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Spatio-Temporal Dynamics and Functional Composition of Microalgae and Cyanobacteria in the Oglat Eddaira Lake (South Western Algeria)

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ABSTRACT

Microalgae have long been used as biological indicators of aquatic ecosystem health worldwide due to their ecological importance and sensitivity to environmental stress. The aim of this study was to identify the microalgae and determine their distribution in Oglat Eddaira (southwest Algeria). Seasonal sampling was conducted at three stations (P1, P2, and P3) from October 2023 to August 2024, covering autumn, winter, spring, and summer periods. The results showed that 32 species of microalgae were distributed across six major taxonomic classes: Bacillariophyceae, Chlorophyceae, Cryptophyceae, Conjugatophyceae, Cyanophyceae, and Euglenophyceae. The dominance of Chlorophyceae suggests mesotrophic to mildly eutrophic conditions, with adequate oxygen and light penetration. Cyanophyceae, in contrast, thrived under warm, alkaline, phosphate-rich conditions—especially during the summer. The presence of Bacillariophyceae and Euglenophyceae may indicate fluctuating organic matter inputs and variable turbidity

INTRODUCTION

A number of previous studies have utilized microalgal communities in monitoring surveys of environmental conditions **(Su Jin *et al.*, 2023)**. Microalgae are a group of unicellular and multicellular photosynthetic organisms that use light energy, carbon dioxide (CO_2), and ions dissolved in water to synthesize complex molecules and produce biomass.

Algeria hosts many little-known wetland complexes that serve as vital sanctuaries for both fauna and flora **(Boubekeur *et al.*, 2020)**. Wetlands are critical components within watersheds, linking groundwater, surface water, lakes, and streams. They are among the most productive ecosystems on the planet, supporting approximately 40% of the world's biodiversity. These ecosystems include inland lakes, swamps, river floodplains, coastal mangroves, coral reefs, tidal mudflats, and salt marshes. In fact, over a million threatened species of plants and animals depend on wetlands for their survival **(Ramsar Convention Secretariat, 2010)**.

Many development practices have targeted wetlands and freshwater habitats due to their ecological, economic, social, and cultural importance. Pollution of aquatic environments is often linked to the introduction of excess nutrients, which can lead to algal blooms. Biodiversity is altered by human activities, as anthropogenic transitions—driven by population growth, economic development, and land use changes for agriculture and urbanization—transform ecosystems.

This study aims to determine the spatio-temporal dynamics and functional composition of microalgae and cyanobacteria in Lake Oglet Eddaira, a Ramsar site since 2004, located in southwestern Algeria. Conducted over four seasons (2023/2024), the study is based on an inventory of all microalgae and cyanobacteria species in order to assess their diversity and to evaluate their ecological status and functional roles in the wetland.

MATERIALS AND METHODS

1. 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 Naama Province **(Benaradj *et al.*, 2022)**. It is a brackish water wetland covering an area of 200 ha (Fig. 1). Its depth ranges between 3.60 m and 4 m. In 2004, it was classified under the RAMSAR Convention as a wetland of international importance (Fig. 2). The average annual rainfall ranges from 230 to 300 mm, with a relatively wet period from October to March–April, followed by a dry season with minimal rainfall (6–8% of the annual total).

Its geographical position makes it a vital transit and resting zone for numerous Palearctic birds migrating across the Sahara during autumn and spring **(Innes *et al.*, 2015; Åkesson *et al.*, 2016; Youcefi *et al.*, 2025)**. The area is characterized by halophilic vegetation, including *Chamaerops humilis*, *Juncus,* and species of *Tamarix*.

2. Sampling and chemical analyses

Seasonal sampling was carried out at three stations (P1, P2, P3) from October 2023 to August 2024, covering autumn, winter, spring, and summer periods. The selection of these points was based on depth variation and the presence or absence of aquatic macrophytes. Stations P1 and P2 are situated near the shoreline of the lake, approximately 100 meters apart. These are shallow zones with different levels of macrophyte colonization. In contrast, Station P3 is located closer to the center of the lake, at a greater distance from the shore, with a measured depth of approximately 1 meter during winter.

The spatial distribution of sampling stations is shown in Fig. (3). At each station and for each season, physicochemical parameters were measured, including temperature (°C), pH, conductivity (µS/cm), salinity (mg/L), MES (suspended solids), and nutrient concentrations (NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}). These variables were used to characterize the limnological conditions influencing microalgal distribution.

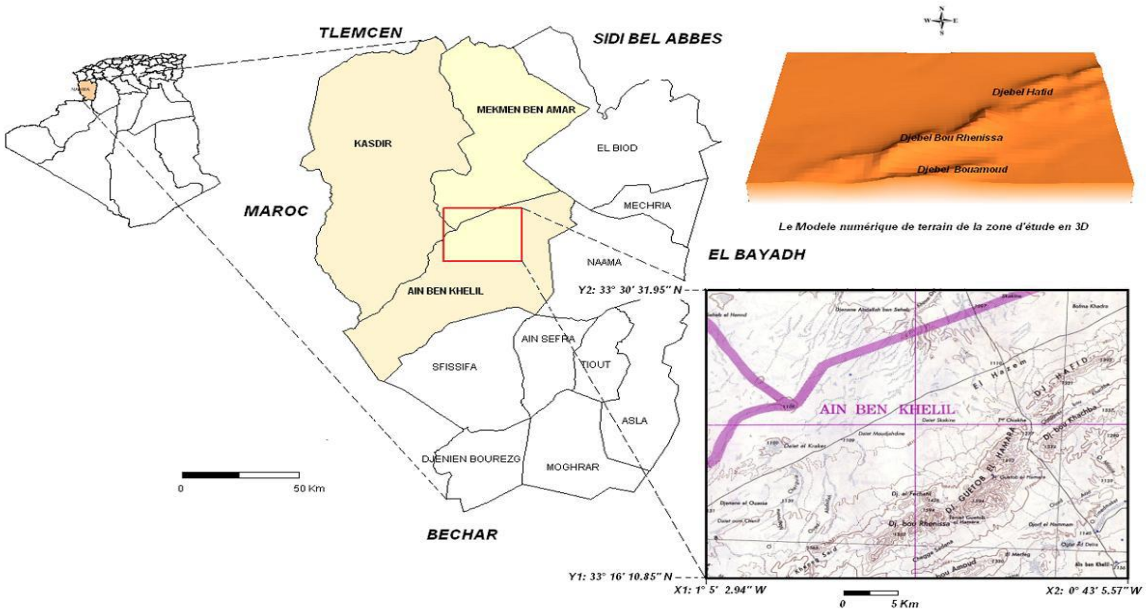


Fig. 1. Localization of Oglet Eddaira lake

Water temperature, pH, conductivity, and salinity were measured *in situ* at the time of sampling. In the laboratory, concentrations of nitrates (NO_3^-), nitrites (NO_2^-), ammonia (NH_4^+), orthophosphate (PO_4^{3-}), and suspended solids (SS) were also analyzed.

Water samples for the identification of microalgae and cyanobacteria were collected using a conical plankton net with a mesh size of 20 µm. The filtrates were immediately preserved in a final concentration of 5% formaldehyde (v/v). Additional water samples intended for this purpose were collected aseptically in sterile 250 mL bottles, following the standards described by **(Rodier *et al.*, 2009)**, and transported to the laboratory in a cooler to maintain a temperature of 4°C.

3. Identification of Cyanobacteria and Data Analysis

Species identification was based on microscopic observations of morpho-anatomical characteristics (e.g., appearance, size, and color), using multiple taxonomic keys from **(Stainer *et al.*, 1971; Bourrelly, 1985; Ferris *et al.*, 1991; Castenholz, 2001; Komárek & Anagnostidis, 2005; Komárek *et al.*, 2014; Komárek, 2016; Guiry &**

Guiry, 2022). Identification and enumeration of cyanobacteria (cells/mL) were conducted using an optical microscope equipped with a digital camera.

Statistical analyses were performed using RStudio software. Microsoft Office Excel was used for data entry and coding. Inter-seasonal comparisons were conducted using the non-parametric Kruskal-Wallis test, followed by Dunn’s post hoc test for pairwise comparisons. Seasonal variations in biotic and abiotic variables were illustrated using multiple boxplots.

The relationships between variables were explored through correlation analysis, specifically using Spearman's rank correlation coefficients and associated p-values. Lastly, a principal component analysis (PCA) was applied to standardized data to examine the temporal variation of biotic and abiotic variables in Lake Oglet Eddaira.

Fig. 2. Panoramic view of Oglet Eddaira lake **(Sennour, 2015)**

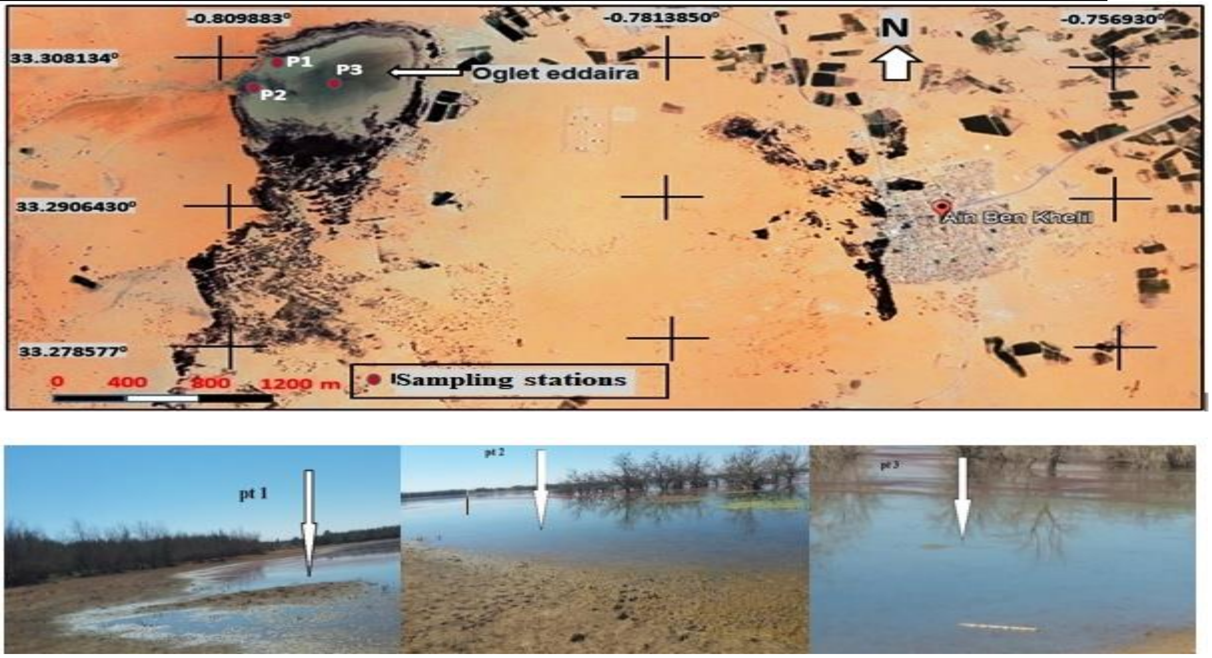


Fig. 3. Sampling stations (P1, P2 and P3) of Oglet Eddaira lake

RESULTS

1. Environmental factors

The environmental factors—temperature, pH, conductivity, salinity, suspended solids, NO_2^-, NO_3^-, NH_4^+, and PO_4^{3-}—of the water samples collected from the three stations (P1, P2, and P3) are presented in Table (1). The analysis of physicochemical parameters of Lake Oglat Eddaira, conducted between October 2023 and August 2024 at these distinct sampling points, revealed significant seasonal variations. These fluctuations were influenced by local abiotic factors such as temperature, water depth, proximity to the lakebanks, and potential organic load (Fig. 4).

Table 1. Physicochemical parameters of the sampled sites

Seasons / Species	Autumn			Winter			Spring			Summer		
	P1	**P2**	**P3**	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**
T° C	15	18	16	12	13	11	22.9	21.1	19	24.4	25	20.6
pH	7.8	8.5	8.2	7.1	7.5	7.8	8.5	8.6	8.6	9.1	9.3	8.9
Conductivity (µS. cm^{-1})	285	300	270	260	255	260	310	310	299	393	450	345
Salinity mg/l	3	4	2	1	1.5	0.5	3	3	2	4	5	4
SS mg/l	7	14.5	5.5	9.5	15	5.98	21	21	19	29.8	35.5	29
NO_3 mg/l	1.1	1.2	1	0.8	0.9	0.7	0.5	0.6	0.5	0.3	0.2	0.3
NO_2 mg/l	0.01	0.0	0.01	0.04	0.03	0.04	0.03	0.02	0.03	0.02	0.01	0.02
NH_4 mg/l	0.05	0.06	0.05	0.04	0.03	0.02	0.06	0.05	0.06	0.03	0.04	0.04
PO_4 mg/l	0.04	0.03	0.02	0.01	0.02	0.01	0.08	0.09	0.08	0.16	0.14	0.11

Water temperature followed a typical seasonal pattern, ranging from 12–18 °C in winter to 24–25 °C in summer. The highest temperature was recorded at P2 (25 °C), suggesting localized thermal exposure that could favor the development of certain microalgal groups, particularly Cyanophyceae.

pH values varied from 7.1 (P1, winter) to 9.3 (P2, summer), indicating a pronounced alkaline shift during summer, likely driven by intense photosynthetic activity and carbonate precipitation. Conductivity increased significantly in summer, peaking at 450 µS/cm at P2, reflecting the accumulation of dissolved salts, possibly due to elevated evaporation rates. Salinity, while generally low, also rose in summer, reaching up to 5 mg/L at P2—a trend likely exacerbated by the site's arid climate and high evapotranspiration.

Suspended solids (SS) showed a marked increase in summer, particularly at P2 (35.5 mg/L), which may be attributed to sediment resuspension by currents or bioturbation, or to external inputs from livestock and human activity.

Nitrate (NO_3^-) concentrations declined progressively from 1.1 mg/L (P1, autumn) to 0.2–0.3 mg/L in summer, likely due to uptake by phytoplankton or denitrification processes. Nitrite (NO_2^-) and ammonium (NH_4^+) levels remained relatively low throughout the study, with slightly elevated values in autumn and winter, possibly due to organic matter mineralization or incomplete nitrification.

Orthophosphate (PO_4^{3-}) concentrations increased markedly in summer, reaching 0.16 mg/L at P1. This rise, coupled with elevated temperatures and alkaline pH, created favorable conditions for the proliferation of cyanobacteria such as *Microcystis aeruginosa* and *Oscillatoria lacustris,* both of which were identified in the phytoplankton samples.

One-way ANOVA tests revealed statistically significant differences ($P < 0.05$) between stations (P1, P2, and P3) for the following parameters:

- pH, conductivity, suspended solids (SS), and PO_4^{3-} showed significant spatial variation, indicating heterogeneity in water quality across the sampling sites.
- In contrast, NO_2^- and NH_4^+ concentrations did not differ significantly between stations ($P > 0.05$), suggesting a more uniform distribution of these nitrogen forms throughout the lake.

This spatial heterogeneity is likely driven by a combination of topographical features (e.g., proximity to banks, depth), biological influences (e.g., presence of aquatic macrophytes), and anthropogenic pressures (e.g., surface runoff, livestock grazing).

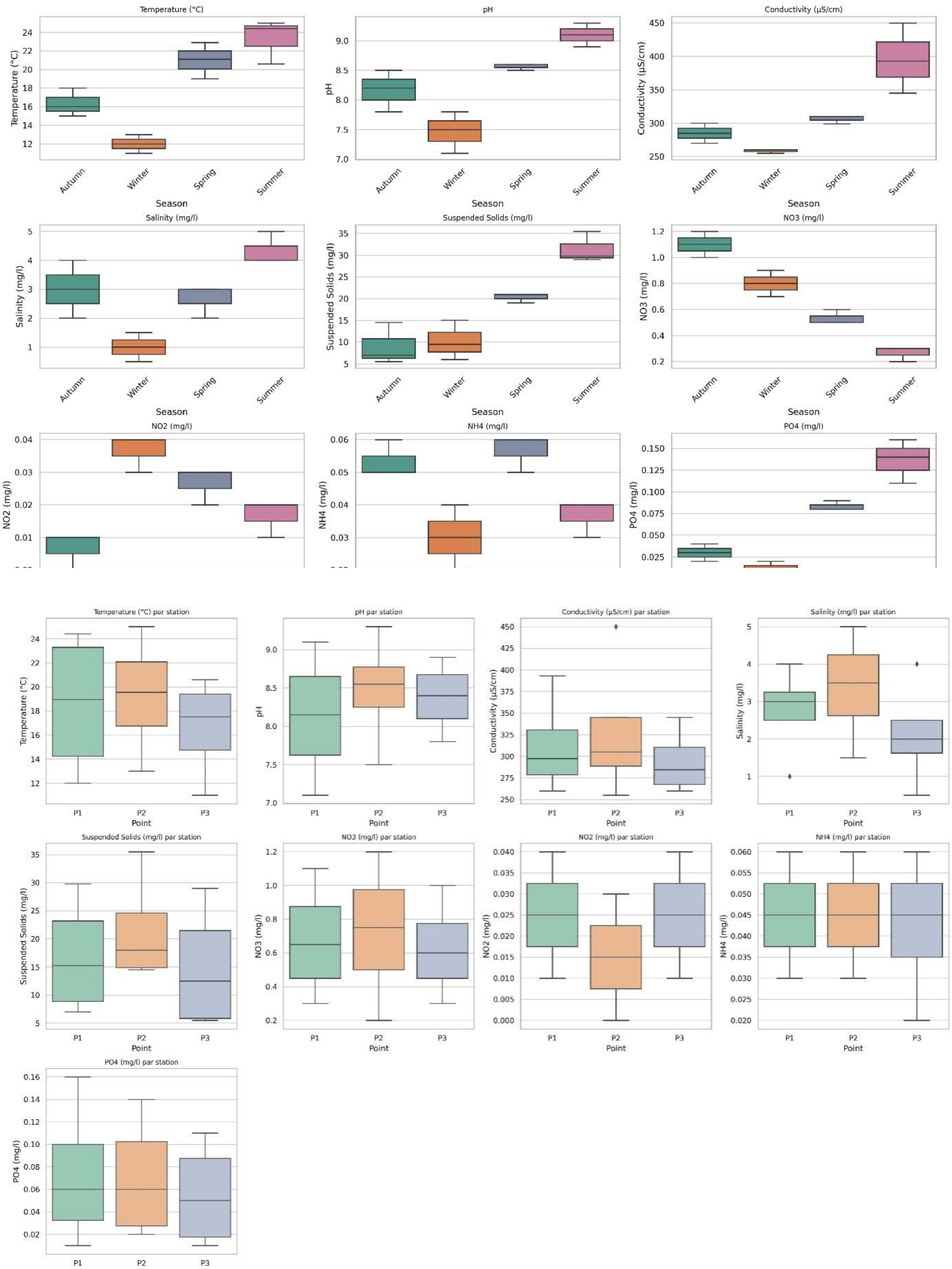


Fig. 4. Boxplots illustrating seasonal and spatial variability of physicochemical parameters in Oglat lake

2. Ecological perspective: Link to microalgal distribution

The 32 identified species of microalgae, distributed across six major taxonomic classes, exhibited community structures closely aligned with environmental gradients. The dominance of Chlorophyceae suggests mesotrophic to mildly eutrophic conditions, characterized by adequate oxygen availability and light penetration. In contrast, Cyanophyceae thrived under warm, alkaline, phosphate-rich conditions—particularly during summer at station P2. The presence of Bacillariophyceae and Euglenophyceae is indicative of fluctuating organic matter inputs and variable turbidity.

These 32 microalgal species were grouped into the following six classes:

- Bacillariophyceae (diatoms): *Epithemia adnata*, *Navicula* sp., and *Synedra* sp. (3 species)
- Chlorophyceae (green algae): the most diverse group, with 15 species including *Botryococcus braunii*, *Ankistrodesmus falcatus*, *Chlamydomonas parvula*, *Chlamydomonas* sp., *Chlorella vulgaris*, *Kirchneriella lunaris*, *Monoraphidium contortum*, *Oedogonium* sp., *Scenedesmus acutus*, *Scenedesmus quadricauda*, *Scenedesmus pseudarmatus*, *Scenedesmus* sp., *Hematococcus* sp., and *Tetraëdron minimum*
- Cryptophyceae: represented by a single species, *Cryptomonas ovata* Ehrenberg
- Conjugatophyceae: *Cosmarium* sp., *Spirogyra* sp., and *Staurastrum* sp. (3 species)
- Cyanophyceae (cyanobacteria): 7 species, including *Nostoc* sp., *Chroococcus dispersus*, *Limnothrix* sp. 1, *Limnothrix* sp. 2, *Anabaena torulosa*, *Microcystis aeruginosa*, and *Oscillatoria lacustris*
- Euglenophyceae: *Euglena spirogyra* and *Euglena viridis* (2 species)

3. Multivariate analysis of microalgal assemblages

To better understand the spatial and temporal dynamics of microalgal communities in Lake Oglat Eddaira, multivariate statistical analyses were performed on presence/absence data for the 32 identified taxa, sampled across four seasons and three stations (P1, P2, and P3). These analyses aimed to identify ecological patterns and relationships between community structure and environmental gradients.

A Principal Component Analysis (PCA) was conducted on a binary matrix representing the presence/absence of species across 12 sampling units (3 stations × 4 seasons). The first two principal components (PC1 and PC2) accounted for a substantial portion of the total variance in community composition (Fig. 5).

The PCA ordination revealed distinct seasonal and spatial patterns. Autumn and winter samples were generally clustered together, indicating a more homogeneous microalgal composition during colder periods. In contrast, summer samples—particularly from stations P2 and P3—formed a separate cluster, highlighting a significant shift in community structure. This seasonal differentiation is likely driven by elevated temperatures, increased conductivity, and phosphate enrichment during summer months.

The PCA highlighted a clear temporal gradient, with species turnover influenced by seasonal environmental variability. This pattern was especially pronounced for cyanobacterial taxa, which dominated during the summer, likely in response to elevated PO_4^{3-} concentrations and thermal conditions conducive to their proliferation.

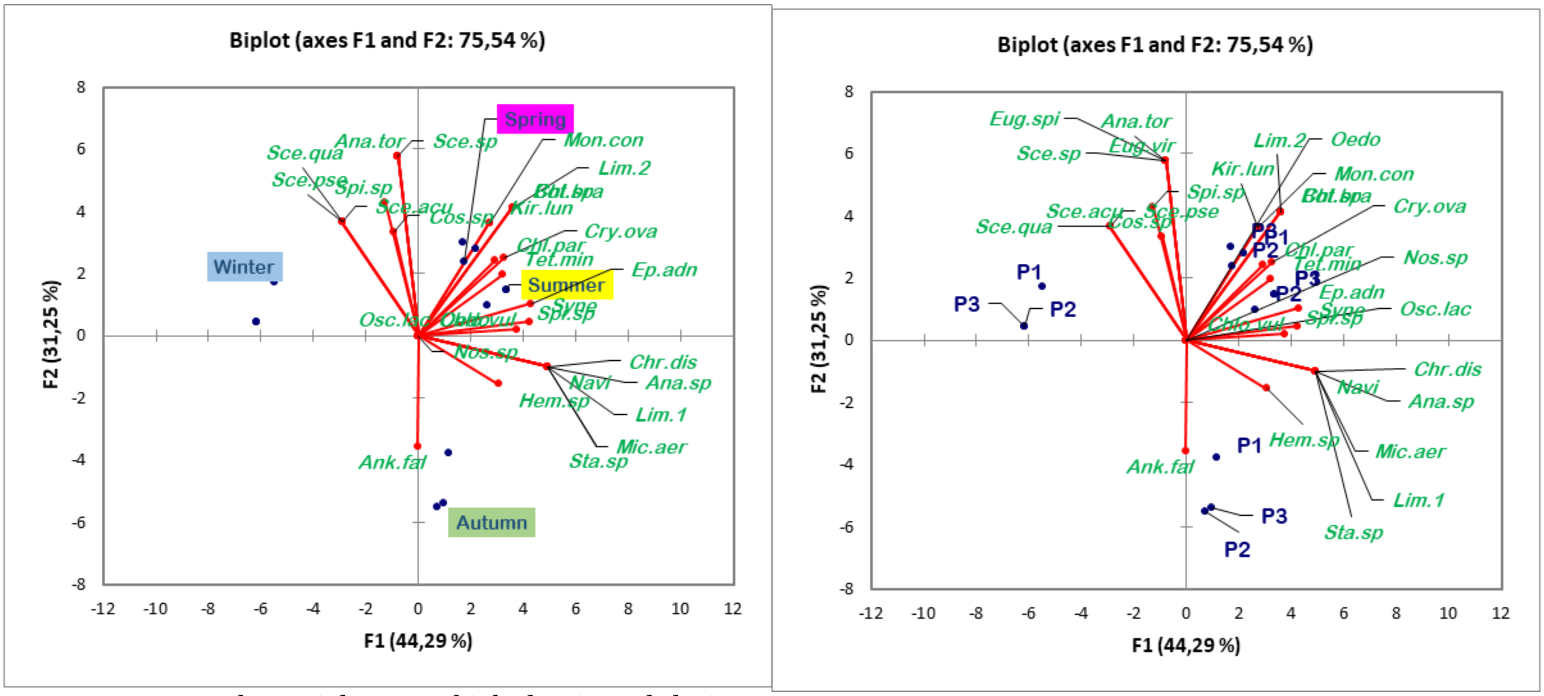


Fig. 5. Seasonal spatial results of multivariate analysis of microalgal assemblages

The eigenvalue decomposition revealed that the first two principal components (PCs) explained a total of 75.59% of the total variance in the dataset, with PC1 accounting for 46.33% and PC2 for 29.26%. This high cumulative variance suggests a strong structuring of the data along two major ecological gradients, likely corresponding to seasonal and taxonomic differences in species presence.

- PC1 (46.33%) appears to represent a gradient of dominance by Bacillariophyceae, Chlorophyceae, and Cyanophyceae, which show strong positive correlations with this axis.
- PC2 (29.26%) may reflect a contrast between cryptophyte/conjugate algal presence and taxa such as Var10–Var13, which exhibit higher loadings on this component.

  Variables most strongly correlated with PC1 include:
- Bacillariophyceae (r = 0.85),
- Chlorophyceae (r = 0.82),

- Cryptophyceae (r = 0.69),
- Multiple chlorophycean variables (Var1, Var2, Var18–Var25) (r > 0.85), indicating that these taxa were major drivers of sample differentiation across seasons.

Interestingly, cyanobacterial classes (Cyanophyceae, Euglenophyceae) had zero variance across the samples (standard deviation = 0), suggesting they were consistently present in all samples. This constant presence, though ecologically significant, limits their contribution to PCA variance and thus they appear neutral (0 loading) in the factorial plane.

PC2 was mainly structured by:

- Var13, Var21, Var26 (all loading ~0.95), suggesting a set of taxa peaking in a specific season (likely spring or summer),
- As well as Var10–12, negatively correlated with PC1 and positively with PC2, possibly indicating early-season or low-light adapted taxa.
- PC1 likely reflects seasonal turnover in dominant taxa, separating samples with high diversity and functional groups typical of spring/summer (chlorophytes, cryptophytes) from autumn/winter samples with a simplified community dominated by stable cyanobacterial forms.
- PC2 may capture secondary variation, possibly linked to station-specific differences or microhabitat conditions (e.g., macrophyte presence, light penetration).

This multivariate ordination confirms that:

- Seasonal changes are the main structuring force in the microalgal composition in Lake Oglat Eddaira.
- Spring and summer samples were richer and more heterogeneous, contributing most strongly to the diversity captured in the PCA space.
- Autumn and winter samples clustered more tightly, reflecting reduced richness and variability, possibly due to limiting abiotic conditions (temperature, light).

These findings align with the observed increase in chlorophyte and conjugate algae richness during warm months, while cyanobacterial dominance remained stable throughout, potentially indicating resistance to seasonal stressors.

To explore the spatial and seasonal dynamics of phytoplankton in Lake Oglat Eddaira, a Principal Component Analysis (PCA) was performed using presence/absence data for 32 microalgal taxa sampled across four seasons and three stations (P1, P2 and P3). This multivariate approach aimed to identify the main ecological gradients shaping microalgal community structure and reveal which taxonomic groups contributed most to observed patterns. The PCA results showed that the first two principal components together explained 75.59% of the total variance, with PC1 accounting for 46.33% and PC2 for 29.26%. The first axis (PC1) was mainly structured by Bacillariophyceae, Chlorophyceae, and Cyanophyceae (correlations r > 0.80), reflecting a strong seasonal gradient, while PC2 appeared to capture contrasts likely linked to local habitat conditions such as macrophyte density and nutrient availability among stations.

In terms of temporal patterns, autumn and winter samples clustered closely together, indicating a more homogeneous and diatom-dominated community typical of colder, less productive conditions. In contrast, spring and summer samples, especially from stations P2 and P3, were widely spread in the PCA space, highlighting higher richness and community heterogeneity during warmer months. This seasonal turnover was largely driven by the presence of chlorophytes, cryptophytes, and conjugate algae that thrive under higher temperatures, increased conductivity, and phosphate enrichment. Interestingly, cyanobacterial taxa such as *Microcystis* remained consistently present across all seasons, showing ecological resilience. However, due to their stable occurrence and low variance, they contributed less to the differentiation captured by the PCA axes, despite being ecologically significant indicators of eutrophication. Overall, the PCA confirms that seasonality is the dominant force shaping microalgal assemblages in this shallow Mediterranean wetland. Spring and summer bring richer, more dynamic communities, while colder seasons favor simplified assemblages dominated by diatoms and persistent cyanobacteria. These insights illustrate how nutrient availability, temperature, and habitat structure interact to influence community succession, and underscore the value of multivariate analyses in assessing ecological health and trophic dynamics in wetland ecosystems.

4. Correlation analysis and cluster patterns

Spearman correlation matrices and hierarchical clustering (CAH) further corroborated the PCA results. Sampling points belonging to the same season or adjacent seasons (e.g., spring-summer) clustered together, reflecting similarity in species composition. The correlation heatmap also demonstrated strong internal correlations between spring and summer samples, particularly at P2, supporting the hypothesis of a summer-driven ecological shift.

The dendrogram of stations showed that P1 and P3 during autumn and winter grouped separately from the summer cluster, reinforcing the idea that seasonal transitions significantly shape the biological structure of the lake.

5. Spatio-temporal dynamics and functional composition of microalgae

The Principal Component Analysis (PCA) based on the seasonal and spatial distribution of 32 microalgal species highlights significant ecological differentiation across stations and seasons**.** The first two axes (F1: 46.33%; F2: 29.26%) together explain 75.59% of the total variance, revealing strong structuring of the microalgal assemblages. The F1 axis is primarily shaped by the dominance of Cyanophyceae (blue-green algae), particularly *Oscillatoria lacustris*, *Spirulina* sp., *Microcystis aeruginosa*, *Anabaena* sp., *Limnothrix* sp., and *Chroococcus dispersus*. These taxa are especially abundant at stations P2 and P3 during spring and summer, reflecting conditions of elevated nutrient enrichment, high temperatures, and eutrophic tendencies. The simultaneous increase of Bacillariophyceae (*Navicula* sp., *Synedra* sp., *Epithemia adnata*) along F1 in the same periods suggests co-bloom dynamics, likely triggered by internal nutrient release and optimal photoperiod.

The F2 axis captures seasonal transitions, separating species typical of cooler or intermediate conditions. The Chlorophyceae, especially *Scenedesmus acutus*, *S. quadricauda*, *S. pseudarmatus*, *Scenedesmus* sp., *Tetraëdron minimum*, and *Hematococcus* sp., contributed strongly to F2. These taxa peaked during autumn and early winter, often at station P1, which shows lower anthropogenic pressure and deeper water. In parallel, species like *Chlamydomonas parvula*, *Botryococcus braunii*, and *Kirchneriella lunaris* show moderate contributions to both axes, suggesting they act as generalists across a wide range of environmental conditions. *Cryptomonas ovata* (Cryptophyceae) and *Euglena viridis* (Euglenophyceae) also emerged significantly on F2, particularly in late summer and autumn, indicating organic enrichment or mixotrophic activity during periods of reduced light or elevated organic matter.

A finer ecological reading reveals patterns at the functional and class levels**.** Bacillariophyceae are prominent in spring, suggesting stable water conditions and silica availability. Chlorophyceae dominate transitional seasons (autumn), indicating mesotrophic conditions and moderate turbulence. Cyanophyceae dominate in warmer periods and nutrient-rich zones (especially P2 and P3), pointing to a risk of harmful algal blooms (HABs). Conjugatophyceae (*Cosmarium* sp., *Spirogyra* sp., *Staurastrum* sp.) are associated with early spring or winter, favoring cooler, less disturbed waters. Finally, the presence of *Euglena spirogyra* and *Euglena viridis* during warm seasons marks episodes of organic loading or oxygen depletion. These results emphasize the dynamic interplay between hydro-ecological gradients and algal succession, offering a basis for biomonitoring strategies and wetland conservation in arid and semi-arid regions.

6. Spatial patterns of phytoplankton assemblages based on PCA by station

Principal Component Analysis (PCA) was applied to assess the spatial variability of phytoplankton assemblages across different sampling points (P1, P2, P3) within Oglet Eddaira wetland. The first two axes (F1 and F2) together explain 75.59% of the total variance, with F1 accounting for 46.33% and F2 for 29.26%**,** indicating that most of the community structure variation can be effectively visualized in the biplot.

Stations P1 (various seasonal replicates) show varying contributions across axes. One replicate of P1 contributes notably to F1 (17.9%)**,** indicating a strong representation of taxa aligned with axis F1, including benthic diatoms and filamentous cyanobacteria such as *Navicula sp.*, *Chroococcus dispersus*, and *Oscillatoria lacustris*. Another replicate of P1 contributes significantly to F2 (12.09%), suggesting temporal or microhabitat heterogeneity within the same station.

Station P2 consistently shows strong contributions to both F1 and F2, particularly. F1 (up to 23.53%) in certain replicates, suggesting a dominance of indicator taxa associated with nutrient-rich or light-variable environments. F2 (up to 29.51%)**,** linked to a group of species such as *Scenedesmus* sp., *Anabaena torulosa*, and *Euglena viridis*, which often thrive in warmer, stratified, or more eutrophic waters.

Station P3 has similar contributions to P2 for both axes (e.g., F1: 23.53%, F2: 28.78%), reinforcing the similarity of phytoplankton composition between these two sampling locations during certain seasons.

The species with the highest contribution to F1 include: *Navicula* sp., *Spirulina sp.*, *Oscillatoria lacustris*, *Limnothrix* spp., and *Chroococcus dispersus* (each contributing >6.5%), all of which are commonly associated with elevated nutrient levels, light adaptability, and the presence of benthic substrates. Axis F2 is dominated by contributions from: *Scenedesmus* sp., *Euglena viridis*, *Anabaena torulosa*, and *Cosmarium sp.*, each contributing over 6%**,** suggesting a seasonal shift toward taxa that are responsive to stratification, temperature increases, and higher organic content**.** The taxa contributing most to F3, although not visualized in the current biplot, include: *Cosmarium* sp. (15.77%), *Ankistrodesmus falcatus* (14.45%), and *Scenedesmus acutus/quadricauda/pseudarmatus* (each ~9–9.1%), pointing to a third latent environmental gradient, potentially linked to dissolved oxygen or micro-nutrient fluxes. Several taxa such as *Chlorella vulgaris*, *Oedogonium* sp., and *Nostoc* sp. exhibit zero contribution, implying either very low abundance or negligible variability across stations and seasons, and therefore a low discriminatory power in the PCA model.

7. Spatio-temporal patterns of phytoplankton taxas-parameters based on PCA

The Principal Component Analysis (PCA) performed on the physicochemical parameters of Oglet Eddaira Lake revealed that the first two principal components **(**F1 and F2) together account for 88.07% of the total variance, with F1 alone contributing 67.30% and F2 contributing 20.77% (Fig. 6)**.** This high cumulative percentage indicates that these two components sufficiently explain the major structure of the dataset. The F1 axis is strongly and positively correlated with several variables, including temperature (r = 0.96)**,** pH (r = 0.94)**,** conductivity (r = 0.95)**,** salinity (r = 0.89), suspended solids (MES) (r = 0.94**)**, and orthophosphates (PO_4^{3-}) (r = 0.96). This suggests that F1 represents a mineralization and productivity gradient, likely influenced by evapoconcentration during warmer seasons and potentially linked to nutrient-rich inputs**.** Conversely, nitrate **(**NO_3^-) shows a strong negative correlation with F1 (r = –0.75)**,** suggesting that when mineral and thermal conditions are high, nitrate levels tend to drop, likely due to biological uptake or denitrification. The F2 axis, although less influential than F1, is particularly associated with nitrogenous compounds. It shows a strong positive correlation with nitrites (NO_2^-) (r = 0.81) and a strong negative correlation with ammonium (NH_4^+) (r = –0.76)**.** This pattern may reflect nitrification processes, where ammonium is oxidized into nitrites under favorable oxygenation and microbial activity conditions. Overall, the PCA indicates that seasonal and spatial fluctuations in temperature, salinity, and nutrients (especially phosphates and nitrogen compounds) play a critical role in shaping the water quality dynamics of Oglet Eddaira Lake. The first factorial axis (F1) distinguishes periods or locations of high mineral content and productivity, while the second axis (F2) captures the dynamic equilibrium of nitrogenous species influenced by biogeochemical processes such as nitrification and uptake by microalgae.

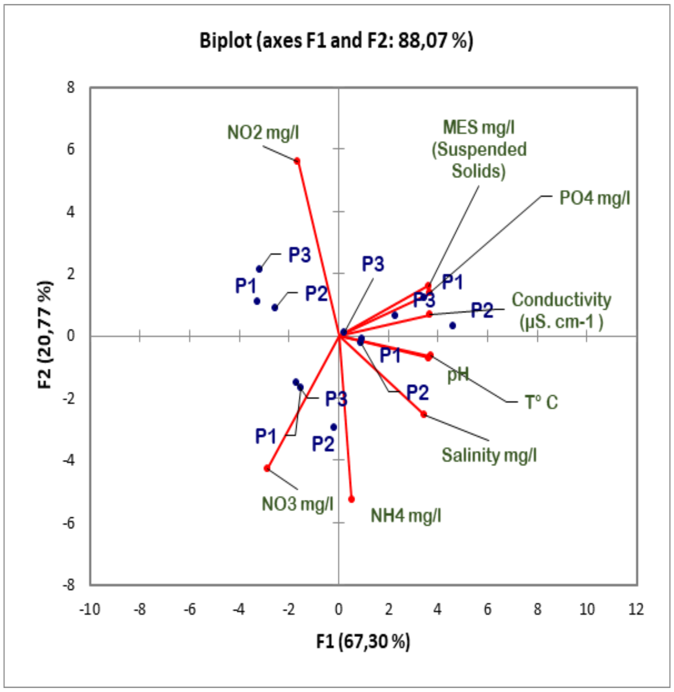
The Hierarchical Cluster Analysis (HCA), applied to binary presence/absence data of the 32 identified phytoplankton species, clearly revealed structured groupings of samples based on floristic affinity. Three major clusters emerged from the dendrogram, reflecting distinct ecological profiles (Fig. 7).

The autumn group (P1 and P2 - autumn) is characterized by high species richness and a dominance of Chlorophyceae taxa (e.g., *Chlorella vulgaris*, *Ankistrodesmus falcatus*), associated with moderate temperatures (15–18 °C), slightly alkaline pH (~8.0–8.5), and conductivity between 285–300 µS/cm. These environmental conditions promote phytoplankton growth, supported by moderate nitrate and ammonium levels ($NO_3^- \approx$ 1.1–1.2 mg/l; $NH_4^+ \approx$ 0.05–0.06 mg/l).

The winter group (P1 to P3 - winter**)** displayed reduced diversity, dominated by a few euglenoid species (e.g., *Euglena viridis*), reflecting harsher environmental conditions: lower temperatures (12–13 °C), reduced salinity (1.0–1.5 mg/l), and higher suspended solids (MES up to 15 mg/l), which limit light penetration and hence primary production.

The P3 - autumn station, forming a distinct cluster, presented a mixed profile with freshwater Bacillariophyceae and Chlorophyceae species. This could indicate an ecotone or ecological transition zon**e**, influenced by lower salinity (2.0 mg/l) and reduced turbidity (MES = 5.5 mg/l), favoring opportunistic taxa.

These patterns confirm that phytoplankton community structure is strongly modulated by seasonal variations and abiotic parameters, especially temperature, salinity, and nutrient availability. HCA thus proves to be a powerful ecological tool for environmental monitoring in aquatic systems.



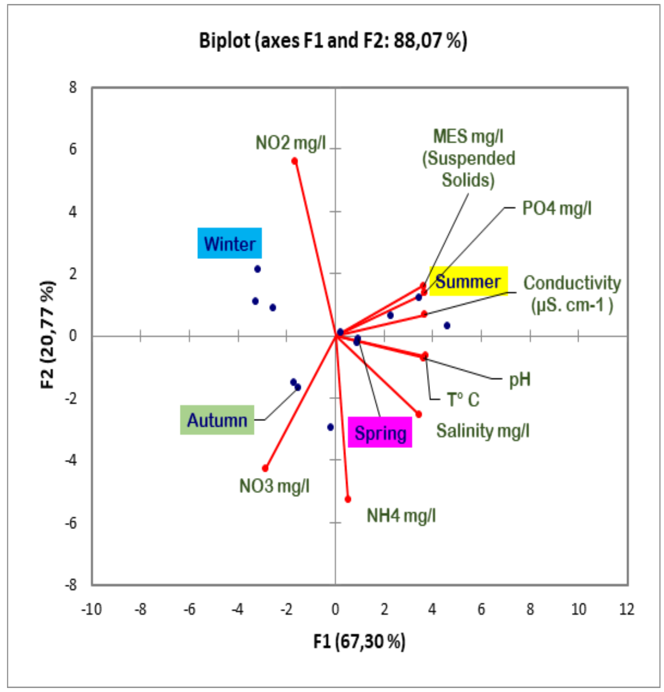


Fig. 6. Spatio-Seasonal variation of Phytoplancton taxa and parameters at Oglat Edaria

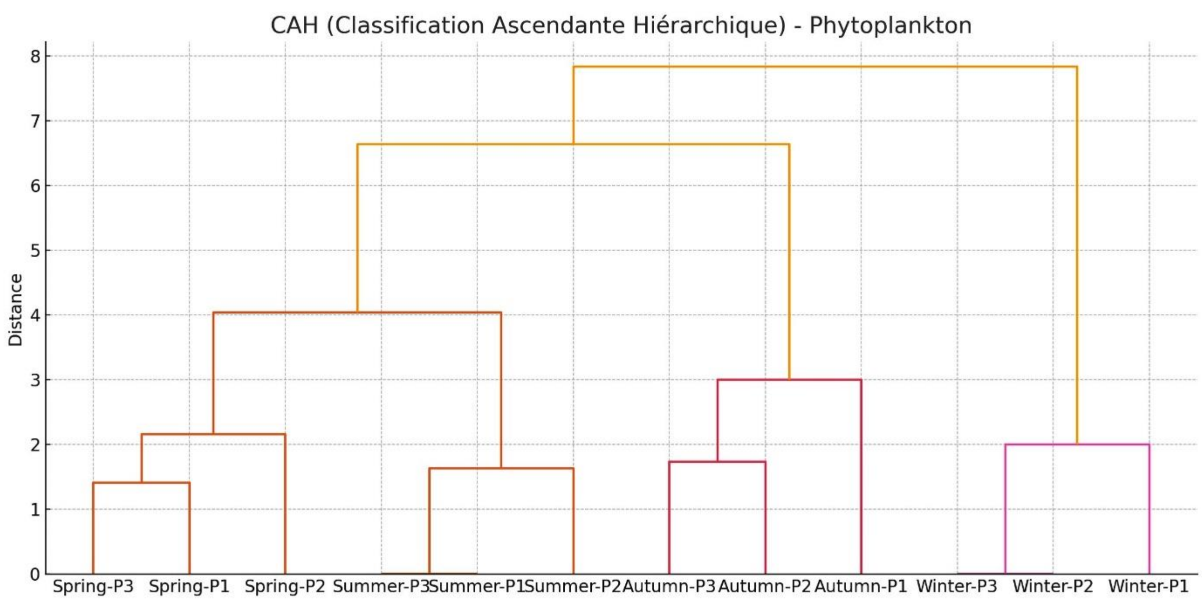


Fig. 7. Hierarchical cluster analysis (HCA)

DISCUSSION

PCA and clustering analyses confirmed a strong temporal gradient and identified summer as a distinct ecological phase. Ecological indices and correlations revealed that biotic structure is tightly linked to physicochemical variability, especially nutrients (PO_4^{3-}) and thermal conditions.

These results highlight the need for seasonally adapted management strategies, especially to prevent potential cyanobacterial bloom episodes that may impair water quality and ecosystem health in Oglat Eddaira. These findings suggest spatial redundancy between P2 and P3, potentially due to comparable hydrological or nutrient conditions, while P1 exhibits more compositional variability, possibly reflecting differences in water depth, sediment interaction, or anthropogenic influence.

The PCA ordination confirms that stations P2 and P3 share a common phytoplankton structure, while P1 displays more ecological fluctuation. This spatial pattern, aligned with species contributions, suggests that environmental gradients such as nutrient input, water renewal, and seasonal thermal stratification are major drivers of phytoplankton community composition in the wetland. The clear separation of taxa along F1 and F2 also supports the use of certain algal groups (e.g., *Scenedesmus*, *Oscillatoria*) as bioindicators of eutrophication or disturbance in this Ramsar-listed ecosystem.

The distribution of microalgae in Oglet Eddaira Lake exhibits clear spatio-temporal variations, strongly influenced by the physicochemical conditions of the water. The PCA analysis revealed that the first two components (F1 and F2) explain 88.07% of the total variance, providing a robust basis for interpreting ecological patterns.

During the hot season (summer), higher values of temperature, conductivity, salinity, and PO_4^{3-} (all strongly positively correlated with F1) were recorded. These conditions favored the dominance of Chlorophyceae, particularly *Scenedesmus* spp., *Chlorella vulgaris*, and *Ankistrodesmus falcatus*, which are known for their tolerance to eutrophic, warm, and mineral-rich environments. Additionally, Cyanophyceae such as *Microcystis aeruginosa* and *Oscillatoria lacustris* were abundant, reflecting eutrophic and thermophilic conditions often associated with elevated phosphate levels.

In contrast, the cold season (winter), characterized by lower temperatures, reduced salinity, and increased NO_3^- levels, saw a rise in Bacillariophyceae (Diatoms), especially *Navicula* sp., *Synedra* sp., and *Epithemia adnata*. These species are adapted to oligotrophic or mesotrophic conditions and are more prevalent when inorganic nitrogen forms such as nitrate dominate the nutrient pool.

Spatially, the stations with higher mineralization (e.g., conductivity, salinity, and PO_4^{3-}) as shown by strong F1 loadings—harbored dense populations of Chlorophyceae and Cyanophyceae, indicative of eutrophic zones. In particular: Station P3 and P2, likely influenced by evaporative concentration or anthropogenic input, showed abundant Chlorophyceae such as Scenedesmus quadricauda, Monoraphidium contortum, and

Chlamydomonas spp. Station P1 and P3, with moderate nutrient levels and lower mineral content, supported a higher proportion of Diatoms and Conjugatophyceae like Spirogyra and Staurastrum, indicating better oxygenation and moderate nutrient availability.

The second factorial axis (F2) highlighted the nitrogen balance, with NO_2^- positively correlated and NH_4^+ negatively correlated. This pattern was reflected in the distribution of Cryptophyceae (e.g., *Cryptomonas ovata*) and Euglenophyceae (e.g., *Euglena viridis*), which prefer environments undergoing nitrogen transformation. For instance, *Cryptomonas ovata* appeared in stations or seasons where NO_2^- levels were high, indicating active nitrification or organic matter degradation. Moreover, the dominance of Cyanophyceae (especially *Anabaena* spp. and *Microcystis aeruginosa*) during periods of ammonium depletion and phosphate abundance suggests competitive advantage under phosphorus-enriched but nitrogen-variable conditions, potentially linked to N-fixation capacity.

CONCLUSION

The primary objective of this study was to assess the diversity and community structure of microalgae in Oglet Eddaira Lake (Southwestern Algeria). The findings demonstrate that the distribution and abundance of microalgal taxa are strongly influenced by physicochemical gradients, primarily driven by seasonal dynamics and local environmental conditions. The first PCA axis (F1) captured a gradient of mineralization and phosphate enrichment, associated with the dominance of Chlorophyceae and Cyanophyceae, especially during warmer periods. The second axis (F2) represented a nitrogen transformation gradient, favoring taxa such as Cryptophyceae and Euglenophyceae, particularly under conditions of active nitrification or organic matter degradation. This integrative multivariate approach confirms the value of microalgae as bioindicators of eutrophication, nutrient cycling, and water quality changes in arid and semi-arid wetland ecosystems. The study underscores the importance of incorporating microalgal monitoring into wetland conservation strategies, particularly for Ramsar-listed sites vulnerable to climate and anthropogenic pressures.

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