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Original Article

Microalgal community structure and environmental drivers of water quality in the Guadaine wetlands complex, North-Eastern Algeria

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Abstract: This study provides the first assessment of microalgal community structure and water quality in the Guadaine natural wetlands (Batna, north-eastern Algeria), a semi-arid complex comprising several interconnected chotts. Water and microalgal samples were collected from five stations in spring. Physicochemical parameters were analyzed alongside taxonomic identification, abundance, and phytoplankton diversity. Water in the Guadaine natural wetlands was alkaline and moderately mineralized, with nitrite showing marked spatial variability. A total of 35 microalgal genera distributed across 10 classes were identified, with Cyanophyceae (46.57%) and Bacillariophyceae (37.90%) accounting for over 84% of total cell density. *Anabaena* sp. and *Navicula* sp. were the numerically dominant taxa. Shannon diversity indices revealed marked spatial heterogeneity among sub-sites (H′ = 1.61-2.46 bits), shaped by contrasting physicochemical gradients. Canonical Correspondence Analysis identified nitrite concentration and hydrogen ion concentration as the primary drivers of phytoplankton spatial structuring, with temperature acting as a secondary amplifying factor. Anomalous nitrite enrichment at station 5, which is characterized by scattered hamlets and intensive livestock farms, selectively promoted diatom-dominated assemblages, whereas elevated hydrogen ion and mineralization at Station 1 and Stations 2 favored Cyanophyceae dominance through carbon-concentrating mechanisms and nitrogen fixation. These findings underscore the value of microalgal communities as sensitive bioindicators of water quality in shallow semi-arid wetlands and establish a baseline ecological assessment for the Guadaine wetlands complex, planned as a Ramsar site, to guide future monitoring and conservation strategies.

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Introduction

Wetlands are among the most productive ecosystems on Earth and host substantial biological diversity (Ghermandi et al., 2008). North Africa harbors a wide diversity of wetlands, spanning coastal areas, uplands, and arid desert environments (Hammana et al., 2024). Mediterranean wetlands, in particular, are recognized as regional biodiversity hotspots, hosting an exceptional diversity of plant and animal species, many of which are endemic or rare, positioning them among the most biologically diverse ecosystems on the planet (Véla and Benhouhou 2007; Rifai et al., 2018). Driven by its diverse climate and distinctive physiography, Algeria exhibits a remarkable wealth of wetlands within the North African region. The latest national inventory identifies 2375 wetlands, comprising 2056 natural and 319 artificial sites, including 50 Ramsar-designated wetlands of international importance (Benzina et al., 2022-2024). Despite this notable diversity, the Algerian wetlands remain poorly known and weakly protected, leaving them increasingly threatened by anthropogenic pressures, including pumping, drainage, overgrazing, pollution, and salt mining (Bougoffa et al., 2023).

As key primary producers within wetlands, microalgal communities are characterized by rapid turnover rates and acute sensitivity to environmental variations (Bhat et al., 2015). Species composition,

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abundance, and dominant species are key community-structure characteristics and critical indicators of water quality (Zhang et al., 2016). They are a critical component in shaping the primary productivity of autotrophic water bodies, material cycling, and energy flow (Ochs et al., 2010).

Environmental conditions exert both direct and indirect influence on microalgal community structure (Whitton, 2012). Specifically, nutrient levels, temperature, and light conditions strongly influence phytoplankton community structure (Mesquita et al., 2020), as reflected in growth and reproduction rates. Consequently, monitoring phytoplankton community structure and diversity has become a key approach for assessing aquatic ecosystem health and water quality, with environmental factors being increasingly used to predict and explain microalgal community dynamics (Huang et al., 2022). Despite the recognized value of microalgae as bioindicators of water quality, studies addressing their community structure and diversity in arid and semi-arid areas remain scarce. The Algerian Basin is considered among the least studied areas of the Mediterranean Sea, even regarding marine microalgae (Aït-Kaci et al., 2024), and this knowledge gap is even more pronounced for inland and continental wetlands, which face growing anthropogenic pressures likely to alter water quality and, consequently, microalgal community dynamics.

The Guadaine wetlands complex in Algeria is a representative example of this data-deficient category of semi-arid shallow continental wetlands. Although this site is undergoing an administrative process to become a designated natural reserve and later be classified as a Ramsar site, it has, to date, eluded scientific investigation regarding its microalgae. Because microalgal communities closely reflect water-quality parameters, studying this system will not only provide the first characterization of its diversity but also validate its potential as a bioindicator for ecological monitoring. In this context, the present study aims to: (i) characterize the physicochemical quality of its waters with comparison to national and international standards, (ii) provide the first inventory of microalgal community structure and diversity in Guadaine wetland, and (iii) identify the key environmental drivers structuring microalgal assemblages. Building on these results would help us better understand the ecosystem's ecological functioning and support future conservation efforts.

Materials and Methods

Study area: The Guadaine wetlands complex ‘’GWC’’ is situated in the Batna Province, north-eastern Algeria (35°46'; 35°50' N and 6°14'; 6°24' E) and lies at a mean altitude of 813 m (Fig. 1). This wetland complex covers a total surface area of approximately 748 ha and comprises 14 interconnected sub-sites or sub-chotts (’chott’ refers to seasonal endorheic salt wetlands). This region has a semi-arid climate, with annual average precipitation over the past 10 years ranging from 160.82 to 362.19 mm, with an average of 310.24±74.74 mm. Mean temperature was 17.46±0.27°C, with a maximum of 25.86±0.49°C and a minimum of 8.94±0.38 °C. From an ecological perspective, GWC waters are brackish, with relatively low salinity and an alkaline pH, and water depth typically fluctuates between 0.2 and 1 meter depending on the season.

Five stations distributed across the GWC were selected for this study based on accessibility and their ability to represent the different sub-sites composing this ecosystem: Gamra (stations St1 and St2), Mellal (stations St3 and St4), and Draâ Boultif (station St5). Environmental conditions differed slightly among these three wetlands and five stations: elevation ranged from 796 m at St5 to 820 m at St1 and St2, and water depth remained shallow throughout, not exceeding 60 cm (Table 1). Sampling was restricted to the spring season (March-May 2026), when microalgal development typically reaches its annual peak in shallow semi-arid wetlands of north-eastern Algeria (Labed et al., 2024), ensuring that both water quality and community structure were characterized under the most ecologically informative conditions.

Sample collection and physicochemical measurements: At each station, we collected water at a depth of 0.2 to 0.4 m and stored it in plastic bottles in a cooler box until transport to the laboratory. Four

Table 1. Characteristics of the sampling stations across the Guadaine wetlands complex.

Sub-site	Station	Altitude (m)	Depth (cm)
Gamra	St1	820	10
	St2	820	20
Mellal	St3	806	40
	St4	811	50
Draâ Boultif	St5	796	60

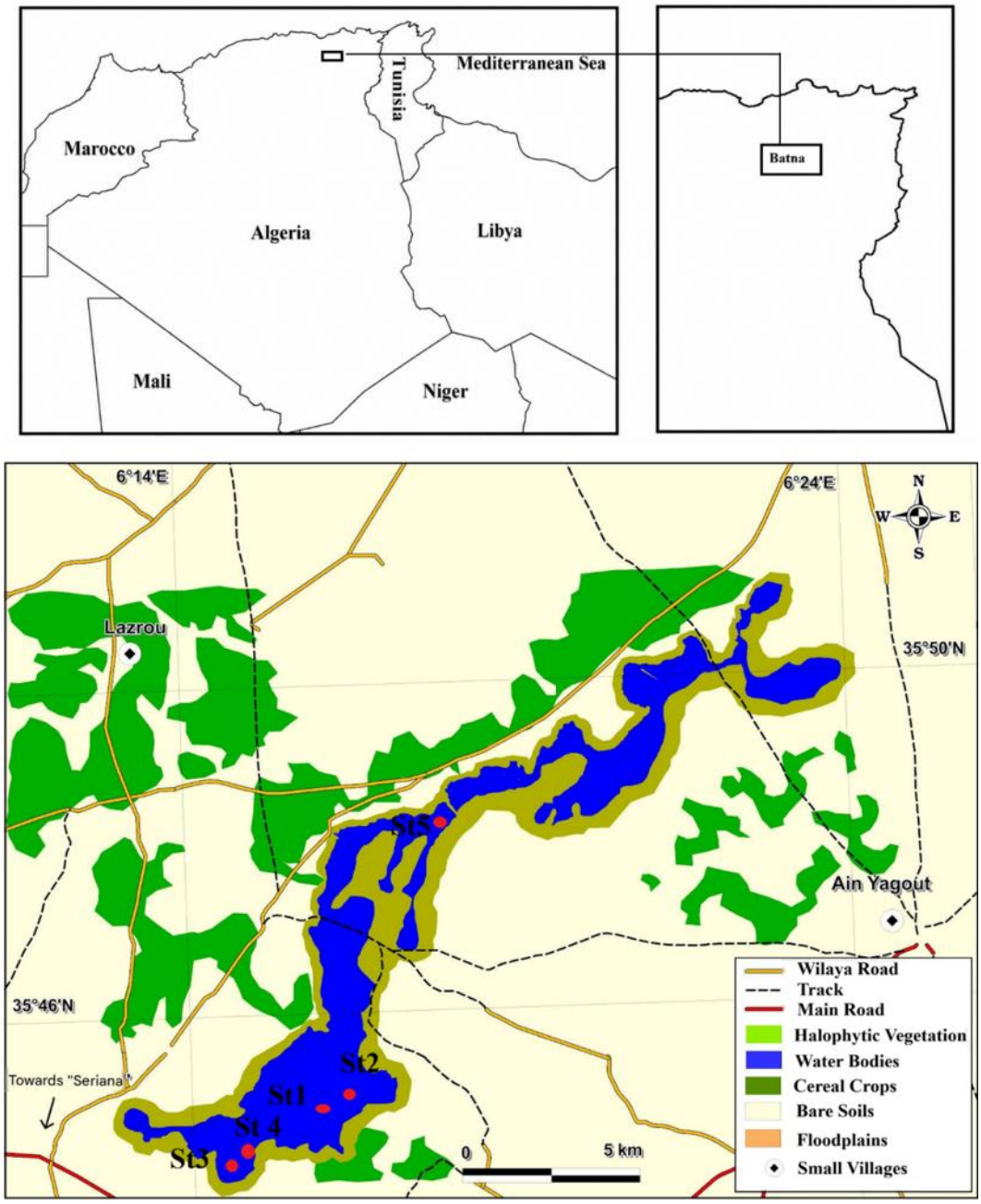


Figure 1. Geographic location of the Guadaine wetlands complex and distribution of sampling stations (St1-St2: Gamra, St3-St4: Mellal, St5: Draâ Boultif).

variables were measured *in situ* using a portable multiparameter probe, providing instant readings: water temperature (°C), pH, electrical conductivity (µS cm^{-1}), and turbidity (NTU). The remaining parameters: total dissolved solids (mg L^{-1}), salinity (‰), ionic species sodium (Na^{+}), chloride (Cl^{-}),

ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), and orthophosphate (PO_4^{3-}) (mg L^{-1}) were determined in the laboratory on the day of collection, following standardized water quality monitoring procedures (AFNOR, 2005).

Microalgae sampling, identification and counting: Microalgae were sampled at the same five stations and the same depth range (0.2-0.4 m) used for water sampling. At each site, 50 L of water were filtered through a plankton net (20-µm mesh size) to collect all types of algae (Effendi et al., 2016). The resulting samples were placed in amber glass vials, fixed with 5% formalin, and transported to the laboratory, where they were kept in the dark before analysis.

Taxonomic identification was carried out to the lowest feasible level, generally genus, using the reference identification keys of Prescott (1954), Compère (1974-1975), Sournia (1984-1986), and Bourrelly (1988); nomenclature was then cross-checked against the AlgaeBase (http://www.algaebase.org) database.

Cell counting was performed in the laboratory under an inverted microscope, scanning horizontal transects across a 10 mL settling chamber Utermöhl (1958). To obtain a reliable estimate of true abundance, each sample was counted at least three times, and the mean of these counts was used as the final value (Chaibi, 2013).

Data analysis: The relative abundance of each microalgal taxon was calculated as $F\ (\%) = (n_i/N) \times 100$, where n_i is the number of individuals belonging to a given taxon, and N is the total number of microalgal individuals. The taxon constancy index (Ci, %) was determined following Dajoz (2003) using the formula $Ci\ (\%) = (n_i/N) \times 100$, where n_i represents the number of samples in which a given taxon occurred and N is the total number of samples analyzed. Based on this index, taxa were classified into four occurrence categories according to the scale proposed by Bigot and Bodot (1973): constant taxa (C: Ci > 50%), accessory (Ac: Ci = 25-49%), accidental (A: Ci = 10-24%), and very accidental (Va: Ci < 10%).

Diversity was assessed using three complementary parameters and indices: (i) taxa richness (S), defined as the total number of microalgal taxa recorded in each sample; (ii) Shannon diversity index (H′), calculated as $H' = -\sum Pi \log_2 Pi$, where Pi is the relative abundance of the taxa i (ni/N), with ni representing the number of individuals of taxon i and N the total number of individuals in the sample (Magurran, 2004); and (iii) Pielou's evenness index (E), calculated as $E = H'/\ln(S)$, where H′ is the Shannon diversity index and S is taxa richness. Shannon diversity and Pielou's evenness indices were computed using PAST software (Palaeontological Statistics, version 3). The percentage contribution of each taxonomic class to total phytoplankton abundance was calculated as $F\% = (Nc/N) \times 100$, where Nc is the total number of individuals in class c, and N is the total count across all taxa.

To explore relationships between microalgal community composition and the studied environmental parameters, we performed Canonical Correspondence Analysis (CCA) using the vegan package in R (Oksanen et al., 2024). Environmental variables were standardized prior to analysis (Z-score transformation). Two variables were retained as constraining variables, water temperature and nitrite (NO_2^-), selected based on multicollinearity screening (VIF < 10) and degrees-of-freedom constraints. The remaining variables (pH, turbidity, salinity, NO_3^-) were projected as passive vectors onto the ordination space. Model significance was assessed by Monte Carlo permutation tests.

Results

Physicochemical quality of water: Overall, the water remained alkaline throughout the GWC, with pH values ranging narrowly from 8.38 (St5) to 8.65 (St1) (mean: 8.51±0.10). Water temperature varied moderately among the five stations, ranging from 21.1°C at St3 to 27.6°C at St5 (mean: 24.30±2.67°C). Electrical conductivity ranged widely from 2110 µS/cm (St5) to 3745 µS/cm (St3), with a mean of 3152.6±640.7 µS/cm. Consistently, total dissolved solids (TDS) varied between 1026 mg/L (St5) and 1758 mg/L (St4), and salinity remained relatively low and stable across stations (1.2-1.8‰; mean:

Table 2. Physicochemical parameters of water recorded at the five stations of the Guadaine wetlands complex.

Parameter	St1 (Gamra)	St2 (Gamra)	St3 (Mellal)	St4 (Mellal)	St5 (Draâ Boultif)	Mean±SD
Temperature (°C)	24.40	26.10	21.10	22.30	27.60	24.30±2.67
pH	8.65	8.54	8.48	8.48	8.38	8.51±0.10
Conductivity (µS/cm)	3347.00	3022	3745.00	3539.00	2110,00	3152.60±640.70
Turbidity (NTU)	7.40	6.20	15.70	3.43	5.10	7.57±4.78
TDS (mg/L)	1677.00	1151.4	1535.00	1758.00	1026	1429.48±324.21
Salinity (‰)	1.70	1.20	1.50	1.80	1.20	1.48±0.28
Cl^- (mg/L)	303.00	402.00	633.00	494.00	101.60	386.72±200.44
NO_2^- (mg/L)	0.0023	0.006	0.008	0.004	0.90	0.183±0.448
NO_3^- (mg/L)	0.58	0.41	0.87	0.52	0.55	0.586±0.172
PO_4^{3-} (mg/L)	4.51	4.33	5.92	10.20	5.17	6.03±2.42
Na^+ (mg/L)	211.00	218.00	289.00	294.00	232,00	248.80±39.93
NH_4^+ (mg/L)	2.52	3.21	5.48	4.60	5.36	4.23±1.25

Table 3. Comparison of observed values with WHO and Algerian water quality standards.

Parameter	Observed range	WHO limit	Algerian standard	Observation
Nitrate NO_3^- (mg/L)	0.41-0.87	50	50	Below both WHO and Algerian standards at all stations
Ammonium NH_4^+ (mg/L)	2.52-5.48	0.5	4	Exceeds WHO limit at all stations; exceeds Algerian standard at St3 and St5
Phosphate PO_4^{3-} (mg/L)	4.51-10.20	< 0.1	0.1	Exceeds both standards at all measured stations
Electrical Conductivity EC (µS/cm)	2110-3745	1400	2800	Exceeds WHO limit at all stations; exceeds Algerian standard at St1 (3347), St3 (3745), and St4 (3539)
Chloride Cl^- (mg/L)	101.60-633	—	< 600	Exceeds Algerian standard at St3 only (633 mg/L)
pH	8.38-8.65	6.5–9	≥ 6.5 - ≤ 9	Within both WHO and Algerian standards at all stations

1.48±0.28‰). Turbidity varied moderately, with the highest at St3 (15.7 NTU) and the lowest at St4 (3.43 NTU) (Table 2).

Regarding nutrient concentrations, nitrite (NO_2^-) showed the most pronounced spatial variability, ranging from 0.0023 mg/L at St1 to 0.9 mg/L at St5 (mean: 0.184±0.448 mg/L). Nitrate (NO_3^-) concentrations were comparatively low and less variable (0.41-0.87 mg/L; mean: 0.586±0.172 mg/L). Ammonium (NH_4^+) concentration ranged from 2.52 mg/L (St1) to 5.48 mg/L (St3), with a mean of 4.23±1.37 mg/L. Orthophosphate (PO_4^{3-}) concentration ranged from 4.33 (St2) to 10.20 mg/L (St4), with a mean value of 6.03±2.42 mg/L. Sodium (Na^+) concentration ranged from 211 to 294 mg/L, with a mean of 248.80±39.93 mg/L, peaking at St4 and reaching a minimum at St1 (Table 2). Comparison of the physicochemical results with WHO limits (WHO, 2018) and Algerian surface water quality standards (JORADP, 2011) revealed that several parameters exceeded recommended thresholds (Table 3).

Structure and diversity of microalgal communities

Taxonomic composition and abundance frequency: A total of 35 microalgal taxa were detected, distributed across 10 classes, 22 orders, 32 families, and 35 genera. The assemblage was numerically dominated by the Cyanophyceae (7 taxa). Within this class, *Anabaena* sp. exhibited the highest abundance frequency recorded across all taxa (F = 34.91%) and was classified as a constant taxon (C). *Calothrix* sp. (F = 1.95%) and *Cyanobacterium* sp. (F = 1.81%) occurred as accessory and constant taxa, respectively (Table 4).

Bacillariophyceae represented the most taxonomically diverse class, comprising 11 genera across 7 orders. The Melosirophyceae, represented solely by *Melosira* sp., showed a low abundance

Table 4. Taxonomic list, abundance frequency, constancy index and accuracy scale of microalgal taxa identified in the Guadaine wetlands complex. F%: Abundance frequency, Ci %: constancy index. Constant taxa (C), accessory taxa (Ac), accidental taxa (A).

Class	Order	Family	Genus	F%	Ci%	Accuracy scale
Bacillariophyceae	Naviculales	Naviculaceae	*Navicula* sp. Bory de Saint-Vincent, 1822	19.69	100	C
		Plagiotropidaceae	*Plagiotropis* sp. Pfitzer, 1871	0.56	40	Ac
	Sellaphorales	Pinnulariaceae	*Pinnularia* sp. Ehrenberg, 1843	0.97	100	C
	Mastogloiales	Stauroneidaceae	*Craticula* sp. Grunow, 1868	1.53	100	C
		Amphipleuraceae	*Brachysira* sp. Kützing, 1836	4.32	100	C
			Amphipleura sp. Kützing, 1844	0.83	20	A
	Cocconeidales	Cocconeidaceae	*Cocconeis* sp. Ehrenberg, 1836	0.28	40	Ac
	Bacillariales	Achnanthaceae	*Achnanthes* sp. Bory, 1822	0.14	20	A
		Bacillariaceae	*Nitzschia* sp. Hassall, 1845	8.65	40	Ac
	Surirellales	Surirellaceae	*Amphora* sp. Kützing, 1844	0.69	40	Ac
	Cymbellales	Cymbellaceae	*Cymbella* sp. Agardh, 1830	0.14	20	A
Fragilariophyceae	Tabellariales	Tabellariaceae	*Diatoma* sp. Bory, 1824	3.49	60	C
	Fragilariales	Fragilariaceae	*Fragilaria* sp. Lyngbye, 1819	0.28	20	A
Melosirophyceae	Melosirales	Melosiraceae	*Melosira* sp. Agardh, 1824	0.28	40	Ac
Cyanophyceae	Nostocales	Aphanizomenonaceae	*Anabaena* sp. Bory de Saint-Vincent ex Bornet & Flahault, 1886	34.91	100	C
		Nodulariaceae	*Nodularia* sp. J.V.Lamouroux, 1825	4.88	80	C
		Rivulariaceae	*Calothrix* sp. Agardh ex Bornet & Flahault, 1886	1.95	40	Ac
	Oscillatoriales	Oscillatoriaceae	*Oscillatoria* sp. Gomont, 1892	0.42	40	Ac
		Microcoleaceae	*Lyngbya* sp. Gomont, 1892	0.14	20	A
	Chroococcales	Geminocystaceae	*Cyanobacterium* sp. Rippka & Cohen-Bazire, 2022	1.81	80	C
	Gomontiellales	Cyanothecaceae	*Cyanothece* sp. Komárek, 1976	2.37	60	C
Chlorophyceae	Sphaeropleales	Scenedesmaceae	*Coelastrum* sp. Nägeli, 1849	0.14	20	A
	Volvocales	Palmellopsidaceae	*Asterococcus* sp. Scherffel, 1908	0.14	20	A
		Volvocaceae	*Pandorina* sp. Bory de Saint-Vincent, 1824	6.70	40	Ac
		Chlamydomonadaceae	*Chlamydomonas* sp. Ehrenberg, 1833	0.14	20	A
Trebouxiophyceae	Chlorellales	Oocystaceae	*Oocystis* sp. Nägeli ex A. Braun, 1855	1.11	40	Ac
Euglenophyceae	Euglenales	Phacaceae	*Lepocinclis* sp. Perty, 1849	0.14	20	A
			Phacus sp. Dujardin, 1841	0.14	20	A
		Euglenaceae	*Euglena* sp. Ehrenberg, 1830	0.42	60	C
			Trachelomonas sp. Ehrenberg, 1834	0.56	40	Ac
Zygnematophyceae	Desmidiales	Closteriaceae	*Closterium* sp. Nitzsch ex Ralfs, 1848	0.56	40	Ac
		Peniaceae	*Penium* sp. Brébisson ex Ralfs, 1848	0.28	20	A
	Zygnematales	Zygnemataceae	*Zygnema* sp. C. Agardh, 1817	0.69	60	C
Eustigmatophyceae	Eustigmatales	Chlorobotryaceae	*Vischeria* sp. Pascher, 1939_	0.56	60	C
Chrysophyceae	Hibberdiales	Derepyxidaceae	*Derepyxis* sp. Stokes, 1885	0.14	20	A

frequency (F = 0.28%). The Chlorophyceae ranked among the more abundant classes, with *Pandorina* sp. reaching a notable frequency (F = 6.70%, accessory), markedly higher than the other genera within this class, namely *Coelastrum* sp., *Asterococcus* sp., and *Chlamydomonas* sp., all of which were recorded as accidental taxa (F = 0.14%). The Trebouxiophyceae, represented by *Oocystis* sp., exhibited a moderate abundance frequency (F = 1.11%). The Euglenophyceae were poorly represented, with *Euglena* sp. (F = 0.42%) and *Trachelomonas* sp. (F = 0.56%). Within the Zygnematophyceae, *Zygnema* sp. (F = 0.69%) was recorded as a constant taxon, whereas *Closterium* sp. (F = 0.56%, accessory) and *Penium* sp. (F = 0.28%, accidental). Eustigmatophyceae (*Vischeria* sp., F = 0.56%, constant) and Chrysophyceae (Derepyxis sp., F = 0.14%, accidental) were each represented by a single genus and contributed marginally to overall community composition (Table 4).

Relative abundance contribution of microalgal classes: The analysis of cell density data confirmed

Table 5. Individual numbers and diversity metrics of microalgal assemblages at the studied sites of the Guadaine wetlands complex.

Sites	Taxa richness (S)	Individuals(N)	Shannon index (H')	Equitability(E)
Gamra	19	322	1.61	0.54
Mellal	27	144	2.46	0.74
Draâ Boultif	10	250	1.75	0.76

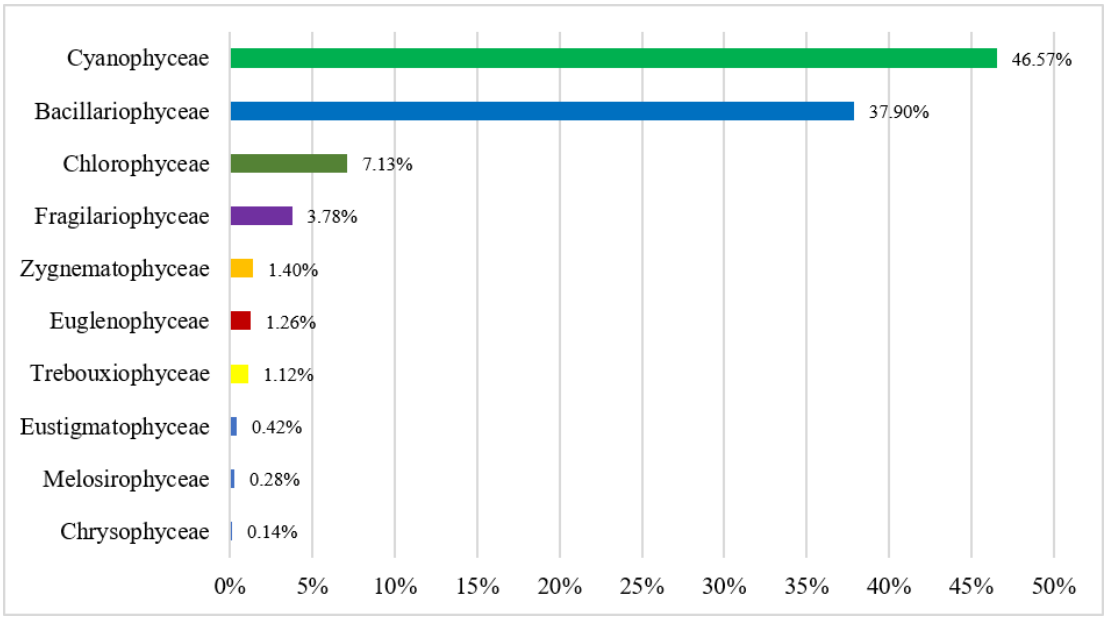


Figure 2. Relative abundance contribution of each microalgal class to total phytoplankton abundance across the Guadaine wetlands complex.

the dominance patterns previously identified through abundance frequency analysis (Table 4), while further quantifying the relative contribution of each taxonomic class to total phytoplankton abundance in the GWC (Fig. 2). A mean total density of 71,500 cells/L was recorded across all sampling stations, with the assemblage being dominated by two classes: the Cyanophyceae, which accounted for nearly half of total phytoplankton abundance (F = 46.57%), and the Bacillariophyceae, contributing more than one-third of the total community (F = 37.90%). Together, these two classes represented 84.47% of the cumulative phytoplankton abundance (Fig. 2).

Chlorophyceae were the third most abundant class, with a markedly lower contribution (F = 7.13%), followed by Fragilariophyceae (F = 3.78%). The remaining six classes, Zygnematophyceae (F = 1.40%), Euglenophyceae (F = 1.26%), Trebouxiophyceae (F = 1.12%), Eustigmatophyceae (F = 0.42%), Melosirophyceae (F = 0.28%), and Chrysophyceae (F = 0.14%), each contributed less than 1.5% to total abundance (Fig. 2), despite their taxonomic richness at the genus level reported.

Taxonomic richness and diversity of phytoplankton: Taxa richness (S) was highest at Mellal (27 taxa), followed by Gamra (19 taxa), while Draâ Boultif harboured the lowest richness (10 taxa), despite recording the second highest total individual count (250 individuals). Mellal had the highest Shannon diversity index (H' = 2.46 bits), consistent with its higher taxonomic richness, while Gamra had the lowest value (H' = 1.61 bits) despite comparable individual counts (322 individuals). Draâ Boultif showed an intermediate Shannon value (H' = 1.75 bits). Gamra had the lowest equitability (E = 0.54), while Mellal and Draâ Boultif had markedly higher equitability values (E = 0.74 and E = 0.76, respectively) (Table 5).

Environmental drivers of microalgal community structure: The Canonical Correspondence Analysis (CCA) revealed strong relationships between microalgal community composition and the 6 measured environmental variables in the GWC (Fig. 3). The first two canonical axes accounted for 96.4%

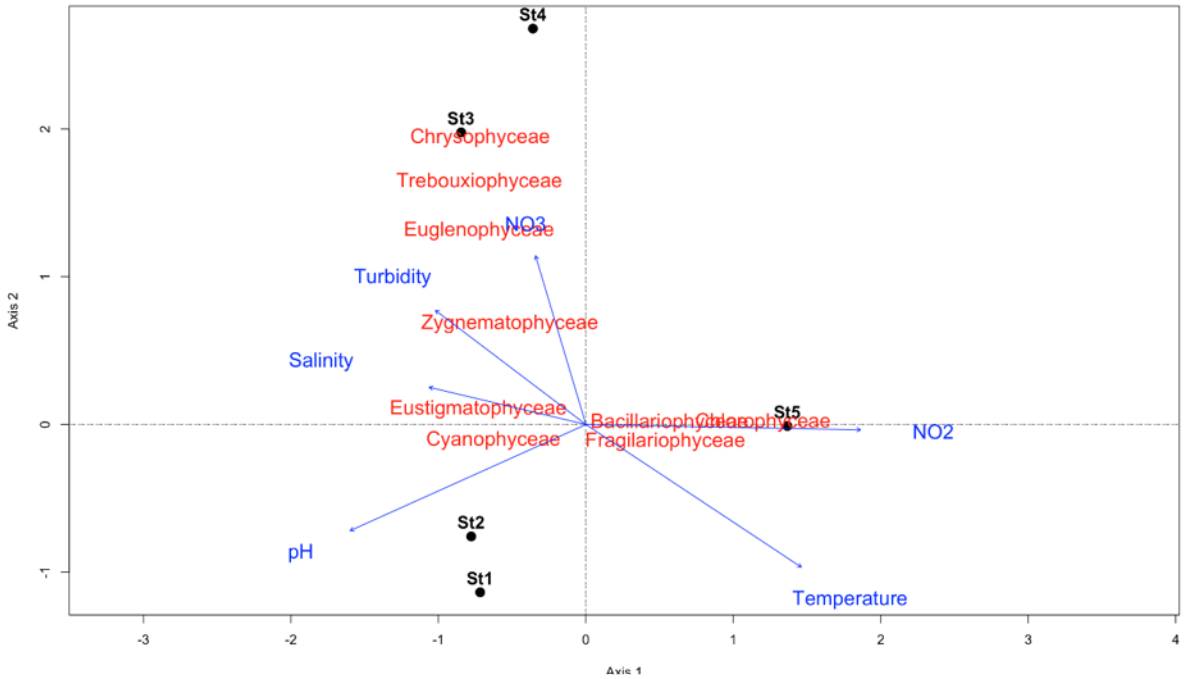


Figure 3. Canonical Correspondence Analysis (CCA) ordination diagram showing the relationships between microalgal classes and environmental variables in the Guadaine wetlands complex.

of the constrained inertia (Axis 1 = 77.2%; Axis 2 = 19.1%). Axis 1 was positively correlated with temperature and NO_2^-, while pH, salinity, and turbidity were negatively correlated. St5 was clearly placed on the positive side of Axis 1 and was associated with NO_2^- and temperature. In contrast, stations St1 and St2 were positioned on the negative side of the axis and were associated with higher pH values. Axis 2 was positively related to NO_3^-. Stations St3 and St4 were located in the upper part and showed a positive association with NO_3^-. Chrysophyceae, Trebouxiophyceae, and Euglenophyceae were distributed along the NO_3^- vector, whereas Chlorophyceae, Bacillariophyceae, and Fragilariophyceae were associated with the temperature and NO_2^- gradient (Fig. 3).

Discussions

The physicochemical characterization of the Guadaine wetlands complex revealed marked spatial heterogeneity among stations, showing the impact of local environmental conditions and hydrological processes. Overall, the water was alkaline, which is typical of wetlands and shallow water bodies in arid and semi-arid regions (Meradi et al., 2024). Such alkaline conditions are generally associated with carbonate-rich substrates, intense evaporation, and elevated photosynthetic activity, all of which endorse the accumulation of bicarbonate and carbonate ions in the water column (Wetzel, 2001). Water temperatures were relatively warm during the sampling period. Temperature is recognized as a major driver of phytoplankton growth, nutrient cycling, and metabolic activity in aquatic ecosystems (Ma et al., 2021). The higher temperatures recorded at Draâ Boultif may enhance biological productivity and nutrient turnover. The conductivity values indicate a relatively high degree of mineralization. These values exceed the WHO limit and, at some stations, surpass Algerian surface-water standards. Houhamdi et al. (2026) found similar results in nearby wetlands in the region. High conductivity in arid wetlands is commonly associated with intense evaporation, concentration of dissolved salts, and weathering of surrounding geological formations. Elevated sodium and chloride concentrations measured at several stations, particularly in Mellal, support this interpretation.

Salinity remained relatively stable, showing persistent influence of dissolved salts and selectively favoring tolerant microalgal taxa adapted to

moderately mineralized waters (Labed, 2025). Turbidity varied substantially among stations, peaking at St3. The increased turbidity noted in the Mellal sub-site may result from suspended sediments, organic matter inputs, or phytoplankton biomass (Domaizon et al., 2012). High turbidity can reduce light penetration and consequently influence the composition and productivity of microalgal communities. Nitrate concentration remained low at all stations and was below both WHO and Algerian standards, limiting nitrate pollution. In contrast, ammonium concentration was consistently high, exceeding recommended thresholds by several fold. Elevated ammonium levels generally reflect recent inputs of organic matter, agricultural runoff, livestock activities, or incomplete nitrification processes. Because ammonium is energetically more favorable for phytoplankton assimilation than nitrate, its abundance may stimulate algal growth and influence species composition (Dortch, 1990; Carpenter et al., 1998). Particularly noteworthy were the very high phosphate concentrations recorded, reaching values up to 10.2 mg/L. These concentrations greatly exceed international and national guideline values and indicate substantial phosphorus enrichment of the ecosystem, representing a major ecological pressure on the GWC.

The pronounced spatial variability observed for nitrite concentration, especially the high value recorded at St5, may indicate localized sources of organic contamination or intensified microbial transformation processes (Fustec and Lefeuvre, 2000). Nitrite is generally an intermediate and unstable product of the nitrogen cycle; therefore, elevated concentration often reflects disturbances in nitrification-denitrification pathways or recent anthropogenic inputs (Wetzel, 2001). Taken together, our results confirm a eutrophic status in GWC waters, driven primarily by ammonium and phosphate enrichment, with spatial heterogeneity reflecting differential exposure to anthropogenic inputs among stations.

The microalgal community was numerically dominated by Cyanophyceae and Bacillariophyceae, which together accounted for over 84% of total cell density. This dominance is common in shallow, nutrient-enriched freshwater ecosystems, where cyanobacteria and diatoms are among the most successful phytoplankton groups under eutrophic to mesotrophic conditions (Reynolds, 2006). In shallow, nutrient-rich freshwater ecosystems, cyanobacteria often dominate phytoplankton, particularly during warm, stable periods. Diatoms often remain an important community component, especially in spring when water mixing, silica availability, and relatively low temperatures favor their development (Reynolds, 2006; Sommer et al., 2012). The numerical dominance of *Anabaena* sp., a nitrogen-fixing genus, is consistent with the elevated phosphate concentration recorded in the GWC. High phosphorus availability, combined with warm temperatures and eutrophic conditions, promotes the proliferation of filamentous, nitrogen-fixing cyanobacteria such as *Anabaena* sp. (Paerl and Huisman, 2008). The co-dominance of *Navicula* sp. among the Bacillariophyceae is consistent with their known ecological preferences for alkaline, moderately mineralized waters with high organic matter content (Krammer and Lange-Bertalot, 1986).

Shannon diversity indices showed spatial heterogeneity across sub-sites. The low diversity and strong abundance recorded at Gamra are consistent with the elevated pH and ionic load at St1 and St2, which may favour dominant cyanobacterial taxa under reduced CO_2 availability and high mineralization (Paerl and Huisman, 2008). Shallow water depth and good light penetration at this site further promote phytoplankton proliferation under stable trophic conditions (Reynolds, 2006). The dominance of a small number of opportunistic taxa suggests that competitive interactions under nutrient-enriched conditions may have reduced diversity, consistent with the resource-competition framework proposed by Tilman (1977). The higher taxonomic richness and Pielou index at Mellal may reflect greater environmental heterogeneity between St3 and St4, particularly the marked contrast in turbidity, which likely generated a wider range of ecological niches supporting a more diverse microalgal assemblage. The

relatively high equitability at Draâ Boultif may reflect reduced species richness rather than an absence of environmental stress, as numerical dominance was less pronounced across fewer competing taxa.

The CCA revealed a clear spatial structuring of phytoplankton assemblage along two orthogonal environmental gradients, interpreted within a strictly exploratory framework given the limited sample size. Axis 1 was dominated by the opposition between NO_2^- and pH, separating St5 associated with Bacillariophyceae and Fragilariophyceae from St1 and St2, where elevated pH and salinity coincided with Cyanophyceae dominance. The co-occurrence of diatoms at St5 is consistent with their well-documented capacity for efficient nitrogen uptake under enriched conditions (Collos, 1982; Lomas and Glibert, 1999), further amplified by the elevated temperature at this station (27.6°C; Eppley, 1972). On the negative side of Axis 1, carbon-concentrating mechanisms and nitrogen fixation confer a decisive advantage to cyanobacteria under elevated pH, where dissolved CO_2 becomes limiting (Paerl and Huisman, 2008). Axis 2 was structured by a NO_3^-/turbidity gradient, positioning St3 and St4 in the upper part of the biplot, where the most taxonomically diverse but least abundant classes occurred. The persistence of Euglenophyceae and Chrysophyceae at St3 despite high turbidity is consistent with mixotrophic strategies that confer a competitive advantage under light-limited conditions (Mitra et al., 2016).

The community structure documented in the Guadaine wetland shares broad similarities with phytoplankton assemblages reported from comparable Algerian and Mediterranean wetlands. The Cyanophyceae-Bacillariophyceae co-dominance pattern is consistent with findings from Meggarine Lake (Manamani and Bensouilah, 2023) and the Belezma biosphere reserve pond (Labed et al., 2024), where similar trophic conditions promote Cyanophyceae proliferation alongside Bacillariophyceae persistence. *Anabaena* sp., *Lyngbya* sp., and *Oscillatoria* sp. are recurrent dominant genera in Mediterranean shallow systems under elevated nutrient loading, a pattern mirrored here, where *Anabaena* sp. alone accounted for nearly 35% of total abundance. Shannon diversity values at Gamra and Draâ Boultif (H' = 1.61-1.75 bits) fall within the range reported for eutrophic North African wetlands, while the higher value at Mellal (H' = 2.46 bits) approaches values typical of mesotrophic Mediterranean systems (H'>2.5 bits), reflecting greater environmental heterogeneity at this sub-site. Overall, the GWC falls among shallow, nutrient-enriched continental water bodies whose microalgal communities are structured primarily by nitrogen speciation, pH, and organic matter inputs, with spatial heterogeneity driven by localized point-source contamination rather than regional gradients.

Conclusion

This study provides the first ecological assessment of microalgal community structure and water quality in the Guadaine wetlands complex, addressing a notable knowledge gap for inland semi-arid wetlands in north-eastern Algeria and in North Africa. The identification of 35 microalgal genera, dominated by Cyanophyceae and Bacillariophyceae, along with systematic exceedances of ammonium, phosphate, and conductivity thresholds, confirms the ecosystem's eutrophic to hypereutrophic status. Microalgal assemblages are primarily structured along a nitrite-pH gradient, with temperature as a secondary amplifying factor; diatoms are favored under nitrite enrichment, and cyanobacteria dominate under elevated pH and mineralization, highlighting phytoplankton communities' sensitivity to localized environmental heterogeneity. These findings support the value of microalgae as early-warning bioindicators of trophic status in semi-arid wetlands and are directly relevant to the ongoing designation of the Guadaine wetlands complex as a protected reserve and Ramsar site, calling for targeted measures to mitigate phosphorus and ammonium inputs. Future studies should extend sampling across seasons and increase station coverage to strengthen the robustness of environment–community relationships and better support long-term conservation planning.

References

AFNOR (2005). Qualité de l'eau - Dosage des matières en suspension - Méthode par filtration sur filtre en fibres de verre. Norme NF EN 872. (in French)

Aït-Kaci M., Louanchi F., Keraghel M.-A., Harid R., Zerrouki M., Mortier L. (2024). Phytoplankton distribution under late summer conditions in the Algerian Basin during SOMBA cruise (2014): A chemotaxonomic approach. Deep Sea Research Part I: Oceanographic Research Papers, 204: 104230.

Benzina I., Si Bachir A., Perennou C. (2022). Waterbird diversity at the Sebkhet of Aures wetlands complex, North East Algeria. Der Ornithologische Beobachter, 119: 318-329.

Benzina I., Si Bachir A., Arar A., Perennou C., Guelmami A. (2024). Using DPSIR framework for the implementation of wetlands observatory: Case study Sebkhates of Aures wetlands complex (Northeast Algeria). Present Environment and Sustainable Development, 18(1): 293-309.

Bhat N.A., Wanganeo A., Raina R. (2015). Seasonal dynamics of phytoplankton community in a tropical wetland. Environmental Monitoring and Assessment, 187: 4136.

Bigot L., Bodot P. (1973). Contribution à l'étude biocénotique de la garrigue à Quercus coccifera — Composition des invertébrés. Vie et Milieu, 23: 229-249. (in French)

Bougoffa S., Benzina I., Telailia S., Si Bachir A. (2023). Ecosystem services, vulnerability and threat levels of Ramsar wetlands in the complex of Aurès Sbkhates, North-Eastern Algeria. Environmental and Socio-economic Studies, 11(2): 16-28.

Bourrelly P. (1988). Les algues d'eau douce. Complément tome I: Les algues vertes. Éditions Boubée. (in French)

Carpenter S.R., Caraco N.F., Correll D.L., Howarth R.W., Sharpley A.N., Smith V.H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications, 8(3): 559-568.

Chaibi R. (2013). Connaissance de l'ichtyofaune des eaux continentales de la région des Aurès et du Sahara septentrional avec sa mise en valeur. Thèse de doctorat, Université Mohamed Khider de Biskra. (in French)

Collos Y. (1982). Transient situations in nitrate assimilation by marine diatoms. 2. Changes in nitrate and nitrite following a nitrate perturbation. Limnology and Oceanography, 27(3): 528-535.

Compère P. (1974). Algues de la région du lac Tchad. II: Cyanophycées. Cahiers ORSTOM, Série Hydrobiologie, 8(3-4): 165-198. (in French)

Compère P. (1975). Algues de la région du lac Tchad. IV: Diatomophycées. Cahiers ORSTOM, Série Hydrobiologie, 9(4): 205-290. (in French)

Dajoz R. (2003). Précis d'écologie, 7e éd. Dunod. (in French)

Davidson N.C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. Marine and Freshwater Research, 65(10): 934-941.

Domaizon I., Laine L., Lazzarotto J., Perga M.E., Rimet F. (2012). Suivi de la qualité des eaux du lac d'Annecy: Rapport 2011. SILA & INRA Thonon. 92 p. (in French)

Dortch Q. (1990). The interaction between ammonium and nitrate uptake in phytoplankton. Marine Ecology Progress Series, 61: 183-201.

Effendi H., Kawaroe M., Lestari D.F., Mursalin, Permadi T. (2016). Distribution of phytoplankton diversity and abundance in Mahakam Delta, East Kalimantan. Procedia Environmental Sciences, 33: 496-504.

Eppley R.W. (1972). Temperature and phytoplankton growth in the sea. Fishery Bulletin, 70(4): 1063-1085.

Fustec E., Lefeuvre J.C. (2000). Fonctions et valeurs des zones humides. Dunod. (in French)

Ghermandi A., van den Bergh J.C.J.M., Brander L.M. (2008). The economic value of wetland conservation and creation: A meta-analysis. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.1273002

Hammana C., Pereña-Ortiz J.F., Meddad-Hamza A., Hamel T., Salvo-Tierra Á.E. (2024). The wetlands of Northeastern Algeria (Guelma and Souk Ahras): Stakes for the conservation of regional biodiversity. Land, 13(2): 210.

Huang Y., Shen Y., Zhang S., Li Y., Sun Z., Feng M., Li R., Zhang J., Tian X., Zhang W. (2022). Characteristics of phytoplankton community structure and indication to water quality in the lake in agricultural areas. Frontiers in Environmental Science, 10: 833409.

Huston M.A. (1994). Biological diversity: The coexistence of species on changing landscapes. Cambridge University Press. 671 p.

Journal Officiel de la République Algérienne Démocratique et Populaire (2011). Décret exécutif n° 11-219 du 10 Rajab 1432 correspondant au 12 juin 2011 fixant les objectifs de qualité des eaux superficielles et souterraines destinées à l'alimentation en eau des populations. Journal Officiel de la République

Algérienne, 34: 4-6.

Kingsford R.T., Basset A., Jackson L. (2016). Wetlands: Conservation's poor cousins. Aquatic Conservation: Marine and Freshwater Ecosystems, 26: 892-916.

Krammer K., Lange-Bertalot H. (1986). Bacillariophyceae. 1. Teil: Naviculaceae. In: H. Ettl, J. Gerloff, H. Heynig, D. Mollenhauer (Eds.). Süsswasserflora von Mitteleuropa, Gustav Fischer Verlag. pp: 1-876.

Labed A. (2025). Structure, dynamique et typologies physicochimiques et phytoplanctoniques des zones humides du Parc National de Belezma Batna. Thèse de doctorat, Université Batna 2. (in French)

Labed A., Si Bachir A., Benzina I., Ghazi C., Chaibi R. (2024). Structure and seasonal distribution patterns of phytoplankton in a natural mountain pond of the Belezma biosphere reserve (Northern East Algeria). Die Bodenkultur: Journal of Land Management, Food and Environment, 75(2): 77-89.

Lomas M.W., Glibert P.M. (1999). Interactions between nitrate and ammonium uptake and assimilation: Comparison of diatoms and dinoflagellates at different growth temperatures. Marine Biology, 133(3): 541-551.

Ma C., Zhao C., Mwagona P.C., Li Z., Liu Z., Dou H., Zhou X., Bhadha J.H. (2021). Bottom-up and top-down effects on phytoplankton functional groups in Hulun Lake, China. Annales de Limnologie: International Journal of Limnology, 57: 3.

Madhavi K., Amin A., Vidya Sagar Reddy G., Devi Varaprasad Reddy A. (2014). Wetlands, the waterlogged wealth: A review. Continental Journal of Fisheries and Aquatic Science, 8(1): 1-9.

Magurran A.E. (2004). Measuring biological diversity. Blackwell Publishing. Oxford. 256 p.

Manamani R., Bensouilah M. (2023). Water physicochemical characterization and phytoplankton diversity of arid region in Meggarine Lake, Ouargla, Algeria. Biodiversitas Journal of Biological Diversity, 24(3): 1660-1669.

Mesquita M.C.B., Prestes A.C.C., Gomes A.M.A., Marinho M.M. (2020). Direct effects of temperature on growth of different tropical phytoplankton species. Microbial Ecology, 79: 1-11.

Mitra A., Flynn K.J., Tillmann U., Raven J.A., Caron D., Stoecker D.K., Not F., Hansen P.J., Hallegraeff G., Sanders R., Wilken S., McManus G., Johnson M., Pitta P., Våge S., Berge T., Calbet A., Thingstad F., Jeong H.J., Burkholder J., et al. (2016). Defining planktonic protist functional groups on mechanisms for energy and nutrient acquisition: Incorporation of diverse mixotrophic strategies. Protist, 167(2): 106-120.

Ochs C.A., Capello H.E., Pongruktham O. (2010). Bacterial production in the Lower Mississippi River: Importance of suspended sediment and phytoplankton biomass. Hydrobiologia, 637: 19-31.

Oksanen J., Simpson G., Blanchet F., Kindt R., Legendre P., Minchin P., O'Hara R., Solymos P., Stevens M., Szoecs E., Wagner H., Barbour M., Bedward M., Bolker B., Borcard D., Carvalho G., Chirico M., De Caceres M., Durand S., et al. (2024). vegan: Community ecology package. Version 2.7-5. CRAN. https://CRAN.R-project.org/package=vegan

Paerl H.W., Huisman J. (2008). Blooms like it hot. Science, 320(5872): 57-58.

Palafox-Juárez E.B., Callejas-Jiménez M.E., Herrera-Silveira J.A., Teutli-Hernández C., Camacho-Valdez V., López-Martínez J.O. (2025). Effects of land use change on ecosystem services in freshwater wetlands in Bacalar, Mexico. PeerJ, 13: e18954.

Perennou C., Beltrame C., Guelmami A., Tomàs V.P., Caessteker P. (2012). Existing areas and past changes of wetland extent in the Mediterranean region: An overview. Ecologia Mediterranea, 38(2): 53-66.

Prescott G.W. (1954). How to know the freshwater algae. Wm. C. Brown Company. https://archive.org/details/howtoknowfreshwa00pres

R Core Team (2024). R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/

Reynolds C.S. (2006). The ecology of phytoplankton. Cambridge University Press. 535 p.

Rifai N., Khattabi A., Moukrim S., Arahou M., Rhazi L. (2018). Évaluation de la dynamique de l'occupation du sol dans la zone humide RAMSAR de Tahaddart (Nord-Ouest du Maroc). Revue d'Écologie (Terre et Vie), 73: 142-152. (in French)

Sommer U., Adrian R., De Senerpont Domis L., Elser J.J., Gaedke U., Ibelings B., Jeppesen E., Lürling M., Molinero J.C., Mooij W.M., van Donk E., Winder M. (2012). Beyond the Plankton Ecology Group (PEG) model: Mechanisms driving plankton succession. Annual Review of Ecology, Evolution, and Systematics, 43: 429-448.

Sournia A. (1984). Classification et nomenclature de divers Dinoflagellés marins (Dinophycées). Phycologia, 23: 245-355. (in French)

Sournia A. (1986). Atlas du phytoplancton marin. Vol. I:

Introduction, Cyanophycées, Dictyophycées, Dinophycées et Raphidophycées. CNRS. (in French)

Tilman D. (1977). Resource competition between plankton algae: An experimental and theoretical approach. Ecology, 58(2): 338-348.

Utermöhl H. (1958). Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. Mitteilungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie, 9(1): 1-38. (in German)

Véla E., Benhouhou S. (2007). Évaluation d'un nouveau point chaud de biodiversité végétale dans le Bassin méditerranéen (Afrique du Nord). Comptes Rendus Biologies, 330(8): 589-605. (in French)

Visser P.M., Verspagen J.M.H., Sandrini G., Stal L.J., Matthijs H.C.P., Davis T.W., Paerl H.W., Huisman J. (2016). How rising CO2 and global warming may stimulate harmful cyanobacterial blooms. Harmful Algae, 54: 145-159.

Wetzel R.G. (2001). Limnology: Lake and river ecosystems, 3rd ed. Academic Press.

Whitton B.A. (2012). Changing approaches to monitoring during the period of the "Use of Algae for Monitoring Rivers" symposia. Hydrobiologia, 695(1): 7-16.

Williams W.D. (2001). Anthropogenic salinization of inland waters. Hydrobiologia, 466(1): 329-337.

World Health Organization (2018). WHO guideline values for drinking-water quality: Chemical contaminants I. Available from: https://www.ncbi.nlm.nih.gov/books/NBK535301/

Zhang N., Liu Y., Zang S. (2016). Relationships between phytoplankton community in different functional regions and environmental factors in Zhalong Wetland, Heilongjiang Province. Journal of Lake Sciences, 28: 554-565.