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Taxonomic diversity of phytoplankton and trophic status of the waters of the Jacqueville aquaculture station (Ebrié lagoon, Côte d'Ivoire)

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Abstract

Water quality at the Jacqueville aquaculture station was assessed using physico-chemical parameters and phytoplankton communities. Six stations were surveyed monthly from January to December 2020. In situ measurements were taken using conventional methods. Water samples were taken using polyethylene bottles, a plankton net and a hydrological bottle to analyse nutrient salts and phytoplankton respectively. In addition, taxonomic composition, structure, chlorophyll a and trophic status were determined. A total of 165 phytoplankton taxa were identified, including approximately 35.15% Cyanoprocaryota, 32.12% Chlorophyta, 18.79% Bacillariophyta, 9.02% Euglenophyta, 4.24% Dinophyta and 0.61% Chrysophyta. Variations in the composition of the populations between stations were relatively low, with higher diversity at station S1 (*Heterobranchus longifilis* rearing, located 130 m from the bank) (117 taxa) and low diversity at stations S5 and S6 (no rearing, located 100 m and 500 m from S1 respectively) (100 taxa). Taxa most commonly encountered during the study were *Microcystis aeruginosa*, *Pseudanabaena limnetica*, *Peridinium inconspicum*, *Aphanocapsa incerta* and *Aulacoseira granulata*. Cyanoprocaryota branches is the most abundant taxonomic group at all stations, with 61 taxa in common. Abundance of phytoplanktonic algae reached maximum values in the rainy season at all the stations except station S4 (no breeding, located 30 m from S1). Trophic status based on chlorophyll biomass and the Carlson trophic index shows that the waters of the Jacqueville aquaculture station are eutrophic.

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Introduction

Located in West Africa, Côte d'Ivoire has immense physical, hydrological (150.000 ha of lagoons, 350.000 ha of lakes and numerous lowlands, etc.), climatic and human potential, in addition to a rich aquatic fauna containing more than 100 families of fish, several species of which have definite aquaculture potential (FAO, 2015). Thus, coastal lagoons are complex socio-ecological systems that rank among the most biologically productive and important ecosystems on the Planet, providing goods and services valuable for human welfare (Kennish and Paerl, 2010; Newton *et al.,* 2018). Among these lagoons, the Ebrié lagoon, with a surface area of 566 km², is one of the most important aquatic ecosystems due to its ecological values and its aquaculture operations. As part of the pilot projects for the development of lagoon aquaculture and fisheries in Côte d'Ivoire, the Ivorian government has initiated the creation of the Jacqueville aquaculture station. The station is located on the banks of sector V of the Ebrié lagoon. However, aquaculture can have an impact on water quality. Preservation and management of these environments requires knowledge of abiotic and biotic factors. Thus, the study of planktonic communities appears to be important for understanding the functioning of farming structures (Ndour *et al.,* 2017). According to Anneville *et al.* 2019, plankton comprises several organisms, one of the most important of which is phytoplankton. That's right, phytoplankton are the main producers of aquatic ecosystems and can respond to environmental changes in a short period of time and are better indicators of environmental changes (Padisák *et al.,* 2006). It also provides aquatic food webs with energy, high-quality biochemical compounds and minerals (Peltomaa *et al.,* 2017). However, phytoplankton blooms have a direct impact on aquatic ecosystems, leading to changes in diversity and population dynamics (Groga, 2012). This makes this compartment a potential bioindicator of the quality of water bodies. In addition, temperature and nutrient increases have been shown to alter phytoplankton total biomass, community structure and the biochemical composition of individual Cells (Winder and Hunter, 2008; Taipale *et al.,* 2019). Knowledge of phytoplankton diversity is essential for the preservation and efficient management of aquatic ecosystems. Different strategies can therefore be used to assess the limitation of phytoplankton by nutrients. In order to assess the trophic status of a body of water, it is therefore important to be able to monitor and assess the composition, abundance and biomass of phytoplankton communities, as well as their variability in space and time. This assessment can be made using biotic indices such as the planktonic index, the Carlson index and trophic status.

The aim of this study is to determine the composition and structure of phytoplankton in the waters of the Jacqueville aquaculture station in order to assess its trophic status.

Material and methods

Description of the study area

The Jacqueville aquaculture station (SAJ), located on the bank of sector V of the Ebrié Lagoon, is known locally as SIAL (Ivorian Lagoon Aquaculture Company) (Toulé *et al.,* 2017). It is located between 5°14'.24" and 5°16'.48" North latitude and 4°28'.12" and 4°24'.36" West longitude in southern Côte d'Ivoire (Fig. 1).

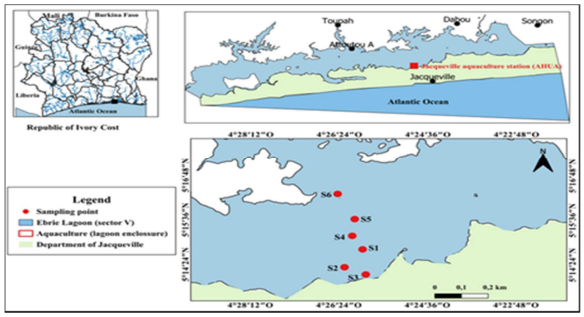

Fig. 1. Sampling locations in the Ebrié.

This station is the only advanced lagoon horsefish (*Chrysischthys nigrodigitatus*) production facility still in operation in Côte d'Ivoire and the sub-region. The station specialises in the production of jawfish fry for fish farmers. Covering an area of 21.113 m², with an occupied surface area of 16.400 m², its production

capacity is estimated at 1 million fry Catfish (*Heterobranchus longifilis*) are also farmed here. This station is influenced by rivers and the sea. These environments are therefore areas of intense human activity, including swimming, defecation, washing, fishing, boating, etc. Six sampling stations were chosen according to the absence/presence of aquaculture activity and the distance from station S1. Stations S1 and S2 were chosen in lagoon enclosures (presence of aquaculture).

Sampling

Eleven sampling campaigns were carried out at each station on a monthly basis. Six stations were surveyed monthly from January to December (except for the month of March due to the corona virus health crisis). At each station, water samples were taken using a polyethylene bottle, plankton net and a hydrological bottle to analyse nutrient salts, the qualitative study and the quantitative study of phytoplankton, respectively. During the various sampling campaigns, certain parameters, in particular temperature, pH, dissolved oxygen, conductivity and salinity, were measured in situ using a HACH LANGE portable digital multiparameter (HQ 40d) equipped with specific probes. Water transparency was determined using a Secchi disc fitted with a graduated string. Nutrient salts (total nitrogen, total phosphorus and silica) were analysed in accordance with the AFNOR standard, 2005.

Collection and conservation of phytoplankton

Phytoplankton sampling was carried out taking into account both qualitative and quantitative aspects. To do this, 30 litres of water were sampled using buckets, then transferred to a plankton net with a mesh size of 20 µm. The algal pellet obtained at the bottom of the water was collected. In addition, this sample was collected using a hydrological bottle within 50 cm of the surface. This operation was designed to obtain a concentration of phytoplankton in order to minimise bias. The samples taken at each station were collected in 100 mL pillboxes and fixed with lugol and 5% formalin.

Observation, identification and conting

In the laboratory, phytoplankton taxa were observed using a photonic microscope with a 40x objective. These taxa were identified using the identification keys of Ouattara *et al.* (2000); John *et al.* (2002); Cocquyt (1998); Ten-Hage *et al.* (2007); Zongo *et al.* (2011). In addition, all species names identified were checked against the Algae Base database (Guiry and Guiry, 2016). Phytoplankton species were counted using the method of Utermöhl (1958) modified (standard NF EN 15204) by Laplace-Treyture *et al.* (2007). The density (D) per unit volume was calculated using the following formula:

$D = \frac{N}{(\frac{a}{A})\times V}$, With $a = C_{40\times} \times (R_{40\times})^2 \times \pi$

Data analysis

The phytoplankton diversity and trophic status of the waters of the Jacqueville aquaculture station were assessed on the basis of.

Rarefied richness

Which is the number of taxa calculated for samples reduced to a fixed number of individuals (Grall and Coïc, 2005). It eliminates any bias linked to differences in abundance between samples (Edia *et al.*, 2016).

Occurrence frequency

Which consists of counting the number of times a 'species i' appears in the samples (Dajoz, 2000). Depending on the value of the frequency, the groups of distinguised species are constant species (F > 50%), accessory species (25% < F < 50%), accidental species (< F 25%)

Shannon-Weaver index (H')

This index takes into account the number of individuals of each taxon (Gray *et al.,* 1992). A high value corresponds to a community composed of several taxa with similar densities, reflecting favourable environmental conditions. Conversely, a low value reflects difficult living conditions that allow few species to become established. It is expression is as follows :

$$H' = -\sum_{i=1}^{s} p_i \times \log_2 p_i$$

Equitability index (E) : whitch index reflects the quality of organization of the community in an environment (Amanieu and Lasserre, 1982 ; Dajoz, 2000) and is expressed as follows :

$$E = \frac{H'}{Log_2 S}$$

E = equitability index ; H' = Shannon-Wiener diversity index ; S = specific richness

Sorensen's similarity coefficient (S)

Sorensen's (1948) similarity coefficient was calculated to determine the similarity rate between the planktonic population harvested in the different lagoon stations. This coefficient is applied to the taxon presence/absence matrix and is calculated according to the following formula: $S = \frac{2C}{(a+b)} \times 100$; Where : S = Sorensen's similarity coefficient ; a = number of taxa present in station 1 ; b = number of taxa present in station 2 ; C = number of taxa common to both stations.

Carlson Trophic Index (CTI)

Which is used to characterise the trophic status or genetic health of a lake (CCME, 2001). The following variables are taken into account in its calculation: chlorophyll a (CA), transparency (SD) and total phosphorus (TP). The average TSI values of these three parameters are taken into account to determine Carlson's trophic state index. This index is calculated using the following formulae (Carlson, 1980):

$$TSI = \frac{TSI(TP) + TSI(CA) + TSI(SD)}{3}$$

With : PT and CA in microgrammes per litre and SD in metres.

Based on TSI values, waters are classified as oligotrophic (low productivity), mesotrophic (moderate productivity) and eutrophic (high productivity). For Carlson Trophic Status Index (TSI) values equal to : oligotrophic (TSI < 40), mesotrophic (40 < TSI < 60), eutrophic (TSI > 60).

Chlorophyll biomass

Chlorophyll biomass was determined using the method of Lorenzen (1967). 250 mL of water was collected in situ on Whatman GF/C paper (0.7 µm porosity) using a vacuum pump. In the laboratory, the sample was placed in a glass tube containing 10 mL of 90% acetone and shaken. The absorbance of the supernatant was determined at wavelengths of 665 nm and 750 nm. The results are given by the following formula:

Chla (µg/L)= {26.7 × (E1-E2) × Va}/ (l×Ve)

With : Va: volume of acetone (mL) ; Ve: volume of filtered water (L) ; l: optical path length of the cell (cm). E1: absorbance before acidification (OD665-OD750) ; E2: absorbance after acidification (OD665-OD750).

The non-parametric Kruskal-Wallis test was used to observe spatial and seasonal variations in physico-chemical and biological parameters (abundance, phytoplankton biomass, chlorophyll biomass and indices). When a significant difference was found following the Kruskal-Wallis test, the Mann-Whitney test of two-to-one comparison was applied. Before the analyses of variance, the variables were subjected to a normality test (using the Shapiro-Wilk test). Differences between medians were considered significant when $p < 0.05$. In addition, a canonical correspondence analysis (CCA) was used to highlight the influence of physico-chemical parameters on the distribution, abundance and biomass of phytoplankton species. The boxplot and all analyses were carried out using R software (R Version 3.6.0) and the CANOCCO version 4.5 program.

Results

Spatial variations in physico-chemical parameters

Table 1 shows the spatial variations in physico-chemical parameters of the water at the Jacqueville aquaculture station. Parameters such as dissolved oxygen, transparency and silica varied significantly from one station to another (Mann-Whitney test ; $p < 0.05$). Median water temperature values ranged from 29.4°C (S5) to 30.5°C (S1).

Table 1. Spatial variation in physico-chemical parameters of water at the Jacqueville aquaculture station from January to December 2020: pH: Hydrogen Potential, S1-S6: stations.

Parameters	Statistical Parameter	S1	S2	S3	S4	S5	S6	*p*-value
Temperature (°C)	Median±SD	30.5^{a}±1.43	29.72^{a} ±1.48	29.68^{a} ±1.54	29.62^{a} ±1.66	29.4^{a} ±1.59	29.48^{a} ±1.55	0.999
	Range	27.6-31.6	27.5-32.08	27.7-32.4	27.5-31.7	27.5-31.7	27.6-31.87	
pH	Median±SD	8.25^{a} ±0.32	8.31^{a} ±0.32	8.23^{a} ± 0.39	8.24^{a} ±0.41	8.16^{a} ±0.58	8.04^{a} ±0.46	0.9956
	Range	7.74-8.76	7.78-8.83	7.8-9	7.71-8.98	6.81-9.02	7.77-9.31	
Dissolved oxygen (mg/L)	Median±SD	7.42^{a} ±0.81	7.37^{ab}±0.83	7.81^{ab} ±0.88	7.77^{ab} ±0.83	7.93^{ab} ±0.7	8.01^{b}±0.69	0.03181
	Range	5.29-7.99	5.44-8.06	6.28-9.21	6.11-8.72	6.56-8.89	6.32-8.87	
Electrical conductivity (µS/cm)	Median±SD	4552^{a}±692.31	4318^{a}±804.32	4251^{a}±688.31	4391^{a}±827.05	4540^{a}±826.55	4430^{a}±818.4	0.961
	Range	3740-5923	3710-6117	3629-5785	3760-6347	3900-6347	3650-6233	
Transparency (cm)	Median±SD	138^{ad}±9.8	110^{b}±10.29	90^{c}±15.26	167^{ed}±42.17	198^{e}±56.35	205^{e} ±46.77	2.785e-05
	Range	125-154	90-120	58-104	118-250	117-290	146-256	
Salinity (ppt)	Median±SD	2.63^{a} ±0.53	2.64^{a} ±0.48	2.52^{a} ±0.32	2.86^{a} ±0.39	2.77^{a} ±0.44	2.75^{a} ±0.53	0.4823
	Range	2.18-3.75	2.17-3.78	2.15-3.07	2.16-3.41	2.17-3.69	2.16-3.8	
Total nitrogen (mg/L)	Median±SD	3.3^{a} ±0.99^{a}	2.9^{a} ±1.06^{a}	2.8^{a} ±1.06^{a}	3.3^{a} ±1.24^{a}	3^{a} ±1.49^{a}	3.4^{a} ±0.93^{a}	0.8649
	Range	2.2-5.8	1.2-4.7	0.9-4.6	0.4-4.5	0.8-6.7	2-5.7	
Total phosphorus (mg/L)	Median±SD	0.46^{a}±0.25	0.31^{a}±0.58	0.47^{a}±0.77	0.23^{a} ±0.58	0.42±2.03	0.41^{a} ±0.64	0.8582
	Range	0.1-0.79	0.14-2.01	0.11-2.79	0.1-1.53	0.12-7.04	0.11-1.9	
Silicate (mg/L)	Median±SD	9^{ab}±3.92	10^{a}±1.45	9^{ab}±1.57	9^{ab} ±0.89	9^{b}±1.08	8^{b} ±0.5	0.02882
	Range	7-20	8-13	8-14	8-14	7-11	8-9	

Table 2. Seasonal variation in physico-chemical parameters of water at the Jacqueville aquaculture station from January to December 2020: (pH: Hydrogen Potential, LDS: Long Dry season, LRS: Long Rainy season, SDS: Short Dry Season, SRS: Short Rainy Season.

Parameter	Statistical Parameter	LDS	LRS	SDS	SRS	*p*-value
Temperature (°C)	Median±SD	31.3^{a}±0.12	29.72^{b} ±0.04	29.24^{b} ±0.13	28.38^{b} ±0.59	0.001085
	Range	31.1-31.44	29.25-29.36	29.16-29.46	27.95-29.65	
pH	Median±SD	8.62^{a} ±0.1	8.06^{b} ±0.1	8.06^{b} ± 0.04	8.08^{b} ±0.17	0.004476
	Range	8.47-8.76	8.02-8.28	8-8.13	7.97-8.37	
Dissolved oxygen (mg/L)	Median±SD	7.59^{a} ±0.31	7.68^{a}±0.39	8.08^{b} ±0.42	6.90^{ab} ±0.86	0.03101
	Range	7.27-8.08	6.95-7.80	7.57-8.59	6.38-8.80	
Electrical conductivity (µS/cm)	Median±SD	5789^{a}±171.11	4120.88^{b}±145	4637.5^{c}±90.7	4005^{b}±96.25	0.0001391
	Range	5440-5893	4009.75-4363	4415-4650	3953-4213.5	
Transparency (cm)	Median±SD	147.83^{a}±56.5	178.63^{a}±64.07	133.5^{a}±35.16	139.75^{a}±19.63	0.0731
	Range	90-226.33	82.25-232	74-175	98.5-148.5	
Salinity (ppt)	Median±SD	3.22^{a} ±0.3	2.59^{b} ±0.14	2.84^{c} ±0.12	2.55^{b} ±0.1	0.001472
	Range	2.66-3.58	2.37-2.81	2.56-2.87	2.46-2.76	
Total nitrogen (mg/L)	Median±SD	2.8^{a} ±0.3^{a}	3.6^{b}±0.4^{a}	2.8^{ab} ±0.6^{a}	3.7^{c} ±0.4^{a}	0.01495
	Range	2.6-3.4	3-4	2.2-3.5	3-4.3	
Total phosphorus (mg/L)	Median±SD	0.16^{a}±0.3	0.93^{b}±0.21	0.26^{a}±0.14	0.86^{a} ±1.31	0.002174
	Range	0.12-0.89	0.59-1.1	0.14-0.46	0.66-3.39	
Silicate (mg/L)	Median±SD	9.5^{a}±1.57	9.25^{a}±0.87	8.5^{a}±0.32	9.5^{a} ±0.55	0.1669
	Range	8-11.67	8.5-11	8-9	8.50-10	

Those for pH ranged from 8.04 (S6) to 8.31 (S2) and conductivity from 4251 to 4540 µS/cm at stations S3 and S5 respectively. Median dissolved oxygen values ranged from 7.37 mg/L (S2) to 8.01 mg/L (S6). However, this parameter is significantly higher at station S6 and lower at station S2 (Mann-Whitney test ; $p < 0.05$). Extreme median salinity values (2.52 ppt and 2.86 ppt) were recorded at stations S3 and S4 respectively. Transparency values varied between 90 cm (S3) and 205 cm (S6). In terms of nutrient salts, median total nitrogen values ranged from 2.8 mg/L (S3) to 3.4 mg/L (S6). Total phosphorus values ranged from 0.23 mg/L (S4) to 0.47 mg/L (S3), while silica values were significantly higher (10 mg/L) in S2 and significantly lower (8 mg/L) in S6 (Mann-Whitney test ; $p < 0.05$).

Table 3. List of phytoplankton taxa recorded in the different sampling sites of the Jacqueville Aquaculture Station (SAJ) during the year 2020

Taxa	Acro	Sampling stations					
		S1	S2	S3	S4	S5	S6
Cyanoprocaryota							
Cyanophyceae							
Chroococcales							
Microcystaceae							
Microcystis aeruginosa (Kützing) Kützing	Miae	***	***	***	***	***	***
Microcystis botrys (Teiling)	Mibo	**	**	**	**	**	**
Microcystis elachista (West and West) Starmach	Miel	*	*	*	**		*
Microcystis flos-aquae (Wittrock in Wittrock & Nordstedt) Kirchner	Mifa					*	
Microcystis novacekii (Komárek) Compère	Mino	*					
Microcystis wesenbergii (Komarek) Komarek	Miwe	***	***	***	***	***	***
Aphanothecaceae							
Aphanothece sp.	Apsp	**	*			*	
Gloeothece sp.	Glsp	**	**	**	**	***	***
Chroococcaceae							
Chroococcus dispersus (Keissler) Lemmermann	Chdi	***	***	***	***	***	***
Chroococcus minutus (Kützing) Nägeli	Chmi	***	***	***	***	***	***
Chroococcus sp.1	Chsp1	*	*	*	*		
Chroococcus sp.2	Chsp2	*	*		*	*	*
Chroococcus sp.3	Chsp3	*		*			
Chroococcus sp.4	Chsp4					*	
Eucapsis aphanocapsoides (Skuja) Komárek & Hindák	Euap				*	*	
Gloeocapsa punctata Nägeli	Glpu				*	*	*
Chroococcaceae							
Gloeocapsa sanguinea (C.Agardh) Kützing	Glsa	**	*	*	*	*	*
Limnococcus limneticus (Lemmermann) Komárková, Jezberová, O.Komárek & Zapomelová	Lili	***	**	***	***	***	***
Microcrocis sp.	Misp						*
Pseudocapsa dubia Ercegovic	Psdu	*	**	*	*	*	
Nitrospiraceae							
Synechocystis aquatilis sauvageau	Syaq	**	**	**	***	**	***
Synechocystis pevalekii Ercegovic	Sype	***	***	***	***	***	***
Synechocystis sp.1	Sysp1	***	***	***	***	***	***
Synechocystis sp.2	Sysp2	*	**	**	*	*	*
SYNECHOCOCCALES							
Merismopediaceae							
Aphanocapsa elachista (West & G.S.West)	Apel	***	**	**	**	**	**
Aphanocapsa grevillei (Berkeley) Rabenhort	Apgr		*				
Aphanocapsa holsatica (Lemmermann) G.Cronberg & Komárek	Apho	**	**	**	***	*	**
Aphanocapsa incerta (Lemmermann) G. Cronberg & Komárek	Apin	***	***	***	***	***	***
Aphanocapsa smithii (Lemmermann) G. Cronberg & Komárek	Apsm	*	*	*	*	*	*
Aphanocapsa sp.1	Apsp1	**	**	**	*	*	**
Aphanocapsa sp.2	Apsp2						*
Aphanocapsa sp.3	Apsp3	*	**		**	*	*
Merismopedia elegans A.Braun ex Kützing	Meel	***	***	***	***	***	***
Merismopedia glauca (Ehrenberg) Kützing	Megl	***	***	***	***	***	***
Merismopedia tenuissima Lemmermann	Mete	**	**	*	***	**	*
Merismopedia tranquilla (Ehrenberg) Trevisan	Metr	**	**	**	***	**	**
Coelomoron pusillum (van Goor) Komárek	Copu	**	*	*	*	**	*
Coelomoron sp.	Cosp	*			*	*	*
Woronichinia microcystoides (Komárek) Joosten	Womi		*				*
Coelosphaeriaceae							
Coelosphaerium confertum West & G.S.West.	Coco	*		*			
Coelosphaerium kuetzingianum Nägeli	Coku	**	**	**	**	**	**
Coelosphaerium sp.	Coesp	*	*				
Pseudanabaenaceae							
Pseudanabaena catenata Lauterborn	Psca	***	***	***	***	**	***
Pseudanabaena limnetica (Lemmermann) Komárek	Psli	***	***	***	***	***	***
Pseudanabaena sp.	Psps	*	*				
NOSTOCALES							
Nostocaceae							
Dolichospermum affine (Lemmermann) Wacklin, L. Hoffmann & Komárek	Doaf	*	*	*	**	**	**

Dolichospermum circinale (Rabenhorst ex Bornet & Flahault) Wacklin , L. Hoffmann & Komárek	Doci	**	***	**	***	**	**
Dolichospermum planctonicum (Brunnthaler) Wacklin , L.Hoffmann & Komárek	Dopl	*	*		*	*	*
Dolichospermum sp.	Dosp		*		*		*
Aphanizomenonaceae							
Raphidiopsis raciborskii (Woloszynska) Aguiler & al.	Rara	**	**	**	**	**	*
OSCILLATORIALES							
Oscillatoriaceae							
Lyngbya martensiana Meneghini ex Gomont	Lyma	**			*	*	
Lyngbya sp.1	Lysp1	***	**	**	***	***	***
Lyngbya sp.2	Lysp2	**	**	***	***	**	*
Oscillatoria simplicissima Gomont	Ossi	*	*	*	*		**
Oscillatoria subbrevis Schmidle	Ossu	*		**			*
Oscillatoria sp.1	Ossp1				*		*
Oscillatoria sp.2	Ossp2				*		
SPIRULINALES							
Spirulinaceae							
Spirulina sp.	Spsp	**	*	***	***	**	***
EUGLENOPHYTA							
EUGLENOPHYCEAE							
EUGLENALES							
Euglenaceae							
Euglena ehrenbergii G.A.Klebs ou Georg Albrecht Klebs	Eueh	**	**	**			*
Euglena sp.	Eugsp	**					
Trachelomonas armata (Ehrenberg) F. Stein	Trar	***	**	*	**	*	**
Trachelomonas curta A.M.Cunha	Trcu	**	*	*			*
Trachelomonas hirta Da Cunha	Trhi		*				
Trachelomonas oblonga Lemmermann	Trob	***	**	**	**	*	**
Trachelomonas rugulosa F.Stein ex Deflandre	Trru	***	***	***	***	**	***
Trachelomonas volvocina (Ehrenberg)Ehrenberg	Trvo	***	**	***	*	**	*
Trachelomonas volvocinopsis Swirenko	Trvol	***	***	***	***	***	***
Trachelomonas sp.1	Trsp1			*			
Trachelomonas sp.2	Trsp2	*					
Trachelomonas sp.3	Trsp3	*					
Phacaceae							
Lepocinclis acus (O.F.Müll.) B.Marin & Melkonian	Leac	*	*	*			
Lepocinclis salina F.E.Fritsch	Lesa	*			*		
Lepocinclis texta (Dujardin) Lemmermann	Lete	*		*	*	*	
CHLOROPHYTA							
ZYGNEMATOPHYCEAE							
DESMIDIALES							
Desmidiaceae							
Actinotaenium capax (Joshua) Teiling	Acca		*				
Cosmarium contractum O.Kirchner	Cocon	**	**	*	**	*	*
Cosmarium isthmochondrum Nordstedt	Cois	*					*
Cosmarium sp.	Cossp		*				
Spondylosium sp.	Sposp				*	*	
Closteriaceae							
Closterium cynthia De Notaris	Clcy					*	
Closterium ehrenbergii Menegh. ex Ralfs	Cleh						
Closterium gracile Brébisson ex Ralfs	Clgr	**	*	**	**	**	***
Closterium moniliferum (Bory) Ehrenberg	Clmo					*	*
Closterium sp.	Clsp		*	*	**	*	**
CHLOROPHYCEAE							
SPHAEROPLEALES							
Scenedesmaceae							
Acutodesmus obliquus (Turpin) Hegewald & Hanagata	Acob						
Acutodesmus acutiformis (Schröder) P.M Tsarenko & D.M John	Acac			*			
Coelastrum cambricum W.Archer	Coca						
Coelastrum microporum Nägeli	Comi						
Desmodesmus aculeolatus (Reinsch) P.M.Tsarenko	Deac		*		*	*	
Desmodesmus bicaudatus (Dedusenko) P.M.Tsarenko	Debi	***	**	**	**	**	***
Desmodesmus commununis (E. Hegewald)	Deco	**	***	*	***	**	***
Hariotina reticulatum (P,A,Dangeard)	Hare	**	*	**	**	**	**
Scenedesmus brevispina (G.M.Smith) Chodat	Scbr	*			*		
Scenedesmus disciformis (Chodat) Ahlstrom	Scdi	***	**	***	***	**	**

Scenedesmus obtusus fo.econis Compère	Scof	*	*	*	*		
Scenedesmus opoliensis P.G.Richt	Scop	*	**	*	*	*	*
Scenedesmus quadricauda var. ellipticus (West & G.S. West)	Scqu	*				*	
Tetradesmus acutus (Turpin) M.J.Wynne	Teac		*	*	*	**	*
Tetradesmus dimorphus (Turpin) M.J.Wynne	Tedi						
Tetradesmus incrassatulus (Bohlin) M.J. Wynne	Tein	***	***	***	***	***	***
Tetradesmus obliquus (Turpin) M.J.Wynne	Teob		*	*			
Tetrastum elegans (Chodat) Komárek	Teel	***	***	***	***	***	***
Tetrastrum triangulare (Chodat) C. Bock & Krienitz	Tetri	***	***	***	***	**	***
Tetrastum sp.	Tesp	**	**	**	*	**	**
Ankistrodesmaceae							
Quadrigula korsikovii Komárek	Quko						*
Hydrodictyaceae							
Tetraedron hemisphaericum (Skuja)	Tehe	*	*				
Tetraedron triangulare Korshikov	Tetr	*	*	**	**	**	**
Stauridinium tetras (Ehrenberg) E. Hegewald	Stte	*		*	*	*	
Selenastraceae							
Ankistrodesmus bernardii Komárek	Anbe						*
Messastrum gracilis (Reinsch) T.S. Garcia	Megr			*			
Monoraphidium arcuatum (Korshikov) Hindák	Moar	**		*	*	*	**
Selenastracea							
Monoraphidium circinale (Nygaard) Nygaard	Moci	**		***	***	**	**
Monoraphidium contortum (Thuret) Komárková-Legnerová	Moco	***	***	***	***	***	**
Monoraphidium griffitii (Berkeley) Komarkova-Legnerova	Mogr		**	**	*	**	
Monoraphidium sp.	Mosp	*	*	**	**	***	**
Chlorellaceae							
Lemmermannia tetrapedia (Kirchner) Lemmermannn	Letet	**	**	*		***	*
Willea rectangularis (A. Braun) D.M.John, M.J.Wynne & P.M.Tsarenko	Wire	**	*	**	**	**	**
Willea crucifera (Wolle) D.M.John, M.J.Wynne & P.M.Tsarenko	Wicr	*					
CLAMYDOMONADALES							
Volvocaceae							
Pandorina morum (O.F.Müller) Bory	Pamo				*		
OEDOGONIALES							
Oedogoniaceae							
Oedogonium globosum Nordstedt ex Hirn	Oegl	*				*	
Oedogonium sp.1	Oesp1		*				
Oedogonium sp.2	Oesp2	*	**	**	*	*	*
TREBOUXIOPHYCEAE							
CHLORELLALES							
Oocystaceae							
Oocystis borgei J. Snow.	Oobo	**	**	**	***	**	***
Oocystis gigas W.Archer.	Oogi		**	*	**	**	**
Oocystis sp.	Oosp	*	*		*	*	*
Chlorellaceae							
Chlorella vulgaris Beijerinck	Chvu	*		**	**		*
Triceratiaceae							
Amphipentas pentacrinus Ehrenberg	Ampe				*	*	
DINOPHYTA							
DINOPHYCEAE							
PERIDINIALES							
Protoperidiniaceae							
Protoperidinium conicoides (Paulsen) Balech	Prco				*	*	
Protoperidinium sp.	Prsp	***	***	***	***	***	**
Peridiniaceae							
Peridinium inconspicuum Lemmermann	Pein	***	***	***	***	***	***
Peridinium sp.	Pesp		*			*	
GYMNODINIALES							
Gymnodiniaceae							
Gymnodinium rotundatum G.A. Klebs	Gyro	*	*	*			
GONYAULACALES							
Ceratiaceae							
Tripos furca (Ehrenberg) F.Go´mez	Trfu						*
Tripos trichoceros (Ehrenberg) F.Go´mez	Trtr	*					
CHRYSOPHYTA							
MALLOMONADACEAE							
SYNURALES							
Synurophyceae							
Mallomonas sp.	Masp			*			

BACILLARIOPHYTA							
COSCINODISCOPHYCEAE							
Aulacoseiraceae							
Aulacoseira granulata (Ehrenberg) Simonsen	Augr	*	**	*	*	*	
Aulacoseira granulata var. angustissima (O.F.Müller) Simonsen	Auga	*					*
MELOSIRALES							
Melosiraceae							
Melosira sp.1	Mesp1	*	**	**	***	**	**
Melosira sp.2	Mesp2		**	*	*		*
COSCINODISCALES							
Coscinodiscaceae							
Coscinodiscus asteromphalus Ehrenberg	Coas	*	*	*	*		
Coscinodiscus centralis Ehrenberg	Coce	*	*	*		*	*
Coscinodiscus lacustris Grunow in Cleve & Grunow	Cola		*	*			
CHAETOCEROTALES							
Chaetocerotaceae							
Chaetoceros diversus Cleve	Chdiv	*	*				*
Chaetoceros subtilis Cleve	Chsu	*		*	*	*	
Chaetoceros sp.1	Csp1		*				
Chaetoceros sp.2	Csp2	**	**	*	*		
BACILLARIOPHYCEAE							
BACILLARIALES							
Bacillariaceae							
Bacillaria sp.	Basp	**	***	***	*	*	*
Denticula kuetzingii Grunow	Deku	*		*	*		**
Nitzschia sp.	Nisp			*			
MEDIOPHYCEAE							
STEPHANODISCALES							
Stephanodiscaceae							
Stephanocyclus meneghinianus (Kützing) Kulikovskiy, Genkal &Kociolek	Stme	***	***	***	***	***	***
CYMBELLALES							
Cymbellaceae							
Cymbella turgida W.Gregory	Cytu	*	*	*	*		
EUNOTIALES							
Eunotiaceae							
Eunotia sp.	Eunsp	*		*	*	*	
LICMOPHORALES							
Ulnariaceae							
Ulnaria ulna (Nitzsch) Compère	Ulul	**	**	*	*	*	*
Ulnaria sp.	Ulsp			*			*
NAVICULALES							
Diadesmidaceae							
Luticola sp.	Lusp	**		*	*		
Naviculaceae							
Navicula sp.	Nasp	*	**			*	*
Pinnulariaceae							
Pinnularia acrospharia W. Smith	Piac						*
Pinnularia sp.	Pisp	*	*	*			
Pleurosigmataceae							
Gyrosigma acuminatum (Kützing) Rabenhorst	Gyac	**	**	*		*	
Gyrosigma attenuatum (Kützing) Rabenhorst	Gyat		*	*			
Gyrosigma sp.	Gysp	*				*	
Neidiaceae							
Neidium iridis Cleve	Neir			*			
RHOPALODIALES							
Rhopalodiaceae							
Epithemia arguiformis Q.You & Y.Wang	Epar	**	**	**	***	**	*
THALASSIOPHYSALES							
Catenulaceae							
Amphora sp.	Amsp		*				
SURIRELLALES							
Surirellaceae							
Surirella sp.	Susp	*					
FRAGILARIALES							
Fragilariaceae							
Meridion sp.	Mesp	*	*				
TOTAL	165	117	113	104	104	100	100

Acro: Acronyms. S1 – S6= sampling station; * = accidental taxa; ** = accessory taxa; *** = constant taxa.

Seasonal variations in physico-chemical parameters

Seasonal variations in physico-chemical parameters measured in the waters of the Jacqueville aquaculture station are shown in Table 2. With the exception of transparency, they do not differ significantly from one station to another (Mann-Whitney test; $p < 0.05$) with the exception of transparency (Kruskal-Wallis test ; $p > 0.05$). The maximum median values for temperature (31.3°C), conductivity (5789 µS/cm), pH (8.62) and salinity (3.22 ppt) were obtained during the long dry season (LDS). The minimum for these parameters (temperature: 28.38 °C ; conductivity: 4005 µS/cm ; salinity: 2.55 ppt) were observed during the short rainy season (SRS), except for pH (8.06), which was recorded during the long rainy season (LRS). Dissolved oxygen recorded its maximum value (8.08 mg/L) during the short dry season (SDS) and its minimum value (6.90 mg/L) during the short rainy season (SRS). The maximum values of transparency (178.63 cm) were recorded during the long rainy season (LRS) while the lowest values (133.5 cm) were noted during the short dry season (SDS).

With regard to nutrient salts, total nitrogen concentrations varied from 2.8 mg/L to 3.7 mg/L during the dry season (LDS and SDS) and the long rainy season (LRS) respectively. Total phosphorus concentrations fluctuated from 0.16 mg/L during the long dry season (LDS) to 0.93 mg/L during the long rainy season (LRS). For silica, the highest concentrations (9.5 mg/L) were recorded during the long dry season (LDS) and the short rainy season (SRS). However the lowest concentrations (8.5 mg/L) were recorded during the short dry season (SDS).

Qualitative analysis of the phytoplankton community

Taxonomic composition

The phytoplankton community at the Jacqueville aquaculture station comprises a total of 165 taxa (Table 3). These taxa are divided into six branches, 10 Classes, 29 Orders, 48 Families and 73 Genus. The six branches recorded are Cyanoprocaryota (58 taxa), Euglenophyta (15 taxa), Chlorophyta (53 taxa), Dinophyta (7 taxa), Chrysophyta (1 taxa) and Bacillariophyta (31 taxa). The greatest diversity is represented by the Cyanoprocaryota and the Chlorophyta, with 58 taxa and 53 taxa respectively. Taxa from these two branches account for 35.15% and 32.12% of taxonomic richness respectively. These are followed by the Bacillariophyta (31 taxa) or 18.79%, the Euglenophyta (15 taxa) or 9.09% and the Dinophyta (7 taxa) or 4.24%.

The least diverse branches is the Chrysophyta, with one taxon or 0.61%. A single Chrysophyta taxon was recorded at station S3, while the other stations (S1, S2, S4, S5 and S6) were characterised by the absence of any taxon from this branches. At all stations (S1, S2, S3, S4, S5 and S6) the Cyanoprocaryota and Chlorophyta branches recorded the greatest diversity. The phytoplankton inventory of the stations surveyed at the Jacqueville aquaculture station shows that station S1 has the highest taxa richness (117 taxa), while stations S5 and S6 have the lowest taxa richness (100 taxa). Genuslly speaking, in terms of Orders and Families, the branches Bacillariophyta obtained the highest numbers of taxa (14 and 18 respectively). In terms of Classes, the branches Chlorophyta and Bacillariophyta recorded the highest number of taxa, 3 for each of the 10 classes obtained. At genus level, the greatest number of taxa was obtained within the Chlorophyta and Bacillariophyta branches (20 each) out of the 66 recorded. Specifically, among the Chlorophyta, the order Sphaeropleales (33 taxa) is the most diverse. Within this order, the best represented genus are *Scenedesmus* (12 taxa) and *Monoraphidium* (5 taxa). A single order (Euglenales) characterises the branches Euglenophyta. This order is mainly represented by the genus *Trachelomonas* (10 taxa). *Lepocinclis* (3 taxa) and Euglena (2 taxa). Of the 48 taxa recorded within the Cyanoprocaryota, the best represented orders are the Chroococcales (26 taxa) and the Synechoccales (19 taxa). Of these two orders. The best represented genus are *Microcystis* (8 taxa), *Chroococcus* (8 taxa), *Synechocystis* (4 taxa), *Aphanocapsa* (6 taxa), *Merismopedia* (4 taxa) and *Pseudanabaena* (3 taxa). In the Bacillariophyta branches, of the 14 orders obtained, the genus *Chaetoceros* (4 taxa), *Coscinodiscus* (3 taxa) and

Gyrosigma (3 taxa) are the most diverse. However, the order Naviculales recorded the highest number of taxa (7). Chrysophyta branches is represented only by the order Synurales and the genus *Mallomonas*. As for Dinophyta branches, the most diverse orders are Peridiniales (2 taxa) and Gonyaulacales (2 taxa), with the genus *Protoperidinium* and *Neoceratium* respectively. Of the 165 taxa inventoried, 61 are common to the six stations (S1, S2, S3, S4, S5 and S6) of the Jacqueville aquaculture station (SAJ). As for the taxa specific to each station, eight were collected at station S1. Four taxa were specific to stations S2 and S6. Station S4 recorded only one specific taxon, compared with 2 for station S5.

Table 4. Proportions of constant, accessory and accidental taxa in the waters of the Jacqueville aquaculture station according to their occurrence.

Stations	Constant taxa (%)	Accessory taxa (%)	Accidental taxa (%)	Total
S1	29	36	52	117
S2	24	39	50	113
S3	28	28	48	104
S4	36	21	47	104
S5	23	31	46	100
S6	29	26	45	100

Table 5. Values of Sorensen similarity index between sampling points at the Jacqueville aquaculture station from January to December 2020: S-S6 = stations.

Stations	S1	S2	S3	S4	S5
S2	0.80				
S3	0.80	0.83			
S4	0.78	0.79	0.77		
S5	0.76	0.76	0.74	0.83	
S6	0.76	0.77	0.77	0.82	0.80

Table 6. Values of indices trophique de Carlson (TSI) des eaux de la station de Jacqueville from January to December 2020: S1-S6 = stations.

Indicateurs	S1	S2	S3	S4	S5	S6
TSI (CA) (µg/L)	50.85	41.76	47.68	42.64	47.13	55.17
TSI (SD) (m)	55.24	59.11	62.20	52.24	50.53	49.87
TSI (PT) (µg/L)	92.51	97.18	96.91	94.85	107.50	96.91
TSI	66.20	66.02	68.93	63.24	68.39	67.32
Trophic status	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Eutrophic

Occurence of taxa at Jacqueville station

Table 4 below provides information on the frequency of occurrence of taxa recorded at the Jacqueville aquaculture station. Overall, there are more accidental taxa at all stations. These ranged from 45% (S6) to 5% (S1). As for the proportion of accessory taxa, the highest proportion (39%) was observed at station S2, while the lowest proportion (21%) was noted at station S4. With regard to constant taxa, the highest proportion was noted at station S4 (36%) while the lowest proportion was observed at station S3 (23%).

Sorensen index for taxa at the Jacqueville aquaculture station

Sorensen's similarity index values are greater than 70% between all the stations (Table 5).

At the specific level, Sorensen's similarity index values between the different stations varied between 76% and 83%. Stations (S2-S3) and (S4-S5) showed the highest similarity (83%). The lowest similarity was observed between stations S3 and S5 (74%).

Spatial and seasonal variations in phytoplankton abundance in the waters of the Jacqueville station

Total abundances

Variations in total phytoplankton abundance in the waters of the Jacqueville station are illustrated in Fig. 2. Spatially, there was no significant trend from one station to another (Kruskal-Wallis test; $p > 0.05$). Overall, total phytoplankton abundance values were low. The maximum median value (85 10^5 Cells/L) for

total phytoplankton density was observed in S1, while the minimum median value (40 10^5 Cells/L) was recorded in S3. Seasonally, a significant variation in total density was observed between seasons (Mann-Whitney test; $p < 0.05$). The highest total density (342.5 10^5 Cells/L) was recorded during the long dry season (LDS), while the lowest total density (39.5 10^5 Cells/L) was noted during the short dry season (SDS).

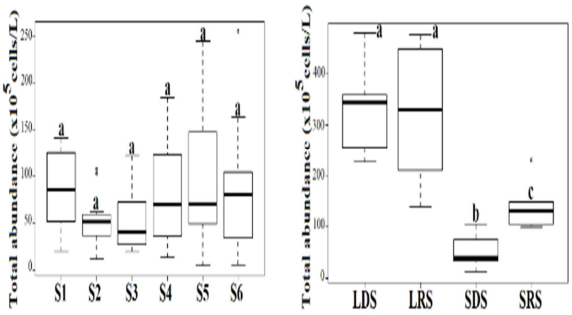

Fig. 2. Spatial and seasonal variations in the total abundance of phytoplankton in the waters of the Jacqueville aquaculture station, S1-S6= stations, LDS = Long Dry Season; LRS = Long Rainy Season; SDS = Short Dry Season; SRS = Short Rainy Season; median values having a letter in common do not differ significantly (Mann-Whitney test; $p > 0.05$).

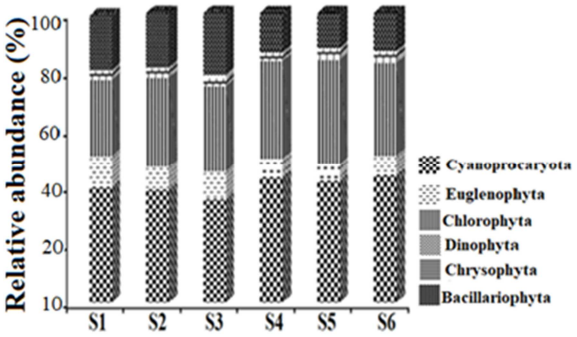

Fig. 3. Spatial variations in the relative abundance of phytoplankton in the waters of the Jacqueville aquaculture station, S1-S6= stations.

Relative abundances

The respective abundance of the different algal groups (Fig. 3) shows the clear predominance of Cyanoprocaryota (more than 35 % of the branches recorded) at all the sampling stations. At station S1, Cyanoprocaryota are followed by the branches Chlorophyta (26.27%), Bacillariophyta (18.37%) and Euglenophyta (11.02%). The Dinophyta and Chrysophyta branches represented only 3.39 % and 0% respectively of the relative abundance at this station. At station S2, Cyanoprocaryota were followed by Chlorophyta (30.97%), Bacillariophyta (18.58%), Euglenophyta (7.96%), Dinophyta (3.54%) and Chrysophyta (0%). At station S3, after Cyanoprocaryota, come Chlorophyta (29.81%), Bacillariophyta (21.15%), Euglenophyta (9.62%) and Dinophyta and Chrysophyta (2.88% ; 0.96%) respectively. At stations S4 and S5, after the Cyanoprocaryota, come Chlorophyta (33.65% ; 36%), Bacillariophyta (13.46% ; 12%), Euglenophyta (6.73% ; 6%) and Dinophyta (2.88% ; 4%), and the absence of Chrysophyta respectively. At station S6, after the Cyanoprocaryota group, it was the Chlorophyta (32%), followed by the Bacillariophyta with 13% and then the Euglenophyta (7%), Dinophyta and Chrysophyta groups with 4% and 0% of relative abundance respectively.

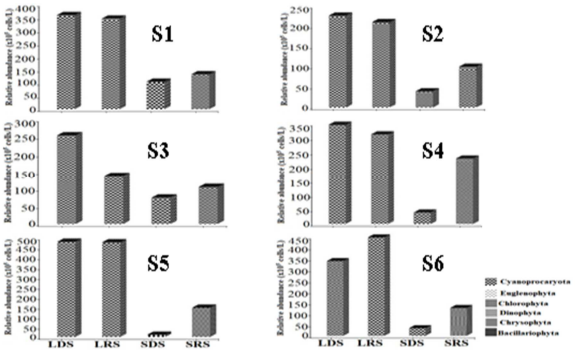

Fig. 4. Seasonal variation in the relative abundance of phytoplankton in the waters of the Jacqueville aquaculture station, LDS = Long Dry Season; LRS = Long Rainy Season; SDS = Short Dry Season; SRS = Short Rainy Season.

Seasonally, Cyanoprocaryota dominated regardless of the season or station (Fig. 4). These densities ranged from 473.06 10^5 Cells/L during the long dry season (LDS) to 10.09 10^5 Cells/L during the short dry season (SDS). The highest densities were recorded during the long dry season (LDS) at all stations except station S6, which was recorded during the long rainy season (LRS). On the other hand, the lowest densities were obtained in Chrysophyta branches regardless of the season or station.

At station S1, the highest densities of the Cyanoprocaryota branches were noted during the long dry season, followed by those of Chlorophyta (3.64 10^5 cells/L), Dinophyta (1.52 10^5 cells/L), Bacillariophyta (0.57 10^5 cells/L) all during the long rainy season and no presence of Chrysophyta (0 cells/L in all seasons). At station S2, the highest density was recorded in the Cyanoprocaryota branches (221.77 10^5 cells/L in LDS), followed by the Chlorophyta branches (6.48 10^5 cells/L in SRS), Bacillariophyta (1.09 10^5 cells/L in LRS), Dinophyta (0.72 10^5 cells/L in SRS, Euglenophyta (0.25 10^5 cells/L in LDS) and no Chrysophyta.

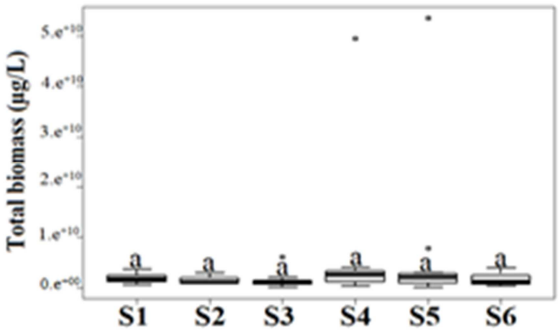

Fig. 5. Spatial variation in total phytoplankton biomass in the waters of the Jacqueville aquaculture station, S1-S6 = stations. Median values having a letter (a or b) in common do not differ significantly (Mann-Withney test; $p > 0.05$).

At station S3, after the Cyanoprocaryota branches (250.10 10^5 cells/L in LDS), come the Chlorophyta (2.43 10^5 cells/L in LDS), Bacillariophyta (0.74 10^5 cells/L in SRS), Dinophyta (0.72 10^5 cells/L in LDS), Euglenophyta (0.25 10^5 cells/L in LDS) and Chrysophyta (0.006 10^5 cells/L in SDS).

At station S4, the highest density was Cyanoprocaryota (340.58 10^5 cells/L in LDS), followed by Chlorophyta (5.99 10^5 cells/L in SRS), Bacillariophyta (1.002 10^5 cells/L in LDS), Dinophyta (0.75 10^5 cells/L in SRS), Euglenophyta (0.18.10^5 cells/L in LDS) and no Chrysophyta.

At station S5, after Cyanoprocaryota branches (473.06 10^5 cells/L in LDS) come the densities of the Chlorophyta branches (4.10 10^5 cells/L in LRS), Euglenophyta (0.74 10^5 cells/L in LDS), Bacillariophyta (0.64 10^5 cells/L in LDS), Dinophyta (0.36 10^5 cells/L in SRS) and Chrysophyta (0 cells/L in all seasons).

At station S6, the highest density was found in Cyanoprocaryota branches (443.8 10^5 cells/L in LRS), followed by the Chlorophyta (2.57 10^5 cells/L in LDS), Bacillariophyta (0.78 10^5 cells/L in LRS), then Euglenophyta (0.27 10^5 cells/L in LDS), Dinophyta (0.21 10^5 cells/L in LDS) and finally no Chrysophyta.

Spatial and seasonal variations in phytoplankton biomass in the waters of the Jacqueville station

Total biomass

Fig. 5 shows the spatial variations in the total biomass of the phytoplankton community in the waters of the Jacqueville aquaculture station. The lowest phytoplankton biomass was recorded in S3 (1.05 10^9 µg/L), while the highest biomass was noted in S4 (2.51 10^9 µg/L). Phytoplankton biomass did not vary significantly between stations (Mann-Whitney test; $p > 0.05$). Analysis of the seasonal evolution of phytoplankton biomass (Fig. 6) indicates that the total biomasses obtained in the long dry season are significantly lower than those recorded in other seasons (Mann-Whitney test; $P < 0.05$). Cyanoprocaryota, Chlorophyta and Dinophyta are the main branches that dominate the biomass of phytoplankton communities at the stations surveyed. In general, the highest biomasses (6.35 10^9 µg/L ; 9.04 10^9 µg/L ; 5.78 10^{10} µg/L ; 6.53 10^9 µg/L) were obtained during the long dry season at stations S2, S3, S5 and S6 respectively. Those at stations S1 and S4 (6.88 10^9 µg/L ; 5.43 10^{10} µg/L) were recorded during the main rainy season. On the other hand, the lowest biomasses (3.66 10^9 µg/L ; 1.72 10^9 µg/L ; 1.85 10^9 µg/L ; 0.65 10^9 µg/L ; 0.69 10^9 µg/L ; 0.652 10^9 µg/L) were observed during the short dry season at all stations. Specifically, with regard to the Cyanoprocaryota branches, at station S1, the highest biomass was noted during the long dry season and the long rainy season. The biomass at station S2 was recorded during the long dry season.

The biomass at stations S3 and S4 was recorded during the dry season (long dry season and short dry season). Station S5 recorded the highest biomass during the long rainy season, while station S6 recorded biomass in all seasons. In the Chlorophyta branches, the highest biomass was recorded at stations S1 and S4 during the short dry season and the long rainy season respectively. Biomass at stations S2 and S5 was recorded during the long dry season.

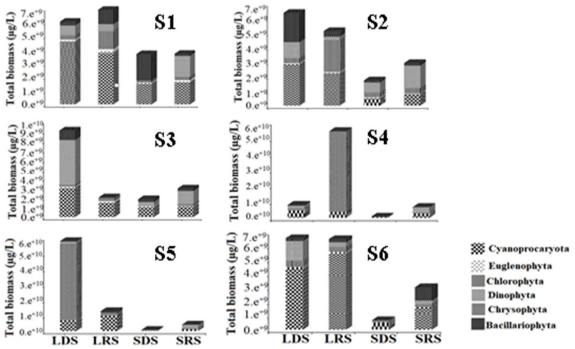

Fig. 6. Seasonal variations in the total biomass of phytoplankton groups recorded in the waters of the Jacqueville aquaculture station (Côte d'Ivoire): S1-S6 = sampling stations; LDS = Long Dry Season; LRS = Long Rainy Season; SDS = Short Dry Season; SRS = Short Rainy Season.

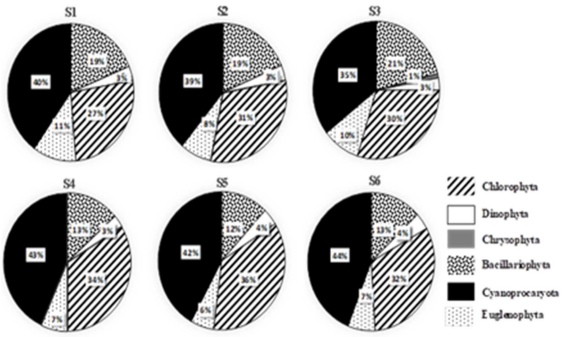

Fig. 7. Relative biomasse of phytoplanktonic branches in the waters of the Jacqueville aquaculture station.

The highest biomass of Bacillariophyta was recorded at stations S1 and S2 during the short dry season. With regard to Dinophyta branches, the highest biomass was recorded at stations S1 and S2 during the short rainy season, while that at stations S3 and S6 was recorded during the long dry season.

The highest biomass in the Euglenophyta branches was recorded at all stations during the long dry season, with the exception of station S3 (long rainy season). Chrysophyta biomass was absent at all stations except station S3 (short dry season).

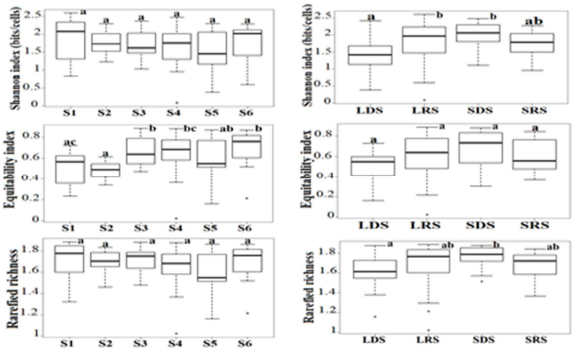

Fig. 8. Spatial and Seasonal variations of rarefied richness, Shannon index and Equitability index measured at the Jacqueville aquaculture station from January to December 2020: S1-S6 = sampling stations; LDS = Long Dry season; LRS = Long Rainy season; SDS = Short Dry Season; SRS = Short Rainy Season; median values with a common letter do not differ significantly (Mann-Whitney test; $p > 0.05$).

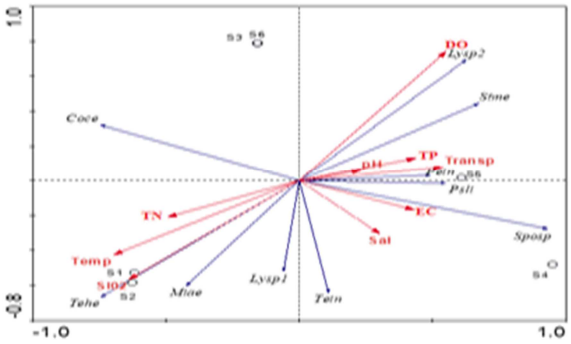

Fig. 9. Spatial ordering in RDA of the dominant phytoplankton taxa and physico-chemical parameters of the water at the Jacqueville aquaculture station on the first two axes. S1-S6: stations; Acronyms: see Table 3; Temp: temperature; pH: hydrogen potential; EC: conductivity; DO: dissolved oxygen; Sal: salinity; Transp: transparency; TN: total nitrogen, TP: total phosphorus; SIO2: silica.

Biomasses relatives

In terms of the relative biomass of the phytoplankton branches of the major phytoplankton groups (Fig. 7), the Cyanoprocaryota branches accounts for more

than 35 % of the relative biomass at all the sampling stations. This is followed by the branches Chlorophyta (S2 = 31% ; S3 = 30% ; S4 = 34% ; S5 = 36% ; S6 = 32%), Bacillariophyta (S2 = 19% ; S3 = 21% ; S4 = 13% ; S5 = 12% ; S6 = 13%), Euglenophyta (S2 = 8% ; S3 = 10% ; S4 = 7% ; S5 = 6% ; S6 = 7%) respectively. Then the Dinophyta branches (S2 = 3% ; S4 = 3% ; S5 = 4% ; S6 = 4%) and no Chrysophyta at any of the surveyed stations except station S3 (1%).

Spatial and seasonal variations in the Shannon and equitability indices

Spatial variation in Shannon and equitability indices

Fluctuations in the Shannon index, equitability index and rarefied of the water at the Jacqueville aquaculture station are shown in (Fig. 8). The values of the Shannon index fluctuate between 1.45 bits/cell (S5) and 2.07 bits/cell (S1). Equitability values ranged from 0.49 (S2) to 0.76 (S6). The values Rarefied richness values ranged from 1.55 to 1.78 at stations S5 and S1 respectively. Only the equitability index shows a significant difference from one station to another (Mann-Whitney test; $p > 0.05$). Seasonal, Only equitability varies from one season to the next (Mann-Whitney test; $p < 0.05$). The high values of the Shannon and Equitability indices (H'= 1.28 bits/cells and E = 0.79) are recorded during the short dry season. On the other hand, low values are obtained during the short rainy season for Equitability (E= 0.72) and during the long dry season for the Shannon index (H'= 0.67 bits/cells). The minimum value of rarefaction richness (1.65) was obtained during the long dry season (SDS), while the maximum value (1.82) was observed during the short dry season (SDS).

Determinism of the phytoplankton community

A canonical redundancy analysis (RDA) was carried out on all phytoplankton algae (whose relative abundance was greater than 2% in the waters of the Jacqueville aquaculture station) and nine ecological descriptors (temperature, pH, conductivity, dissolved oxygen, transparency, salinity, total nitrogen, total phosphorus and silica). The first two axes express 90.3% of the total variance (69.7% and 20.6% respectively for axes I and 2). The first RDA axis (Fig. 9) is strongly and positively correlated with transparency, total phosphorus, conductivity and salinity, and negatively correlated with temperature, total nitrogen and silica. It contrasts the more mineralised sites with warmer sites rich in total nitrogen and silica. Phytoplankton taxa such as *Peridinium inconspicuum* (Pein), *Stephanocyclus meneghinianus* (Stme), *Pseudanabaena limnetica* (Psli) and *Spondylosium* sp. (Sposp) are strongly and positively correlated with the variables pH, transparency, total phosphorus and conductivity.

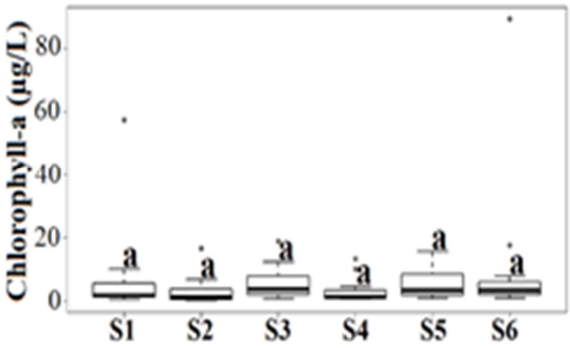

Fig. 10. Spatial variation in total phytoplankton biomass in the waters of the Jacqueville aquaculture station, S1-S6 = stations. Median values having a letter (a or b) in common do not differ significantly (Mann-Whitney test; $p > 0.05$).

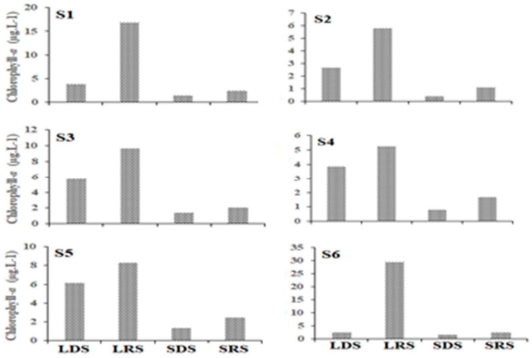

Fig. 11. Seasonal variation of chlorophyll a concentration in the waters of the Jacqueville aquaculture station, LDS = Long Dry Season; LRS = Long Rainy Season; SDS = Short Dry Season; SRS = Short Rainy Season.

Axis 2 is strongly and positively correlated with dissolved oxygen and strongly and negatively correlated with temperature and total nitrogen. It contrasts the more oxygenated stations with stations

richer in total nitrogen and silica, which are rich in species. Phytoplankton taxa such as Lyngbya sp.2 (Lysp2) are strongly positively correlated and *Stephanocyclus meneghinianus* (Stme), *Tetraedron hemisphaericum* (Tehe), *Microcystis wesenbergii* (Miwe), *Lyngbya* sp.1 (Lysp1), *Tetradesmus incrassatulus* (Tein) are strongly and negatively correlated with temperature and silica variables.

Spatial and seasonal variation of Chlorophyll a (Chl-a)

Spatial evolution of the chlorophyll-a content within the six stations of the Jacqueville aquaculture station is illustrated in Fig. 10. The highest level (3.59 µg/L) was recorded at station S3 and the lowest (1.10 µg/L) at station S2. Chlorophyll a levels did not vary significantly between stations Kruskal-Wallis test; $p>0.05$). Seasonally, the highest values were noted in the long rainy season (LRS) at all stations (Fig. 11). The lowest values were obtained in the short dry season (SDS). Chlorophyll a concentration showed a significant difference between the stations studied (Mann-Whitney test; $p < 0.05$).

Carlson Trophic Status Index (TSI)

Table 6 presents the Carlson Trophic Status Index (TSI). A summary of the averages for chorophyll a, transparency and total phosphorus indicates that all the stations surveyed are eutrophic.

Discussion

Qualitative analysis of the phytoplankton population in the waters of the Jacqueville station revealed 165 taxa divided into six (6) branches, 10 classes, 29 orders, 48 families and 73 genus. The algal flora inventoried in the waters of this station is therefore considered to be rich in terms of the number of taxa it contains. This high phytoplanktonic taxonomic richness could be attributable to the fact that the waters of the Ebrié lagoon system are not constantly renewed. This favours biological processes such as the complete reproduction and development cycles of algae. The same observation was made by Komoé *et al.* (2009) and Seu-Anoï (2012), who showed that algal richness is related to water stability. Thus, according to Gonzalez and Descamps-Julien (2004), this high taxonomic richness would indicate greater stability in the functioning of the ecosystem in the face of environmental disturbances. The phytoplankton taxonomic richness of the Jacqueville aquaculture station is higher than that obtained by Khellou, 2020 in the waters of the Megarine lakes in Algeria (58 taxa), but higher than those obtained by Komoé (2014) in the Grand-Lahou lagoon complex (316 taxa) in Côte d'Ivoire. This difference in taxonomic richness observed between these different studies could be linked to the size of the hydrosystems explored. Lake Megarine, with a surface area of 120 km², is smaller than the Grand-Lahou lagoon system (190 km²), which in turn is larger than the Ebrié lagoon complex (180 km²). This assertion was confirmed by Roland (2010), who showed that phytoplankton richness increases with reservoir size.

The dominance of Cyanoprocaryota (> 35%) at all the sampling stations is thought to be due to the adaptation of this branches to a multitude of environmental conditions and the ability of these microalgae to proliferate even under extreme conditions (Meissner *et al.,* 2014). In addition, this predominance may be the result of strategies developed by these Cyanobacteria to avoid grazing by grazers such as zooplankton and phytophagous fish. According to (Rohrlack *et al.,* 2013), in order to defend themselves against herbivores and parasites and to eliminate competitors vying for the same resources, they can release toxins (microcystins) that give them a "bad taste" (Haney, 1987). The preponderance of cyanobacteria in the waters studied is not due to the large number of species they contain, but rather to the very high number of filaments or cells in colonies belonging to a very small number of dominant species. This assertion was verified in this study by the presence of secondary metabolite-producing genus such as *Microcystis*, *Pseudanabaena* and *Oscillatoria*. These results corroborate those of Coulibaly *et al.* (2017) and Niamien-Ebrottié *et al.* (2017). Nevertheless, the genus *Microcystis* was the most present among the Cyanobacteria. This could be due to the ubiquity of this genus, especially during blooms (El Ghazali *et al.,*

2011). This dominance of Cyanoprocaryota has also been reported in brackish waters in Nigeria (Onyema and Nwankwo, 2010) and India (Badylak and Phlips, 2004).

The rarefied richness and Shannon index are higher at station S1. Equitability was significantly higher at station S6. The phytoplankton community is therefore relatively more diverse at station S1 and better organised at station S6. This shows that these stations offer a more favourable environment for a large number of taxa. In fact, the fish farming practised at station S1 favours the availability of nutrients from fish feeding. Hence the higher taxonomic richness recorded (117 taxa) compared with the other stations surveyed. Station S6, on the other hand, is more oxygenated and therefore provides more favourable conditions for aquatic life and a fair phytoplankton population. On the other hand, the rarefied richness and Shannon index are lower at station S5 and equitability is significantly lower at station S2. This would indicate that the phytoplankton community is poorly diversified and organised at stations S5 and S2 respectively. The low values of the biocenotic indices (rarefied richness and Shannon index) recorded at station S5 would be linked to the higher conductivity and total phosphorus levels recorded at this station. Our results are in agreement with those of Daifi and Saci (2019) on Lake Tonga in Algeria, who obtained low phytoplankton diversity values.

Seasonally, the higher Shannon and equitability index values obtained in the dry season (SDS) than in the rainy season mean that the phytoplankton population is more balanced and diverse in this season. The increase in phytoplankton diversity during the dry season observed in our study would appear to be linked to environmental conditions that are favourable to phytoplankton development. Conversely, the low values of these indices observed during the long dry season indicate that there are predominant species (Tchapgnouo *et al.,* 2012) during this period in the waters of the stations surveyed. According to the latter, in exceptionally diverse environments, the Shannon index hardly exceeds 4.5. The low equitability values obtained suggest that the phytoplankton population is out of balance as a result of the proliferation of a limited number of species. This proliferation would be due to the antrophic activities carried out in the vicinity of the Jacqueville aquaculture station.

The Sorensen similarity index values revealed a high degree of similarity (> 70%.) between the different sampling stations. Such an observation shows that the physico-chemicals recorded are quite similar as mentioned by Adon (2012) in their study. Furthermore, the strong similarities (83%) observed between stations (S2-S3) and (S4-S5) could be explained by the fact that these stations are located on the same radial and the relatively smaller distances that separate (30 m respectively) these sampling stations in order to constitute a barrier for the dispersion of the species. This observation is confirmed by Hillebrand *et al.* (2001), which states that unicellular organisms, such as algae, may have higher dispersal rates due to their small size.

The results obtained for the overall trophic level using the Carlson Trophic Index (TSI) confirm the results obtained from the trophic classification according to the OECD (1982), which indicates that all the waters at the Jacqueville aquaculture station are eutrophic. It should be noted that this station is characterised by the fish farming practised in lagoon enclosures and the proximity of villages (Goue'm and ndri campement) where human activities are practised (agriculture, fishing, etc.). In fact, these waters receive organic matter and nutrients from run-off from terrigenous inputs. It is likely that there is a proliferation of algae due to the high levels of nutrients, particularly nitrogen and phosphorus, coming from run-off from the catchment areas and from products such as detergents used by local residents for washing clothes and dishes. We should also note the presence of certain taxa, notably *Scenedesmus*, *Microcystis*, *Aulacoseira granulata* and *Lepocinclis* at very high densities and regularly recorded during the study. These taxa are known for

their predilection for eutrophic environments (Huisman *et al.,* 2005 and Niamien-Ebrottié *et al.,* 2008). This is confirmed by Cogels *et al.* (1993), who attest that certain cyanobacteria collected during this sampling, mainly the species *Anabaena affine* and *Microcystis aeruginosa*, are typical algae of eutrophic waters. Pollution taxa are also more abundant and diverse at the stations surveyed. The trophic status of the waters of the Jacqueville aquaculture station (sector V of the Ebrié lagoon) is similar to those of the Aghien and Adjin et Potou lagoons obtained by Koffi (2020) and Yeo (2015) respectively.

The canonical redundancy analyses (RDA) carried out showed the correlation between the environmental parameters and the taxa abundant in the waters of the Jacqueville station. These abiotic parameters would appear to influence the dominant taxa in the waters of the sampling stations. However, these phytoplanktonic taxa do not seem to have the same responses according to the parameters at each station. According to Anneville *et al.* (2008), the development and distribution of phytoplankton taxa are the result of the individual and simultaneous actions of various environmental factors.

Conclusion

The study provided information on the floristic diversity and trophic status of the waters at the Jacqueville aquaculture station. It provides an essential basis for gaining a better understanding of how aquatic communities function, so that aquatic ecosystems can be preserved and managed efficiently. The floristic inventory showed a rich flora with a total of 165 taxa of little varying environmental importance, divided into six branches. The branches represented in order of prevalence are Cyanoprocaryota (35.15%), Chlorophyta (32.12%), Bacillariophyta (18.79%), Euglenophyta (9.09%), Dinophyta (4.24%) and Chrysophyta (0.61%). Station S1 is the most diverse (117 taxa). The abundance of phytoplanktonic algae reached maximum values in the rainy season at all stations except station S4 (no breeding, located 30 m from S1). The trophic status of all the sampling stations is eutrophic, which suggests that the Jacqueville aquaculture station should pay particular attention to making users and those involved in the various activities in the vicinity aware of the health risks to which they are exposed. In addition, any strategy to secure mobility and sustainable resource management must be part of a land-use planning dynamic and concerted management of space and resources.

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