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Microalgae of lentic water bodies as drivers of ecosystem service provision

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Abstract. Due to their significant species diversity and sensitivity to environmental changes, microalgae are important indicators of the ecological state of water bodies and, together with other hydrobionts, contribute to the provision of ecosystem services in aquatic systems. Since their contribution to ecosystem service provision in stagnant water bodies remains insufficiently studied and requires further substantiation to assess the ecological value of such systems, this study aimed to examine the relationships between the species composition of microalgae and the formation of relevant ecosystem services in stagnant water bodies, using the example of the Korostyshiv Quarry (Zhytomyr Region, Ukraine). To determine the species composition and distribution of microalgae, standard methods were used (sampling and preservation of water samples, isolation, identification, and quantitative analysis of microalgae using microscopy). The results revealed a relatively balanced phytoplankton community structure with low species diversity: five microalgal species belonging to four different divisions (*Chlorophyta*, *Bacillariophyta*, *Chrysophyta*, and *Dinophyta*). The biomass concentration was relatively low, reaching up to 2 g/L. The species composition of phytoplankton and the results of water chemistry analysis indicate a good ecological state of the water body. Relationships between the functional characteristics of microalgae and ecosystem services were identified. It was found that the species composition of microalgae is a key factor in the formation of ecosystem services, determining primary production, nutrient cycling, and the condition of the aquatic environment. Within the framework of the

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CICES classification, it was demonstrated that microalgae in the studied quarry water body contribute to the formation of nearly all types of ecosystem services (3 provisioning, 9 regulating and supporting, and 4 cultural services), albeit with varying intensity. The dominant contribution of microalgae in the quarry ecosystem was associated with regulating and supporting ecosystem services. The results obtained can be used for the development of a national framework for assessing ecosystem services in freshwater lentic ecosystems

Keywords: phytoplankton; quarry ecosystems; biotopes; indicator species; biogeochemical cycling

Introduction

In the context of significant anthropogenic pressure and its destructive impact on the environment, there is an increasing need for detailed investigation of the role of microalgae in lentic water bodies as key factors in the formation of ecosystem services and as indicators of the ecological status of aquatic ecosystems. Microalgae, owing to their high species diversity and sensitivity to environmental changes, can serve as effective indicators of water quality and the ecological status of lakes and other water bodies, as evidenced by recent international studies on this topic. For instance, the study by C.M. Dobrescu *et al*. (2023) elucidated the response patterns of algae to chemical changes in aquatic environments (including variations in temperature, pH, and dissolved substances), thereby confirming their role as bioindicators of water quality. Irish researchers E. O'Neill & N. Rowan (2022) focused on the use of microalgae as natural ecological bioindicators for real-time, simplified monitoring of aquaculture wastewater quality, while also examining their potential for assessing the impacts of extreme climate change, including responses to stress factors. The study by E. Delgado-Fernández *et al*. (2025) demonstrated that microalgae, due to their high species diversity and sensitivity to environmental changes, can serve as effective indicators of water quality and the ecological status of lakes and other water bodies. Based on an assessment of microalgal diversity in the Kimsacocha lake system in Azuay (Ecuador), the authors found that phytoplankton plays a crucial role as a primary producer in lakes, providing valuable information on environmental conditions and water quality.

Particular attention was also given to the comprehensive review by S. Jahan & A. Singh (2023), which examined the role of phytoplankton in the environment and human life as primary producers and as the foundation of trophic chains in aquatic ecosystems. In this context, other international studies have confirmed that monitoring phytoplankton dynamics can serve as a valuable bioindicator for assessing aquatic environments. For example, A. Mondal *et al*. (2020) focused on three categories of phytoplankton species – non-toxic, toxic, and those interacting with zooplankton – and the dynamics of their interactions within an open marine system. Furthermore, P. Chandel *et al*. (2024) expanded upon previous research by highlighting the ability of plankton to adapt to specific ranges of chemical, physical, and biological conditions as an important bioindicator for environmental quality assessment.

International studies have demonstrated that freshwater hydrobionts play a key role in the formation of ecosystem services in aquatic ecosystems. In particular, a close relationship has been identified between the species composition and distribution of microalgae in water bodies and the ecosystem services they provide. For example, L. Naselli-Flores & J. Padisák (2023) argued that the services provided by phytoplankton account for nearly half of global primary production and oxygen generation. In addition, phytoplankton significantly accelerates biogeochemical cycles and nutrient cycling not only in aquatic but also in terrestrial ecosystems, makes a substantial contribution to climate regulation (a regulating service), provides food, fuel, bioactive compounds, pharmaceuticals, and genetic resources (provisioning services), and delivers important cultural services.

The study by D. Updhai *et al*. (2025) emphasised that the value of phytoplankton ecosystem services, beyond their contribution to approximately half of global oxygen production through photosynthesis, also lies in their potential for carbon sequestration. This capacity contributes to mitigating climate change through the biological capture and storage of atmospheric carbon dioxide. Furthermore, phytoplankton plays an important role in water purification, as certain species are capable of removing pollutants from aquatic ecosystems through processes of bioaccumulation or biotransformation. The study by S.M. Thomaz (2023) complements existing knowledge on the formation of ecosystem services by microalgae through investigations of macrophytes. Specifically, the study examines macrophytes as providers of 26 types of ecosystem services, among which supporting and regulating services are identified as the most significant.

In Ukraine, hydrobionts of natural water bodies have been studied in considerable depth. In particular, the morphology, physiology, and ecology of microscopic algae and benthic assemblages have long been a focus of researchers at the Institute of Hydrobiology of the National Academy of Sciences of Ukraine. The habitat preferences of algae within the water column of different types of freshwater ecosystems were investigated by V.I. Shcherbak *et al*. (2025). Their analysis of algal habitat preferences demonstrated that the floristic composition and the ratio of life forms of algae vary significantly depending on environmental conditions and are determined by a combination of abiotic and biotic factors. The proportion of planktonic, benthic, and planktonic-benthic forms differs among lotic, lentic, and transitional ecosystems, forming characteristic spectra for each type of water body and reflecting their adaptive capacities. Despite this variability, algae remain informative indicators.

The reviewed literature highlights the growing significance of microalgae as bioindicators of water quality and ecological health in aquatic ecosystems. International research emphasises the crucial role of microalgae in supporting ecosystem services, including primary production, nutrient cycling, and climate regulation, while also noting their sensitivity to environmental changes. The studies underline the potential of microalgae to provide valuable insights into the ecological state of water bodies, offering a foundation for future environmental monitoring and management efforts. At the same time, the scope and magnitude of ecosystem services associated with microalgae in non-flowing artificial water bodies, such as quarry lakes, require further investigation to enable their assessment and sustainable management. Therefore, this article aimed to examine the species composition and distribution of microalgae in non-flowing water bodies, as well as the formation of their ecosystem services, using the Korostyshiv Quarry as a case study.

Materials and Methods

The object of the study was the Korostyshiv Quarry, which belongs to non-flowing freshwater bodies of a lacustrine type formed after the cessation of quarry exploitation. It represents a complex, multifunctional ecosystem that provides a wide range of ecosystem services essential for maintaining ecological balance and environmental stability. This quarry was chosen because successional processes in such ecosystems occur on a mineral substrate and are essentially primary in nature: water rising from underground horizons creates an environment in which hydrobionts gradually emerge and develop over time. The Korostyshiv Quarry is located on the eastern outskirts of the town of Korostyshiv, Zhytomyr Region (Fig. 1). Its coordinates are 50º19'24.72"N, 29º04'44.53"E. Granite was extracted from the quarry for many years; however, in the early 1990s, it was decommissioned, after which it became naturally filled with water. The surface area of the lake is approximately 48,803 m^2, with a length of 500 m, a width of 150 m, and a depth of up to 40 m (Ulyhanets & Shynkarenko, 2023). A map showing the location and water sampling sites of the Korostyshiv Quarry is presented in Figure 2. The sampling site was chosen randomly, taking into account accessibility of the water – the selected location lacked rocky cliffs and dense aquatic vegetation (in particular, reeds and cattails).

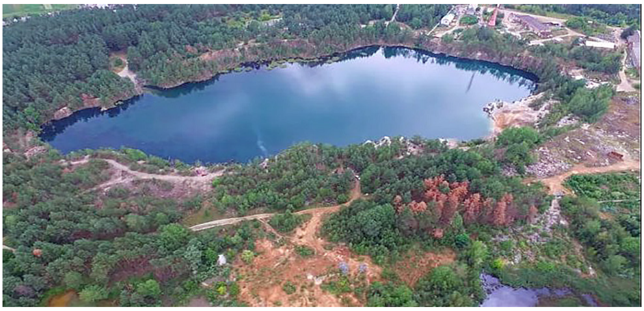

Figure 1. *General view of the Korostyshiv Quarry*

Source: Google Maps (n.d.)

Figure 2. *Map showing the location and water sampling sites in the Korostyshiv Quarry*

Source: Google Maps (n.d.)

Water samples for phytoplankton assessment were collected from the surface layer of the water (15-20 cm) using a Ruttner bathometer. The surface water layer is more strongly heated by sunlight, more oxygenated, and richer in organic substances entering the water body from the air, which is important for microalgal development. Samples of 0.5 dm^3 were fixed with a 40% formaldehyde solution at a ratio of 1:100 and concentrated by sedimentation for at least 10 days. Sampling was conducted in September 2025, when the summer heat had subsided, and the autumn rains had not yet begun, which could otherwise have significantly affected the state of phytoplankton and its distribution within the water body. Algal abundance was determined by direct counting in a Najott chamber (0.02 cm^3), and biomass was measured using the stereometric method. Algal abundance is reported in thousands of cells per dm^3 and biomass in mg/dm^3. Species contributing ⩾10% of the total phytoplankton biomass in a sample were classified as dominants. The species composition of algae was determined using standard methods

(Shcherbak, 2006; Arsan *et al.,* 2006). For this purpose, MBB-1A and Axio Imager microscopes (Carl Zeiss, Germany) were used at magnifications of x20, x40, and x100. To determine species, identification keys for freshwater algae were used (Topachevsky *et al.*, 1984; Vasser *et al.,* 1989).

The Pantle-Buck saprobic index (S), in the Sládeček modification, was calculated according to R.A.E. Knoben *et al*. (2006). This index helps to assess the ecological status of the water body by determining the presence of specific algal species, which serve as indicators of water quality. Chemical analyses of water samples were performed at the certified laboratory AKVO (n.d.). Water samples were analysed for physicochemical, organoleptic, and chemical indicators that characterise the quality of the water body and indicate the conditions under which aquatic organisms exhibit an appropriate level of vital activity, thereby supporting the formation of ecosystem services. The ecosystem services provided by microalgae were assessed according to CICES version 5.2 (n.d.). The study complied with the ethical standards set out in the Convention on Biological Diversity (1992). The collected data and applied methods allow for a comprehensive assessment of the ecological status of the water body and the determination of the role of microalgae in ecosystem service formation.

Results and Discussion

Based on its main characteristics, the Korostyshiv Quarry corresponds to the parameters of oligotrophic water bodies with macrophyte vegetation (B1.1.1), according to the classification presented in the National Habitat Catalogue (Kuzemko *et al.*, 2018). According to the habitat classification by EUNIS (n.d.), the quarry can be assigned to class C1.1 (permanent oligotrophic lakes, ponds, and water bodies). The water body was formed by the flooding of the decommissioned quarry with groundwater, followed by the development of successional processes that led to the emergence of typical aquatic vegetation. In the littoral zone, slight overgrowth is observed, with dominant species such as common reed (*Phragmites australis*), riparian sedge (*Carex riparia*), and narrow-leaved cattail (*Typha angustifolia*), among others. It is evident that meltwater and rainwater also contributed to the replenishment of the water body, introducing substances from the atmosphere and the surrounding land surface. These waters also carried microorganisms, algae, and protists that inhabited the mineral surfaces and soils of the catchment area into the quarry. At the same time, the results of chemical analyses indicate high water quality in the quarry. According to all tested parameters, the water quality of the quarry meets high standards (Table 1).

Table 1. *Results of chemical analysis of water samples from the Korostyshiv Quarry*

	Parameter	EU Standard limit	Ukrainian Sanitary Standard (DSanPiN) limit	Result
1	Colour, points	≤1	≤2	2
2	Odour, points	≤1	≤2	2
3	Temperature, °C	25	25	25
4	Total mineral content, mg/dm³	≤1,000	≤1,000	238
5	pH (hydrogen index)	6.5-8.5	6.5-8.5	7.2
6	Total hardness, mg-eq/dm³	≤1.5	≤7	4.48
7	Carbonate hardness, mg-eq/dm³	≤1.5	Not regulated	2.7
8	Calcium (Ca), mg/dm³	≤100	≤130	70.5
9	Total iron, mg/dm³	≤0.2	≤0.2	0.01
10	Manganese, mg/dm³	≤0.05	≤0.05	0.01
11	Total alkalinity, mmol/dm³	≤6.5	≤6.5	0.74
12	Permanganate oxidisability, mg O_2/dm³	≤5	≤5	0.9
13	Polyphosphates (PO_4)	≤1	≤3.5	0.1
14	Residual chlorine, mg/dm³	≤0.05	≤0.05	0.01

Table 1. *Continued*

	Parameter	EU Standard limit	Ukrainian Sanitary Standard (DSanPiN) limit	Result
15	Nitrates (NO_3), mg/dm³	≤10	≤50	0.01
16	Nitrites (NO_2), mg/dm³	≤0.1	≤0.1	0.01
17	Ammonium salts, mg/dm³	≤0.2	≤0.5	0.1
18	Ammonia, mg/dm³	≤0.2	≤0.5	0.01
19	Oxidation-reduction potential (ORP), mV	Not regulated	Not regulated	+183
20	Magnesium, mg/dm³	≤10	≤80	10.5

Source: developed by the authors based on data AKVO (n.d.)

The data presented in Table 1 indicate that the values of almost all physicochemical water parameters are significantly lower than the limits established by EU standards and Ukrainian sanitary regulations. An exceedance was recorded only for carbonate hardness. Overall, the analysis results confirm the high quality of the water and, by implication, the absence of significant pollution sources in this water body. Accordingly, the high quality of water indicators identified through chemical analysis indicate the effective provision of regulating ecosystem services, particularly the biological purification of water by algae. Adequate water quality is a key prerequisite for the functioning of hydrobionts, ensuring supporting ecosystem services and the conservation of biodiversity. In addition, the qualitative characteristics of water determine the potential for recreational use of the water body, thereby contributing to the formation of cultural ecosystem services. The results of the analysis of the water samples used to determine the species composition of microalgae from the Korostyshiv Quarry are presented in Tables 2 and 3.

Table 2. *Species of microalgae identified in the water of the Korostyshiv Quarry*

Algal species	Number of cells in sample	Abundance, thousand cells/L	Biomass, mg/L
Dinobryon divergens	62	186	0.670
Ankistrodemus fusiformis	36	108	0.011
Peridiniopsis quadridens	4	12	0.227
Crucigenia quadrata	32	96	0.009
Nitzschia vermicularis	2	6	0.006

Source: developed by the authors

Table 3. *Quantitative characteristics of microalgal divisions identified in the water of the Korostyshiv Quarry*

Division		Abundance, thousand cells/L	Biomass, mg/L
2	*Chlorophyta* – Green algae	204	0.019
1	*Bacillariophyta* – Diatoms	6	0.006
1	*Chrysophyta* – Golden algae	186	0.670
1	*Dinophyta* – Dinoflagellates	12	0.227
$\sum = 5$		408	0.922

Source: developed by the authors

The phytoplankton results indicate low species diversity, with only five algal species belonging to four different divisions identified in the sample. Such a community structure may suggest good water quality and that the ecosystem is at an early stage of development. The highest abundance among the species was observed for *Dinobryon divergens* (186×10^3 cells/L), which belongs to the division *Chrysophyta*, indicating the dominant role of golden algae in this biotope. The significant development of *Dinobryon* is typical of oligo- and mesotrophic water bodies with relatively clean water and normal transparency. The second most abundant group consisted of green algae (*Chlorophyta*) – 204 thousand cells/L, indicating good light conditions and a moderate trophic status of the water body. Representatives of this division (*Ankistrodesmus fusiformis*, *Crucigenia quadrata*) have low biomass but consistently form part of the community, providing its structural foundation. Diatoms in the sample are represented only by *Nitzschia vermicularis* at low abundance, yet their presence confirms a normal oxygen regime and a typical level of mineralisation. *Dinophyta* algae in this sample are present in very low abundance (12 thousand cells/L). The species *Peridiniopsis quadridens* does not dominate in this sample, indicating the absence of local 'blooms' or excessive organic enrichment.

The total abundance of phytoplankton in the sample is 408 thousand cells/L, and the biomass is 0.922 mg/L, which is typical for water bodies with a moderate trophic level. The predominance of *Dinobryon* in the biomass (0.670 mg/L) indicates the dominant role of mixotrophic nutrition in the community structure, as golden algae are capable of combining photosynthesis with heterotrophic mechanisms. The value of the saprobic index (S = 1.85) indicates β-mesosaprobic conditions, i.e., a moderate level of organic pollution, which overall reflects the good ecological status of the water in the Korostyshiv Quarry.

The biomass concentration is relatively low – up to 2 g/L. Based on approximate calculations, in the 1-meter-thick surface layer of the quarry water, algal biomass reaches 90 kg. It is evident that in the deeper horizons of the water body, this value would be significantly lower, because the surface layers have more favourable conditions for the development of microalgae (in particular, greater availability of organic matter, better illumination, and higher temperature). Such algal biomass plays a role in oxygen production, the purification of the aquatic ecosystem from pollutants, and the cycling of elements.

Overall, the analysed water sample demonstrated a heterogeneous phytoplankton community without clear dominance of toxic or eutrophic groups. The phytoplankton structure also indicated a stable, moderately trophic, and ecologically favourable condition of the Korostyshiv Quarry water body, with a predominance of golden and green algae. Determining the composition of microalgae as producers of ecosystem services in the quarry water environment enabled the identification and systematisation of potential relationships between the functional traits of microalgae and their associated ecosystem services (Table 4).

Table 4. *Linkages between the functional characteristics of microalgae in water bodies and their ecosystem services*

No.	Functional characteristics of microalgae	Influence of functional characteristics on the formation of ecosystem services
1	Provision of primary production of organic matter supporting biocenoses	Microalgae (phytoplankton, diatoms, etc.) represent the first trophic level in aquatic ecosystems and provide primary production of organic matter that supports biocenoses (e.g. fish and zooplankton). They play a key role in maintaining trophic networks and biodiversity, forming the basis of numerous provisioning ecosystem services
2	Oxygen production and regulation of gas composition	The photosynthetic activity of microalgae leads to oxygen production and the regulation of dissolved gases in water. This is an important supporting ecosystem function and part of regulating services associated with maintaining the physicochemical environment
3	Nutrient cycling	Microalgae participate in the cycling of nitrogen, phosphorus, and other biogenic elements in water bodies. They accumulate these substances and, after cell death, return them to the aquatic environment, thereby influencing nutrient cycling processes

***Table 4.** Continued*

No.	Functional characteristics of microalgae	Influence of functional characteristics on the formation of ecosystem services
4	Self-purification and filtration	Certain algal species (e.g. *Chlorella*) contribute to the removal of excess nutrients (nitrogen, phosphorus) from water bodies, thus supporting waste neutralisation and water purification – an important ecosystem service
5	Indicators of environmental condition	Due to their high sensitivity to environmental changes, the species composition of microalgae is widely used as a bioindicator of water quality. This enables the assessment of the ecological status of water bodies and changes in ecosystem services over time
6	Regulation of water conditions	Various characteristics of water bodies (trophic status, nutrient availability, pH) determine the composition and dominance of certain microalgal species. Changes in algal communities reflect shifts in ecological processes that ensure the stability of the aquatic environment
7	Negative effects under imbalance	Certain species (e.g., *Microcystis aeruginosa*, a cyanobacterium) can form toxic blooms that reduce water quality and negatively affect biodiversity and human health. This illustrates how shifts in microalgal species composition may disrupt ecosystem services

Source: developed by the authors based on E. O'Neill & N. Rowan (2022), V. B-Béres *et al*. (2023), C.M. Dobrescu *et al*. (2023), E. Delgado-Fernández *et al*. (2025)

Thus, the species diversity of microalgae directly determines the scope and quality of ecosystem service provision in aquatic ecosystems. In particular, diatoms and green algae are actively involved in biological water purification processes, absorbing nutrients and contributing to the delivery of regulating services. Representatives of green and diatom algae also form the basis of primary production and serve as a food source for zooplankton, ensuring supporting ecosystem services through trophic interactions. At the same time, excessive development of cyanobacteria may deteriorate water quality and limit regulating and cultural services due to toxicity and algal blooms. Therefore, a balanced structure of microalgal communities is a key factor in maintaining ecosystem functional stability and their capacity to deliver a wide range of ecosystem services.

The identified relationships between the functional traits of microalgae in water bodies and ecosystem services indicate the following:

- the species composition of microalgae is an important factor in the formation of ecosystem services, directly influencing primary production in water bodies, the cycling of biogenic elements, and their incorporation into trophic chains;
- the species composition of microalgae reflects the ecological status of water, as well as regulating and supporting processes, including self-purification;
- changes in the species composition of microalgae can either improve (through selfregulation and purification) or disrupt (through toxic blooms) water quality and, consequently, the quality of ecosystem services.

Considering the structure of ecosystem services provided by freshwater and marine algae according to the Millennium Ecosystem Assessment (MEA) classification, and taking into account the findings of V. B-Béres *et al*. (2023), the relationships between microalgae, ecosystem services, and their impacts on humans and biodiversity are presented in Figure 3. It is shown that the species composition of microalgae determines supporting, regulating, provisioning, and cultural services, including photosynthesis, water purification, and the formation of food resources. Microalgae also serve as indicators of water quality and play a key role in ecosystem self-purification processes. At the same time, changes in their composition can either improve environmental conditions or cause negative phenomena, such as toxic algal blooms.

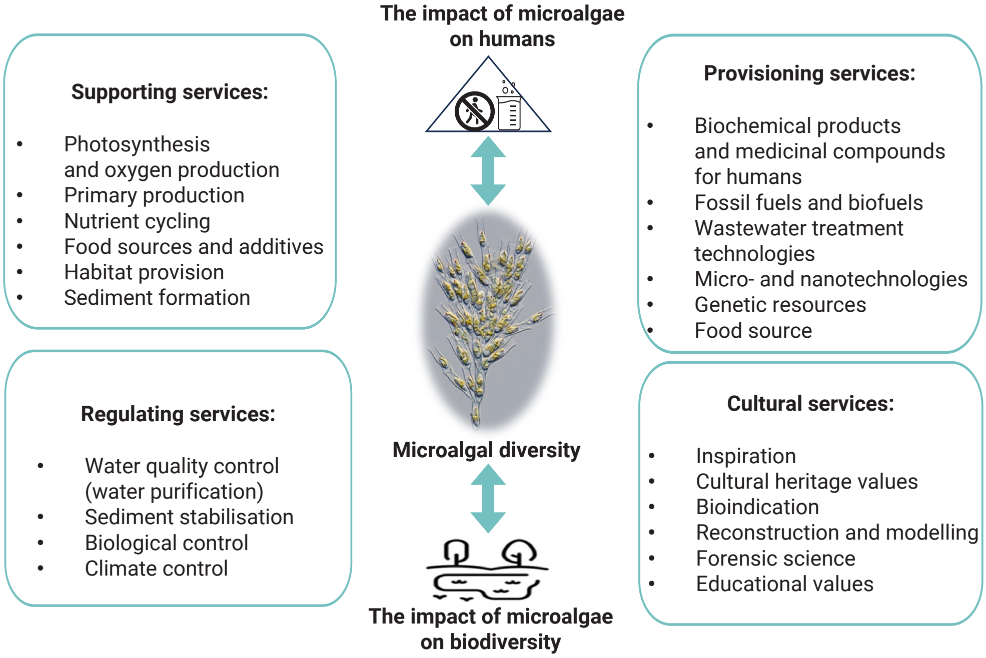

Figure 3. *The impact of microalgae on humans and biodiversity as mediated through ecosystem services*

Source: interpreted by the authors based on V. B-Béres *et al.* (2023)

Given that the species diversity of microalgae is a factor in the formation of ecosystem services, their potential was analysed in the context of ecosystem service provision by lentic freshwater bodies (flooded quarries), which are associated with three service categories according to the CICES classification (CICES Version 5.2, n.d.). The proposed refinements to this classification may be useful in applied studies of microalgal ecosystem services, as they are based on the expansion and detailing of codes following the logic: 'Class' → 'Subclass'. The ecosystem services of microalgae in lentic freshwater bodies, specifically the Korostyshiv Quarry, are presented in Table 5.

Table 5. *Ecosystem services formed by microalgae in lentic freshwater bodies (quarries)*

ES codes	Ecosystem services
1.1.4.1	***Provisioning (biotic)*** Primary production of microalgal biomass as the foundation of trophic chains (formation of the food base for zooplankton, benthos, and fish)
1.1.6.1	Microalgal biomass as a potential raw material for feed, bioactive substances, biofuels, and pharmaceutical products
1.1.6.2	Genetic resources of microalgae (a source of biochemical and biotechnological materials)
2.2.1.1	***Regulating and maintenance services*** Biological filtration, sequestration, and accumulation of nutrients (nitrogen, phosphorus) during photosynthesis
2.2.1.2	Reduction of eutrophication processes through the regulation of nutrient levels in water
2.2.2.1	Maintenance of primary productivity and energy balance of aquatic ecosystems

***Table 5.** Continued*

ES Codes	Ecosystem services
2.2.2.3	Formation and maintenance of habitats for aquatic organisms (oxygen provision, creation of micro-niches)
2.2.3.1	Biological control of pathogenic microorganisms and potentially harmful algae
2.2.4.2	Participation in organic matter decomposition and biogeochemical cycles
2.2.5.1	Regulation of the chemical composition of freshwater systems (pH, dissolved oxygen content, nutrient concentrations)
2.2.6.1	Regulation of atmospheric gas composition through photosynthetic oxygen production
2.2.6.2	Biological carbon uptake and sequestration (participation in the carbon cycle)
3.1.1.2	***Cultural services*** Aesthetic and educational value (influence on water transparency and colour; observation of natural processes)
3.1.2.1	Scientific research and monitoring of aquatic ecosystem condition (microalgae as bioindicators of water quality)
3.2.2.2	Heritage (existence) value – conservation of biodiversity and unique microalgal taxa
6.1.1.1	Indirect contribution to recreational services (maintenance of the ecological status of water bodies suitable for recreation)

Source: interpreted by the authors based on CICES Version 5.2 (n.d.)

As shown in the table, the ecosystem services of microalgae in lentic quarry water bodies constitute a factor influencing the formation of virtually all ecosystem services. The magnitude of these services primarily depends on biomass production. This aspect is crucial for provisioning, regulating, and supporting services. The analysis of species composition and biomass of microalgae in the Korostyshiv Quarry aquatic ecosystem (Tables 1 and 2) indicates limited species diversity and relatively low productivity, which may be associated with seasonal factors and the relative youth of the ecosystem. For example, such responses of algae to chemical changes in water bodies, such as variations in temperature, pH, and dissolved substances, confirm their role as bioindicators of water quality (Dobrescu *et al.*, 2023), which, in turn, influences the formation of the majority of ecosystem services. Consequently, the ecosystem services of microalgae in lentic quarry water bodies are predominantly of a regulating and supporting nature, while simultaneously providing an important ecological foundation for the realisation of provisioning and cultural services throughout the aquatic ecosystem.

Newly created quarry reservoirs have their own characteristics that distinguish them from the ecosystems of previously formed water bodies. There are many mechanisms by which aquatic plants and animals can colonise new habitats that were not previously present. Several actual and potential pathways can be identified through which living organisms may populate a newly established aquatic system. Firstly, although there may be a considerable distance between the surface of a quarry and that of the nearest water body, they can be connected through groundwater. In such cases, invertebrates or algae may reach the quarry via aquatic pathways. Storm runoff and meltwater represent another potential mechanism for the migration of organisms from inundated land surfaces and other water bodies into the quarry water body.

Some organisms lay eggs that adhere to plants or even to the feet of birds migrating from other water bodies to quarries (Hirsch *et al.*, 2018). In this way, not only representatives of ichthyofauna but also other organisms, including freshwater jellyfish, can disperse. At the polyp stage, they inhabit aquatic plants. When these plants are transported to other water bodies – via underwater dispersal, by birds or other animals, or by humans – the jellyfish can enter their freeswimming or medusa stage. Humans moving from one water body to another may also inadvertently carry aquatic organisms on their equipment, such as fishing or diving gear. Through such mechanisms, the distribution range of freshwater jellyfish of the genus *Craspedacusta*, originally from China, has extended to freshwater bodies in Europe, North and South America, Africa, and Australia (Lüskow *et al.*, 2024). These water bodies include isolated lakes and quarry water bodies.

The presence of unicellular algae in quarry waters can be explained more simply: algae are widespread in soils, on rock surfaces, and in other moist biogeocoenoses surrounding the quarry water body, and they migrate via water and air currents. Young quarry ecosystems are characterised by clean water, minimal levels of pollutants, and a corresponding microbial community. During the development of these systems, higher aquatic plants appear and spread, and the diversity of hydrobiont species, including fish, increases. Ecosystem services in young quarry ecosystems differ in scale from those of well-established, long-term quarry water bodies, yet they encompass provisioning, regulating, supporting, and cultural services. The manifestation and availability of these services are closely linked to the condition of the aquatic environment and its biotic components. Hydrobionts play a particularly important role in the formation of ecosystem services (Naselli-Flores & Padisák, 2023; Thomaz, 2023).

A comparison of the results of the phytoplankton study conducted in the Korostyshiv Quarry with other similar studies makes it possible to identify both common patterns and certain differences determined by the stage of ecosystem development and local environmental conditions. First and foremost, the results obtained from the phytoplankton investigation in the Korostyshiv Quarry are consistent with general approaches to the formation of hydrobiota in natural water bodies, as outlined in the studies of V.I. Shcherbak (2006) and O.P. Bilous *et al.* (2018). Furthermore, the findings correlate with the general understanding of the functioning of young quarry ecosystems. In this study, a limited species diversity of phytoplankton was identified (five species representing four divisions), which corresponds to the characteristic features of the initial stages of aquatic biocoenosis formation in quarry water bodies, as demonstrated in previous studies by P. Hirsch *et al.* (2018) and F. Lüskow *et al.* (2024).

The study emphasised that the water quality indicators of the Korostyshiv Quarry comply with European standards, while the phytoplankton biomass level is moderate. Accordingly, the results obtained further confirm the relationship between high water quality and the characteristics of the biota, which is consistent with findings reported in other studies. In particular, C.M. Dobrescu *et al.* (2023) examined the response of algae to chemical changes in aquatic environments (including variations in temperature, pH, and dissolved substances), thereby confirming their role as bioindicators of water quality. E. Delgado-Fernández *et al.* (2025) emphasised the capacity of microalgae to serve as effective indicators of water quality and the ecological status of lakes and other water bodies, as certain species exhibit high sensitivity to environmental changes.

Another important aspect of the consistency between the results obtained and contemporary scientific approaches to assessing the role of microalgae in the functioning of aquatic ecosystems is the determination of their contribution to the formation of ecosystem services. In this study, it is substantiated that phytoplankton predominantly provides regulating and supporting services, as well as, to some extent, cultural and provisioning services, particularly through its influence on water quality and the recreational potential of the water body. Similar conclusions have been presented in studies by E. Acevedo-Trejos *et al.* (2018) and J.F. Tweddle *et al.* (2018), which emphasise that microalgae play a key role in regulating the chemical composition of water and biogeochemical cycles, and also act as sensitive indicators of the ecological status of aquatic ecosystems. At the same time, certain differences can be observed between the results obtained and the generalisations presented in other studies. These differences are primarily related to the stage of ecosystem development. In the present study, a relatively low species diversity of phytoplankton was recorded under conditions of structural balance, indicating a stable yet not fully developed biocoenosis. In contrast, studies by P. Hirsch *et al.* (2018) and F. Lüskow *et al.* (2024) highlighted that, during further succession, quarry water bodies undergo increasing biotic complexity: algal diversity rises, higher aquatic plants emerge, and the composition of hydrobiota expands, including the development of ichthyofauna.

Differences are also evident in the approaches to assessing ecosystem services. In this study, the CICES classification was applied to substantiate the contribution of phytoplankton to the provision of provisioning, regulating, supporting, and cultural ecosystem services, with an emphasis on their quantitative and functional assessment. At the same time, studies by V. BBéres *et al.* (2023) and L. Naselli-Flores & J. Padisák (2023) predominantly adopted a more generalised approach, in which ecosystem services are considered as a derivative of the overall state of biota and hydroecological conditions, without detailed differentiation of the roles of individual taxonomic groups.

The results of the present study are generally consistent with the established principles regarding the patterns of biota formation and ecosystem service development in quarry water bodies reported in other studies. The identified combination of relatively low species diversity and favourable hydrochemical conditions indicates an early or intermediate stage of ecological succession in the studied Korostyshiv Quarry water body. This confirms that the formation of biotic structure and ecosystem functions occurs gradually and depends on a complex interplay of natural and anthropogenic factors. At the same time, the presented results highlight the important role of phytoplankton as an indicator of ecological status and as a key component in the provision of regulating and supporting ecosystem services.

Conclusions

In summary, the data obtained allow for the formulation of key conclusions that reflect the main results of the study, demonstrating the importance of identifying relationships between the species composition of microalgae and the formation of corresponding ecosystem services. It was established that the phytoplankton of the studied water body of the Korostyshiv Quarry is characterised by a relatively balanced community structure under conditions of limited species diversity: five microalgal species belonging to four divisions (*Chlorophyta*, *Bacillariophyta*, *Chrysophyta*, and *Dinophyta*) were identified, which generally indicates a favourable ecological status of the aquatic environment. The biomass level remained moderate and does not exceed 2 g/L, which is consistent with the results of chemical analysis confirming that water quality indicators comply with European regulatory requirements and Ukrainian standards.

The study also revealed functional relationships between the taxonomic structure of microalgae and the processes of ecosystem service formation. It was shown that the species composition of phytoplankton determines the intensity of primary production, the characteristics of nutrient cycling, and the overall state of the aquatic ecosystem. Taking into account the CICES classification, it was substantiated that microalgae act as an important factor in the formation of a wide range of ecosystem services (provisioning, regulating, supporting, and cultural), with their contribution varying across different service groups. The study further indicates that the high quality of water indicators of the quarry, as established by chemical analysis, reflects the effectiveness of the regulating ecosystem services provided by algae. Good water quality is a key determinant for the development of hydrobionts (supporting ecosystem services) and for the recreational use of the water body by the population.

Further research will make it possible to address the questions arising at this stage of the analysis of non-flowing aquatic ecosystems. Additional attention should be paid to determining the species composition and quantitative characteristics of epiphyton in quarry water bodies. This approach may contribute to the development of a national framework for assessing ecosystem services of freshwater lentic ecosystems.

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Conflict of Interest

None.

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Мікроводорості непроточних водойм як фактори формування екосистемних послуг

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Анотація. Завдяки значному видовому різноманіттю та чутливості до змін середовища мікроводорості є важливими індикаторами екологічного стану водойм та у складі інших гідробіонтів формують екосистемні послуги гідросистем. Оскільки їх внесок у забезпечення екосистемних послуг непроточних водойм досліджений обмежено й потребує подальшого обґрунтування для визначення екологічної цінності водойм, мета роботи полягала у дослідженні взаємозв'язків між видовим складом мікроводоростей та формуванням відповідних екосистемних послуг непроточних водойм на прикладі Коростишівського кар'єра (Житомирська область, Україна). Для визначення видового складу та розподілу мікроводоростей застосовували стандартні методики (відбір та консервація проб води, виділення, ідентифікація та кількісні характеристики мікроводоростей за допомогою мікроскопії). Виявлено відносно збалансовану структуру фітопланктонного угруповання водойми кар'єру з невисоким видовим різноманіттям: п'ять видів мікроводоростей, що належать до чотирьох різних відділів (*Chlorophyta*, *Bacillariophyta*, *Chrysophyta* та *Dinophyta*). Концентрація біомаси була відносно невисокою – до 2 г/л. Видовий склад фітопланктону та результати хімічного аналізу проб води вказують на добрий екологічний стан водойми. Визначені взаємозв'язки між функціональними характеристиками мікроводоростей та екосистемними послугами. Показано, що видовий склад мікроводоростей є ключовим чинником формування екосистемних послуг, визначає первинну продукцію, кругообіг біогенних елементів і стан водного середовища. З урахуванням класифікації екосистемних послуг CICES показано, що мікроводорості досліджуваної водойми кар'єру є фактором, що впливає на формування практично усіх типів екосистемних послуг (3 – забезпечувальних, 9 – регулювальних та підтримувальних, 4 – культурних), але з різною інтенсивністю. Показано, що домінуючим в умовах екосистеми кар'єру був внесок мікроводоростей у формування регулювальних та підтримувальних екосистемних послуг. Результати можуть бути використані для розроблення механізму оцінювання екосистемних послуг прісноводних лентичних водойм

Ключові слова: фітопланктон; екосистеми кар'єрів; біотопи; індикаторні види; кругообіг біогенних елементів