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Research Article

Environmental factors influencing Cyanobacteria community structure in Sidi Salem reservoir (North of Tunisia)

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Abstract: The reservoir of Sidi Salem (North of Tunisia) suffered from eutrophication during the second part of the 20th century, like many large freshwater ecosystems in Tunisia. In the present study, we analyze a dataset comprised of field measurements of physicochemical and biological variables in Sidi Salem reservoir covering the period from February 2009 to January 2011, in order to understand the variability of cyanobacteria community structure during recent years and the main drivers of these changes.

Monthly sampling of cyanobacteria was carried out from the deepest station of the reservoir according to the water column (surface 0m, 5m,10m,15m,20m and 25m). In this way, a total of 15 cyanobacterial species, spread over 4 orders, were identified. This study investigates the vertical and temporal dynamics of phytoplankton and cyanobacterial communities in Sidi Salem Reservoir. Phytoplankton biovolume exhibited strong temporal variability, ranging from near 0 to 60 × 10^6 mm^3 L^{-1}, with mean values generally below 5 × 10^6 mm^3 L^{-1} for most months. Maximum biovolumes were recorded in autumn and winter, particularly at 20 m depth, reflecting bloom events.

Cyanobacteria dominated the phytoplankton community, with *Planktothrix* accounting for 70–90% of relative abundance in deeper layers (≥10 m) and *Oscillatoria* showing seasonal peaks in surface layers (0–5 m) during summer. Subdominant genera, including *Microcystis*, *Raphidiopsis*, and *Pseudanabaena*, were sporadically distributed. Principal component analysis (PCA) revealed that vertical distribution patterns were strongly associated with nutrient gradients, light availability, and physicochemical conditions, with surface layers acting as hotspots of productivity and bloom formation, and deeper layers functioning as nutrient reservoirs and zones of biogeochemical transformation.

Keywords: Algal blooms; freshwater ecology; ecological control; monitoring; Sidi Salem reservoir (Tunisia).

1. Introduction

Cyanobacterial harmful algal blooms (CyanoHABs) have become a major global concern in freshwater ecosystems due to their increasing frequency, persistence, and ecological impacts. These blooms frequently dominate phytoplankton communities under eutrophic and warm conditions and can produce potent toxins that threaten water quality, aquatic biodiversity, ecosystem services, and human health (Paerl et al., 2016; Huisman et al., 2018). Their proliferation is strongly linked to nutrient enrichment, particularly elevated inputs of phosphorus and nitrogen originating from agricultural activities, wastewater discharges, and urban runoff. In addition, climate change plays a significant role by promoting higher water temperatures, enhanced thermal stratification, and altered hydrological regimes, all of which favor the development and persistence of bloom-forming cyanobacteria (O'Neil et al., 2012; Paerl et al., 2018). Compared with other phytoplankton groups such as diatoms, chlorophytes, and dinoflagellates, many cyanobacterial taxa possess a wide range of adaptive traits that confer competitive advantages under changing environmental conditions. These adaptations include buoyancy regulation through gas vesicles that enable vertical migration in the water column to optimize access to light and nutrients, efficient phosphorus uptake and storage mechanisms, and the ability of certain genera to fix atmospheric nitrogen. In addition, many cyanobacteria exhibit tolerance to high irradiance and oxidative stress, allowing them to thrive under conditions that limit the growth of other phytoplankton groups (Huisman et al., 2018; Burford et al., 2015). Some species are also capable of forming resistant resting stages (akinetes) or persisting in sediments, facilitating bloom recurrence and seasonal resilience.

A major ecological and public health concern associated with cyanobacterial blooms is the production of cyanotoxins. Among these toxins, microcystins are the most frequently detected and are known for their hepatotoxic properties and potential carcinogenic effects. These compounds inhibit protein phosphatases and can accumulate within aquatic food webs, posing risks to aquatic organisms, livestock, and human populations relying on contaminated water resources (Carmichael, 2001; Zhang et al., 2022). Over the past decades, numerous studies have shown that cyanobacterial blooms in freshwater ecosystems are typically associated with eutrophic conditions and low water exchange, which promote their persistence and dominance (Paerl, 1988; Carmichael, 1995; Oliver et al., 2000; Albay et al., 2003; Downing et al., 2001; Borics et al., 2012; Le Moal et al., 2021).

In Tunisia, freshwater reservoirs play a crucial role in water supply for drinking, irrigation, and industrial uses. However, many of these systems are increasingly affected by eutrophication due to agricultural runoff, urban inputs, and prolonged drought conditions. These pressures promote shifts in phytoplankton communities toward prokaryotic cyanobacteria, which frequently dominate during the summer-autumn period. Studies conducted in Tunisian reservoirs, including the Sidi Salem Reservoir, have reported a high diversity of cyanobacterial taxa and recurrent blooms of *Microcystis aeruginosa* and related species, many of which can produce microcystins (Fathalli et al., 2015; Ben Rejeb Jenhani et al., 2019). Although other algal groups may contribute significantly to total phytoplankton biomass, cyanobacteria often reach disproportionately high abundances associated with elevated toxin levels and deteriorating water quality.

Despite their ecological importance and potential health impacts, detailed investigations into the environmental

drivers sustaining long-lasting cyanobacterial dominance in large Mediterranean reservoirs remain limited. Therefore, the present study aims to investigate the environmental factors responsible for the persistence of a prolonged cyanobacterial bloom in the Sidi Salem Reservoir. By combining hydrochemical and hydrobiological monitoring over two consecutive years, this study evaluates the role of nutrient dynamics, thermal stratification, and anthropogenic pressures in promoting bloom development and toxin production and discusses the potential implications for reservoir management and water quality protection.

1. Materials and methods

2.1. Sampling site

The Sidi Salem dam (36°35'20''N and 9°23'45''E) is located in Béja Governorate, in the Northwest region of Tunisia (Figure 1).

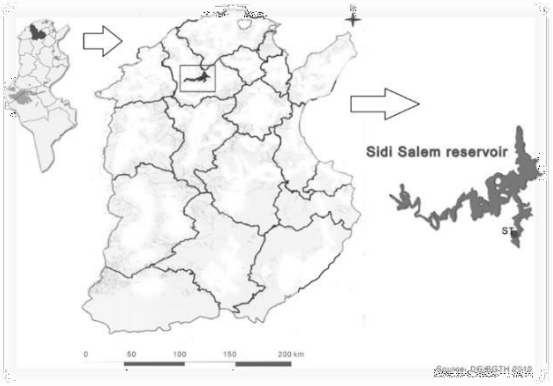

Figure 1. Geographic location of the Sidi Salem reservoir. ST• symbolizes the sampling station that corresponds to the deepest part of the reservoir.

It was constructed on the Medjerda, the biggest Tunisian river since 1981. It is considered as the largest dams in Tunisia with a 4300 Ha area. It has a volume of 555 10^6 m^3 with a maximum depth of 57 m. This dam is used for irrigation, drinkable water, fish breeding and the electric power supply.

2.2. Sampling methodology

Water samples, for physicochemical and biological analyses, were collected monthly from February 2009 to January 2011, using 1-L Niskin bottle at different depths (0, 5, 10, 15, 20 and 25 m) from the deepest station in the reservoir. The chosen station is located in the central pelagic zone of the reservoir, which represents the area most influenced by hydrodynamic mixing processes and the integration of inflowing waters. In such systems, the central basin typically reflects the cumulative effects of nutrient inputs, thermal stratification, and vertical mixing dynamics, making it particularly suitable for assessing cyanobacterial development.

2.3. Hydrological parameters

Water temperature, salinity, pH, and dissolved oxygen concentrations were measured using a multi-parameter probe (WTW model). Transparency was measured using the Secchi disk. Dissolved inorganic nutrients (nitrite: NO^{2-}, nitrate: NO^{3-}, ammonium: NH^{4+}, phosphate: PO_4^{3+}, total nitrogen: TN and total phosphorus: TP) were measured using colorimetric methods with the autoanalyzer Bran-Luebbe III. The chlorophyll *a* (chl *a*) concentration was determined from 300 mL of water filtered on Whatman GF/C filters, followed by acetone extraction (Lorenzen, 1967) before spectrophotometric measurements by a UV visible spectrophotometer (Jenway model 6705).

In this study, the euphotic zone (Zeu) was estimated from the Secchi disk depth (ZSD) using the empirical relationship: Zeu=2.56×ZSD (witzel, 2000).

2.4. Biological parameters

Phytoplankton enumeration was performed with an inverted microscope following the method of Utermöhl (1958) after fixation with a Lugol solution (final concentration of 4%). The identification of

phytoplankton taxa was achieved according to Bourrelly (1985) and Baker (1991, 1992). Biovolumes, which were calculated from microscopic measurements of length and width, and assuming simple geometrical shapes (Lohmann, 1908; Hillebrand et al., 1999).

2.5. Statistical analysis

The data recorded in this study were submitted to a normalized principal component analysis (PCA) (Doledec and Chessel, 1994). Simple log(x+1) transformation was applied to data in order to stabilize the variance correctly (Frontier, 1976). A multivariate analysis was used to relate the cyanobacterial communities' distribution pattern to environmental variables.

3. Results

3.1. Monthly fluctuations of physicochemical and biological parameters

Based on the table 1, the water column shows warmer and more variable surface temperatures, ranging from 10.5 to 29.3 °C (mean 19.8 °C), compared to 10.5–24.2 °C at the bottom (mean 16.4 °C). Salinity is nearly uniform at all depths, averaging 1.04 PSU. Surface pH is slightly higher and more variable (6.99–9.25, mean 8.16) than at the bottom (7.06–8.42, mean 7.99), and dissolved oxygen follows a similar trend (surface 4.02–9.34 mg L^{-1}, mean 7.36 mg L^{-1}; bottom 3.97–8.88 mg L^{-1}, mean 6.95 mg L^{-1}).

Table 1. Summary environmental variables in Sidi Salem reservoir (February 2009 - January 2011) (n = 3) (St Dev: Standard deviation)

	Surface (0 m)				Bottom (25m)			
	Min	**Max**	**Mean**	**StDev**	**Min**	**Max**	**Mean**	**StDev**
Temperature (°C)	10.50	29.30	19.81	6.00	10.50	24.20	16.43	3.79
Salinity (PSU)	0.70	1.30	1.04	0.18	0. 80	1.30	1.04	0.17
pH	6.99	9.25	8.16	0.56	7.06	8.42	7.99	0.32
Dissolved O_2 (mg L^{-1})	4.02	9.34	7.36	1.45	3.97	8.88	6.95	1.24
NO_2^- (µmol L^{-1})	0.06	1.24	0.44	0.28	0.05	0.89	0.36	0.25
NO_3^- (µmol L^{-1})	2.35	14.29	5. 77	3.55	2.69	24.81	5.54	4.76
NH_4^+ (µmol L^{-1})	0.84	5.24	2.69	1.26	0.59	5.01	1.71	1.03
PO_4^{3-} (µmol L^{-1})	0.08	0.75	0.30	0.19	0.04	1.03	0.34	0.31
TN (µmol L^{-1})	15.03	31.55	23.88	4.36	17.08	30.52	22.04	3.65
TP (µmol L^{-1})	1.55	6.58	3.,24	1.22	1.60	6.51	3.30	1.38
Chl *a* (mg L^{-1})	2.55	10.31	5.12	1.76	2.16	7.85	4.30	1.56

Nutrient profiles indicate active vertical cycling: ammonium decreases with depth (surface 2.69 µmol L^{-1}, bottom 1.71 µmol L^{-1}), while nitrate shows higher maxima at depth (surface 5.77 µmol L^{-1}, bottom 5.54 µmol L^{-1}, peak 24.81 µmol L^{-1}) and phosphate slightly increases (surface 0.30 µmol L^{-1}, bottom 0.34 µmol L^{-1}).

Chlorophyll a is more concentrated at the surface (5.12 mg L^{-1}) than at the bottom (4.30 mg L^{-1}), reflecting light availability. In general, the data indicates that the Sidi Salem reservoir is characterized by dynamic surface waters, relatively stable bottom waters, and moderate vertical nutrient fluxes

3.2. Cyanobacterial species composition

A total of 15 cyanobacterial species, spread over 4 orders, were identified in Sidi Salem reservoir (Table 2). Phytoplankton biovolume exhibited strong temporal variability throughout the study period (Figure 2). Values ranged from near 0 to approximately 60 × 10^6 mm^3 L^{-1} across the water column. For most months, biovolume

remained low, generally below 5 × 10^6 mm^3 L^{-1}, particularly during spring and summer. Several marked peaks were observed during autumn and winter. The maximum biovolume (60 × 10^6 mm^3 L^{-1}) occurred in October at 20 m depth. Other high values, ranging between 30 and 50 × 10^6 mm^3 L^{-1}, were recorded mainly between December and January at different depths. Intermediate peaks (10-35 × 10^6 mm^3 L^{-1}) were also detected during winter months. Vertically, higher biovolume values were more frequently observed in the upper and intermediate layers (0-10 m), although occasional maxima occurred in deeper layers (15-25 m).

The mean biovolume across the water column followed the same pattern, with generally low values punctuated by short-term increases corresponding to phytoplankton bloom events

Table 2. List of cyanobacterial species recorded in Sidi Salem reservoir (February 2009 - January 2011).

Order	Species
Oscillatoriales	*Limnothrix sp.*
	Lyngbya sp.
	Oscillatoria sp.
	Planktothrix rubescens
	Pseudanabaena limnetica
	Pseudanabaena sp.
	Spirulina sp.
Nostocales	*Anabaena sp.*
	Raphidiopsis curvata
Synechococcales	*Eucapsis sp.*
	Merismopedia sp.
Chroococcales	*Chroococcus sp.*
	Gloecapsa sp.
	Microcystis aeruginosa
	Microcystis sp.

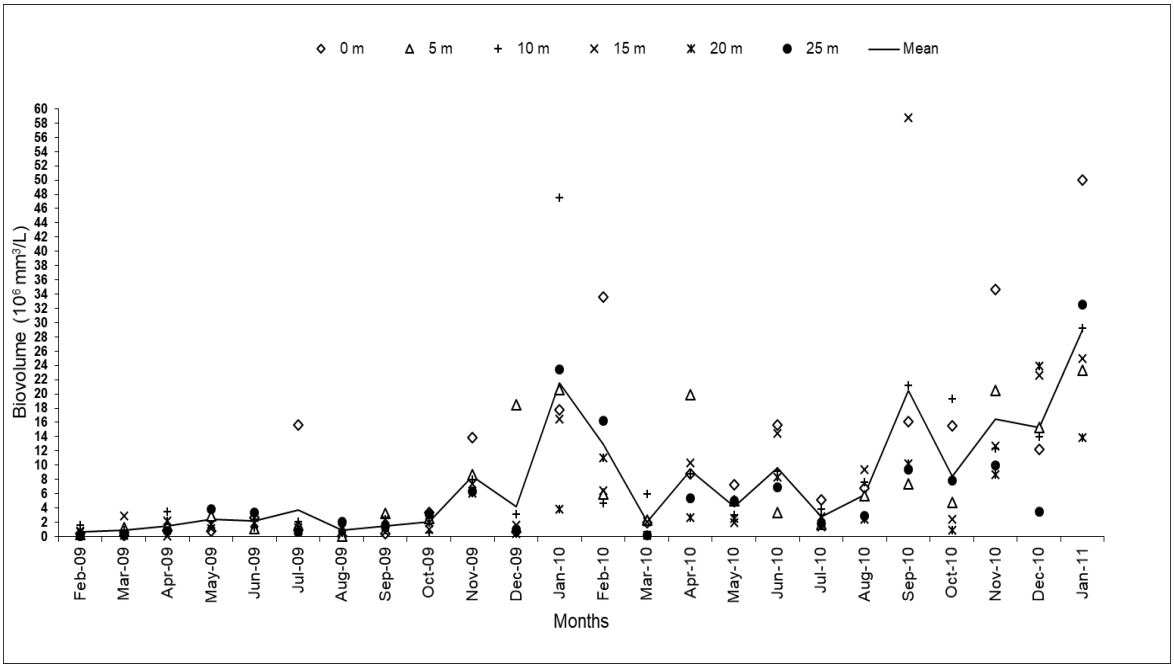

Figure 2. Temporal variations of cyanobacterial biovolume in the water column in Sidi Salem reservoir (Tunisia) (February 2009 - January 2011)

3.3. Integrated and seasonal synthesis of cyanobacterial abundance (0–25 m)

Filamentous cyanobacteria clearly dominate the phytoplankton community throughout the water column, exhibiting marked vertical and seasonal variations (Figure 3). *Planktothrix* is the predominant genus across all depths (0 to 25 m), often accounting for over 70-90% of relative abundance, particularly in deeper layers (≥10 m). This dominance indicates strong adaptation to low-light and stable stratification conditions found in deeper waters, where *Planktothrix* benefits from favorable environmental settings.

Oscillatoria displays more pronounced seasonal dynamics, with significant abundance mainly in the upper layers (0-5m) and more variable presence at depth (20-25 m). Peaks between May and August 2010 suggest that *Oscillatoria* exploits higher light availability and possibly seasonal nutrient inputs or physical disturbances such as mixing events. Other genera (*Limnothrix, Anabaena, Lyngbya, Microcystis, Pseudanabaena, Raphidiopsis*) occur sporadically and at low relative abundance, contributing to overall community diversity that decreases with depth.

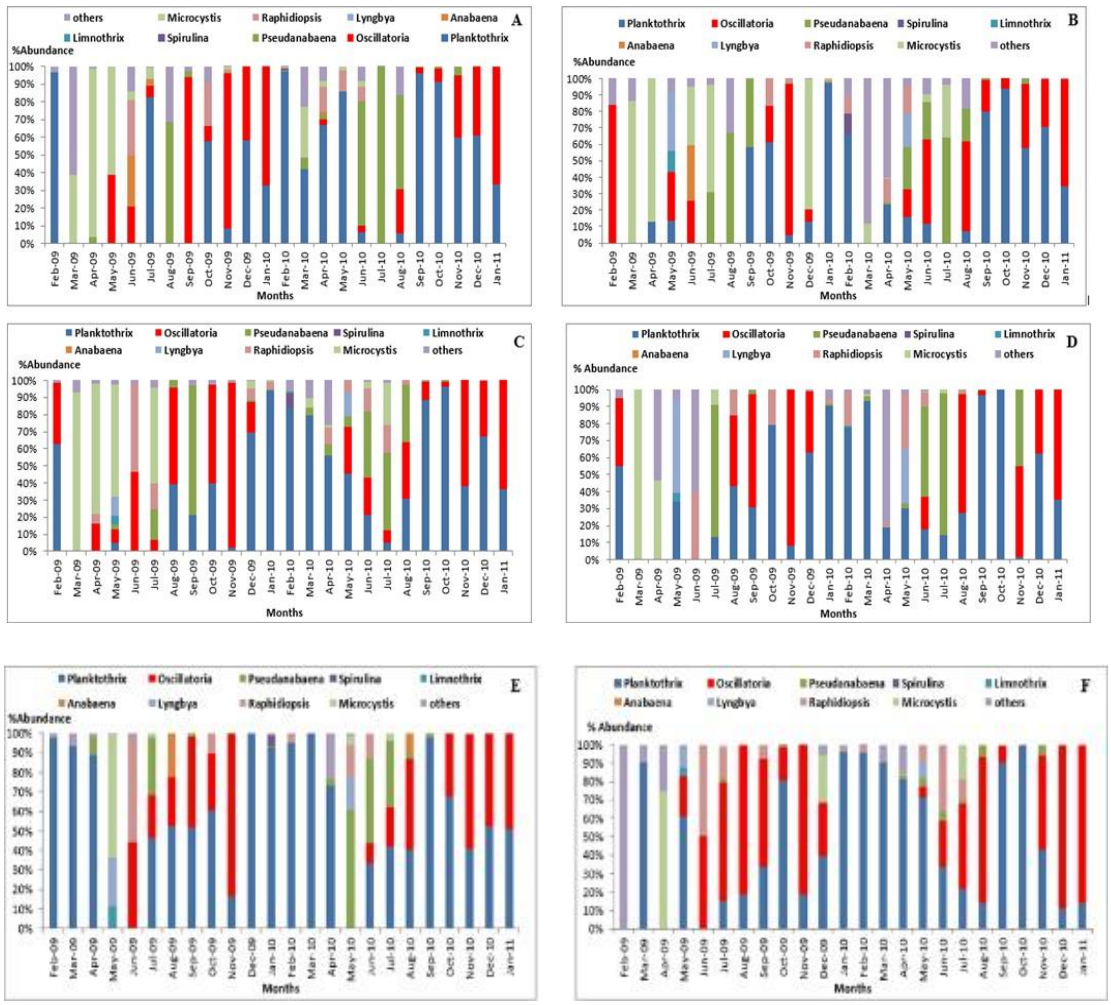

Figure 3. Monthly evolution of cyanobacterial community composition in different depths of water column: (A) 0 m, (B) 5 m, (C) 10 m, (D) 15 m, (E) 20 m and (F) 25 m in Sidi Salem reservoir (Tunisia) (February 2009 - January 2011).

The diversity is highest near the surface (0-5 m), with alternating dominance among *Planktothrix, Oscillatoria*, and *Limnothrix*, while it gradually declines with depth, reaching near-monodominance of *Planktothrix* at 15-25 m.

This vertical and temporal distribution likely reflects ecological stratification driven by gradients in light availability, temperature, and nutrient concentrations. *Planktothrix* appears to prefer the more stable, low-light conditions of deeper waters, whereas *Oscillatoria* thrives in more dynamic, illuminated surface layers. *Oscillatoria* peaks during summer and autumn may correspond to periods of enhanced mixing or nutrient pulses, while the year-round persistence of *Planktothrix* underscores its key role in sustaining phytoplankton biomass in this ecosystem.

The principal component analysis (PCA) performed on the physicochemical and biological variables (Figure 4), reveals the major environmental gradients controlling the distribution of cyanobacteria within the water column. The first two axes explain 67.17% of the total variance, with 44.33% attributed to axis F1 and 22.84% to axis F2, indicating that these axes represent most of the ecological structure of the system. A clear vertical structuring of the water column, reflecting the combined influence of physicochemical parameters and the distribution of cyanobacteria from the surface down to the deeper layers. The surface station (0 m) is located on the positive side of the F1 axis and shows a strong association with chl *a,* nitrite, salinity, temperature and dissolved oxygen, as well as with several cyanobacterial genera such as *Microcystis, Oscillatoria* and *Planktothrix*.

This configuration suggests that the surface layer represents the zone of maximum primary production, where light availability and favorable thermal conditions promote intense photosynthetic activity and the proliferation of cyanobacteria typically associated with eutrophic environments. At a depth of 5 m, the station is more closely related to ammonium, temperature and dissolved oxygen, together with some genera such as *Microcystis* and *Pseudanabaena*.

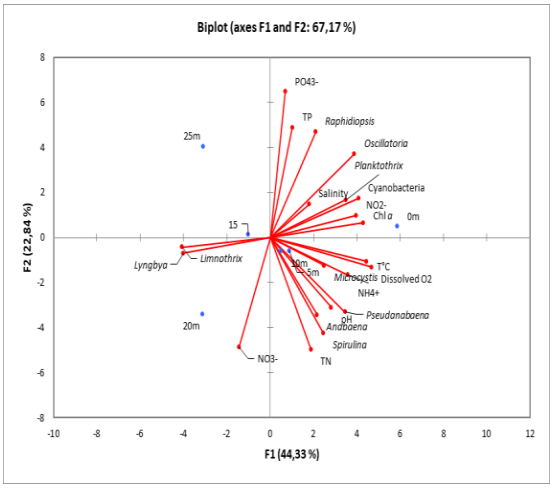

Figure 4. Principal Component Analysis (PCA) performed on abiotic and biotic parameters in Sidi Salem reservoir during two years of investigation

This zone may correspond to a subsurface layer where demineralization processes release reduced forms of nitrogen, facilitating their assimilation by cyanobacteria capable of efficiently exploiting these nutrient resources. The station located at 10 m appears to be more influenced by total nitrogen and higher pH conditions and is associated with genera such as *Anabaena* and *Spirulina*. This distribution may reflect the adaptation of these cyanobacteria to particular nutrient regimes and to environments where pH variations result from biological activity and biogeochemical processes occurring within the water column. At 15 m depth, the position of the station is closer to the vectors representing total phosphorus and orthophosphate, suggesting an intermediate zone where phosphorus availability may play an important role in structuring the phytoplankton community. The relative proximity of *Raphidiopsis* to these variables indicates that this genus may be favored by higher phosphorus concentrations, which is consistent with its capacity to develop in eutrophic

environments where this nutrient becomes available. Deeper layers exhibit a different organization of the system. The station located at 20 m is strongly associated with nitrate, suggesting an accumulation of this oxidized form of nitrogen in the deeper layers of the water column. This accumulation may result from nitrification processes and the degradation of organic matter originating from primary production in the upper layers. Reduced light conditions at this depth likely limit phytoplankton growth, which explains the absence of a clear association with cyanobacteria. Finally, the station located at 25 m appears relatively distant from the main environmental and biological vectors, indicating a weak direct influence of the variables associated with primary production. This depth most likely corresponds to a zone dominated by sedimentation and demineralization processes, where phytoplankton activity is strongly reduced due to light limitations. Overall, the PCA reveals that the vertical distribution of cyanobacteria in the studied system is primarily controlled by nutrient gradients, physicochemical conditions and light availability. The surface layer is characterized by high productivity and the dominance of cyanobacteria potentially responsible for bloom formation, whereas deeper layers are mainly governed by biogeochemical processes related to nutrient transformation and accumulation

4. Discussion

According to Ryding & Rast (1994), the values of TP, Chl *a* and transparency indicate that Sidi Salem reservoir oscillated between a mesotrophic and eutrophic status. It was clear; that the deduction of dam Mediterranean area is subjected to high climate and anthropic pressures, and that the diagnosis of their trophic state will have imperatively gone through a model that will be more adapted. The same results were found by Mouelhi (2000) in the same reservoir. This doesn't correlate with the study of Sellemi et al. (2012) concluding that the reservoir of Sidi Saâd oscillated between oligotrophic and mesotrophic level. Also, our results don't corroborate with the result of Ben Rejeb Jenhani et al. (2012) showing that the reservoir of Bir M'cherga can be considered as hypertrophic.

4.1. Temporal variability of cyanobacteria biovolume

The results show strong temporal variability in cyanobacteria biovolume throughout the study period, with values ranging from nearly 0 to 60 × 10^6 mm^3 L^{-1}, and an average biovolume generally below 5 × 10^6 mm^3 L^{-1} for most of the year. These trends are consistent with observations in other aquatic systems, where physical dynamics, particularly thermal stratification and turbulence, regulate access to light and essential nutrients for phytoplankton growth (Caratela et al., 2023). The observed peaks in biovolume during autumn and winter, including the maximum of 60 × 10^6 mm^3 L^{-1} at 20 m depth in October, are consistent with recent studies reporting that filamentous cyanobacteria can thrive under low-light, stable stratification conditions, especially when seasonal mixing redistributes nutrients (Fernandez et al., 2021). Intermediate winter maxima (10–35 × 10^6 mm^3 L^{-1}) likely correspond to episodic blooms triggered by local physicochemical conditions.

4.2. Dominance of filamentous cyanobacteria

Filamentous cyanobacteria, particularly *Planktothrix* and *Oscillatoria*, dominated the phytoplankton community across all depths. *Planktothrix* frequently accounted for 70–90% of relative abundance, especially in deeper layers (≥10 m), reflecting its adaptation to low-light, vertically stable environments characteristic of deeper water (Caratala et al., 2023). This strategy allows *Planktothrix* to maintain substantial biomass year-round. *Oscillatoria*, by contrast, exhibited a

more dynamic and seasonal distribution, with peak abundance in the upper layers (0–5 m) between May and August. This pattern reflects its ability to exploit higher light availability and transient nutrient inputs, often associated with seasonal mixing events (Walsby et al., 2005). Minor genera, including *Limnothrix, Anabaena, Microcystis,* and *Pseudanabaena*, occurred sporadically and contributed to surface layer diversity, which decreased with depth, reaching near-monodominance of *Planktothrix* between 15 and 25 m.

In Dianchi Lake in China, Rigosi et al. (2014) showed that the importance of temperature and nutrients and their interaction was dependent on lake trophic state and cyanobacterial taxon. Nutrients played a larger role in oligotrophic lakes, while temperature was more important in mesotrophic lakes: Only eutrophic and hyper-eutrophic lakes exhibited a significant interaction between nutrients and temperature. Likewise, some taxa, such as *Anabaena*, were more sensitive to nutrients, while others, such as *Microcystis*, were more sensitive to temperature.

4.3. *Mechanisms of competition and adaptation to environmental gradients*

The dominance of *Oscillatoria,* and the potentially toxic *Planktothrix* in Sidi Salem reservoir, and their omnipresence in the different period of investigation are also analogous to that obtained from the graphical models of competition for two resources elaborated by Tilman (Taylor and Williams, 1975; Tilman 1977, 1982, 1985). Tilman's resource ratio theory predicts that the coexistence between two competing species is unstable if each species consumes relatively more of the resource of which it also tolerates the lowest levels. These results have been demonstrated that temporal variation of the environment is another important process preventing competitive exclusion in algal communities (Padisak et al., 1993 Behrenfeld et al., 2025,). Although these algae can stay dominant throughout the year in eutrophic lakes (Sas, 1990), the seasonal pattern depends on the temperature conditions. It is commonly noted that *Oscillatoria* dominance is associated with eutrophication (Berger, 1975; Sas, 1989; Romo et al., 1994) and that these Cyanobacteria can disappear again in response to a reduction of the nutrient loading (Sas, 2017; Mur et al., 1993). It is the low light level rather than the high nutrient availability leads to dominance by Oscillatoriaceae in eutrophic situations. In the present study, the maxima of *Planktothrix* recorded in the autumnal and winter period are similar to those obtained in the Lake Zurich, in Switzerland. These results indicate that the maximum growth rates of *Planktothrix* are among the lowest for planktonic cyanobacteria, which are low compared with those of other phytoplankton algae (Reynolds, 1984; 1997).

These organisms are K strategists, which build their populations slowly but minimize losses through sinking (by buoyancy regulation) and grazing (perhaps by their toxicity). It should be pointed out, however, that in the low irradiance in the metalimnion their growth rates equal or exceed those of other phytoplankton. They might also complete favorably in the epilimnion during late autumn and winter when low insolation and deep circulation combine to decrease available light. The very features that confer the ability to grow at low irradiances (such as high phycobiliprotein content) might impose a protein burden on the cell that limits its maximum growth rate (Bright and Walsby, 2000). The observed patterns of competition and coexistence between *Oscillatoria* and *Planktothrix* in Sidi Salem Reservoir reflect broader dynamics of cyanobacterial communities. Recent studies indicate that cyanobacterial competitive success is not determined solely by static resource availability, but by environmental variability**,** and complex

nutrient-temperature interactions (Cao et al., 2024; Wu et al., 2024; Silva et al., 2025). These factors allow certain species to maintain dominance or coexist with others under fluctuating conditions by adjusting growth rates, light tolerance, and resource utilization. Therefore, the vertical and seasonal structuring observed in this reservoir reflects the adaptation of cyanobacteria to gradients of light, temperature, and nutrients, rather than simple, direct competition for a single limiting resource.

The PCA revealed a clear vertical structuring of the water column, driven by gradients in nutrient availability, physicochemical conditions, and light penetration. The surface layer was primarily characterized by high chlorophyll-a, elevated temperature, and increased dissolved oxygen, supporting the dominance of bloom-forming cyanobacteria such as *Microcystis*, *Oscillatoria*, and *Planktothrix*. This pattern is consistent with observations in other eutrophic systems, where high light and nutrient availability promote intense primary production (Silva et al., 2025). However, deeper layers were dominated by nitrate accumulation and reduced light, likely reflecting nitrification and organic matter degradation below the euphotic zone. Wu et al. (2024) highlighted low-light conditions and deep mixing limit cyanobacterial growth, which explains the weak associations between environmental vectors and cyanobacteria in the deeper strata. Similarly, studies have shown that turbulent mixing can transport cyanobacterial cells to deeper layers with reduced light availability, thereby decreasing their photosynthetic efficiency and limiting bloom development (Zhang et al., 2025).

5. Conclusion

This study demonstrated that cyanobacterial communities in Sidi Salem reservoir exhibit strong temporal and vertical variability, shaped by gradients in nutrients, light, and physicochemical conditions. Surface layers were dominated by bloom-forming taxa and exhibited higher diversity due to favorable conditions for photosynthesis and primary production. Subsurface and intermediate layers were structured by nutrient availability, particularly nitrogen and phosphorus, while deeper layers were characterized by nitrate accumulation, reduced light, and limited phytoplankton activity. The vertical distribution and seasonal dynamics of cyanobacteria are controlled not only by resource availability but also by environmental variability and species-specific adaptations. Surface layers' function as hotspots of productivity and bloom formation, whereas deeper layers act as nutrient reservoirs, mediating biogeochemical transformations. These findings highlight the importance of considering vertical environmental gradients and adaptive traits when assessing cyanobacterial ecology. Such knowledge is essential for predicting bloom occurrences, managing water quality, and designing effective monitoring strategies in eutrophic reservoirs.

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