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Phytoplankton functional groups structures and ecological quality of tropical lake (Taabo, Côte d'Ivoire)

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ABSTRACT

Phytoplankton functional groups structure and their relationship to physical and chemical parameters were investigated in the tropical man-made lake of Taabo from November 2017 to October 2018 at five sites along a transect during four seasons. Water quality was determined using Q index. In this study, 242 algal species were identified belonging to seven taxonomic groups. Chlorophyta predominated with 114 taxa, followed by Euglenophyta, Cyanobacteria, and Bacillariophyta with 54, 38 and 24 taxa, respectively. The highest phytoplankton biomass was recorded during the short rainy season at site S2 (146.4 mg L^{-1}), and the lowest biomass occurred in the long dry season at site S5 (9.01 mg L^{-1}). With a proportion of more than 29%, the functional group Lm dominated at/in all sites and seasons. The Redundancy analysis indicated that the highest concentrations of nutrients influenced the biomass of taxa of the functional groups Lo, Lm, P, G and S1 at all sites and in the short rainy season. Index Q showed a good ecological status during the dry season and tolerable status during the rainy season. Based on a database for research, the current study focused on the use of phytoplanktonic functional groups and Q index for the assessment of the ecological quality of tropical lakes.

INTRODUCTION

The mode of watershed occupation linked to anthropogenic activities are negatively influencing the aquatic plant community **(Yuan *et al*., 2020; Znachor *et al*., 2020)**.
In Côte d'Ivoire, a large part of population resides in the lacustrine watershed, and their pressure on these environments is constantly increasing **(Anoh *et al*., 2012)**. The artificial lake of Taabo, built on Bandama stream for the production of electricity, has a negative impact on the ecosystem. However, it is used for water supply, fishery and irrigation. All these activities strongly affect the water quality of the lake **(Bovo-Scomparin & Train, 2008)**. In recent years, a floating cage fish farm for tilapia *Oreochromis niloticus* has been established in the open water area of the lake. The waste from the fish farm loaded the lake with additional nutrients and organic matter **(Adewumi *et al*., 2011)**. This load

could inevitably have a significant impact on water quality and aquatic community, in particular the phytoplankton structure **(Nahirnick *et al*., 2020; Yan *et al*., 2020)**. To monitor water quality, it is important to understand the different interactions between phytoplankton, abiotic and biotic factors to better manage the aquatic resources **(Wetzel, 2001; Znachor *et al*., 2020)**. Phytoplankton, the first link in the trophic chain of aquatic ecosystems **(Sterner *et al*., 2017)**, maintains the transformation of mineral matter into organic matter. According to **Medina-Contreras *et al***. (**2020**), phytoplankton structure, carbon cycle and food webs are undergoing transformations induced by environmental disturbances. For a better understanding of the ecological functioning of phytoplankton, the application of functional group approach is necessary **(Reynolds *et al*., 2002; Padisák *et al*., 2006)**.

Although some data are available on physical, chemical and phytoplanktonic characteristics of Lake Taabo **(Groga *et al*., 2012**), there are no data on phytoplankton biomass and functional groups of this lake. Thus, this research focused on determining the ecological quality of the lake's waters by analysing the structure of phytoplankton functional groups in relation to the environmental parameters.

MATERIALS AND METHODS

1. Study area

Taabo Lake (Fig. 1) is located in the central part of Côte d'Ivoire (6°25'- 6°56' N, 5°07'-5°33' W). The area of the lake is 69km^2. The maximum depth is about 30m; the mean depth is 16m, and water residence time is approximately 49.2 days **(Kouassi *et al*., 2007)**. The climate is characterized by four seasons: two rainy seasons (long rainy season (LRS) for April to July and the short rainy season (SRS) for October to November) and two dry seasons (long dry season (LDS) for December to March and the short dry season (SDS) for August to September). The annual precipitation varies between 1100 and 1600 mm, and the mean annual air temperature ranges between 24.5°C and 34°C **(Aliko *et al*., 2010; Kouassı *et al*., 2013)**.

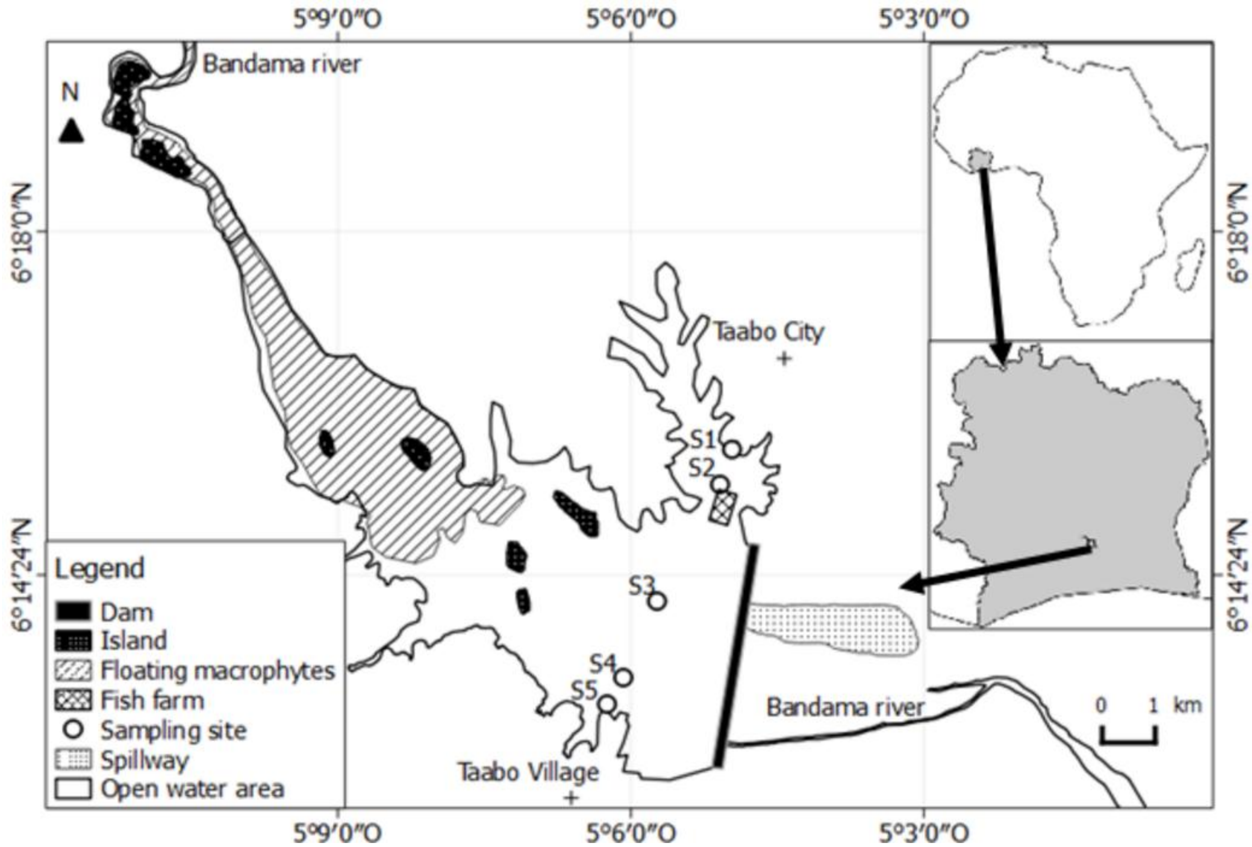

Fig. 1. Map showing the location of sampling sites in Taabo Lake (2017-2018, Côte d'Ivoire): S1- S5: sampling sites.

Data were collected during one year survey from November 2017 to October 2018 at five sampling sites of the lake along a transect about seven kilometres in the open water area: two sites at nearshore area (S1 and S5), two sites adjacent to the littoral zone (S2 and S4) and one in the deepest area (S3) of the lake. The sampling sites (S1, S2 and S5) were heavily affected by anthropogenic activities (agriculture, domestic waste, fish farming etc.) compared to S3 and S4, which were less polluted compared to other sites. The characteristics of the sampling sites are described in Table (1). Samples were collected every 45 days.

Table 1. Coordinates and characteristics of the sampling sites in Taabo Lake (2017-2018, Côte d'Ivoire)

Sampling sites	**Latitude (N)**	**Longitude (W)**	**Mean depth (m)**	**Characteristics of the sampling sites**
S1	06°15'46.6"	05°04'57.4"	2.8	Urban area of the reservoir, cattle farming on the bank, agriculture, bathing and washing activities
S2	06°15'42.5"	05°04'59.3"	8	Fish farming operation into the reservoir
S3	06°15'06.3"	05°05'11.2"	19.7	Fishing area
S4	06°13'00.8"	05°06'13.7"	8.5	Fishing area
S5	06°12'59.2"	05°06'14.6"	3.2	Rural zone of the reservoir, fishing area, agriculture

2. Environmental variables

Physical and chemical parameters (temperature, conductivity, pH, dissolved oxygen, transparency, nutrients) were measured in *situ* order to characterize the water quality of this limited geographical sampling area. Water parameters were measured at two depths (0.5 and 1 m). Water temperature and conductivity were measured using a conductivity meter, WTW COND 340-i model and pH with a pHmeter, HANNA, Hi 991001 model. Dissolved oxygen, water depth and water transparency were measured with an oximeter HANNA (Hi 9146) model, a portable sounder ECHOTEST model and a 20 cm diameter black and white Secchi disk, respectively. Water nutrient concentrations were measured with a spectrophotometer Model HACH DR 2010. Samples for total nitrogen (TN) and total phosphorus (TP) analysis were determined using standard method **NF EN ISO 10304-1 (2009)**.

3. Phytoplankton sampling

Phytoplankton samples were obtained by taking two vertical hauls (0.5 m and 1 m) using a Van Dorn bottle at each sampling point. Samples were fixed with neutral Lugol solution. Estimation of species composition of phytoplankton samples was carried out by examining several small fractions of the samples under microscope (Zeiss). The component organisms were identified as far as possible using identification manuals **(Cocquyt, 1998** ; **Ouattara *et al*., 2000** ; **John *et al*. 2002** ; **Ten-Hage *et al.* 2007** ; **Zongo *et al*., 2011)**. Additionally, all species names were checked for current status and names in the database of AlgaeBase **(Guiry & Guiry, 2016)**. Phytoplanktons were counted (cellule) according to **Utermöhl (1958**) using an inverted microscope (OPTIKA) at 200X/400X magnification by following the standard **NF EN 15204 (2006)**. Biomass (mg L^{-1}) was estimated using the biovolume calculated values and multiplying each species density by the mean volume of its cells considering, whenever possible, the mean dimension of 30 individuals of each species following **Hillebrand *et al***. (**1999)** and **Sun and Liu (2003)**. The fresh-weight unit was expressed in mass, with 1 mm^3 L^{-1} = 1mg L^{-1} **(Wetzel & Likens, 2000)**.

For determining the Q index, the species contributing > 5% of the total biomass were combined into functional groups. For the functional groups, the criteria of **Reynolds *et al*. (2002)** and **Padisák *et al*. (2009)** was used. The Q-index of **Padisák *et al***. (**2006**) was used, taking into account the relative share (pi, where pi = ni N^{-1}; ni biomass of the i-th functional group; N: total biomass) of the functional groups in the total biomass and the Fi-factor assigned to each functional group according to the lake type. For this, the biological data were integrated arithmetically. A value of F ranging from 0 to 5 was assigned. The more-pristine assemblages was indicated by the higher value of F and less-pristine conditions by lower values. Five levels of classification for the Q index were used: 0-1: poor ecological status (Bad); 1-2: tolerable; 2-3: medium; 3-4: good; and 4-5: excellent.

4. Statistical analyses

Differences in phytoplankton biomass, Q index and in environmental parameters between sampling sites and sampling months were evaluated using Kruskal-Wallis test, a nonparametric analysis of variance, followed by Mann-Whitney test. Before performing the comparison test, normality of data was checked by Shapiro test (P > 0.05 at all sampling sites). Analyses were conducted using Rstudio R 3.1.3 **(R Core Team, 2013)**. Statistical analyses were performed at a significance level of $P < 0.05$.

A constrained ordination was conducted to examine relationships between phytoplankton functional groups and physical/chemical factors. A previous detrended correspondence analysis (DCA) displayed short gradient lengths (units) indicating that a linear model was the most valuable **(Ter Braak & Smilauer, 2002)**. DCA is carried out before hand on the species data. This analysis makes it possible to determine the length of the gradient in units of standard deviation (SD). When the maximum length of the gradient does not exceed 4 SD, a linear method (DCA) is preferable to a unimodal method (RDA). Thus, the RDA (ReDundancy Analysis), a direct multivariate analysis technique in which several authors showed interest for the treatment of floristic and ecological data **(Van Tongeren *et al*., 1992)**, appeared to be the most appropriate for our data. A ReDundancy Analysis (RDA) was hence processed using the program CANOCO 4.5. The *P*-value was obtained by a Monte Carlo permutation test (499 permutations), carried out for all canonical axes. All biomass data were $\log_{10}(X+1)$ transformed.

RESULTS

1. Physical and chemical data

Changes in physical and chemical parameters during the study period at the studied sites are shown in Fig. (2). Sampling sites depths varied between dry season (LDS: January, February; SDS: September) and rainy season (LRS: April, June, July; SRS: October, November). Depths were higher in site S3 (15-22m) during this study. Results revealed that water temperatures exhibited similar trend throughout the sampling period. Values were higher at all sampling sites in January (up to 31°C) and gradually decreased to record lower temperatures in October (26.9°C). In this study, water conductivity values ranged between 71.9 (long dry season (LDS) at S4) and 134 $\mu S\ cm^{-1}$ (short rainy season (SRS) at S2). Dissolved oxygen varied between S1 (3.7 $mg\ L^{-1}$) in long rainy season (LRS) and S3 (7.1 $mg\ L^{-1}$) in SRS. Generally, pH was higher in the littoral zone of S1 and S2 (above 9) in short dry season (SDS) than in the other sites. Low pH values (close to 6.5) were measured in SRS in accordance with extremely low transparency (0.2m). The great enrichment of nutrient concentrations in water was recorded in rainy season in all sampling sites. High values of total nitrogen (TN) were measured in October at S2 (0.38 mg L^{-1}). For the total phosphorus (TP), the high values were observed in October at S2 (0.84 mg L^{-1}).

Deducting the results of depth; despite its slight variations, no significant difference was noted along the sites (Kruskal-Wallis test; $P > 0.05$), but there were significant seasonal variations in all parameters (Mann-Whitney; $P < 0.05$).

2. Phytoplankton dynamics

A total of 242 algal species were identified in the lake including seven taxonomic groups: Chlorophyta (114 taxa), Euglenophyta (54 taxa), Cyanobacteria (38 taxa), Bacillariophyta (24 taxa), Xanthophyta (6 taxa), Dinophyta (4 taxa), and Chrysophyta (2 taxa). Phytoplankton biomass was generally low but varied widely among samples sites and month (Fig. 3). The lowest biomass of phytoplankton occurred at S5 (9.01 mg L^{-1}) in LDS and the highest biomass at S2 (146.4 mg L^{-1}) in SRS. Phytoplankton biomass were significantly different between S2 and other sampling sites (Mann-Whitney test; $P < 0.05$). Regarding temporal variation, biomass was significantly higher during SRS (Mann-Whitney test; $P < 0.05$).

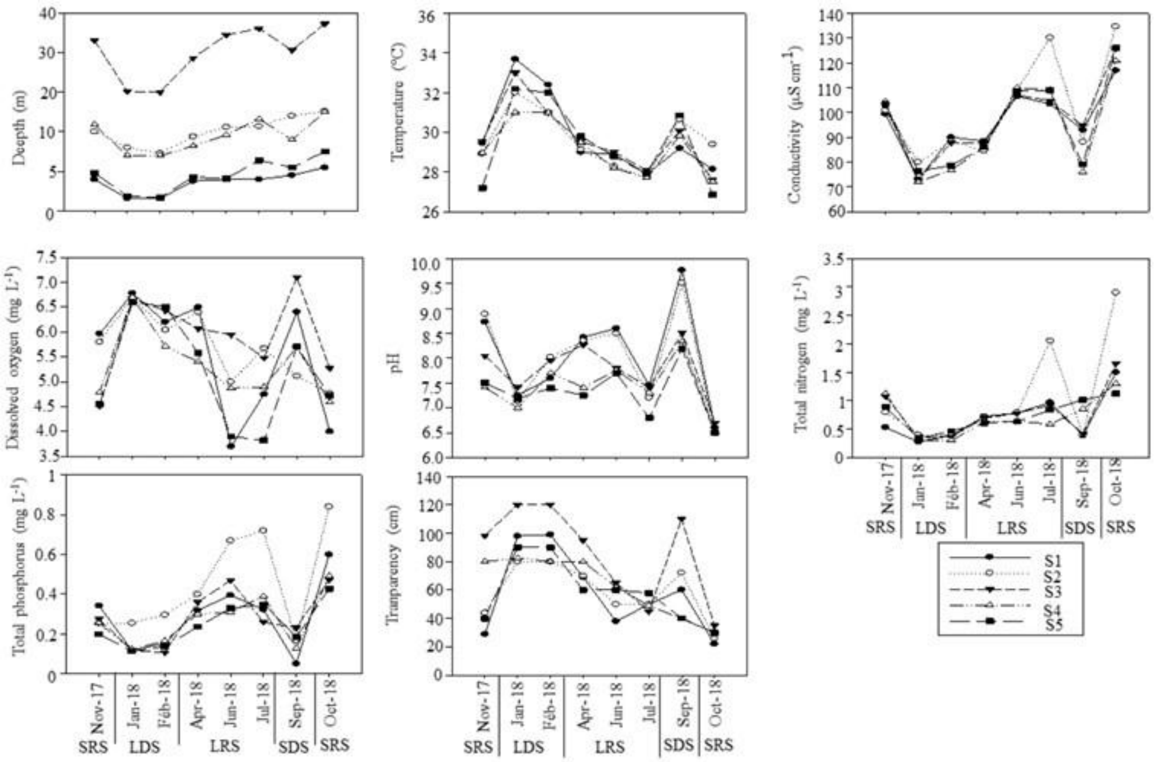

Fig. 2. Spatial and temporal variation in physical and chemical variables of Taabo Lake (2017-2018, Côte d'Ivoire)

S1-S5 = sampling sites; LRS: long rainy season; SDS: short dry season; SRS: short rainy season; LDS: long dry season.

The functional groups of phytoplankton in Taabo Lake followed the basic pattern. The 17 species comprising more than 5 % of the biomass were in four major taxonomic groups (Dinophyta, Bacillariophyta, Cyanobacteria and Chlorophyta) and belonged to 11 functional groups (D, F, G, J, Lm, Lo, MP, P, S1, Tc, Y) (Table 2). Groups Lo, P, Lm, D, and S1 were classified as the dominant phytoplankton functional groups, mainly represented by *Peridiniopsis armebeensis*, *Aulacoseira granulata*, *Aulacoseira granulata* f. *spiralis*, *Aulacoseira granulata* var. *angustissima*, *Cosmarium baileyi*, *Microcystis aeruginosa*, *Peridinium cinctum*, *Pseudanabaena limnetica* (Fig. 4). Relative to the different functional groups that make up the phytoplankton population (Fig. 5), the groups Lm were dominant at all sites and sampling months, with significant proportions (more than 21%). Groups P, Lo and S1 followed this group. Generally, these phytoplankton functional groups were co-dominant at all sites and during the sampling period.

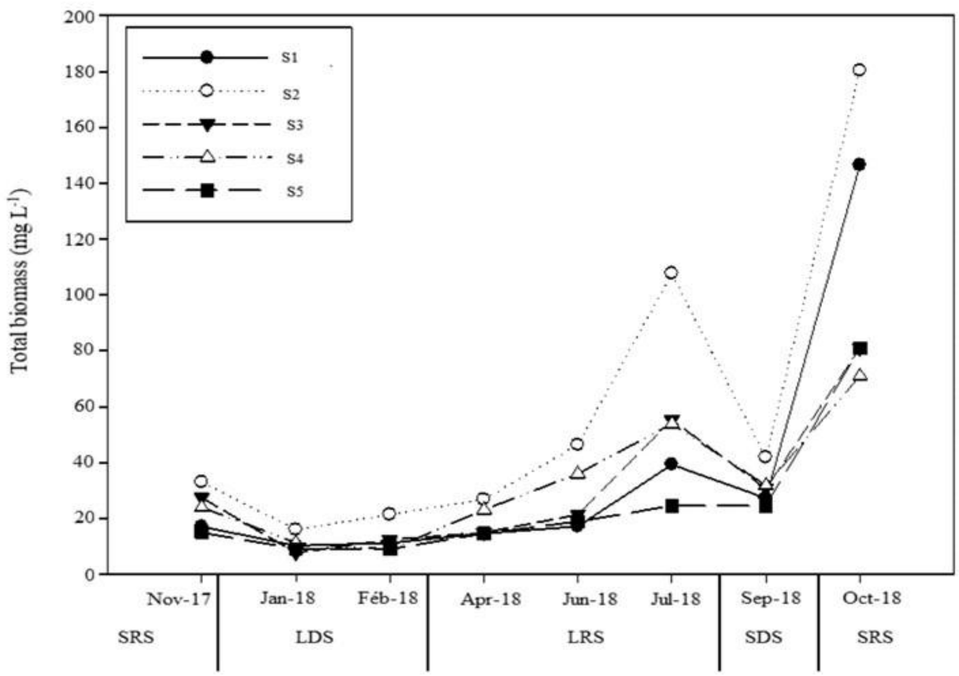

Fig. 3. Spatial and temporal variations in total phytoplankton biomass recorded in Taabo Lake (2017-2018, Côte d'Ivoire)
S1- S5 = sampling sites; LRS: long rainy season, SDS: short dry season, SRS: short rainy season, LDS: long dry season.

Table 2. Main phytoplankton species with their Phyla and functional groups, and respective F factors for the Taabo Lake (2017-2018, Côte d'Ivoire)

Functional groups	Phytoplankton species	Taxonomical Phyla	F factor
D	*Nitzschia* sp.	Bacillariophyta	2
D	*Ulnaria acus*	Bacillariophyta	2
F	*Pandorina morum*	Chlorophyta	3
G	*Eudorina elegans*	Chlorophyta	1
G	*Eudorina unicocca*	Chlorophyta	1
J	*Coelastrum indicum*	Chlorophyta	5
LM	*Microcystis aeruginosa*	Cyanobacteria	0
LM	*Peridinium cinctum*	Dinophyta	0
Lo	*Peridiniopsis armebeensis*	Dinophyta	4
MP	*Ulnaria ulna*	Bacillariophyta	1
P	*Aulacoseira granulata*	Bacillariophyta	2
P	*Aulacoseira granulata* f. *spiralis*	Bacillariophyta	2
P	*Aulacoseira granulata* var. *angustissima*	Bacillariophyta	2
P	*Cosmarium baileyi*	Chlorophyta	2
S1	*Pseudanabaena limnetica*	Cyanobacteria	0
Tc	*Phormidium* sp.	Cyanobacteria	5
Y	*Glenodinium* sp.	Dinophyta	2

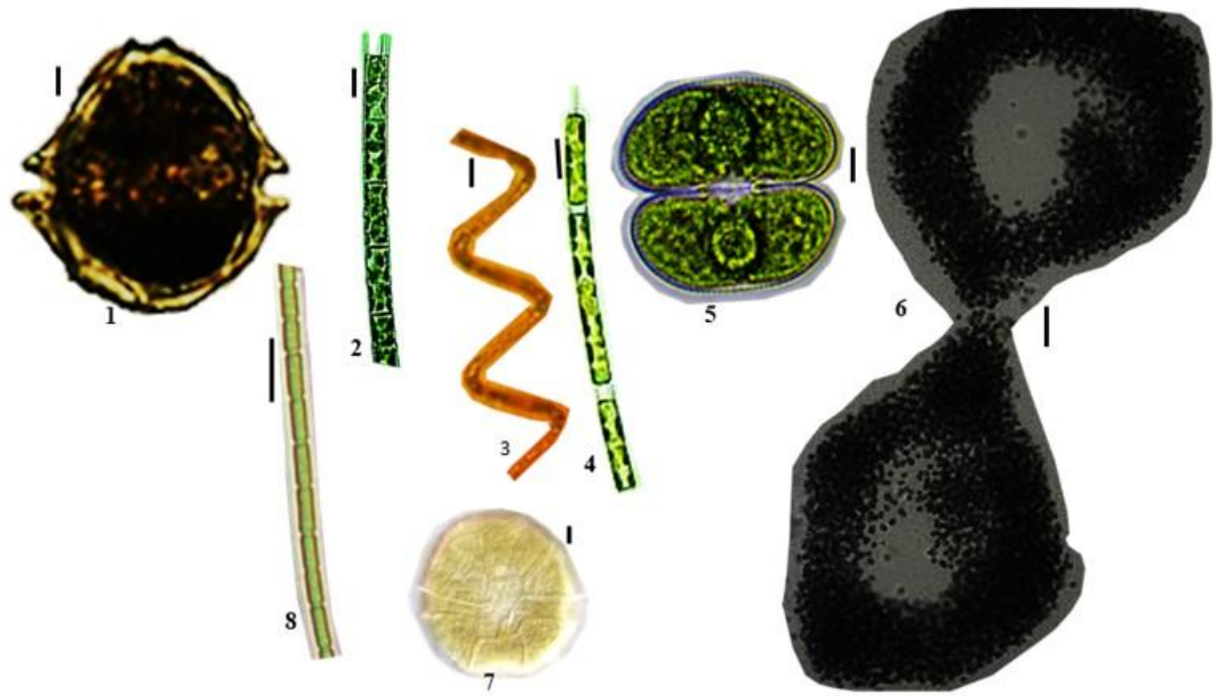

Fig. 4. Photogrophy of species causing dominance of phytoplankton functional groups Lo, P, Lm, D, and S1 in Taabo Lake (2017-2018, Côte d'Ivoire): 1 = *Peridiniopsis armebeensis*, 2 = *Aulacoseira granulata*, 3 = *Aulacoseira granulata* f. *spiralis*, 4 = *Aulacoseira granulata* var. *angustissima*, 5 = *Cosmarium baileyi*, 6 = *Microcystis aeruginosa*, 7 = *Peridinium cinctum*, *Pseudanabaena limnetica*; bar = 10 µm.

3. Environmental factors influencing phytoplankton communities

The RDA summarizes the relationship between the functional groups of phytoplankton and environmental variables (Fig. 6). The results of the ordination showed that the eight values of the first (axis = 67.8 %) and second (axis = 4.1 %) axes accounted for 71.9 % of the variation in the environmental data. Eight variables input were retained as significant contributors to the model, and all canonical axes were significant (Mont Carlo test; P = 0.002). The 11 functional groups of phytoplankton were selected for this analysis. First canonical axis was positively associated with conductivity, depth, TN, TP and negatively with water transparency, temperature, pH and dissolved oxygen. Axis 1 suggested a seasonal gradient and mineralization gradient. This axis makes distinction between the dry seasons located on the negative part to rainy seasons. Functional groups of phytoplankton D, J, Y, MP, Lo, Lm, P, F, G and S1 were main contributors of the positive part of axis 1 and were associated with highest concentrations of nutrients. Based on the RDA analysis, no clear discrimination was detected between the sampling sites.

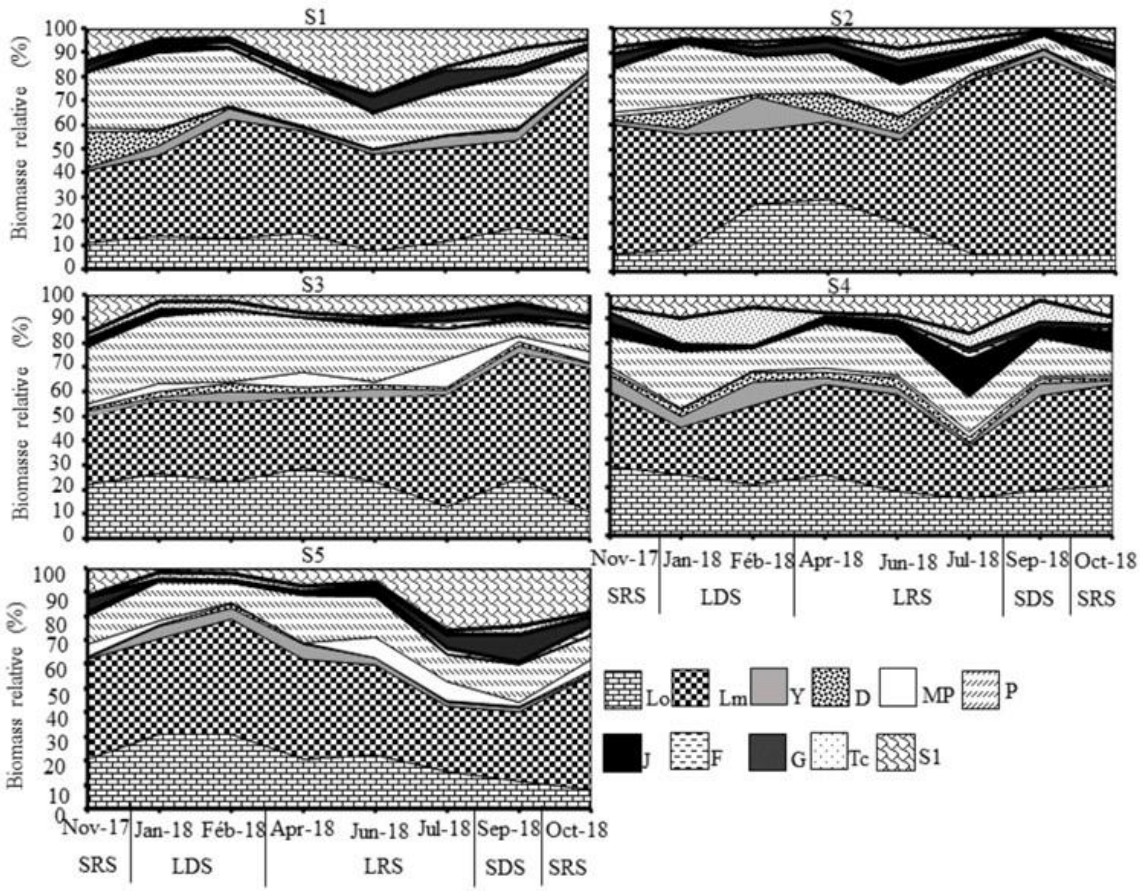

Fig. 5. Spatial and temporal dynamics of relative biomass for phytoplankton functional groups (%) in Taabo Lake (2017-2018, Côte d'Ivoire)

S1- S5 = sampling sites; LRS: long rainy season, SDS: short dry season, SRS: short rainy season, LDS: long dry season; D, F, G, J, Lm, Lo, MP, P, S1, Tc, Y = functional groups.

4. Ecological status assessment by Q index

Based on the application of the Q index, the factor F weights for each functional group identified in Taabo Lake are given in Table (2). The Q index varied with seasons and sites (Fig. 6), and the average Q index value ranged from 0.399 to 2.52, with an annual average of 1.76. The highest qualification (3.26) occurred in the LDS at S3, and the lowest value (0.53) was recorded in SRS at S2. The low values of Q index were observed in the SRS at all sites, and the high values were recorded in LDS at all sites. At the level of the sampling sites, the lowest value of Q index was recorded at S2 in all seasons. Besides, significant difference was found for the Q index between dry seasons and rainy seasons (Mann-Whitney; $P < 0.05$) and between sampling site S2 and the other sites (Mann-Whitney; $P < 0.05$).

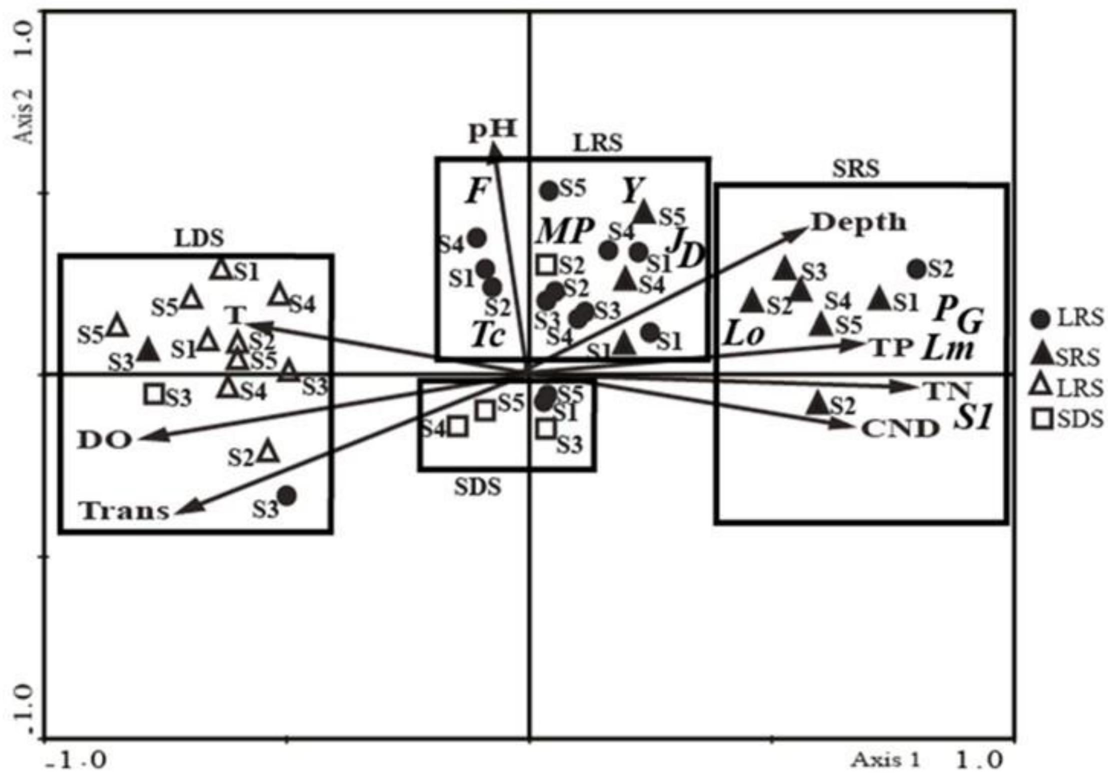

Fig. 6. ReDundancy diagram of the relationship between functional groups and environmental variables at different sampling sites and seasons in Taabo Lake (2017-2018, Côte d'Ivoire)

T = temperature; CND = conductivity; DO = dissolved oxygen; TN = Total nitrogen; TP = Total phosphorus; TRANS = Transparency; Sampling sites = S1 - S5; The functional groups of phytoplankton: Lm, Lo, Y, P, Tc, MP, S1, F, J, G, D; LRS: long rainy season; SDS: short dry season; SRS: short rainy season; LDS: long dry season.

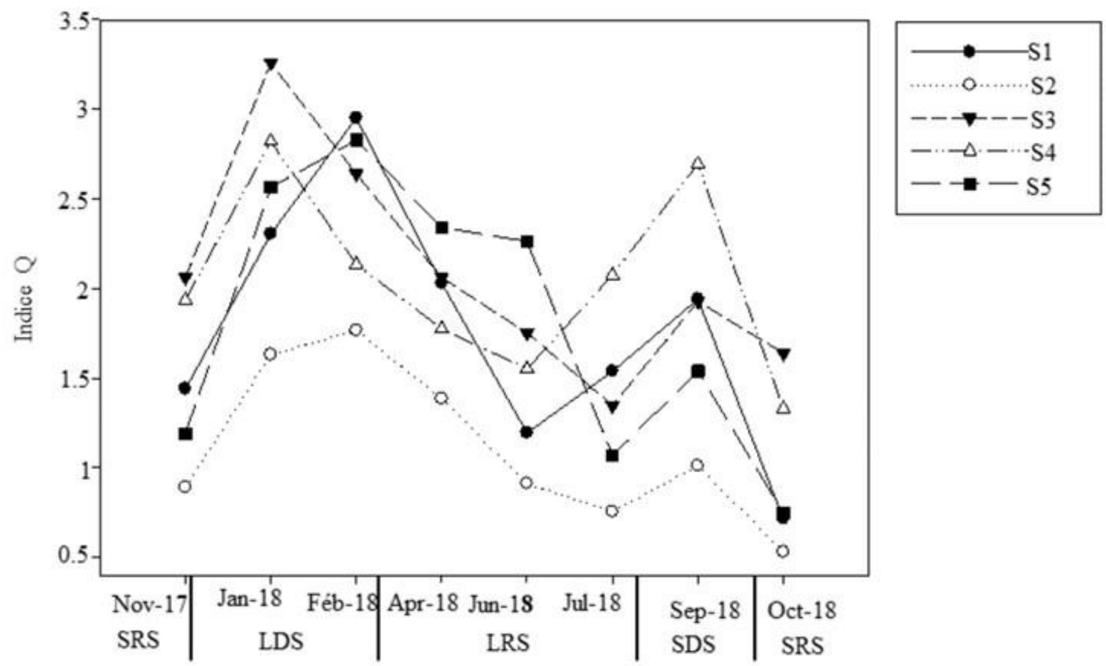

Fig. 7. Spatial and temporal variations in Q index recorded in Taabo Lake (2017-2018, Côte d'Ivoire)

S1- S5 = sampling sites; LRS: long rainy season, SDS: short dry season, SRS: short rainy season, LDS: long dry season.

DISCUSSION

The distribution of phytoplankton biomass in Taabo artificial Lake is influenced by the nutrients concentrations. Remarkably, low phytoplankton biomass was obtained in dry season and high biomass in rainy season. High nutrients concentrations were also recorded in rainy season. During this season, rainfall induces leaching of the catchment, increasing nutrient load from anthropogenic activities **(Anoh *et al*., 2012)**, such as cattle ranching, plantations and urbanisation. The increase in nutrient load of the lake water may be responsible for the development of phytoplankton in rainy season. According to several authors **(Reynolds, 2006;** ; **Havens *et al*., 2009; Becker *et al*., 2010)**, light and nutrients are main factors regulating phytoplankton biomass. In addition, the highest phytoplankton biomass, total nitrogen and total phosphorus values were found at S2. The proximity of this site to the fish farm may be responsible for these high values. In this farm, food scraps and fish faeces are decomposed by the micro-organisms that transform this organic matter into mineral matter; this may be the cause of the increase in nutrient concentrations and thereby in the biomass of plankton. The phenomenon of water mineralization related to fish farming has also been reported in the study of **Osman *et al*. (2010)** and **Adewumi *et al*. (2011)**. In addition, the impact of fish farming on the phytoplankton community was observed in the work of **Barbe *et al*. (1999)**.

Regarding the functional group, group Lm dominantes in all seasons and at all sites. This dominance is related to the high biomass of *Microcystis aeruginosa* (Cyanobacteria) and *Peridinium cinctum* (Dinophyta). The dominance of these species is associated with the enrichment of the environment by the nutrients **(Liu *et al*., 2008; Tian *et al.*, 2013; Yang *et al*., 2017)**. In addition, the possession of flagella and gas vacuoles by species of group Lm enhances their competitiveness. These traits allow species to migrate vertically through water layers to reach optimal conditions of light and nutrient concentration **(Bovo-Scomparin & Train, 2008)**. Furthermore, groups P, Lo and S1 are co-dominant at all sites and in all seasons in Lake Taabo. The dominance of these functional groups indicates that Lake Taabo is eutrophic. **Padisák *et al*. (2009)** and **Varol** (**2019**) reported that, the eutrophic lakes are characterised by a dominance of the functional groups Lm, Lo, P and S1. Concerning RDA, we noticed a seasonal mineralization gradient. Waters with higher mineralisation in short rainy season influence the growth of algae of the functional groups Lm, Lo, Y, P, Tc, MP, F, J, G, D and S1. With regard to the ecological status of Taabo Lake, the results of the Q-index indicate a good status during the dry season (LDS, SDS), and a tolerable status during the rainy season (SRS, LRS). Spatially, the values of Q index classify waters of stations S1, S3, S4 and S5 as of a tolerable quality. While, the water quality of station S2 varies from tolerable to poor. This status of S2 is related to its proximity to the fish farm. Taabo lake is located in an area where heavy agricultural activity, combined with urbanisation, is gradually leading to hyper-eutrophication. In order to maintain economic activities such as fish farming, fishing and to continue using this reservoir for water supply, it is necessary to improve and maintain good water quality. In conclusion, this study would provide a database for research focusing on the use of phytoplankton functional groups and the Q-index for ecological quality assessment of tropical lakes.

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