

PHYTOPLANKTON AS AN INDICATOR OF TROPHIC STATUS OF LAKE OHRID

Suzana Patcheva

Hydrobiological Insitute – Ohrid, North Macedonia, spatceva@hio.edu.mk

ORCID ID: 0000-0003-0509-9110

Abstract: Lake Ohrid is the oldest extant lake in Europe with more than 200 endemic species. It is a transboundary lake located on the Balkan Peninsula with two thirds of its area belonging to Macedonia and one third to Albania. This research aimed to analyze the abundance and diversity of phytoplankton, its spatial and seasonal distribution and chlorophyll *a* concentration to assessment the trophic status of Lake Ohrid. The study was conducted in five sampling campaign, seasonally from September 2025 to August 2026 at a sample station in the pelagic zone at eight depths and at six sampling stations in the littoral zone. Water samples were collected from each target depth using Niskin bottles and subsequently stored in accordance with standard protocols. Phytoplankton identification and enumeration were performed using an inverted microscope and the Utermöhl method. Chlorophyll *a* concentration was determined spectrophotometrically after extraction with 90 % ethanol. The trophic status of the lake was estimated using the values of Carlson's Trophic State Index according to chlorophyll *a* concentration. Phytoplankton community included six divisions as Cyanophyta, Bacillariophyta, Chlorophyta, Chrysophyta, Charophyta and Pyrrophyta. Bacillariophyta, was the most important group in terms of species number, followed by Charophyta and Chlorophyta. Algal diversity in the littoral zone was higher than in the pelagic zone, particularly regarding diatoms. In Lake Ohrid, there was a significant difference in the composition of the phytoplankton community at different depths in the same season, as well as at the same depths in different seasons. The phytoplankton abundance in Lake Ohrid was the highest in spring period, and then significantly decreased in the summer when the values in the upper layer were especially low. In the autumn period, the values were lower compared to the winter period. The concentration of chlorophyll *a*, as an indicator of phytoplankton production, the highest value, corresponding to the phytoplankton density, was recorded in winter at 20 meters depth with $1.62 \mu\text{g l}^{-1}$ and at 10 meters depth with $1.54 \mu\text{g l}^{-1}$ and the lowest values were observed at 150 meters depth. In summer the highest chlorophyll *a* concentration was observed at 50 m depth with value of $1.02 \mu\text{g l}^{-1}$. The distribution of chlorophyll *a* in Lake Ohrid completely coincides with the general distribution of chlorophyll *a* in oligotrophic lakes from the temperate zone. According to the Trophic State Index, the pelagic and all littoral zones of Lake Ohrid are characterized as oligotrophic. In accordance with the Water Framework Directive, we can define the status of the pelagic and littoral zones of Lake Ohrid as high. In conclusion, phytoplankton are effective bioindicators for assessing trophic status and lake primary productivity. To preserve the oligotrophic status of Lake Ohrid in future, it is essential to reduce anthropogenic pressures and nutrient input in order to prevent the process of eutrophication.

Keywords: Lake Ohrid, phytoplankton, chlorophyll *a*, trophic status.

1. INTRODUCTION

The primary threat to the water quality of lakes is eutrophication. Phytoplankton serve as rapid biological indicators of aquatic trophic states because their community composition, biomass, and chlorophyll *a* concentrations respond directly to shifting nutrient levels like phosphorus and nitrogen. Phytoplankton regularly serves as a key metric for assessing water quality and eutrophication levels (Wellborn et al., 1996; Dutta et al., 2023; Mineeva, 2024) because these populations respond sensitively to ecological changes, making them a useful biological parameters for lake monitoring programs. Evaluating specific indicator species provides a strong rationale for assessing overall aquatic health and tracking shifts in lake environments (Paerl et al., 2007; Oliveira et al, 2024). Changes in the taxonomic composition of phytoplankton communities represent one of the most sensitive biological indicators for detecting water quality degradation caused by eutrophication and increasing anthropogenic nutrient loads (Evayani et al., 2026). In particular, chlorophyll *a* acts as a representative measure for primary producer biomass (Kasprzak et al., 2008), playing a crucial role in establishing ecologically appropriate targets for lake water quality (Poikane et al., 2014).

The expansion of human activity within the watershed of the oligotrophic Lake Ohrid, Europe's oldest lake, has begun to compromise its unique ecosystem (Schneider et al., 2020; Vermaat, et al., 2022). Larger tributaries, in particular, exert a significant negative impact on the lake's littoral zone (Patceva et al., 2004). To evaluate the lake's overall trophic status, this study aims to analyze phytoplankton abundance, diversity, spatial, seasonal distribution, and chlorophyll *a* concentrations in the pelagic and littoral zone of Lake Ohrid.

2. MATERIALS AND METHODS

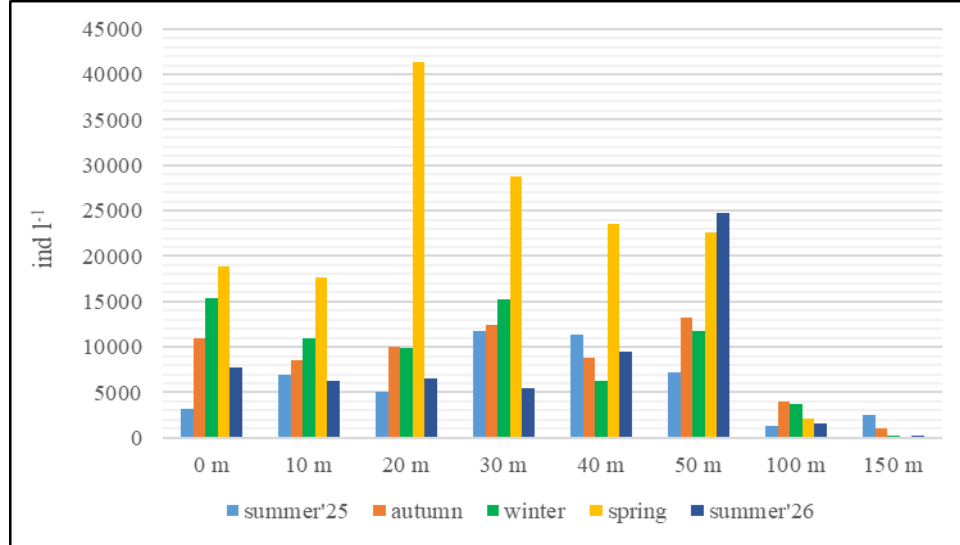
Phytoplankton investigations within the Macedonian part of Lake Ohrid was conducted across six littoral sampling stations and one pelagic station. At the pelagic site, samples were collected from eight distinct depths (0, 10, 20, 30, 40, 50, 100, and 150 m) using a Niskin water sampler and immediately fixed with 4%

formaldehyde. Phytoplankton taxonomic identification and enumeration of individuals per volume of water were performed via the Utermöhl (1958) method using a trinocular inverted microscope (LW101-2) equipped with an epi-illumination module and an 8.0 MP OmniVID camera. To evaluate the lake's trophic status, Carlson's Trophic State Index (TSI) was determined from chlorophyll *a* concentrations (Carlson, 1977), which were extracted in 90% ethanol and quantified spectrophotometrically (UV-VIS SPECORD 10, Zeiss) adhering to ISO 10260 (1992) standards.

3. RESULTS

Phytoplankton abundance in Lake Ohrid peaked during the spring before dropping significantly in the summer months, with particularly low concentrations recorded in the surface waters. During the autumn, population counts were notably lower than those observed during the winter season (Fig. 1, 2).

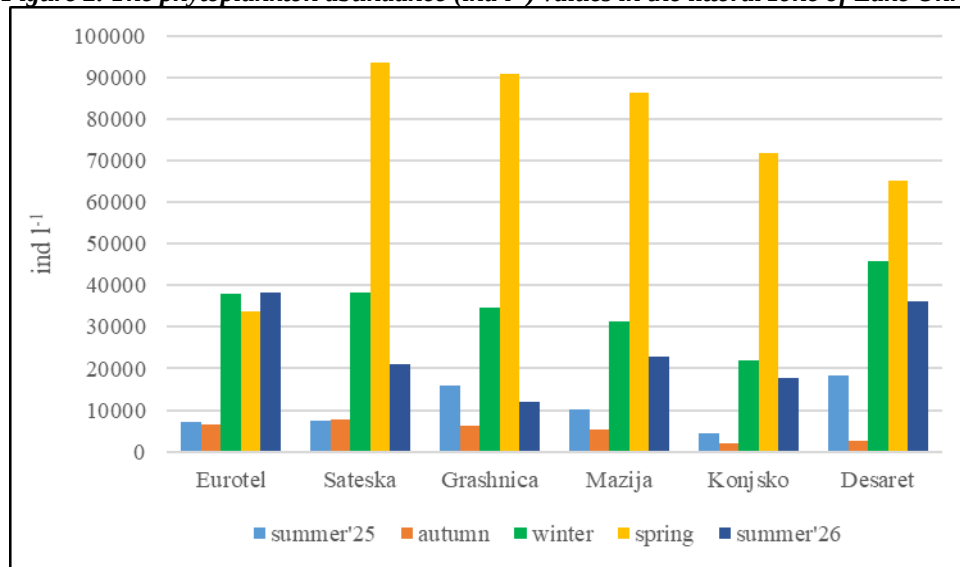
Figure 1. The phytoplankton abundance (ind l⁻¹) values in the pelagic zone of Lake Ohrid



Source: Author's research

The maximum phytoplankton abundance value in the pelagic zone during the study was 41 400 ind l⁻¹ at 20 m depth in spring period. Phytoplankton abundance was the highest in the water layer between 20 and 40 m depth. Abundance was the lowest in the deepest layers at depths of 100 and 150 m. (Fig. 1).

Figure 2. The phytoplankton abundance (ind l⁻¹) values in the littoral zone of Lake Ohrid

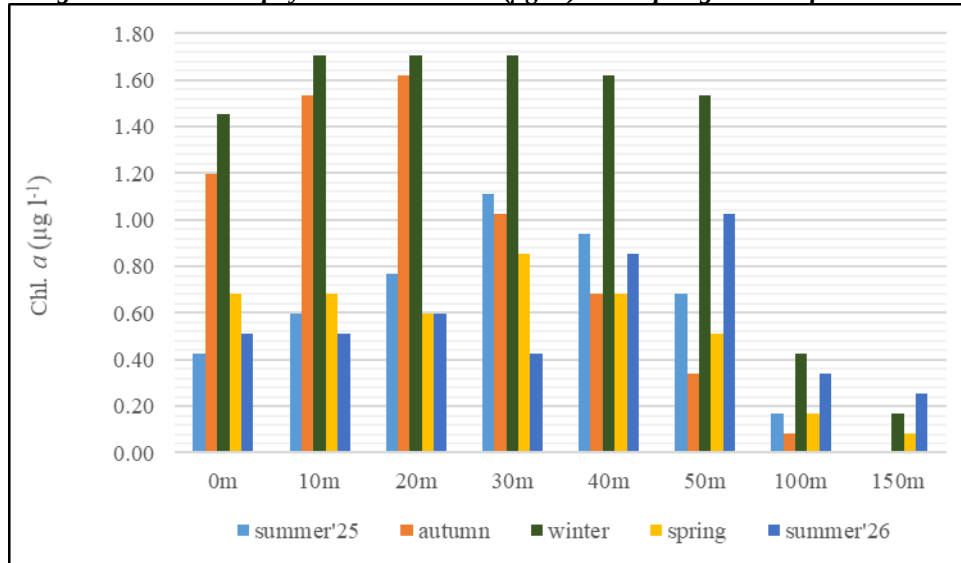


Source: Author's research

At investigated sampling stations of the littoral zone phytoplankton abundance was the highest in spring at Sateska with value of 93 600 ind l⁻¹ followed by Grashnica with 90 800 ind l⁻¹.and Mazija with 86 200 ind l⁻¹. In

the other periods values were significantly lower and the lowest values were observed in autumn period between 4 400 ind l⁻¹ at Konjsko and 16.000 ind l⁻¹ at Grashnica (Fig. 2).

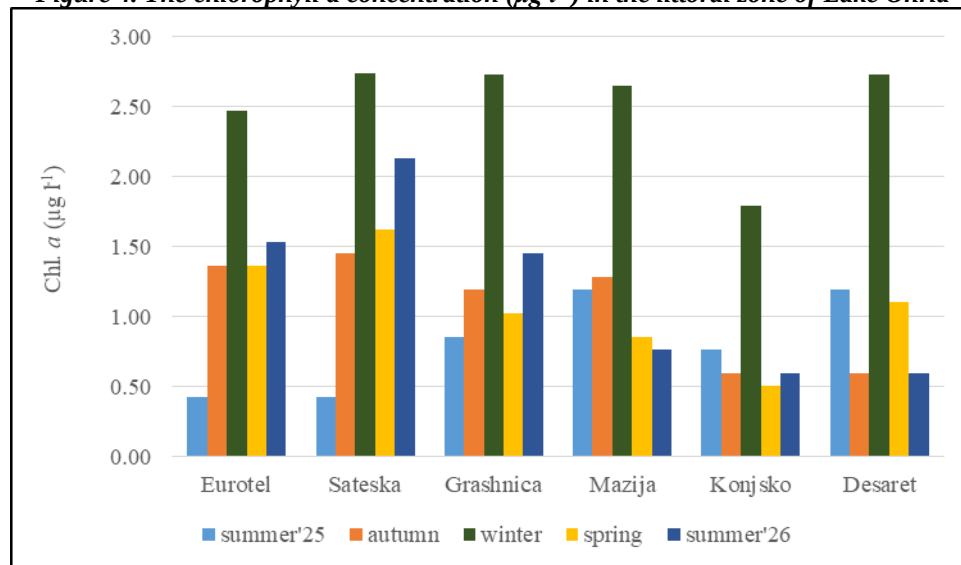
Figure 3. The chlorophyll a concentration ($\mu\text{g l}^{-1}$) in the pelagic zone of Lake Ohrid



Source: Author's research

Throughout the study period, chlorophyll a concentrations in the pelagic zone of Lake Ohrid remained below 1.8 $\mu\text{g l}^{-1}$, peaking during the winter and reaching their minimum in the summer. Autumn concentrations were lower than those recorded in winter. However, during the summer 2026 sampling campaign, a peak chlorophyll a concentration of 1.02 $\mu\text{g l}^{-1}$ was detected at a depth of 50 meters (Fig. 3).

Figure 4. The chlorophyll a concentration ($\mu\text{g l}^{-1}$) in the littoral zone of Lake Ohrid



Source: Author's research

The concentration of chlorophyll a in the littoral zone was the highest in winter and the lowest in the summer period, just like in the pelagic zone. The highest value of 2.74 $\mu\text{g l}^{-1}$ was observed at Sateska, followed by Grashnica and Desaret with 2.73 $\mu\text{g l}^{-1}$ and the lowest value of 0.43 $\mu\text{g l}^{-1}$ at Eurotel and Sateska in the summer period 2025 (Fig. 4).

Table 1. The results of Carlson's Trophic State Index (TSI) of Lake Ohrid

	Summer'25	Autumn	Winter	Spring	Summer'26	Average	Trophic status
Pelagic zone	22	32	34	27	24	28	Oligotrophic
Eurotel	34	34	39	34	35	35	Oligotrophic
Sateska	34	34	40	35	38	36	Oligotrophic
Grashnica	32	32	40	31	34	34	Oligotrophic
Mazija	33	33	40	29	28	33	Oligotrophic
Konjsko	26	26	36	24	26	28	Oligotrophic
Desaret	26	26	40	32	26	30	Oligotrophic

Source: Author's research

Values of Carlson's Trophic State Index (TSI), based on chlorophyll-*a* concentration, ranged from 24 to 40 during the study period. The average value for the entire study period was the lowest in the pelagic zone and at the Konjsko littoral station (28), and highest in the Sateska littoral (36) (Tab. 1).

4. DISCUSSIONS

Phytoplankton community of Lake Ohrid included six divisions as Cyanophyta, Bacillariophyta, Chlorophyta, Chrysophyta, Charophyta and Pyrrophyta. Bacillariophyta, was the most important group in terms of taxa number, followed by Charophyta and Chlorophyta. The pelagic zone was characterised by phytoplankton communities consisting mainly of euplanktonic species. The number of species at the littoral stations was significantly higher because their phytoplankton communities contain littoral species and species that usually live on the bottom and on macrophyte vegetation, particularly diatoms.

The temporal and spatial distribution of phytoplankton in Lake Ohrid is highly complex, involving a range of abiotic and biotic factors. Consequently, the factors crucial to phytoplankton succession cannot be easily pinpointed, succession is rarely determined by a single factor or a few isolated ones, but rather by the complex interplay between them. Significant differences existed in the composition of the phytoplankton community in Lake Ohrid both across varying depths during the same time periods and at the same depths during the different seasons. In the autumn and winter periods diatoms (Bacillariophyta) accounted for the largest percentage of the total phytoplankton abundance. During the spring period, representatives of Chrysophyta accounting for the largest share of total phytoplankton abundance in the littoral zone, as well as in the pelagic zone up to a depth of 50 m. The dominant Chrysophyta species was *Dinobryon divergens*. In the summer period, Pyrrophyta was the dominant algal group at all littoral sampling stations and in the pelagic zone at 0 m and 10 m depths.

The phytoplankton abundance in Lake Ohrid was the highest in spring period, and then significantly decreased in the summer when the values in the upper layer were especially low. In the autumn period, the values were lower compared to the winter period. The concentration of chlorophyll *a*, as an indicator of phytoplankton production, the highest value was recorded in winter at 20 meters depth with $1.62 \mu\text{g l}^{-1}$ and at 10 meters depth with $1.54 \mu\text{g l}^{-1}$ and the lowest values were observed at 150 meters depth. In summer 2026, the occurrence of the deep chlorophyll maximum at a depth of 50 m was notable. This specific vertical distribution is unique to highly transparent, oligotrophic lakes. Such deep chlorophyll maxima have been documented in Lake Ohrid during previous investigations as well. (Mitic, 1993; Patceva, 2001; Patceva, 2005). Lake Ohrid is characterized by the presence of chlorophyll *a* in the deepest layers, at depths of 100 to 150 m. This deep-water concentration is driven by the presence of the endemic diatom *Cyclotella fottii* at those specific depths. Furthermore, the spatial and vertical distribution of chlorophyll *a* in Lake Ohrid aligns perfectly with the overarching patterns documented for temperate oligotrophic lakes by Marshall and Peters (1989). Marshall and Peters (1989).

For comparison, in neighboring Lake Prespa, which is in process of eutrophication, Cyanophyta was a major component of the phytoplankton during the summer period, when the highest abundance was also recorded (Patcheva et al. 2024).

The concentration of chlorophyll *a* in the littoral zone was higher compared to the pelagic zone. According to the Carlson's Trophic State Index, the pelagic zone and all littoral stations of Lake Ohrid were characterized as oligotrophic, poor in nutrients, water clear and well oxygenated. The pelagic zone and littoral station Konjsko had the highest trophic status, and Sateska littoral had the lowest trophic status as a result of the negative impact of the Sateska River, which flows into the lake. In accordance with the Water Framework Directive, we can define the status of Lake Ohrid as high.

The phytoplankton investigations showed no differences in phytoplankton composition, abundance, or its spatial and temporal distribution as well as on the concentration of chlorophyll *a* compared to previous studies of Lake Ohrid (Mitic, 1993; Patceva, S. 2001; Patceva, S. 2005; Patceva et al. 2004; Patceva et al. 2009).

5. CONCLUSIONS

Phytoplankton composition and abundance as well as the concentration of chlorophyll *a* are effective bioindicators for assessing trophic status and lake primary productivity. The structural composition and total abundance of the phytoplankton communities provided a reliable framework for evaluating the trophic state and ecological health of Lake Ohrid. Aquatic environments characterized by low algal biomass and highly specialized species dominance are classically indicative of oligotrophic systems. The current evaluation confirms that Lake Ohrid maintains a stable oligotrophic condition with no overt signs of accelerated eutrophication. Consequently, this unique lacustrine ecosystem continues to demonstrate resilience against the escalating anthropogenic pressures it has faced over the past few decades, the complete removal of wastewater from its catchment area.

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