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Microalgae Diversity and Water Quality Assessment across Seven Hydro Systems in the Lower Sahara Wetland Complex, Algeria

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Abstract: The present work is aimed at establishing, for the first time, the ecological inventory and spatial distribution of the microalgae population in the wetlands of the Lower Sahara eco-complex. Water quality monitoring was carried out on a monthly basis over the period from April 2017 to March 2018 in seven hydro systems in the Lower Sahara wetland complex, while the microalgae sampling was carried out in April 2018. The results obtained indicated that the waters of the study sites did not present a clear thermal stratification and were moderately alkaline to alkaline pH, slightly brackish to very brackish, and generally clear. pH, turbidity, and salinity varied significantly depending on the study sites. The microalgae diversity revealed thirty-seven genera, thirty-one families, twenty-three orders, and six classes, with dominance in the number of genera belonging to the class Bacillariophyceae with an abundance of 80%. The highest values of total richness, Shannon-Weaver and Equitability indices were recorded at Lake Megarine (S=23, H’=3.33, E=74%). Cluster analysis showed four groups by cutting similar tree at a distance of 0.35**,** which suggests the significance of both the site typology and water salinity in the distribution of microalgae in the region.

Keywords: Microalgae; Water Quality; Diversity and Distribution; Hydro systems; Lower Sahara complex

Introduction

As elsewhere in the world and more particularly in the Mediterranean region, in Algeria, especially in the vast Sahara region, water resources are limited, fragile, and threatened (Margat and Vallée, 1999; Khamar *et al*., 2000; Mutin, 2000; Azzaoui *et al*., 2002). Worse still, there is the lack or insufficiency of data on the physicochemical quality of water in continental aquatic ecosystems and their evolution over time in addition to the bioecology of the biodiversity that lives there, in particular, their taxonomies, which are essential for highlighting the interactions between species and their biotope. To this end, Algeria, along with several other countries around the Mediterranean region, has been committed to developing and implementing a wetland strategy based on an ecosystem approach, to ensure the multi-sectoral and sustainable management of wetlands and their resources (DGF, 2016). The implementation of the national wetland strategy has enabled the creation of sixteen complexes, the largest of which is that of the Lower Sahara (DGF, 2016).

Microalgae constitute an important part of the ecology of aquatic environments (Gayral, 1975). They are the first link in the food chain in aquatic environments. They produce nearly 70% of atmospheric oxygen (Caratini, 1985) and are, thus, at the heart of the living world (Chadefaud, 1960). On the other hand, microalgae are considered the compartment that responds most quickly to variations in environmental parameters and, therefore, to the restoration processes, through which the drastic reduction or increase in nutrient inputs leads to increased competition within phytoplankton communities. Indeed, knowledge of the biomass, abundance and composition of a phytoplankton population is essential for evaluation and decision-making through which measurements of a situation or a spatio-temporal trend can be taken as objectively as possible (bio-indicator). (Garrido and Pasqualini, 2013). Better yet,

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is their socio-economic role, particularly in the pharmaceutical, agri-food, cosmetic and aquaculture industries (Spolaore *et al*., 2006). In the Saharan region, on both the ecological and socio-economic levels, little work has been devoted to the study of the physicochemical and biological quality of water, in particular through the exploration of microalgal communities. Few works can be cited here, namely Chaibi (2013), Labed (2013), Babaousmail (2014), Benakli and Meghchouche (2016), Khellou *et al.* (2018) and Adraoui *et al.*(2024). To fill this gap, this study is aimed at enhancing knowledge on phytoplankton biodiversity through the establishment, for the first time, of a taxonomic list, and as exhaustive as possible, the determination of the different ecological indices and their variation across the sites studied. The study also presents an evaluation of the water quality in six hydro-systems located in the complex of the wetlands of the lower Sahara with an analysis of the impact of environmental parameters on the distribution of the microalgae population in the Saharan region

Materials and Methods

Study Sites

The Lower Sahara Wetlands Complex (Fig. ure 1) is located in the southeastern part of Algeria and extends over 29,000 km between longitude 1°54’21.6” and 8°1’51.6” E and latitude 27°55’58.8” and 35°35’2.4” N. It is distinguished by a Saharan climate with a dry period that extends throughout the year. Despite the scarcity of water in the region, it harbors several wetlands of different typologies (Chott, Sebkhat and Wadis), which are classified, in some areas, as the Ramsar sites, including Chott Melrhir, Chott Merouane and Oued Khrouf, Chott Aïn El Beïda, Chott Oum El Raneb, and Chott Sidi Slimane. The Lower Sahara wetlands are subject to remarkable anthropogenic pressure, and they serve as an outlet for wastewater and water from agricultural drainage systems (Ghazi *et al*. 2016).

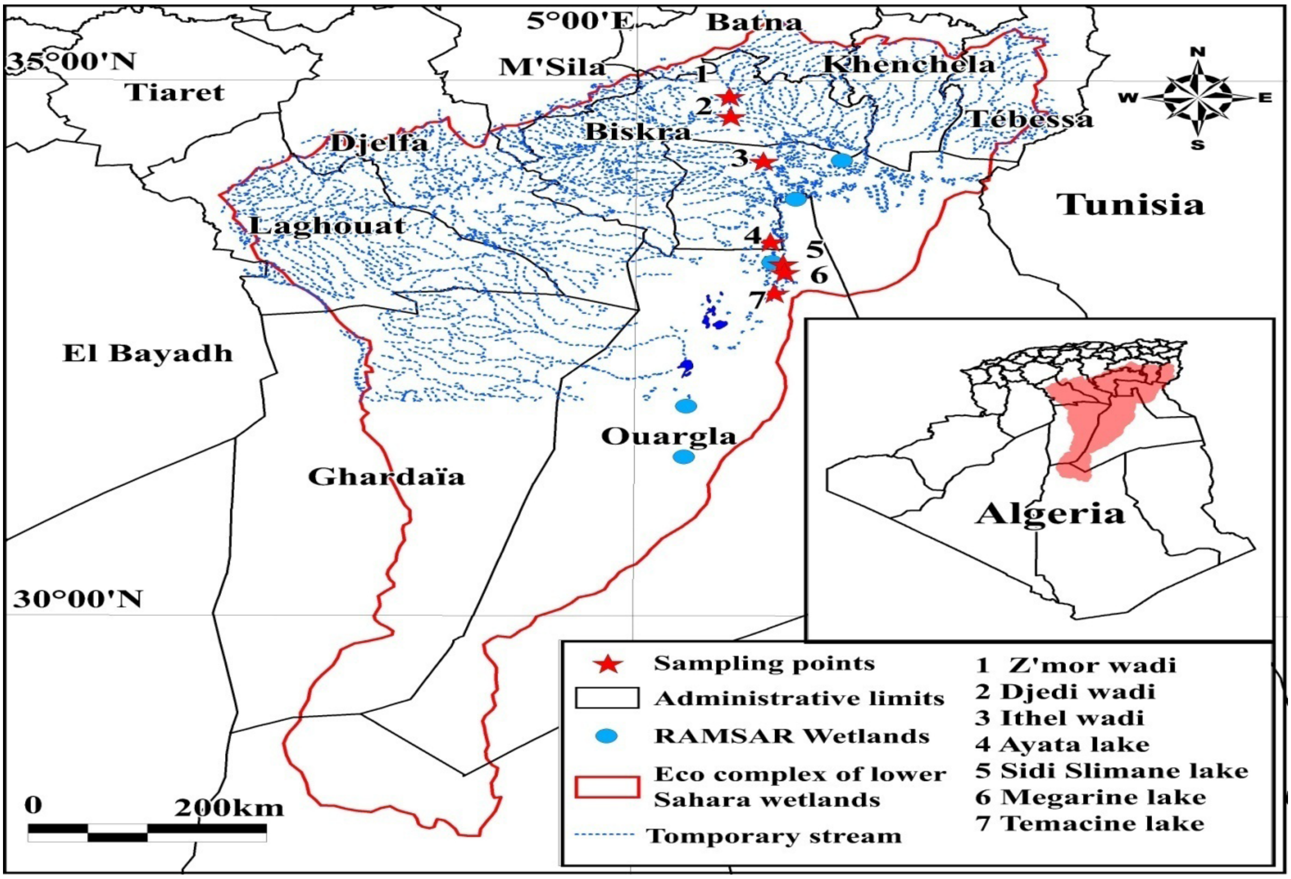

Figure 1. Geographical location of the sampling sites in the Lower Sahara wetland complex (Algeria)

Sample collection

In order to obtain qualitative and quantitative data on the microalgae community in the Lower Sahara Wetlands, seven sites were surveyed in April 2018. These include Z'mor Wadi, Djedi Wadi, Ithel Wadi, Lake Ayata, Lake Sidi Slimane, Lake Megarine, and Lake Temacine (3 lotic and 4 lentic hydro-systems). According to Laplace- Treyture *et al.,* (2010), the suitable sampling period should cover the summer period (hot in this study) extending from April to October. The environmental characteristics were recorded for each site using a range of descriptors, including water temperature in situ measured by a mercury thermometer, pH, turbidity, and salinity were measured using a pH meter, turbidity meter and a conductometer, respectively (excluding Lake Sidi Slimane) at the laboratory of the Algerian Water Agency (ADE) in Batna. A plankton net (silk net with a mesh less than 1 mm in diameter, a cylinder of 35 cm in diameter and a length of 45 cm) was also used in this study. A content of 100 ml was recovered from each site by filtering a constant volume (20 liters of natural surface water) from the first meter of the water column, removing floating particles at a sufficient distance from the bank (Druart and Rimet, 2008).

The samples were preserved in a 5% formaldehyde solution. The cells were counted using an optical microscope (SIZZ type) with different magnifications (Gr x 10) and (Gr x 40), a counting cell (Hemocytometer), a graduated pipette, and a camera to take instantaneous shots preceded by the addition of a few drops of Lugol's solution in a 250 ml sample (filtrate) to kill the algae, and finally weigh them down to facilitate their sedimentation. The identification of the microalgal flora was carried out through the microscopic observation of the morpho-anatomical criteria cited in different identification keys (Bourelly, 1985; Michel, 1987)

Diversity measurement*:*

Relative Abundance (A), richness (S), Shannon-Wiener diversity index (H′), and Equitability index and their variation depending on the study sites were calculated to measure spatial change in the microalgae community. (Shannon and Weaver, 1949; Daget, 1976).

$$A\% = \frac{n_i}{N} \times 100$$

$$H` = -\sum P_i \log_2 P_i$$

$$(P_i = \frac{n_i}{N})$$

$$E = \frac{H`}{\log_2 S}$$

Where *ni* is the individual number of species I; *Pi* is the ratio of the individual number of species i to the total individual number *N*; and *S* is the total number of species.

Statistical analysis

All environmental variables were checked for normality using the Shapiro-Wilks normality test. If the data passed the normality test, ANOVA and Tukey's HSD post-hoc tests were conducted to check the spatial variation in the physico-chemical quality of water in the five hydro-systems. Otherwise, the Kruskal–Wallis test was used. Dunnett's rank-based multiple comparisons were performed to identify which variables have the significant difference. To highlight the groups representing the phytoplankton populations, the hierarchical ascending classification (HAC) using Euclidean distance and "complete linkage" as aggregation criteria was applied to the study the sites.

Results

Physicochemical quality of water

In all the sites studied, the average annual water temperature was always higher than 20 ° C, while in Z'mor Wadi it was equal to 18.83±7.6 °C. This difference is not significant ($P > 0.05$). The minimum temperatures in the sites studied vary from 10.5 ° C in Lake Ayata to 7 ° C in Ithel Wadi, while the maximum values oscillate between 33 ° C in Z'mor Wadi and 46.9 ° C in Djedi

Wadi. (Table 1). The study of the variation of pH across the study sites, indicates that the averages of pH recorded oscillate between 7.8 and 8.4. The highest average was noted in Z'mor Wadi, while Ithel Wadi showed the minimum average. This variation is highly significant ($F = 4.6$; $P = 0.001$) (Table 1). Water turbidity varied from one site to another. It was between 2.5 NTU and 5.5 NTU (nephelometric turbidity unit) for the three studied lakes and the Ithel Wadis. On the other hand, the turbidity averages recorded in Z'mor Wadi and Djedi Wadi were greater than 9.8 NTU. For the latter site, the turbidity average was the highest at 16.6 NTU. The Kruskal–Wallis test indicates that turbidity varies in a highly significant manner depending on the study sites ($K = 36.9$; $P < 0.0001$). The Dunn's bilateral test confirms the results obtained and allows for the distinction of three groups, the first of which is represented by the three lakes, the second by the Z'mor Wadi, and the third by the Djedi Wadi (Table 1). The non-parametric test denotes that the spatial variation of salinity is significant ($K = 58.62$; $P < 0.0001$) and four homogeneous groups were identified. The recorded averages indicate that the salinity in Lake Ayata, Lake Temacine and the Djedi Wadi is low compared to other sites. The averages obtained are respectively of the order of 7.2 ‰; 6 ‰ and 3.5 ‰. On the other hand, in Z'mor and the Ithel Wadis as well as in Lake Megarine, salinity was always higher than 12.5 ‰. (Table 1)

Table 1: Spatial variation of the parameters of the physicochemical quality of water in the studied hydro-systems of the complex of the wetlands of the lower Sahara (SD: Standard deviation ; a, b and c indicate the groups of identical average)

Parameters Sites	water temperature °C		pH		Water turbidity (NTU)		Salinity ‰	
	Mean ±SD	Min/Max	Mean ±SD	Min/Max	Mean ±SD	Min/Max	Mean ±SD	Min/Max
Z'mor Wadi,	$18.8±7^{a}$	9/33	$8.4 ±0.6^{a}$	7.3/9.4	$9.8± 8.4^{b}$	2.25/24	$17.5± 2.5^{a}$	15/24
Djedi Wadi,	$25.8±11^{a}$	10/46	$8.3 ±0.4^{a}$	7.2/8.9	$16.6± 10.2^{a}$	6.7/35	$3.5 ±0.9^{c}$	2.3/5.5
Ithel Wadi,	$20.3±10^{a}$	7/46	$7.8 ±0.3^{b}$	7.2/8.4	$5.5± 3.2^{bc}$	0.5/12	$12.71 ± 6.1^{ab}$	2/24
Lake Ayata,	$22.5±7.4^{a}$	12/38	$7.8±0.34^{b}$	6.9/8.7	$4.1± 3.35^{c}$	0.42/12	$7.24± 6.2^{bc}$	5.2/32.8
Lake Megarine	$23.5±8.2^{a}$	12/38	$7.8±0.42^{b}$	6.9/8.5	$3.5± 2.35^{c}$	0.43/9.3	$16.8± 9.7^{a}$	5.7/32.6
Lake Temacine	$21.6±7.7(^{a})$	7/35	$7.9±0.44^{ab}$	6.8/8.6	$2.5± 1.3^{c}$	0.6/6.3	$6± 1.16^{c}$	1.7/7.1

Diversity and distribution of the microalgae community

In the studied hydro-systems of the northern Sahara, thirty-seven genera were recorded, thirty-one families, twenty-three orders, and six classes. Among the thirty-seven taxa identified, 71% (or 26 genera) belong to the class Bacillariophyceae, 15.8% belong to the class Cyanobacteria and two genera (2.9%) to the class Dinophyceae. The classes Synurophyceae, Trebouxiophyceae, and Dinophyceae are represented by only one genus. In terms of families, Amphipleuraceae which belongs to the class Bacillariophyceae is represented by three genera, followed by Naviculaceae, Tabellariaceae, and Stephanodiscaceae which belong to the class Bacillariophyceae each with two genera. Additionally, Oscillatoriaceae belongs to the Cyanobacteria family and includes two genera. The remaining families are represented by only one genus. Furthermore, the majority of inventoried orders are represented by one and/or two families with the exception of the Naviculales order which is considered the most diverse inclusive of seven families (Table 2).

Bacillariophyceae is omnipresent in the studied hydro-systems with abundance greater than 92%; their maximum abundance was observed at the Dejdi Wadi , with dominance of the genus *Cyclotella* followed by *Pleurosigma*. Cyanobacteria which come second in position in terms of abundance, reached maximum abundance at Lake Megarine, with the dominance of the genus *Merismopeda* at18%. The relative abundance of the genera belonging to Synurophyceae Trebouxiophyceae, Dinophyceae, Chlorophyceae, was always less than 5%. It is to be noted that *Oocystis* was present only in Lake Megarine and that *Synura* was reported only at the Z'mor Wadi and Lake Megarine (Figure 2)

Table 2: Taxonomic inventory of the microalgae recorded in the tested hydro-systems of the Lower Sahara wetlands complex

Class	Order	Family	Genera
Bacillariophyceae	Naviculales	Naviculaceae	*Navicula*
			Caloneis
		Amphipleuraceae	*Amphipleura*
			Frustulia
		Stauroneidaceae	*Stauroneis*
		Pinnulariaceae	*Pinnularia*
		Diploneidaceae	*Diploneis*
		Pleurosigmataceae	*Pleurosigma*
		Cymbellaceae	*Cymbella*
	Bacillariales	Bacillariaceae	*Nitzschia*
	Fragilariales	Fragilariaceae	*Synedra*
	Tabellariales	Tabellariaceae	*Diatoma*
			Asterionella
	Mastogloiales	Achnanthaceae	*Achnanthes*
	Cocconeidales	Cocconeidaceae	*Cocconeis*
	Eunotiales	Eunotiaceae	*Eunotia*
	Thalassophysales	Catenulaceae	*Amphra*
	Surirellales	Entomoneidaceae	*Entomoneis*
		Surirellaceae.	*Campylodiscus*
			Suririlla
	Cymbellales	Gomphonemataceae	*Gomphonema*
	Melosirales	Melosiraceae	*Melosira*
	Rhopalodiales	Rhopalodiaceae	*Epithemia*
	Mastogloiales	Mastogloiaceae	*Skeletomastus*
	Stephanodiscales	Stephanodiscaceae	*Stephanodiscus*
			Cyclotella
Cyanobacteria	Nostocales	Hapalosiphonaceae	*Hapalosiphon*
		Nostocaceae	*Anabaena*
	Oscillatoriales	Oscillatoriaceae	*Oscillatoria*
			Lyngbya
	Chroococcales	Gomphosphaeriaceae	*Gomphosphaeria*
	Synechococcales	Merismopediaceae	*Merismopeda*
Synurophyceae	Synurales	Synuraceae	*Synura*
Trebouxiophyceae	Chlorellales	Oocystaceae	*Oocystis*
Dinophyceae	Gonyaulacales	Pyrophacaceae	*Pyrophacus*
	Gymnodiniales	Gymnodiniaceae	*Gymnodinium*
Chlorophyceae	Sphaeropleales	Scenedesmaceae	*Scendesmus*

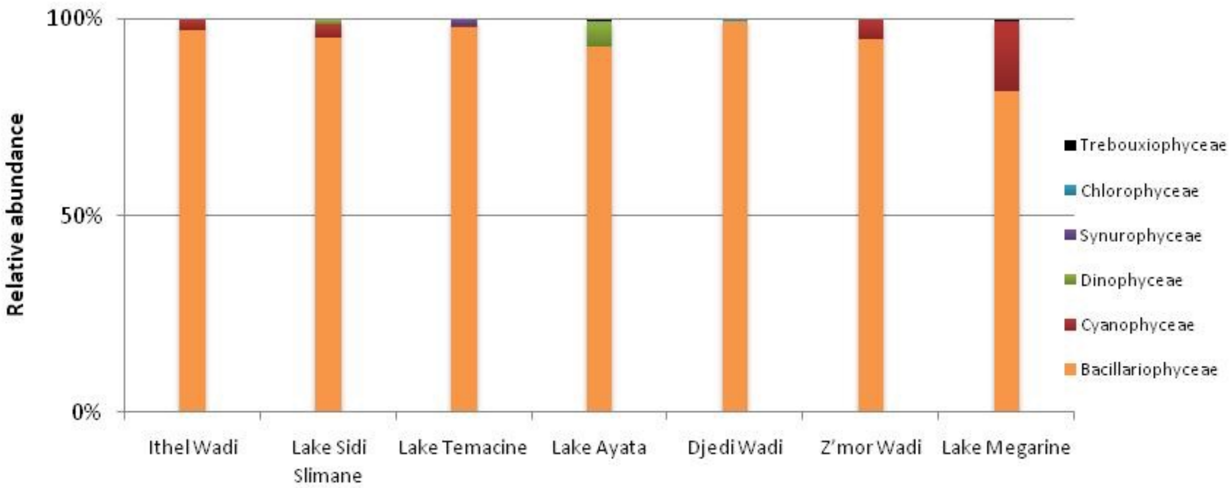

Figure 2. Spatial variation of microalgae abundance in the tested hydro-systems of Lower Sahara wetland complex (Algeria)

The highlighting of the variation in the diversity indices of the microalgae in the study sites indicates that Lake Megarine has the highest total richness with twenty-three taxa, followed by Lake Ayata and Z'mor Wadi. The total richness of the other sites was between fourteen and ten taxa (Table 2). The Shannon diversity index indicates that Lake Megarine is the most diverse site, and that the lowest diversity was noted at Djedi Wadi. In the latter, the calculated equitability was the lowest at 13%, while Lake Ayata showed the highest equitability at 87% (Table 3).

The analysis of the spatial distribution of the different genera of the microalgae in the studied sites produced four groups by cutting the similarity tree at a distance of 0.35 (Figure 3). The first group included only Lake Ayata, with six taxa (*Oscillatoria; Lyngbya; Hapalosiphon; Cymbella; Melosira; Anabaena*). The second group is represented by two sites, namely Lake Megarine and the Z'mor Wadi which showed the largest number of taxa (15 genera: *Caloneis; Gymnodinium; Entomoneis, Campylodiscus, Gomphonema, Asterionella, Synura, Eunotia, Stephanodiscus, Pyrophacus, Scendesmus, Skeletomatus, Achnanthes, Epithemia,*and *Merismopeda)*. The third group included Lake Sidi Slimane represented by eight taxa (*Navicula; Oocystis; Diploneis; Pinnularia; Synedra; Amphra; Gomphosphaeria*, nd *Cocconeis*). Lake Temacine, Ithel Wadi, and Djedi Wadi, make up the last group, which includes eight taxa (*Frustulia; Amphipleura; Cyclotella; Diatoma; Suririlla; Stauronies; Nitzschia,* and *Pleurosigma*).

Discussion

The air temperature and solar energy whose seasonal variations determine the physicochemical and biological characteristics of the waters, especially the water temperature of shallow hydro-systems (Hamed *et al.*, 2012). Added to this is the effect of the warm waters of the groundwater tables in the study region which

Table 3: Total specific richness (S), Shanon diversity index (H') and equal distribution (E) of microalgae communities recorded in the tested hydro-systems of the Lower Sahara wetland complex

Sites Diversity index	Ithel Wadi	Lake Sidi Slimane	Lake Temacine	Lake Ayata	Djedi Wadi	Z'mor Wadi	Lake Megarine
S	13	14	12	20	10	17	23
H'	2,68	1,88	0,86	3,75	0,43	1,94	3,33
H'_{max}	3,70	3,81	3,58	4,32	3,32	4,09	4,52
E%	73%	49%	24%	87%	13%	47%	74%

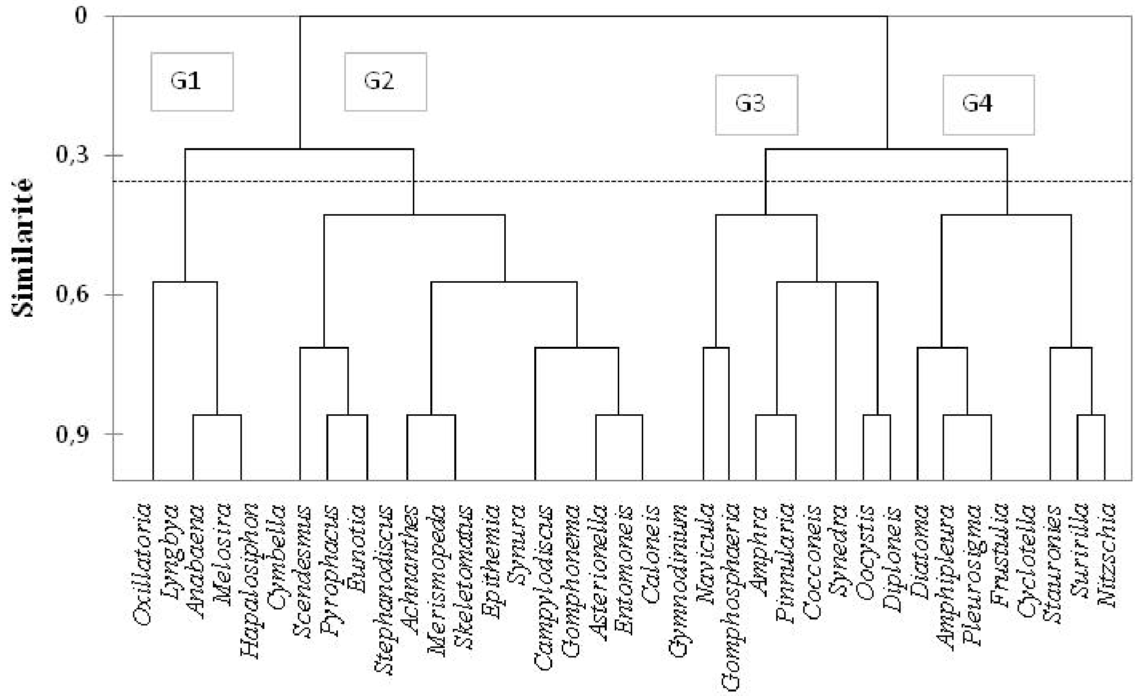

Figure 3. Cluster analysis on the presence-absence matrix of the microalgae taxa recorded in the tested hydro-systems in the Lower Sahara wetland complex (Algeria) (G1: Lake Ayata; G2: Lake Megarine, Z'mor Wadi; G3: Lake Sidi Slimane; G4: Lake Temacine, Ithel Wadi, Djedi Wadi)

are considered as a main source of supply in a direct or indirect way through the irrigation water surpluses coming from the drainage system of the neighboring palm groves; these largely control the variations in water temperatures of the studied sites (Tabouche & Achour, 2004; Debbakh, 2012).

The spatial variation of pH indicates that the sites studied are slightly alkaline to alkaline. According to the scale adopted by Hecker *et al.,* (1996) a pH > 7.4 characterizes alkaline waters. Indeed, pH is influenced by physical, chemical, and biological characteristics (Hade, 2004). The esults of this study indicate that the Z'mor and the Djedi Wadis have a pH higher than that recorded in the three studied lakes. This difference in the pH averages between lotic and lentic hydro systems can be explained by the biological activity; running waters are well oxygenated which increases the intensity of photosynthesis (Westlake and Ladle 1995), while in stagnant waters, the degradation of organic matter can lead to the acidification of the water (Tremblay *et al*, 2014).

In all studied sites, the recorded turbidity averages (<30 NTU) denote clear water according to the U.S. Environment Protection Agency classes. The obtained results reveal that the water quality of the study sites varies from very good to fair. In the three lakes studied, the averages of the turbidity recorded were comparable with those noted by Hammouda (2013), while the significant turbidity was higher in the Djedi wadi compared to the other sites. This reflects the significant status of this wadi as it represents the main collector of runoff waters for an area of approximately 9130 km2 on the southern flank of the Saharan Atlas (Bouchemal, 2017)

In the Saharan region, the origin of salinity is mainly primary but also secondary (Boutouga, 2012). According to Chevallier (2007), the waters of the Djedi Wadi are slightly brackish, while in the other sites, water is brackish to very brackish. Indeed, the intercalary continental aquifer in the northern region of Oued Rhir is more confined compared to the south; consequently, the waters of this aquifer are saltier (OSS, 2003).

The inventory of the microalgal flora recorded in the wetlands of the lower Sahara is comparable with several works carried out in the region, such as that of Chaibi (2013) in

Lake Ayata (23 genera), Babaousmail (2014) in Chott Ain El Baida and the drains of the Ouargla region (19 species), Khellou *et al.* (2018) in Lake Megarine (36 genera), and Adaouri *et al.* (2024) in the Central Sahara (77 species).

On the other hand, in the semiarid and humid bioclimatic stages, the census of the microalgae showed greater richness compared to the current study region. Chaibi (2013) reported the presence of seventy-two genera in the Timagad dam (Batna), and fifty-seven genera were recorded by Hamidouche and Tetah (2017) in the Bejaia region. Also, in most of the aforementioned works, Bacillariophyceae was always the best represented class, which agrees with the results of the current study. Indeed, Bacillariophyceae is one of the most important phytoplankton groups including over 100,000 species (Gorga, 2012). According to Zrinka *et al.* (2007), the abundance of the Cyclotella taxon can be explained by its broad tolerance to fluctuations in environmental factors, including salinity and temperature. Similarly, the genus Pleurosigma is distinguished by high conductance and is frequently found in marine and brackish environments. Thus, Adaouri *et al.* (2024) reported that the species *Cyclotella ocellata* can be found in sites with a lower salinity (0.2), which is the case for the Djedi wadi.

The difference among the four groups found after the hierarchical clustering is most likley due to the typology of the ecosystem on the one hand and the salinity of the water on the other. The homogeneous groups of the spatial variation in salinity obtained in the present study, are similar to the groups of the spatial distribution of microalgae communities formed by the CAH. Record (2009) pointed out the sensitivity of Bacillariophyceae to salinity and that it is very heterogeneous among the different taxa composing this group which affects their survival. In addition, the depth and flow of the hydro-systems play a major role in the growth and density of the algae (Saros *et al*. 2014). Necib *et al.* (2013) reported that some genera of Cyanobacteria are restricted to stagnant waters. Lavoie *et al*. (2007), indicated that some genera of Cyanobacteria including *Anabaena*, *Lyngbya* and *Oscillatoria* are considered very competitive by secreting cyanotoxins of different types to inhibit the growth of other groups of algae and eliminate their predators such as zooplankton.

In general, the diversity of the microalgae populations at the the different studied sites is consistent with the diversity found by previous works, notably that of Chaibi (2013). Also, several works indicate that diversity in artificial hydro-systems is greater compared to that in natural sites (Labed, 2013; Chaibi, 2013). Also, diversity in lentic ecosystems is greater than that in lotic ecosystems. Indeed, the higher the current, the more algae can be detached from the substrates, which reduces the diversity of fixed algae. This justifies the low values of the diversity indices calculated in the Djedi Wadi and Lake Temacine. Similarly, other factors play a very important role in the absence or presence of one or more taxonomic groups of the phytoplankton community. According to Min *et al.* (2021), conductivity, the concentration of organic matter, and the presence of freshwater organisms, control the dispersion of certain algae taxa.

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