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Diversity and community structure of microalgae and cyanobacteria in Oglat Eddaira wetland (south-western Algeria)

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ABSTRACT

This study aimed to identify the microalgae and assess their seasonal distribution in Oglat Eddaira lake (south western Algeria), integrating ecological evaluation through diatom and phytoplankton-based indices (EPI-D and Q Index). Sampling was carried out monthly from October 2023 to August 2024 using a plankton net for microalgae, with three fixed points for seasonal assessments. A total of 32 microalgal species were recorded, belonging to six classes: *Bacillariophyceae*, *Chlorophyceae*, *Cryptophyceae*, *Conjugatophyceae*, *Cyanophyceae*, and *Euglenophyceae*. Seasonal heatmaps revealed clear clustering patterns, with nutrient-related parameters (NO_3^-, PO_4^{3-}, NH_4^+) exerting the strongest influence on microalgal assemblages, followed by physical factors (temperature**,** turbidity) and mineralization parameters (conductivity, salinity**)**. The Q index proved particularly sensitive to detecting bloom-forming species and early eutrophication signals, while the EPI-D index provided a more integrative perspective on long-term diatom community shifts. Notably, cyanobacteria exhibited higher abundances during warmer periods, indicating their role as early indicators of ecosystem imbalance. Additionally, we successfully developed a new ecological mapping of Oglat Eddaira, providing a visual representation of its environmental gradients and biological patterns, which constitutes a valuable tool for wetland management and monitoring.

Keywords: microalgae, cyanobacteria, Oglat Eddaira lake, EPI-D, Q index, south-western Algeria.

INTRODUCTION

Microalgae and cyanobacteria are fundamental components of aquatic ecosystems, acting as primary producers that capture solar energy and convert dissolved inorganic compounds into organic matter, thereby sustaining higher trophic levels [Turner et al., 2009]. Their distribution and community structure are highly sensitive to environmental changes, making them reliable bioindicators of ecological status [Reynolds, 2006]. In freshwater systems, phytoplankton composition reflects not only natural seasonal cycles but also anthropogenic pressures, such as nutrient enrichment and hydrological alteration.

In Algeria, wetlands constitute biodiversity sanctuaries of global importance, yet many remain underexplored in terms of their ecological functioning [Boubekeur et al., 2020; Mansouri et al., 2025; Hellal et al., 2025]. These ecosystems integrate groundwater, surface water, lakes, and streams, thereby regulating watershed processes and providing habitat to numerous species. Wetlands collectively harbor nearly 40% of global biodiversity [Ramsar Convention Secretariat, 2024] and deliver multiple ecosystem services, ranging from nutrient cycling and water purification to fisheries, agriculture, and cultural values [Gildas et al., 2023]. Despite these vital roles, Algerian wetlands face increasing threats from agricultural intensification, wastewater inputs, and climate variability [Ben Naoum et al., 2025].

Eutrophication has emerged as one of the most pervasive global threats to freshwater ecosystems.

Excessive nitrogen and phosphorus loading stimulates algal proliferation and frequently results in harmful cyanobacterial blooms [Anderson et al., 2002]. Such blooms degrade water quality, reduce biodiversity, and pose risks to human and animal health through toxin production. Recent assessments suggest that nearly half of the world's riverine and lacustrine populations are already impacted by nutrient over-enrichment [McDowell et al., 2025]. Understanding the dynamics of phytoplankton under these stressors is therefore crucial for sustainable management of freshwater resources.

Within this context, Oglat Eddaira, a shallow wetland designated as a Ramsar site in 2004, represents a key ecological hotspot in southwestern Algeria [Sennour et al., 2025]. Despite its international recognition, detailed studies on the ecological status and phytoplankton community of this lake are scarce. Its hydrological connectivity with agricultural landscapes suggests that it may be vulnerable to nutrient loading, seasonal eutrophication, and shifts in algal community structure. Previous limnological surveys in North African wetlands have demonstrated that shallow lakes are particularly sensitive to such pressures, often exhibiting rapid transitions between clear-water, diatom-dominated states and turbid, cyanobacteria-dominated conditions [Naselli-Flores, 2018].

The present study addresses these knowledge gaps by conducting a seasonal survey (2023–2024) across three representative stations in Oglat Eddaira Lake. Specifically, the objectives are to: i). Document the diversity and community composition of microalgae and cyanobacteria; ii. Examine their relationships with environmental gradients, grouped as nutrient-related (NO_3^-, PO_4^{3-}, NH_4^+), physical (temperature, turbidity), and mineralization-related (conductivity, salinity); and iii). Apply ecological indices, including the Q Index and the EPI-D index, to assess water quality and evaluate bloom risks.

MATERIALS AND METHODS

Study area

The Oglat Eddaira wetland is a geomorphological depression located in the western part of the city of Ain Ben-Khelil, 30 km southwest of the capital of the wilaya of Naama [Benaradj et al., 2022]. It is a brackish water wetland with an area of 200 ha (Figure 1). The depth is between 3.60 m and 4 m, and it was classified in 2004 as a RAMSAR wetlands of international importance. Average annual rainfall ranges from 230 to 300 mm, with a relatively wet period from October to March-April and a dry period with very little rainfall. Its geographical location makes it an area of transit and rest during autumn and spring migration for many of the Trans-Saharan Palearctic birds [Innes et al., 2015; Åkesson et al., 2016, Youcefi et al., 2025]

Sampling and chemical analyses

Seasonal sampling was conducted at three stations (P1, P2, P3) from October 2023 to August 2024. Stations P1 and P2 are located near the shoreline and are shallow zones with various degrees of macrophyte colonization. Station P3 is located centrally and deeper (~1 m). The criteria for this choice are depth and the presence or absence of aquatic macrophytes. Two points are close to the banks of the lake and 100 m apart from each other, the other two are located more in the center of the lake with depths of around one meter each in winter. Measurements included temperature, pH, conductivity, salinity, and suspended solids (TSS), recorded *in situ* using a multiparameter probe (e.g., YSI Professional Plus). Nutrients (NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}) were analyzed in the laboratory following standard spectrophotometric methods as described by Rodier (2010), using a UV–Vis spectrophotometer (Hach DR 3900). Microalgal samples were collected with a 20 µm plankton net and preserved in 5% formaldehyde for taxonomic identification under an inverted light microscope.

Identification of cyanobacteria and data analysis

Taxonomic identification was performed based on morphological characteristics using standard floras and keys [Stainer et al., 1971; Bourrelly, 1985; Ferris et al., 1991; Castenholz, 2001; Komárek and Anagnostidis, 2005; Komárek et al., 2014; Guiry and Guiry, 2022]. Microalgal samples were collected using a 20 µm plankton net and preserved in 5% formaldehyde for taxonomic identification. Counting of cyanobacteria (cells/mL) was performed using an optical microscope (Olympus CX23, Olympus Corporation, Japan) equipped with a digital camera (Olympus SC50). Images were captured and processed with the CellSens Standard software (Olympus). Cell counts were

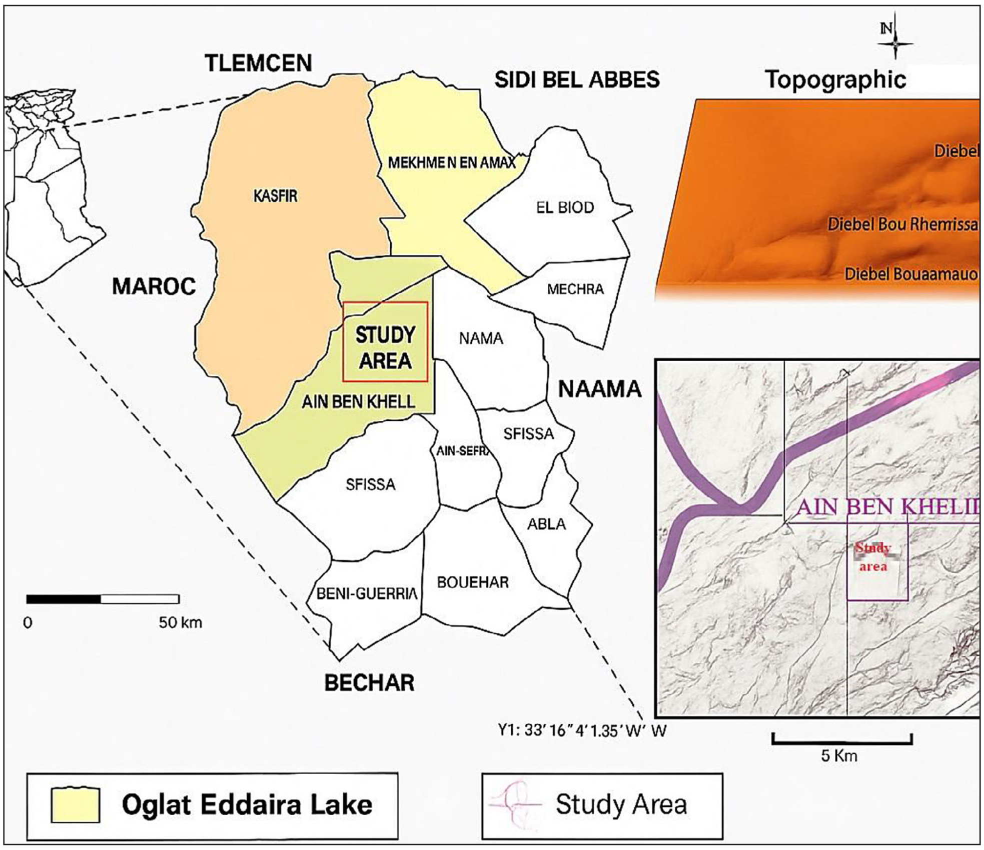

Figure 1. Localization of Oglat Eddaira lake

conducted with a Bürker counting chamber under 400× magnification, following standard phytoplankton counting procedures [Rodier, 2010]. Abundance was then expressed as the relative percentage of each taxon per season.

Index calculation and ecological classification

EPI-D index (diatom pollution index)

The EPI-D index evaluates water quality based on diatom species' abundance, sensitivity, and indicator value [Dell'Uomo, 1996].

$$EPI\text{-}D = \sum(Ai \times Si \times Vi) / \sum(Ai \times Vi) \quad (1)$$

where: Ai – relative abundance of species i,
Si – sensitivity value (1 = tolerant; 5 = sensitive), Vi – ecological indicator value (1–3).

To assess the ecological quality based on diatom assemblages, the EPI-D index was applied. This index integrates species-specific sensitivity and pollution indicator values to calculate a synthetic score for each station and season. The interpretative scale used for classification is presented in Table 1.

The Q index classifies ecological status based on phytoplankton functional traits and trophic preference [Padisák et al., 2009].

$$Q\ Index = \sum(Ai \times Si) \quad (2)$$

where: Ai – relative abundance of taxon i, Si – trophic weight (1 = tolerant, 5 = sensitive).

The Q index was used to evaluate the trophic status and biological integrity of the lake based on phytoplankton functional groups. This index combines the relative abundance of each taxon with its trophic weight (sensitivity to eutrophication). The corresponding interpretation scale is summarized in Table 2, following the framework established by [Vasselon et al., 2019].

Statistical analysis

All statistical analyses were performed using Python (version 3.11) with libraries including pandas, numpy, matplotlib, seaborn, and scikit-learn. Descriptive statistics were used to summarize physico-chemical parameters and microalgal abundances. Principal component analysis (PCA) was applied to identify the main environmental

Table 1. Interpretation scale for the EPI-D index (diatom pollution index) [Lenoir and Coste, 1996; Dell'Uomo, 1996]

Value range	Status	Color name
> 4.5	Excellent	Green
3.5–4.5	Good	Green-Yellow
2.5–3.5	Moderate	Yellow-Orange
1.5–2.5	Poor	Orange
< 1.5	Bad	Red

Note: Q index (phytoplankton functional group-based index)

Table 2. Interpretation scale for the Q index (phytoplankton functional group approach) [Vasselon et al., 2019]

Value range	Status	Color name
> 3.8–5.0	High	Blue
3.0–3.8	Good	Green
2.0–3.0	Moderate	Yellow
1.0–2.0	Poor	Orange
< 1.0	Very Poor	Red

Note: Functional group scores (S_i) examples: *Microcystis*, *Oscillatoria* (Cyanobacteria): 1; *Scenedesmus*, *Chlorella* (Chlorophyceae): 2; *Cyclotella*, *Aulacoseira* (Diatoms): 4–5; *Closterium*, *Staurastrum* (Desmids): 4.

gradients structuring the microalgal communities, while heatmaps were generated to visualize seasonal clustering of species and parameters. Pearson's correlation was used to explore relationships between environmental variables and microalgal taxa. Graphical outputs, including seasonal heatmaps and PCA biplots, were produced to facilitate interpretation of patterns across sampling sites and seasons.

RESULTS

The results showed that there were 32 species of microalgae divided into six classes (Figure 2): *Bacillariophyceae*, *Chlorphyceae*, *Cryptophyceae*, *Conjugatophyceae*, *Cyanophyceae* and *Euglenophyceae*.

The phytoplankton community was represented mainly by *Bacillariophyceae*, *Cyanophyceae*, and *Chlorophyceae*, with additional contributions from *Euglenophyceae* and *Zygnematophyceae*. *Bacillariophyceae* dominated during autumn and winter, particularly with genera such as *Navicula*, *Cyclotella*, and *Aulacoseira*. In contrast, *Cyanophyceae*, including *Microcystis*, *Oscillatoria*, and *Anabaena*, proliferated during spring and summer, coinciding with nutrient enrichment and higher temperatures. *Chlorophyceae*, represented by *Scenedesmus* and *Chlorella*, showed intermediate contributions across seasons (Figure 3).

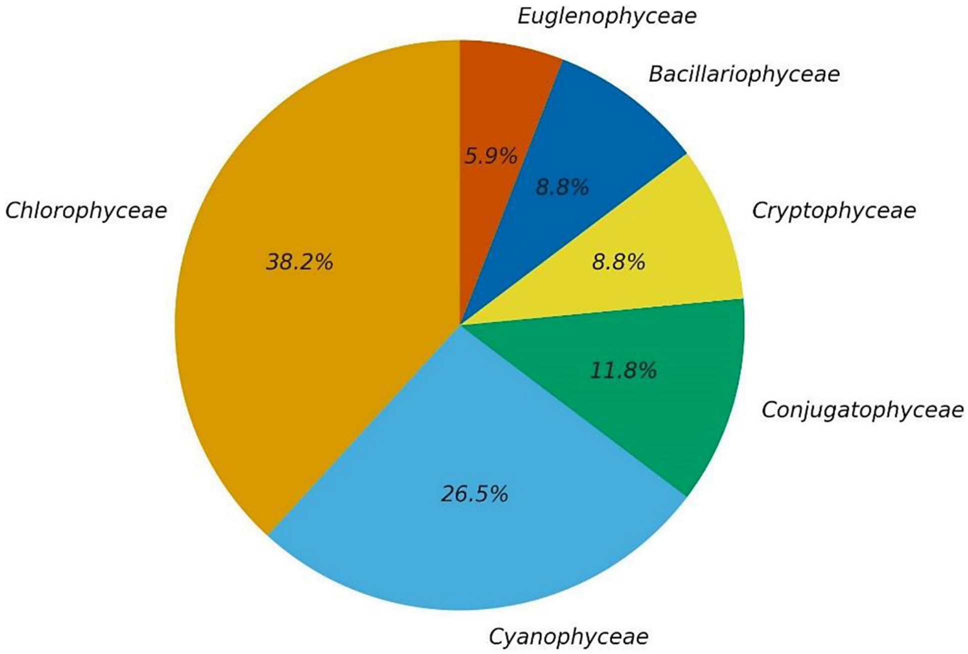

Figure 2. Average percentage distribution of microalgae classes in Lake Oglat Eddaira from October 2023 to August 2024

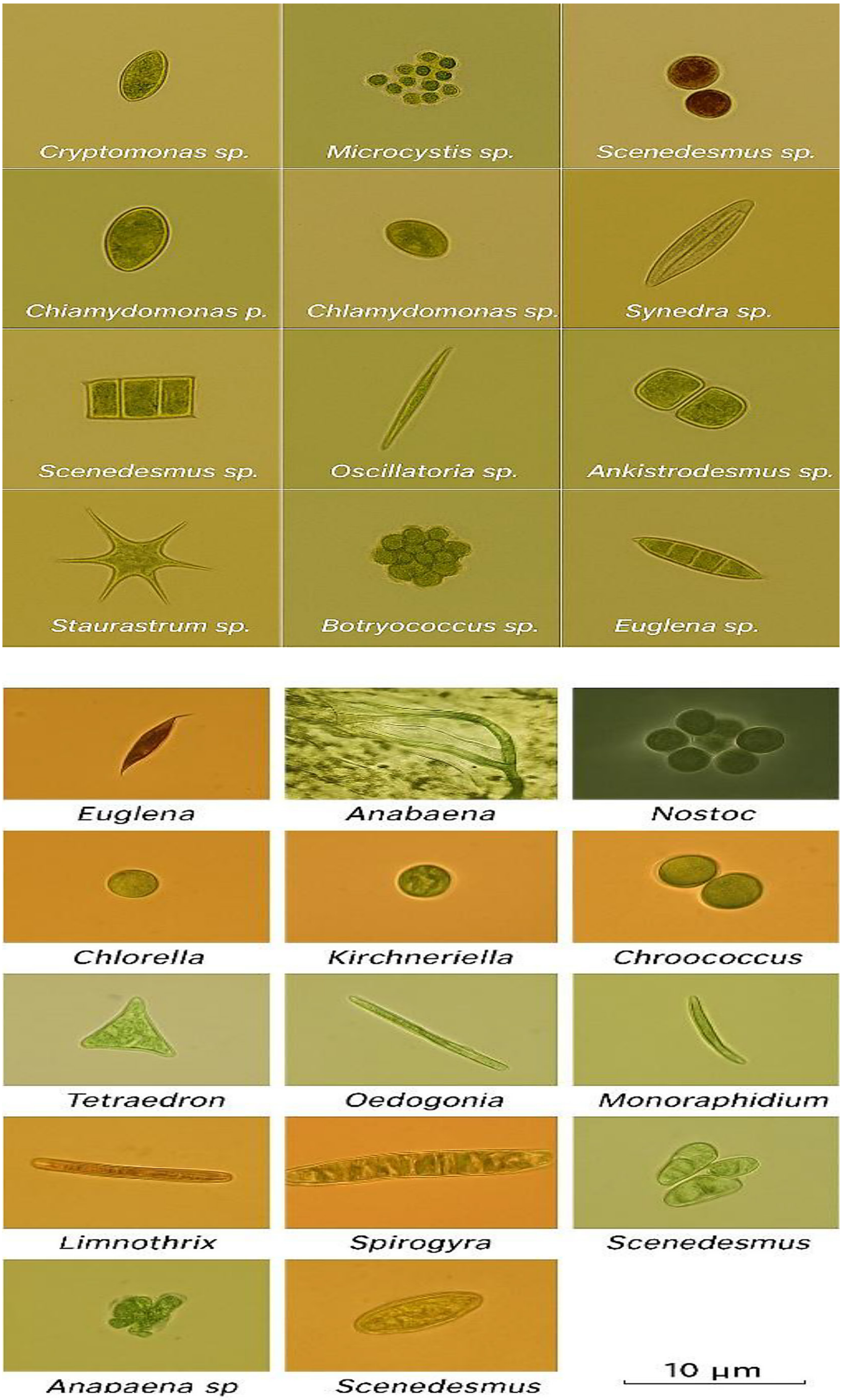

Figure 3. Various microalgae in Lake Oglat Eddaira from October 2023 to August 2024

Diversity index

The Shannon diversity index (H') ranged from moderate to high across all stations, reflecting a relatively diverse phytoplankton assemblage. The richest communities (S) were recorded at stations P1 and P2 during the spring and summer, reaching up to 26–30 taxa, suggesting favorable conditions for species coexistence, such as light availability and moderate nutrient levels.

However, evenness (Pielou's index, J') varied more widely, with lower values during summer, indicating a dominance by a few taxa – mainly cyanobacteria (*Microcystis aeruginosa*, *Oscillatoria lacustris*), which are known to form blooms under eutrophic conditions. In contrast, autumn and winter samples exhibited higher Pielou values, indicative of a more balanced community structure without overwhelming dominance by any single group.

This seasonal fluctuation in both richness and evenness suggests that the system undergoes strong ecological filtering, where only certain functional groups thrive under stressors such as elevated temperature and nutrient loads (Figure 4).

Functional groups and temporal dynamics

The first two principal components (PC1 × PC2; 69.8% and 30.2% of variance, respectively) explain the majority of variability in the dataset. PC1 shows strong positive correlations with temperature (r = 0.96), pH (r = 0.94), conductivity (r = 0.95), suspended solids (MES; r = 0.93), and phosphate (r = 0.95). These parameters are dominant in spring and summer and are associated with increased diversity and abundance of *Bacillariophyceae* (e.g., *Synedra*, *Navicula*, *Epithemia*) and *Chlorophyceae* (e.g., *Scenedesmus sp.*, *Chlorella vulgaris*, *Kirchneriella lunaris*). Nitrate (NO_3^-) and ammonium (NH_4^+) show negative correlations with PC1 and PC2, particularly during autumn and winter, suggesting opposite ecological behavior. However, nitrite (NO_2^-) shows a positive correlation with PC2 (r = 0.81), while ammonium (NH_4^+) shows a negative correlation with PC2 (r = 0.76), indicating a secondary gradient that reflects nutrient dynamics in cooler seasons.

During winter, *Cyanophyceae* such as *Anabaena sp.*, *Limnothrix* sp., and *Microcystis aeruginosa* dominate in nutrient-enriched conditions, with elevated nitrite and ammonium, potentially linked to agricultural runoff or decaying biomass. *Cryptophyceae* (*Cryptomonas ovata*) and *Euglenophyceae* (*Euglena viridis*), known for their tolerance to organic pollution and low-light conditions, are also more abundant when nitrite is high, reflecting eutrophication or anaerobic degradation.

Salinity shows a moderate positive correlation with conductivity and suspended solids, with favorable influence on *Chlamydomonas*, *Monoraphidium*, and *Oscillatoria* sp., particularly in spring and late summer. The dominance of *Oscillatoria* and *Spirulina* in slightly saline and turbid conditions may be explained by their adaptation to stress, high photosynthetic efficiency, and nitrogen fixation capabilities.

These results, supported by the correlation matrix (Figure 5), confirm the strong seasonal structuring of phytoplankton communities in relation to nutrient dynamics and physicochemical conditions.

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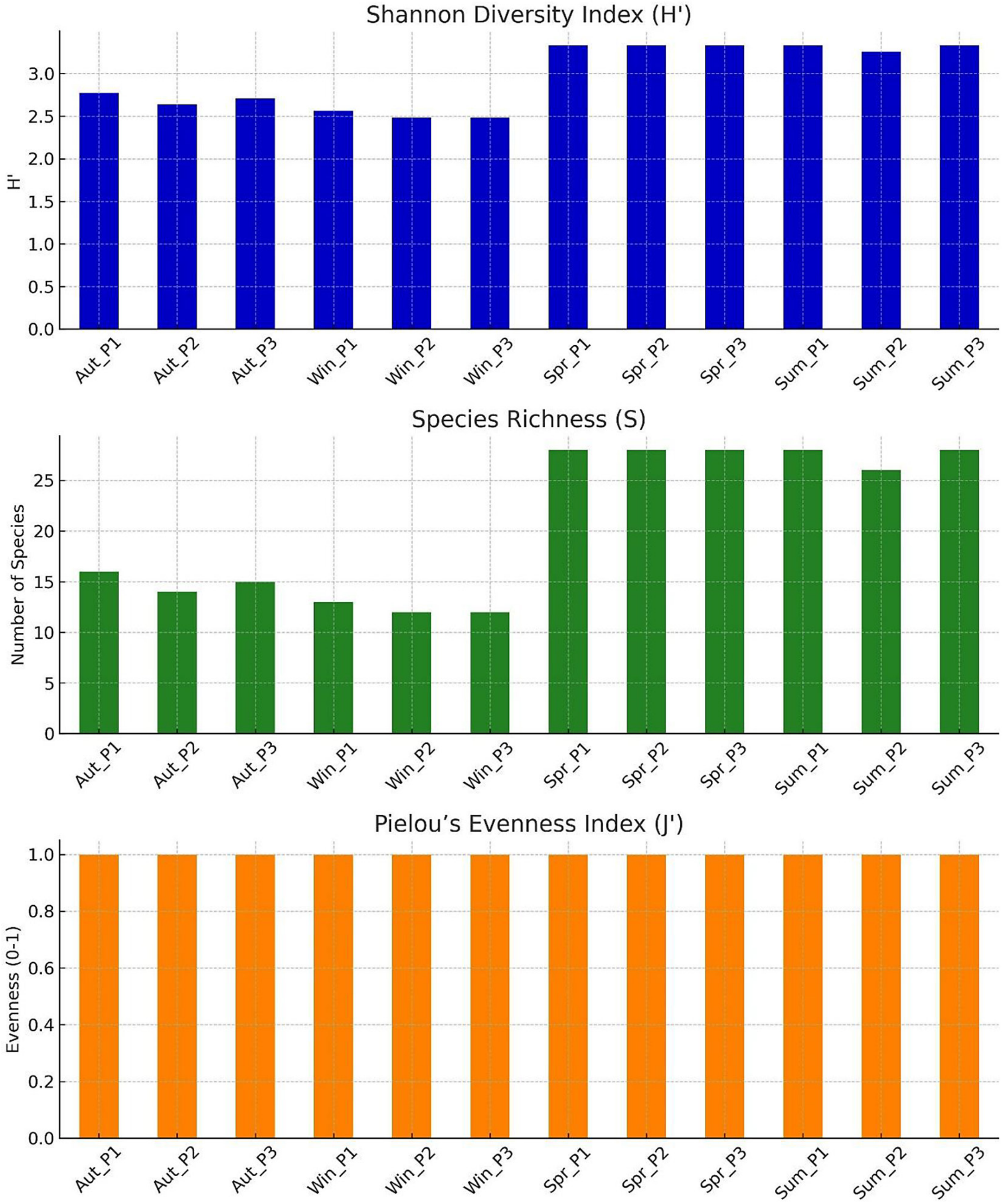

Figure 4. Diversity index – Shannon-Wiener diversity index (H′), species richness (S) and Pielou's evenness index (J′)

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Species names are presented in italics and ions with proper chemical notation (NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}). Warmer colors indicate positive correlations, while cooler colors indicate negative correlations. The matrix highlights seasonal interactions between dominant microalgal taxa (e.g., *Microcystis aeruginosa, Botryococcus braunii, Navicula* spp.) and physico-chemical drivers such as nutrients, salinity, conductivity, and temperature.

Ecological quality assessment

To evaluate the ecological status of Oglat Eddaira Lake, it is essential to integrate the Q Index and EPI-D index, as they provide complementary

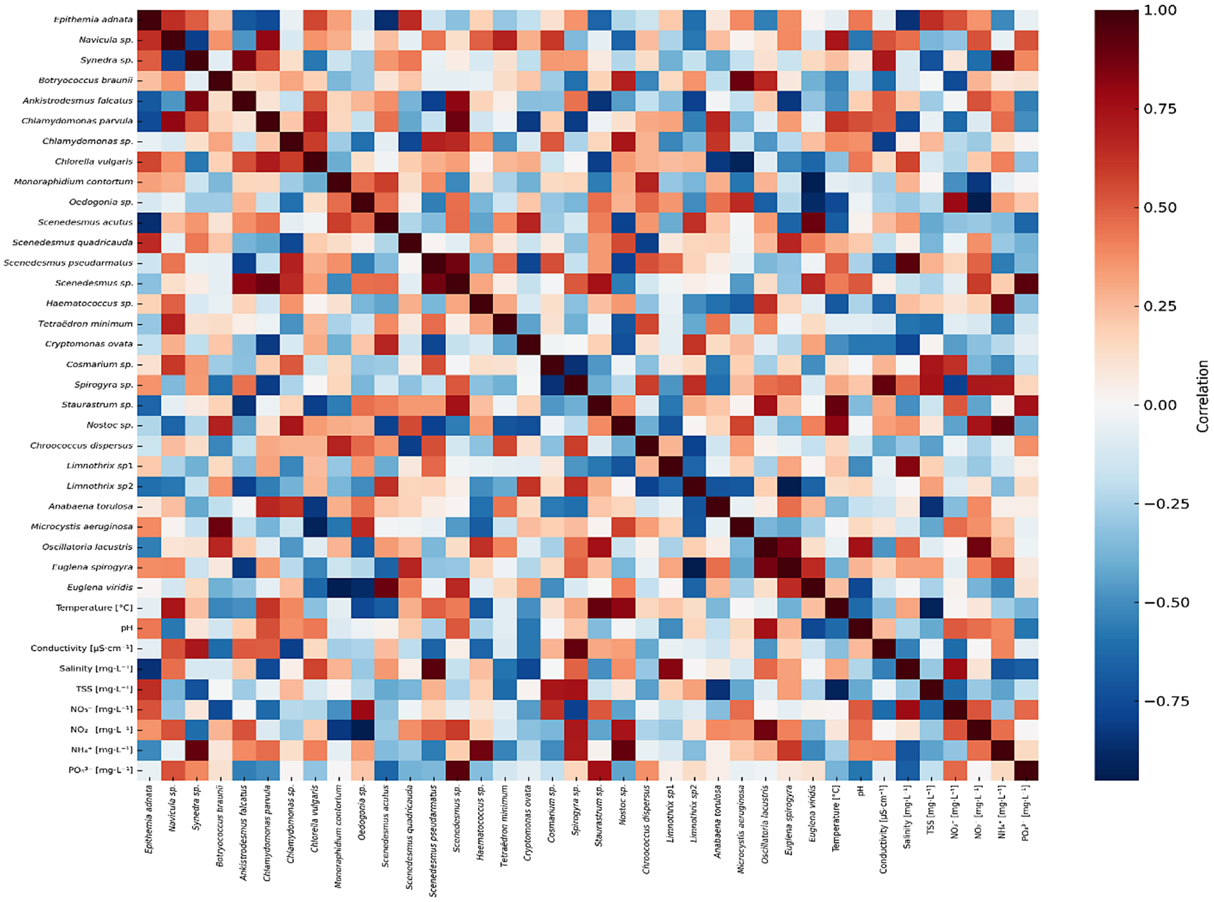

Figure 5. Correlation matrix of phytoplankton species and environmental parameters in Lake Oglat Eddaira, based on average values from October 2023 to August 2024

insights into the ecological condition. Each index evaluates different aspects of the ecosystem – phytoplankton composition for the Q index [e.g., Smith et al., 2023] and diatom communities for the EPI-D index [e.g., Jones and Brown, 2024] – and together, they offer a more comprehensive assessment of the lake's health.

The EPI-D index values indicated significant seasonal variability in the ecological quality of Oglat Eddaira Lake. The diatom communities showed marked changes between the warmer and colder months, highlighting the influence of temperature and nutrient availability.

At P1 (Shoreline Region), during spring and summer, the EPI-D index values were at their lowest (4.0 and 3.7, respectively), indicating a polluted to heavily polluted condition. These low values corresponded with the dominance of tolerant diatom species, including *Nitzschia linearis*, *Navicula* spp., and *Gomphonema parvulum*. These species are typically associated with eutrophic stress and poor ecological conditions. The low EPI-D values during these warmer months reflect the high nutrient availability, organic loading from decaying macrophytes, and reduced water circulation. In contrast, autumn and winter saw an improvement in water quality, with EPI-D values rising to 5.3 and 6.4, respectively. These values corresponded to mesotrophic conditions, indicating a partial recovery of ecological integrity. The shift was marked by the increased presence of sensitive centric diatoms, such as *Cyclotella* and *Aulacoseira*, which are indicative of improved water mixing and reduced eutrophic stress in colder months.

At P2 (Central Zone), the region showed consistently good ecological quality across all seasons, with EPI-D values ranging from 6.5 to 7.5. The dominance of mesotrophic diatom taxa, such as *Cyclotella meneghiniana* and *Aulacoseira*, suggested a stable, well-oxygenated environment throughout the year. In winter, the EPI-D value reached its highest (7.5), reflecting a very good ecological condition and a reduction in nutrient stress, as evidenced by the dominance of sensitive diatom species.

At P3 (Central Zone), the Q index results further confirmed the seasonal changes in the lake's ecological quality, particularly with respect to phytoplankton community composition and nutrient stress. At P1 and P3, both regions experienced eutrophic stress during spring and summer, with Q Index values as low as 0.5–1.0. These low values reflected the dominance of tolerant phytoplankton taxa, such as *Microcystis*, *Oscillatoria*, and Scenedesmus, typical of hypertrophic conditions characterized by high nutrient availability and oxygen depletion. The presence of these taxa suggests frequent harmful algal blooms and deteriorating water quality during warmer months. By autumn and winter, Q Index values improved to a moderate range (2.0–3.0) as the phytoplankton community shifted towards less eutrophic species, indicating a reduction in nutrient stress. This seasonal improvement in the Q Index was consistent with the observed recovery in the EPI-D values at P1.

At P2, the Q index remained consistently higher (3.0–3.5) throughout the year, indicating better resilience and ecological stability. The phytoplankton community at this point was dominated by more sensitive taxa, such as *Synedra* and *Aulacoseira*, which are indicative of a well-balanced, mesotrophic environment. These higher Q values reflect low eutrophic stress and suggest that this part of the lake is more stable and less impacted by nutrient loading compared to the shoreline areas.

DISCUSSION

Environmental parameters and phytoplankton composition

The physicochemical parameters measured across the three sampling points (temperature, pH, conductivity, salinity, suspended solids, NO_2^-, NO_3^-, NH_4^+, and PO_4^{3-}) provided the abiotic framework influencing phytoplankton distribution. Variability in these parameters is well known to regulate algal assemblages by modulating nutrient availability and light penetration [Reynolds, 2006; Wetzel, 2001].

The dominance of *Chlorophyceae* and *Cyanophyceae* is characteristic of eutrophic systems, where their physiological flexibility allows them to exploit fluctuating nitrogen and phosphorus conditions [Padisák et al., 2009; Smith, 2003]. The presence of toxin-producing cyanobacteria (*Microcystis, Anabaena*) indicates nutrient enrichment and potential ecological risks, consistent with observations from anthropogenically stressed freshwater ecosystems [Paerl and Otten, 2013; Chorus and Welker, 2021]. Conversely, the limited representation of diatoms suggests unfavorable silica supply or mixing conditions [Sommer et al., 2012].

Detection of *Euglenophyceae*, taxa typically associated with organic-rich, turbid waters, further points to environmental stress and reduced oxygenation [Leflaive and Ten-Hage, 2007]. Collectively, the assemblage reflects a community shaped by nutrient loading, organic enrichment, and variable physicochemical conditions, in line with studies from other Mediterranean and temperate wetlands [Naselli-Flores and Barone, 2011; Salmaso et al., 2015] (Table 3).

Diversity index

The Shannon diversity index (H′) indicated moderate to high diversity across sites. Richness (S) peaked at stations P1 and P2 during spring-summer (26–30 taxa), coinciding with favorable light and nutrient conditions. However, Pielou's evenness (J′) was lowest in summer due to dominance by cyanobacteria (*Microcystis, Oscillatoria*), reflecting a eutrophication-driven reduction in community balance. During autumn-winter, evenness improved, suggesting a more stable community structure. These patterns align with previous findings that seasonal enrichment promotes high richness but low evenness, as bloom-forming taxa monopolize resources [Reynolds, 2006; Paerl and Otten, 2013]. The proliferation of cyanobacteria under warm, nutrient-rich conditions underscores their ecological advantage [Huisman et al., 2018]. In contrast, higher evenness in cooler seasons highlights the return of competitive balance under reduced nutrient stress.

Spatio-temporal correlations

Canonical correspondence analysis (CCA) and Pearson correlations revealed strong associations between environmental variables and phytoplankton. The first axis (PC1; 69.8% variance) was positively correlated with temperature, pH, conductivity, suspended solids, and phosphate. These conditions supported *Bacillariophyceae* and *Chlorophyceae* during spring–summer, reflecting nutrient stimulation under eutrophic, mixed waters [Reynolds, 2006; Wetzel, 2001].

Table 3. Seasonal ecological assessment using Q index and EPI-D

Station	Season	Dominant taxa (functional group)	Trophic weight (s_i)	Q index score	Ecological status	Color code	Q index interpretation	EPI-D value	EPI-D status	EPI-D color	EPI-D interpretation
P1	Autumn	*Nitzschia, Scenedesmus* (D, J)	2–2	2.5	Moderate	Y	Eutrophication	2.5	Moderate	O	Moderate eutrophication,
	Winter	*Chroococcus, Navicula* (H1, D)	1–2	2.0	Moderate	O	Low diversity;	2.0	Poor	O	Low diversity
	Spring	*Scenedesmus, Oscillatoria* (J, S1)	2–1	1.5	Poor	O	Cyanob-bloom;	1.5	Poor	O	*Cyanobacteria* bloom,
P2	Autumn	*Microcystis, Anabaena* (M, S1)	1–2	0.5	Very Poor	R	Hypertrophic	4.0	Eutrophic	R	High eutrophication,
	Autumn	*Cyclotella, Navicula* (C, D)	4–2	3.0	Good	G	Balanced	5.3	Mesotrophic	O	Partial recovery
	Winter	*Aphanothece, Nitzschia* (H1, D)	1–2	2.0	Poor	O	Elevated organic	6.4	Mesotrophic	G	Slightly mesotrophic,
	Spring	*Microcystis, Oscillatoria* (M, S1)	1–1	1.0	Very Poor	R	Cyanobacteria	3.7	Eutrophic	R	*Cyanobacteria* dominance,
	Summer	*Oscillatoria, Scenedesmus* (S1, J)	1–2	1.0	Poor	R	Eutrophic peak,	3.7	Eutrophic	R	Eutrophic peak
P3	Autumn	*Aulacoseira, Synedra* (C)	4–5	2.5	Moderate	Y	Some sensitivity,	7.2	Oligotrophic	B	Low eutrophy
	Winter	*Cyclotella, Aulacoseira* (C)	4–4	3.5	High	G	High-quality taxa	7.5	Oligotrophic	B	Very good quality
	Spring	*Cyclotella, Synedra* (C, C2)	4–5	3.5	Good	G	Mesotrophic	6.8	Mesotrophic	G	Mesotrophic
	Summer	*Navicula, Aulacoseira* (D, C)	2–4	3.0	Good	G	Mesotrophic	6.5	Mesotrophic	G	Stable mesotrophic

Note: 🔵 Blue (seasonal ecological assessment using Q index and EPI-D>7.0): Very Good – Oligotrophic, 🟩 Green (4.5–7.0): Good to Slightly Polluted – Mesotrophic, 🟧 Orange (3.5–4.5): Moderate – Eutrophic, 🔴 Red (<3.5): Polluted to Heavily Polluted – Eutrophic to Hypertrophic.

By contrast, ammonium and nitrate were negatively correlated with PC1 and PC2, particularly in autumn–winter, when *Cyanophyceae* (*Anabaena, Microcystis, Limnothrix*) dominated, likely reflecting external inputs and organic matter decay [Paerl and Otten, 2013]. *Cryptophyceae* (*Cryptomonas ovata*) and *Euglenophyceae* (*Euglena viridis*) were abundant at sites with elevated nitrite, consistent with their tolerance of organic pollution [Codd et al., 2005]. Salinity correlated with conductivity and suspended solids, favoring taxa such as *Chlamydomonas, Monoraphidium,* and *Oscillatoria*, reflecting adaptation to turbid, slightly saline conditions [Paerl and Huisman, 2009; Whitton and Potts, 2012].

EPI-D index

The EPI-D index highlighted strong seasonal variability. At P2, spring-summer values (3.7–4.0) reflected polluted conditions with dominance of tolerant diatoms (*Nitzschia, Navicula*). Autumn–winter values (5.3–6.4) indicated partial recovery, coinciding with increases in sensitive taxa (*Cyclotella, Aulacoseira*). At P3 consistently maintained higher ecological quality (6.5–7.5), dominated by sensitive diatoms and reflecting stable, mesotrophic conditions [Lange-Bertalot, 2001].

Phytoplankton Q index

Q Index values confirmed spatial contrasts. P2 exhibited consistently low scores (mean ≈ 2.4), with seasonal declines to 1.0 or lower in spring-summer due to cyanobacterial blooms. Central station P3 recorded higher values (3.0–3.5), sustaining good ecological status with resilient diatom dominance (*Aulacoseira, Synedra, Navicula*) even during bloom periods [Reynolds, 2006; Paerl and Huisman, 2009].

Integrated assessment

Integration of Q Index and EPI-D demonstrated pronounced spatial heterogeneity. Both (P1, P2) were the most impacted, showing eutrophic to hypertrophic conditions in spring-summer, while central P3 maintained stable mesotrophic–oligotrophic status year-round. This dual-index approach underscores shoreline vulnerability to nutrient inputs and organic enrichment, while highlighting central zones as ecological refugia with higher resilience.

CONCLUSIONS

The integrated ecological assessment of Oglat Eddaira Lake, based on phytoplankton communities, EPI-D, and Q indices, revealed pronounced spatial and seasonal variations in ecological quality. Shoreline sampling points were identified as the most impacted, exhibiting eutrophic to hypertrophic conditions during spring and summer, dominated by tolerant taxa such as *Oscillatoria*, *Microcystis*, and *Euglena viridis*. These patterns are primarily linked to nutrient enrichment from macrophyte decay, organic matter accumulation, and limited water circulation, resulting in reduced ecological integrity.

Central, deeper sampling points consistently maintained mesotrophic to oligotrophic conditions, characterized by sensitive centric diatoms (*Cyclotella*, *Synedra*, *Aulacoseira*), reflecting higher ecological stability, better oxygenation, and lower anthropogenic disturbance. Intermediate points displayed mixed ecological characteristics, indicating partial resilience and seasonal recovery in response to reduced nutrient stress and enhanced vertical mixing during autumn and winter.

The combined use of the Q index and EPI-D index provided a robust framework for assessing spatial heterogeneity, seasonal dynamics, and ecological resilience. Q index effectively detected early eutrophication and bloom-forming taxa, whereas EPI-D captured longer-term diatom community shifts and overall ecological quality.

These findings underscore the vulnerability of shoreline zones to nutrient inputs and organic enrichment, highlighting the importance of targeted nutrient management, macrophyte control, and seasonal monitoring. Central zones demonstrated ecological resilience, supporting conservation strategies aimed at preserving water quality and ecosystem integrity in Ramsar-designated wetlands.

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