионты и их биология*. Наука, Ленинград, СССР, 52–70.

- Деревенская, О.Ю., 2025. Изменение зоопланктона водоемов г. Казани после проведения мероприятий по экореабилитации. *Трансформация экосистем* 8 (1), 161–184. <https://doi.org/10.23859/estr-230515>
- Деревенская, О.Ю., Палагушкина, О.В., Мингазова, Н.М., 2012. Трофические взаимоотношения фито- и зоопланктона в карстовых озерах. *Теоретическая и прикладная экология* 3, 84–89.
- Деревенская, О.Ю., Мингазова, Н.М., Унковская, Е.Н., 2019. Изменение структуры сообществ зоопланктона в процессе эвтрофирования озер Среднего Поволжья. *Экосистемы* 20, 92–104.
- Домнин, Д.А., Михневич, Г.С., Вершинин, Д.С., Карманов, К.В., Гмыря, Е.И., 2023. Условия взаимодействия морских и пресных вод в системе прибрежных обводненных карьеров Юго-Восточной Балтики. *Ученые записки Казанского университета. Серия Естественные науки* 165 (3), 467–485. <https://doi.org/10.26907/2542-064X.2023.3.467-485>
- Жданова, С.М., Пряничникова, Е.Г., Семенова, А.С., Сиделев, С.И., Беляков, Е.А., Соколова, А.С., 2024. Фитопланктон, зоопланктон и макрозообентос некоторых малых озер (Ярославская область, Россия). *Трансформация экосистем* 7 (1), 85–119. <https://doi.org/10.23859/estr-220802>
- Китаев, С.П., 2007. Основы лимнологии для гидробионтов и ихтиологов. Карельский научный центр РАН, Петрозаводск, Россия, 395 с.
- Корнева, Л.Г., Митропольская, И.В., Макаренкова, Н.Н., Цветков, А.И., 2021. Структура и динамика фитопланктона больших мелководных зарастающих озер (Воже и Лача, Вологодская и Архангельская области, Россия). *Труды ИБВВ РАН* 94 (97), 17–29.
- Крылов, А.В., Березина, Н.А., Воронин, Л.В., Барышев, И.А., Безматерных, Д.М., Герасимова, А.А., 2024. Методы гидробиологических исследований внутренних вод. Филигрань, Ярославль, Россия, 592 с.
- Кулизин, П.В., 2023. Состав, структура и сукцессия фитопланктона водотоков Юга таежной зоны в пределах водосбора Средней Волги. *Автореферат диссертации на соискание ученой степени кандидата биологических наук*. Нижний Новгород, Россия, 24 с.
- Масюткина, Е.А., Шibaева, М.Н., Матвеева, Е.П., 2014. Комары-звонцы сем. Chironomidae как показатель качества воды малых водоемов Калининградской области. *Известия КГТУ* 32, 54–62.
- Медведева, Л.А., Никулина, Т.В., 2014. Каталог пресноводных водорослей юга Дальнего Востока России. Дальнаука, Владивосток, Россия, 271 с.
- Моисеенко, В.В., Цупикова, Н.А., 2023. Рыбоводно-экологическая характеристика обводненного карьера возле п. Нивы (Калининградская область). *Сборник статей II международной научно-практической конференции «Актуальные экологические проблемы и экологическая безопасность в современных условиях»*, Саратов, 25.10.2023. Саратов, Россия, 292–300.
- Моисеенко, В.В., Цупикова, Н.А., Шibaев, С.В., 2023. Исследование экологического состояния обводненного карьера возле п. Ушаково. *Материалы XI Международного Балтийского морского форума*, Калининград, 25–30.09.2023. Калининград, Россия, 192–198.
- Оксиюк, О.П., Стольберг, Ф.В., 1986. Управление качеством воды в каналах. Наукова думка, Киев, СССР, 176 с.
- Определитель зоопланктона и зообентоса пресных вод Европейской России. Т. 1. Зоопланктон, 2010. Алексеев, В.Р., Цалолихин, С.Я. (ред.). Товарищество научных изданий КМК, Москва, Россия, 495 с.

- Определитель зоопланктона и зообентоса пресных вод Европейской России. Т. 2. Зообентос, 2016. Алексеев, В.Р., Цалолихин, С.Я. (ред.). Товарищество научных изданий КМК, Москва, Россия, 457 с.
- Пидгайко, М.Л., 1969. Прибрежный зоопланктон в условиях «цветения» воды в Кременчугском водохранилище. *Гидробиологический журнал* **26** (5), 26–32.
- Пидгайко, М.Л., Александров, Б.М., Иоффе, Ц.И., Максимова, Л.П., Петров, В.В., Саватеева, Е.Б., Салазкин, А.А., 1968. Краткая биолого-продукционная характеристика водоемов СевероЗапада СССР. *Известия ГосНИОРХ* **67**, 205–228.
- Сахарова, Е.Г., Корнева, Л.Г., 2018. Фитопланктон литорали и пелагиали Рыбинского водохранилища в годы с разными температурным и уровнем режимами. *Биология внутренних вод* **1**, 11–18. <https://doi.org/10.7868/S0320965218010023>
- Суховило, Н.Ю., Романчук А.И., 2018. Термодинамические и гидрохимические особенности малых озер и меловых карьерных водоемов Беларуси и Польши. *Материалы VI Международной конференции «Актуальные вопросы наук о Земле в концепции устойчивого развития Беларуси и сопредельных государств»*. Гомель, Беларусь, 42–47.
- Трифонов, И.С., 1990. Экология и сукцессия озерного фитопланктона. Наука, Ленинград, СССР, 184 с.
- Шиббаева, М.Н., Масюткина, Е.А., Матвеева, Е.П., Охупкина, А.А., 2013. Видовое разнообразие зоопланктона как показатель экологического состояния водоемов Калининградской области. *Известия Калининградского государственного технического университета* **28**, 153–163.
- Шитиков, В.К., Розенберг, Г.С., Зинченко, Т.Д., 2003. Количественная гидроэкология: методы системной идентификации. ИЭВБ РАН, Тольятти, Россия, 463 с.
- Aubakirova, M., Krupa, E., Mazhibayeva, Z., Isbekov, K., Assylbekova, S., 2021. The role of external factors in the variability of the structure of the zooplankton community of small lakes (south-east Kazakhstan). *Water* **13** (7), 1–20. <https://doi.org/10.3390/w13070962>
- Blanchette, M., Lund, M., 2016. Pit lakes are a global legacy of mining: an integrated approach to achieving sustainable ecosystems and value for communities. *Current Opinion in Environmental Sustainability* **23**, 28–34. <https://doi.org/10.1016/J.COSUST.2016.11.012>
- De Meester, L., Declerck, S., Stoks, R., Louette, G., Van De Meutter, F. et al., 2005. Ponds and pools as model systems in conservation biology, ecology and evolutionary biology. *Aquatic Conservation* **15**, 715–725.
- Dmitrakova, Y., Rodina, O., Alekseev, I., Polyakov, V., Petrova, A. et al., 2018. Restoration of soil-vegetation cover and soil microbial community at the Pechurki limestone quarry (Leningrad region, Russia). *Soil Science Annual* **69**, 272–286. <https://doi.org/10.2478/ssa-2018-0028>
- Ghirardi, N., Bresciani, M., Pinardi, M., Nizzoli, D., Viaroli, P., 2023. Pit lakes from gravel and sand quarrying in the Po River basin: An opportunity for riverscape rehabilitation and ecosystem services improvement. *Ecological Engineering* **196**, 107103. <https://doi.org/10.1016/j.ecoleng.2023.107103>
- Haberman, J., Haldna, M., 2014. Indices of zooplankton community as valuable tools in assessing the trophic state and water quality of eutrophic lakes: long term study of Lake Võrtsjärv. *Journal of Limnology* **73** (2), 263–273. <https://doi.org/10.4081/jlimnol.2014.828>

- Heerkloß, R., Hlawka, S., 1995. Feeding biology of two brachionid rotifers: *Brachionus quadridentatus* and *Brachionus plicatilis*. *Hydrobiologia* **313**, 219–221. <https://doi.org/10.1007/BF00025954>
- Kolkwitz, R., Marsson, M., 1902. Grundsätze für die biologische Beurteilung des Wassers nach seiner Flora und Fauna. *Mitteilungen der Königlichen Prüfanstalt für Wasserversorgung und Abwasserbeseitigung* **1**, 33–72. (In German).
- Lund, M., Blanchette, M., 2023. Closing pit lakes as aquatic ecosystems: Risk, reality, and future uses. *Wiley Interdisciplinary Reviews: Water* **10** (4), e1648. <https://doi.org/10.1002/wat2.1648>
- Mironova, N., Mateyuk, O., Biletska, H., Shevchenko, S., Kazimirova, L. et al., 2022. Parametric assessment of macrophytes ecological niches in solving problems of sand quarry lakes phytomelioration. *Journal of Human, Earth, and Future* **3** (4), 215–224. <https://doi.org/10.28991/hef-2022-03-04-02>
- Mischke, U., Nixdorf, B., Hoehn, E., Riedmüller, U., 2002. Möglichkeiten zur Bewertung von Seen anhand des Phytoplanktons. Aktueller Stand in Deutschland. In: Deneke, R., Nixdorf, B. (eds.), *Implementierung der EU-Wasserrahmenrichtlinie in Deutschland: Ausgewählte Bewertungsmethoden und Defizite. Aktuelle Reihe*. Eigenverlag der BTU, Cottbus, Germany, 25–37. (In German).
- Napiórkowska-Krzebietke, A., Skrzypczak, A., Kicińska, A., 2023. Abiotic–biotic interrelations in the context of stabilized ecological potential of post-mining waters. *Water* **15** (19), 3328. <https://doi.org/10.3390/w15193328>
- Seelen, L., Teurlincx, S., Armstrong, M., Lürling, M., Van Donk, E., De Senerpont Domis, L., 2021a. Serving many masters at once: a framework for assessing ecosystem services delivered by quarry lakes. *Inland Waters* **12**, 121–137. <https://doi.org/10.1080/20442041.2021.1944765>
- Seelen, L., Teurlincx, S., Bruinsma, J., Huijsmans, T., Van Donk, E., Lürling, M., De Senerpont Domis, L., 2021b. The value of novel ecosystems: Disclosing the ecological quality of quarry lakes. *The Science Of the Total Environment* **769**, 1–9. <https://doi.org/10.1016/j.scitotenv.2020.144294>
- Shannon, C.E., 1949. The mathematical theory of communication. *University of Illinois Press*, Urbana, USA, 117 p.
- Shelyuk, Y.S., Astahova, L.Y., 2021. Phytoplankton succession in the anthropogenic and climate ecological transformation of freshwater ecosystems. *Biosystems Diversity* **29** (2), 119–128.
- Shibaeva, M.N., Masyutkina, E.A., Shibaev, S.V., 2018. Hydrobiological characteristics of water bodies in the Kaliningrad Region. *The Handbook of Environmental Chemistry* **65**, 285–316. https://doi.org/10.1007/698_2017_99
- Sienkiewicz, E., Gąsiorowski, M., 2016. The evolution of a mining lake – From acidity to natural neutralization. *The Science Of the Total Environment* **557-558**, 343–354. <https://doi.org/10.1016/j.scitotenv.2016.03.088>
- Søndergaard, M., Lauridsen, T.L., Johansson, L.S., Jeppesen, E., 2018. Gravel pit lakes in Denmark: chemical and biological state. *The Science Of the Total Environment* **612** (9), 17.
- Sorensen, T., 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analysis of the vegetation on Danish commons. *Det Kongelige Danske Videnskabernes Selskab Biologiske Skrifter* **5** (4), 1–34.
- Stephan, K., Hubbart, J., 2022. Plant community, soil and microclimate attributes after 70 Years of natural recovery of an abandoned limestone quarry. *Land* **12** (1), 117. <https://doi.org/10.3390/land12010117>

- Sumina, O., Koptseva E., 2019. Vegetation monitoring on quarries in the Russian Far North as a basis for creating models and analyzing trends of landscape processes. Current trends in landscape research. In: Mueller, L., Eulenstein, F. (eds.), *Innovations in landscape research*. Springer Nature, Cham, Germany, 559–578. https://doi.org/10.1007/978-3-030-30069-2_25
- Szatyłowicz, E., Matulewicz, D., Skoczko, I., 2015. Assessment of susceptibility to degradation by Schindler factor of selected reservoirs in Podlaskie. *Journal of Ecological Engineering* **16** (4), 81–88.
- Tavernini, S., Viaroli, P., Rossetti, G., 2009. Zooplankton community structure and inter-annual dynamics in two sand-pit lakes with different dredging impact. *International Review of Hydrobiology* **94** (3), 290–307. <https://doi.org/10.1002/iroh.200811124>
- Tropek, R., Kadlec, T., Karešová, P., Spitzer, L., Kočárek, P. et al., 2010. Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropods and plants. *Journal of Applied Ecology* **47**, 139–147. <https://doi.org/10.1111/J.1365-2664.2009.01746.X>
- Xu, J., Yin, P., Hu, W., Fu, L., Zhao, H., 2020. Assessing the ecological regime and spatial spillover effects of a reclaimed mining subsided lake: A case study of the Pan'an Lake wetland in Xuzhou. *PLoS ONE* **15** (8). <https://doi.org/10.1371/journal.pone.0238243>