__Original Research Article__

Species richness, diversity and distribution of phytoplankton in fertilised ponds of the western highlands agro-ecological zone of Cameroon

ABSTRACT

In developing countries, advanced aquaculture techniques are still at the embryonic stage. This study was carried out from January to December 2021 in the ponds of the West Cameroon Region and at the Ichthyology and Applied Hydrobiology Research Unit of the University of Dschang with the aim of contributing to a better understanding of species richness and distribution of phytoplankton populations in fertilised ponds. For this purpose, a total of fifteen (15) ponds including 03 in Bamendou (fertilised with cow dung), four in Batié (two fertilised with pig manure and two with wheat bran), one in Dschang (fertilised with chicken manure), four in Fokoué (two fertilised with pig manure and two unfertilised), and three in Foumbot (fertilised with cow dung), were assessed. These ponds were chosen based on the availability of fish farmers and the type of fertiliser administered. Together with water physicochemical properties measurement, phytoplankton sampling was done between 6 a.m. and 8 a.m. on a monthly basis. The results showed that phytoplankton species and genera richness was higher in unfertilised ponds in Fokoué ponds and in animal feed enriched ponds in Batié, respectively. However, the highest family richness was obtained in Dschang receiving chicken manure with a percentage of 88.8% of the total family richness. The species *Microcystis aeroginosa* exhibited the highest species frequency (57%) out of all the species recorded in the ponds of Batié fertilised with pig manure. The lowest Shannon-Weaver diversity indices and Piélou evenness indices were recorded in the Fokoué ponds independent of the type of fertiliser, and in the Dschang ponds receiving chicken manure. The outputs of this work are better proposals for the production of phytophagous or bulldozer fish, such as carp, in relation to the site and the type of fertilisers in the Western highlands agroecological zone of Cameroon in particular and the world in general.

Keywords: Phytoplankton, Fertilised, Ponds, Species Richness, Fish, Diversity Indices

1. INTRODUCTION

In many sub-Saharan African countries, food shortage remain a reality [1, 2]. According to the Ministry of Agriculture and Rural Development (MINADER), in Cameroon, 2 865 906 people representing 11% of the population suffer from acute food insecurity. The main causes of malnutrition include poverty, lack of access to drinking water, sanitation, medical care, education and food [3]. Undernutrition is mainly due to a lack of animal protein, which is under-consumed by the most helpless populations. Among fishery resources, fish offers 51% of protein to the human diet [4]. Under such circumstances, man must cultivate fish to unravel the problem of food insecurity, imports and capture fishing, which is declining over the years. Fish farming in ponds could thus constitute a way of enlightening production given the complexity of the pond food webs. Phytoplankton forms the support of the pelagic food chain [5] and is responsible for an essential part of the primary production in aquatic ecosystems, especially fish ponds. Phytoplankton refers to all the plant micro-organisms suspended in water, capable of producing their own organic substance via photosynthesis, from solar energy, water, oxygen and nutrient salts [6]. Apart from direct feeding of the fish with exogenous food, fish production in ponds depends on the planktonic richness which is itself a function of the influences of mineral and organic fertilisers. Knowledge of the production proficiency of a fish pond is essential to avoid the appearance of trophic deadlocks. Several studies have been carried out on the biogeography of phytoplankton in Europe and America [7-11] but phytoplankton remains poorly documented in Africa [12]. In Cameroon, some work has been done on faunal surveys and the dynamics of phytoplankton in the Municipal Lake of Yaoundé [13] as well as phytoplankton characterization in a floodplain and in a river in relation to nutrient status [14, 15]. At the current state of knowledge, only the work of Nana et al. [16] focused on the distribution and diversity of phytoplankton in fertilised ponds. Yet, the nature of phytoplankton species must allow their proper integration into the food chain as fish rely on them as food source. Therefore, it is a necessity to intensify the study of planktonic algae in order to access the biodiversity of lentic ecosystems and to clarify the ecology of the species present there. This study was aimed at contributing to a better knowledge of the bio-ecology of fish ponds through a characterization of phytoplankton population in the fertilised ponds of the western highlands agro-ecological zone of Cameroon. More specifically, this research evaluated the effect of the sampling site and the type of fertiliser on the species richness, diversity and distribution of phytoplankton taxa.

2. MATERIAL AND METHODS

2.1. Study sites

This research work was carried out from January to December 2021 in the ponds of the West Cameroon and at the Ichthyology and Applied Hydrobiology Research Unit of the University of Dschang. The geo-climatic features of the study area are as follows: North Latitude: 5° and 6°; East Longitude: 10° and 11°, average altitude: 1400 m, average annual rainfall: 1500 mm, temperature: 14-25°C, dry season: mid-November to mid-March, rainy season: mid-March to mid- November. The map of the study area is shown on Figure 1.

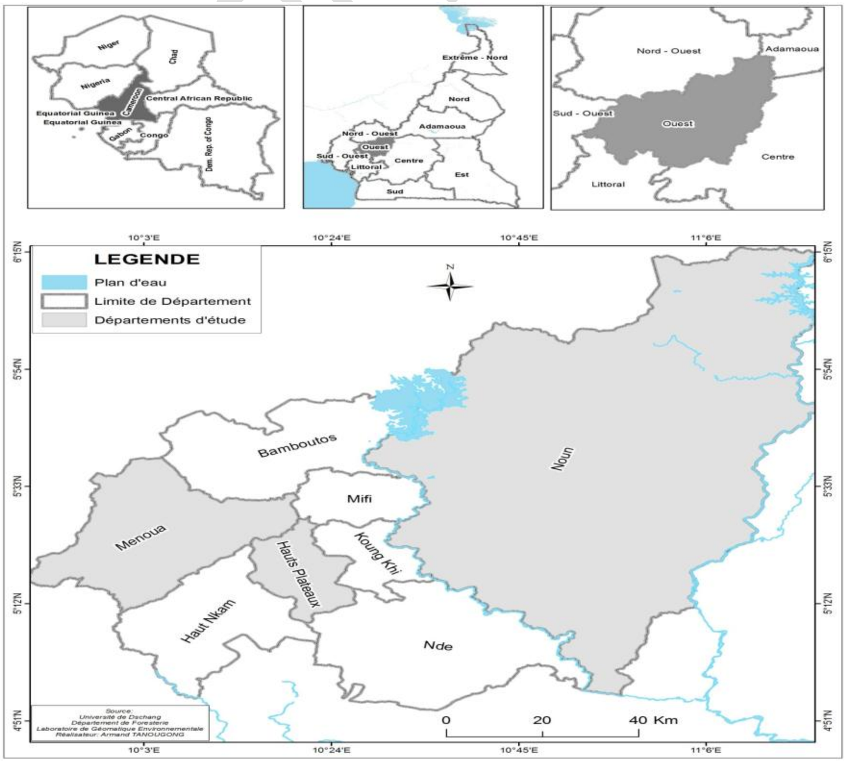


Figure 1: Map of the study area

2.2. Characteristics of phytoplankton collection ponds

Three sites were chosen, far enough apart to be sufficiently representative of the spatial variation of the ecosystem. Using a structured questionnaire and direct observations, information on the characteristics of the ponds and their organisation by fish farmers was collected. For this purpose, a total of 15 ponds were selected depending on the type of fertilizer administered. The choice of these ponds was also based on approachability. The characteristics of the study ponds are summarized in Table 1.

Table 1: Chief characteristics of the study ponds

Sites	Geographical Coordinates	Altitude (m)	Types de Fertilisers	Composition of fertilisers
Batié	LN : 5°17'-5°18' and LE : 10°17'- 10°19'	1 500	Wheat bran Wheat bran Pig manure Pig manure	N : 0,01 ; P : 0,02 ; N/P : 0,5 N : 0,59 ;P : 0,60 ; N/P : 0,93
Bamendou	LN : 5°22'-5°28' and LE : 10°52'-10°54'	1 400	CBV CBV CBV	N : 0,45 ; P : 0,25 ; N/P :1,8
Fokoue	LN : 5°34'-5°36' and LE : 10°14'-10°17'	1 276	Pig manure Pig manure Not fertilized Not fertilized	N : 0,5 ; P : 0,45 ; N/P : 1,11
Dschang	LN : 5°44'-5°48 and LE : 9°85'-10°05'	1 391	Chicken droppings	N : 3 ; P : 2 ; N/P : 1,5
Foumbot	LN : 5º 20' to 5º 22' and LE : 10º 17' to 10º 21'	1 120	CBV CBV CBV	N : 0,3 ; P : 0,15 ; N/P : 2

CBV: Cow dung compost box; N: Nitrogen; P: Phosphorous; N/P: Nitrogen-phosphorous ratio; LN: Latitude (North); LE: Longitude (East)

2.3. Conduct of the study and data collection

2.3.1. Determination of water physicochemical characteristics

Together with the collection of phytoplankton, the physicochemical characteristics of the water were measured monthly according to the techniques advocated by Agadjihouédé et al. [17]. Transparency, depth, pH, dissolved oxygen, temperature and conductivity of the water were analysed *in situ* respectively using a Secchi disk, a water level gauge, a pH- meter, a multimeter and a conductivity meter. For other parameters, a 350 mL water sample was collected from each pond and transferred to the laboratory in a refrigerated enclosure (ice box) for the determination of nutrient (nitrates, ammoniacal nitrogen, nitrites and phosphates) using a HACH brand spectrophotometer DR/2800™ following APHA [18]. The non-ionized ammonia concentration was inferred from that of the ammoniacal nitrogen according to Equation 1 [19].

$$\mathbf{N-NH_3 = \frac{N-NH_4{}^+}{1+10^{10-pH-0,03T°C}}} \quad \textbf{(1)}$$

2.3.2. Phytoplankton sampling

Phytoplankton sampling was done monthly between 6 and 8 am according to the techniques recommended by Agadjihouédé et al. [17]. For this point, 1 litre of water was sampled at 20 points scattered on the entire area of the pond and at a depth of 30 cm. The total volume of water collected (i.e. 20 L) was filtered through plankton net with a 40 µm mesh opening according to Groga [6]. After obtaining the filtrate, a volume of 250 mL of phytoplankton concentrate was introduced into well-labelled containers and fixed with 5% formalin in the proportions of ¾ of the sample and ¼ of formalin as recommended by Nguetsop et al. [20] for quantitative and qualitative examinations.

2.3.3. Qualitative and quantitative analysis of phytoplankton

After homogenization of the phytoplankton concentrate in the laboratory, a 10 µL sample was taken using a micropipette and mounted on a slide for qualitative examination of phytoplankton species. For each sample, three slides were prepared to ensure reproducibility [20]. The identification of the phytoplankton taxa was made with a 40X objective of an optical microscope following vertical transects chosen at random using plates and identification keys [21-25].

Quantitative analysis was executed using a ZEISS 47 12 02 inverted microscope with 40X objective. For this purpose, after homogenization of the filtrate, three sub-samples of 10 mL were taken using a pipette and each dropped into a settling dish. The set-up was allowed for ten to fifteen minutes for sedimentation of the phytoplankton [26]. Counting was done in six fields taken randomly from the counting chamber. Finally, the average number of phytoplankton organisms was evaluated from the total number of fields per dish and reported as number of cells per volume of water.

2.4. Data processing and analysis

Following a normality test, two-way ANOVA was used to test the impact of sampling sites and types of fertilisers on phytoplankton community. The Pearson correlation test was used to determine the relationship between water physicochemical characteristics and phytoplankton density. For these analyses, the statistical software SPSS Version 20.0 was used.

Phytoplankton density was calculated using the following Equation 2:

$$D = (n \times v) / V \quad (2)$$

Where:

- D is the density (expressed in individuals per litre)
- v is the total volume of the sample analysed (mL)
- V is the volume of water filtered in the field (L)

The results of phytoplankton densities gotten were used in the calculations of various indices to characterize the composition and the evolution of phytoplankton communities, namely the Shannon Diversity Index and the Evenness Index.

Shannon Diversity Index

The Shannon Diversity Index [27] was computed according to Equation 3.

$$H' = -\sum_{i=1}^{S} \frac{ni}{N} \, Log_2 \frac{ni}{N} \qquad (3)$$

With:

- H': Shannon Diversity Index
- n_i: Number of individuals of species i

- S: total number of species or taxonomic richness
- N: the total number of individuals of all species found (N)

The Shannon index has the ability to takes into account species abundance and it is sensitive to species with low frequencies [28]; this index can be interpreted as follows [29]:

- H'>4: clean water
- 3≤H'≤4: mildly polluted water
- 2≤H'<3: moderately polluted water
- H'<2: heavily polluted water

The Pielou Evenness Index

The Pielou Evenness Index [30] was calculated according to Equation 4. The Pielou Index varies between 0 (one species dominates) and 1 (all the species tend to have the same abundance).

$$\mathbf{E} = \frac{\mathbf{H'}}{\mathbf{Log_2 S}} \qquad (4)$$

With:

- E is the Pielou Index
- H' is the Shannon diversity index
- S is the total number of species or taxonomic richness

Species frequency was calculated using the formula:

$$\mathbf{F = (Pa/P) \times 100} \qquad (5)$$

With:

- Pa = total number of samples containing the species considered
- P = total number of samples assessed

3. RESULTS

3.1. Richness and distribution of phyla, families, genus and species of phytoplankton depending on the site and type of fertilizer

The richness and distribution of phytoplankton species, genera and families according to site and type of fertiliser is summarised in Table 2.

Table 2: Effect of site and type of fertiliser on the richness and distribution of phyla, families, and genus and phytoplankton species

Phytoplankton species	Sites and types of fertilisers						
	Bamendou	Batié		Dschang	Fokoué		Foumbot
	Cow dung	Pig manure	Wheat bran	Chicken dung	Pig manure	Not fertilised	Cow dung
Cyanophyta							
Merismopediaceae							
Merismopedia							
Merismopedia convoluta	+	-	-	-	-	-	+
Merismopedia glauca	-	+	+	-	-	-	-
Merismopedia tunnissina	-	+	-	-	-	-	-
Chrocococcaceae							
Microcystis							
Microcystis aeruginosa	-	+	+	+	+	+	+
Microcystis densa	-	+	+	+	-	-	+

Microcystis holsatica	-	+	+	+	-	-	+
Microcystis incerta	-	+	+	+	+	+	+
Microcystis robusta	-	+	+	+	+	+	+
Nostocaceae							
Nostoc							
Nostoc parmeloides	+	-	-	-	-	-	-
Oscillatoriaceae							
Oscillatoria							
Oscillatoria amphibia	-	+	+	-	-	-	-
Oscillatoria chlorina	-	+	+	-	-	-	-
Oscillatoria granulata	+	+	+	-	-	-	-
Oscillatoria laxa	-	+	+	-	-	-	-
Oscillatoria teribriformis	+	-	-	-	-	-	-
Gomphosphaeriacaee							
Gomphosphaeria							
Gomphosphaeria naegeliana	-	-	+	-	-	-	+
Chlorophyta							
Chlorophyceae							
Actinastrum							
Actinastrum aciculare	+	+	+	-	-	-	+
Ankistrodesmus							
Ankistrodesmus fusiformis	-	-	-	-	+	+	-
Chlamydomonas							
Chlamydomonas conica	-	+	+	-	-	-	-
Chlamydomonas epiphytica	+	-	-	-	-	-	+
Chlamydomonas globosa	+	+	+	+	+	+	+
Chlamydomonas muriella	+	-	-	-	-	-	-
Monoraphidium							
Monoraphidium braunii	-	-	-	+	-	-	+
Monoraphidium convolutum	-	-	-	-	-	-	-
Monorapphidium contortum	-	+	+	-	-	-	-
Tetraedon							
Tetraedon minimum	-	+	+	-	-	-	-
Hydrodictyaceae							
Kirchneriella							
Kirchneriella lunaris	+	+	-	-	-	-	-
Kirchneriella obesa	+	+	+	+	+	+	+
Pediastrum							
Pediastrum borganum var longicorne	-	-	-	+	-	-	-
Pediastrum duplex	+	+	+	+	+	+	+
Oocystaceae							
Eremosphera							
Eresmosphaera gigas	+	-	-	-	-	-	+
Micractinium							
Micractinium pusillum	-	+	+	-	-	-	-
Scenedesmaceae							
Coelastrum							
Coelastrum cambricum	+	+	+	-	-	-	-
Coelastrum cambricum var intermedium	+	-	-	+	-	-	-
Scenedesmus							
Scenedesmus abondans	-	+	+	-	-	-	-
Scenedesmus acuminatus	-	+	+	-	-	-	-
Scenedesmus armatus var bicaudatus	+	+	+	-	-	-	-
Scenedesmus carinatus	+	+	+	-	-	-	-
Scenedesmus dispa	-	+	+	-	-	-	-
Scenedesmus javanensis	-	+	+	-	-	-	+

Scenedesmus nygocadi	-	+	+	-	-	-	+
Scenedesmus obliqus	-	+	+	-	-	-	+
Scenedesmus obtisus f ecornis	-	+	+	-	-	-	+
Scenedesmus opoliensis var mononesis	-	+	+	+	-	-	-
Scenedesmus perforatus f bicauda	-	+	+	-	-	-	-
Scenedesmus protuberans	-	-	-	-	+	+	-
Scenedesmus quadricauda var longispina	-	+	+	+	+	+	-
Scenedesmus sp	+	-	-	-	-	-	-
Tetrastrum							
Tetrastrum hétéracumthum	-	+	+	-	-	-	-
Tetrastrum staurogeniaforme	-	+	+	-	-	-	+
Ulothrichaceae							
Ulothrix							
Ulothrix bipyrenii	-	-	-	+	-	-	-
Ulothrix bipyronoidosa	+	-	-	-	+	+	-
Ulotrix subtillissina	+	+	+	+			
Ulotrix tenerrina		+	+		+	+	+
Ulotrix tenuissina	+	+	+	+	-	-	-
Closterium							
Closterium abruptum	+	-	-	-	-	-	-
Closterium abruptum var brevius	-	-	-	-	+	+	+
CLosterium calosparum	-	+	+	-	-	-	-
Closterium cherenbergii	-	+	+	-	-	-	-
Closterium dianae	+	-	-	-	-	-	-
closterium lincatul	-	-	-	-	+	+	+
Closterium lineatum var africanum	+	-	-	-	-	-	+
Closterium macilentum	-	+	+	-	-	-	-
Closterium moniliferum f giganteum	+	-	-	-	-	-	-
Closterium turgidum	+	-	-	-	-	-	-
Cloterium jenneri var robustum	+	-	-	-	-	-	-
Cosmarium							
Cosmarium aversiforme	-	+	+	-	-	-	-
Cosmarium decoratum	+	-	-	-	-	-	+
Cosmarium dispersa	+	-	-	-	-	-	+
Cosmarium mononiforme	-	+	+	-	-	-	-
Cosmarium sp	-	-	+	-	-	-	-
Cosmarium undulatum var minutum	-	+	+	-	-	-	+
Cosmarum pusillum	-	+	+	-	-	-	-
Euastrum							
Euastrum spinublosum var lindae	+	-	-	-	-	-	-
Staurastrum							
Staurastrum biencanum	-	+	+	-	-	-	-
Staurastrum brevispina	-	+	+	+	-	-	-
Staurastrum caledonense	+	+	+	+	-	-	-
Staurastrum gladiosum	-	+	+	-	-	-	+
Staurastrum hexacerum	+	+	+	+	-	-	+
Staurastrum hystix	-	+	+	+	-	-	-
Staurastrum inflexum	-	+	+	-	-	-	+
Staurastrum intelliferum	-	-	-	-	-	-	+
Staurastrum mucranatus	-	-	-	+	-	-	+
Staurastrum setigerum var	-	-	-	+	-	-	-

tristichum							
Zygnemataceae							
Spirogyra							
Spirogyra irregularis	-	+	+	-	-	-	-
Chrysophyta							
Chrysophyceae							
Mallomonas							
Mallomonas bronchartiana	+	+	+	+	+	+	-
Bacillariophyta							
Naviculaceae							
Amphora							
Amphora coffaeformis	+	-	-	-	-	-	+
Cymbella							
Cymbella affinis	-	+	+	-	-	-	-
Cymbella amphicephala	+	-	-	-	-	-	-
Cymbella caespitosa	+	-	-	-	-	-	-
Cymbella hybrida	+	-	-	-	-	-	-
Gomphonema							
Gomphonema affine	+	-	-	-	-	-	-
Gomphonema angustum	-	+	+	+	-	-	-
Gomphonema augur	-	+	-	-	+	+	-
Gomphonema gracile	+	+	+		+	+	
Gomphonema parvulum	-	+	+	+	-	-	-
Gomphonema pusilla	-	+	-	-	-	-	-
Navicula							
Navicula americana	+	-	-	-	-	-	-
Navicula brasiliana	-	+	+	-	-	-	-
Navicula laevissina	+	-	-	-	-	-	-
Navicula pseudotuscula	-	+	+	-	-	-	-
Navicula pupula	-	+	+	-	-	-	-
Navicula stroemii	-	+	+	-	+	+	-
Pinnularia							
Pinnularia dactylus	+	-	-	-	-	-	-
Pinnularia gibba	+	+	+	-	-	-	-
Pinnularia lundii	+	-	-	-	-	-	-
Pinnularia macilenta	+	+	+	+	-	-	-
Pinnularia microstauron	+	-	-	-	-	-	+
Pinnularia subgibba	-	-	-	+	-	-	+
Frustulia							
Frustulia rhomboides	-	+	+	-	-	-	-
Frustulia scalpelliformis	-	+	-	-	-	-	-
Fragilariaceae							
Fragilaria							
Fragilaria capucina	+	+	+	+	-	-	+
fragilaria construens	+	-	+	-	-	-	+
Fragilaria SP	-	+	+	-	-	-	+
Fragilaria ulna	+	-	-	-	-	-	-
Surirellaceae							
Surirella							
Surirella elegans	-	+	+	-	-	-	-
Surirella ovalis	-	+	+	-	-	-	-
Surirella robusta	+	-	-	+	-	-	-
Aulacaseiraceae							
Aulacaseira							
Aulacaseira islandica	+	-	-	+	-	-	+
Nitzschiaceae							
Orthoscira							
Orthoscira roeseana	-	-	-	+	-	-	+
Nitzschia sp	-	+	+	-	-	-	-
Euglenophyta							

Euglenaceae							
Euglena							
Euglena acus	-	+	+	-	-	-	-
Euglena anabaena var minima	+	-	-	-	-	-	+
Euglena chrenbergii	+	-	-	-	-	-	-
Euglena chrenbergii var africana	+	-	-	-	-	-	-
Euglena limnophila	-	+	+	+	-	-	-
Euglena oxymis var charkowiensis	+	-	-	-	-	-	-
Euglena oxyuris f minima	-	+	+	-	-	-	-
Euglena pisciforme	+	-	-	-	+	+	-
Euglena rostrifera	-	+	+	-	-	-	-
Euglena sanguinea	+	-	-	-	-	-	-
Euglena sp	-	+	-	-	-	-	-
Euglena spirogyra	+	-	-	-	+	+	-
Euglena texta	+	+	+	-	-	-	+
Euglena variabilis	-	-	+	-	-	-	-
Lepocinclis							
Lepocinclis ovum	-	+	+	-	+	+	+
Lepocinclis ovum var butschu	+	-	-	-	-	-	-
Lepocinclis ovum var gracilicauda	+	-	-	-	-	-	-
Leptocinclis acuminatua	-	-	-	-	+	+	+
Phacus							
Phacus acuminatus	+	+	+	-	-	-	+
Phacus applanatus	-	-	-	-	+	+	-
Phacus brachykentron	+	-	-	-	-	-	-
Phacus caudatus	+	-	-	-	-	-	-
Phacus curvicauda	+	-	-	-	-	-	+
Phacus gamsii	-	-	-	-	+	+	-
phacus glaber	+	+	+	-	-	-	-
Phacus hamatus	+	-	-	-	-	-	-
Phacus horidus	+	-	-	-	-	-	-
Phacus lismorensis	+	-	-	-	-	-	-
Phacus longicauda	+	-	-	-	-	-	-
Phacus platalea	+	-	-	-	-	-	-
Phacus pleuroncetes	+	-	-	-	-	-	-
Phacus ranula	-	+	+	-	+	+	-
Phacus tartus	+	+	+	-	-	-	-
Trachelomonas							
Trachelomonas armata f longicollis	+	-	-	-	-	-	+
Trachelomonas conica	+	+	+	-	-	-	-
Trachelomonas conica var granulata	+	-	-	-	-	-	-
Trachelomonas conica var punctata	+	-	-	-	-	-	-
Trachelomonas cylindrica	-	-	-	-	+	+	-
Trachelomonas hispada var coranata	+	+	+	-	+	+	-
Trachelomonas hispida	+	-	-	-	-	-	-
Trachelomonas hispida var duplex	-	+	+	-	-	-	-
Trachelomonas klebsii	+	-	-	-	-	-	-
Trachelomonas molesta	+	-	-	-	-	-	+
Trachelomonas nigerica	+	-	-	-	-	-	-
Trachelomonas oblonga	+	-	-	-	-	-	-
Trachelomonas planctonica var oblanga	+	-	-	-	-	-	+

Trachelomonas verrucosa	-	+	+	-	-	-	-
Trachelomonas volcascinopsis	-	+	+	-	-	-	+
Trachelomonas volvocina	+	+	+	+	-	-	-
Trachelomonas volvocina var punctata	+	-	-	-	-	-	-
Colaciaceae							
Colacium							
Colacium cyclopicola	+	-	-	-	-	-	-

+ = present - = absent

3.2. Species richness and distribution in the ponds in the western highlands of Cameroon

Table 2 shows that of the 220 species identified, only 3 species (*Chlamydomonas globosa*, *Kirchneriella obesa* and *Pediastrum duplex*) were represented in all the ponds. With the exception of the Foumbot ponds fertilised with cow dung, *Mallomonas bronchartiana* was identified in all environments. However, apart from the ponds of Bamendou fertilized with cow dung, *Microcystis aeruginosa*, *Microcystis incerta* and *Microcystis robusta* were identified in all types of ponds. Independent of the type of fertiliser, the species *Micractinium pusillum* was exclusively exemplified in Batié. *Pediastrum borganum* var *longicorne* and *Ulothrix bipyrenii* were restricted to the Dschang fertilized with chicken manures.

Of the 220 species, 37 (*Nostoc parmeloides, Oscillatoria teribriformis, Chlamydomonas muriella* etc) were represented only in Bamendou. Merely five species (*Ankistrodesmus fusiformis, Scenedesmus protuberans, Phacus applanatus, Phacus gamsii Trachelomonas cylindrica*) were recognised singularly in the ponds of Fokoué. *Staurastrum intelliferum* was the only species unique to the Foumbot municipality ponds.

For the similar type of fertiliser, 13 species (*Merismopedia convoluta, Chlamydomonas epiphytica, Eresmosphaera gigas*, etc.) were identified only in ponds fertilised with cow dung. On the other hand, no species was singularly observed in the ponds fertilised with pig manure.

3.3. Richness and distribution of genera in the ponds of West Cameroon

The distribution of phytoplankton genera is summarised in table 2. Of the 38 genera listed, only 8 or 21.05% (*Chlamydomonas, Kirchneriella, Pediastrum, Scenedesmus, Gomphonema, Navicula, Euglena and Trachelomonas*) were recognised in all the categories of pond.

The genera represented only in the ponds fertilised with the Batié feed (31 genera; *Tetrastrum, spirogira, Cosmarium*, etc.) were more abundant than in all the categories of pond.

When contrasting the sites with the same type of fertiliser, the genera listed specifically in Batié (17 genera; *Merismopemopedia, Oscillatoria, Staurastrum*, etc.) were more abundant than those listed only in Fokoué (0 genus) fertilised with pig manure. Relative to cow dung, the genera listed only in Bamendou (09 genera; *Euastrum, Colastrum, Oscillatoria*, etc.) were more than the three genera (*Gomphosphaeria, Monoraphidium, Tetrastum*) listed in Foumbot.

3.4. Richness and distribution of families in the ponds of West Cameroon

The distribution of phytoplankton families as summarised in Table 2 showed that, of the 19 families, merely 6 or 31.58% (Chlorophyceae, Hydrodictyaceae, Scenedesmaceae, Ulothrichaceae, Naviculaceae and Euglenophyceae) were recorded in all types of ponds.

The Nastoccaceae was exclusively identified in the ponds of Bamendou fertilised with cow dung. However, the Oocystaceae was specific to ponds fertilised with the Batié animal feed. The Zygnemataceae was only listed in Batié irrespective of the type of fertiliser used. The Surirellaceae was only represented in the ponds of Batié fertilized with pig manure and of Dschang fertilised with chicken manures.

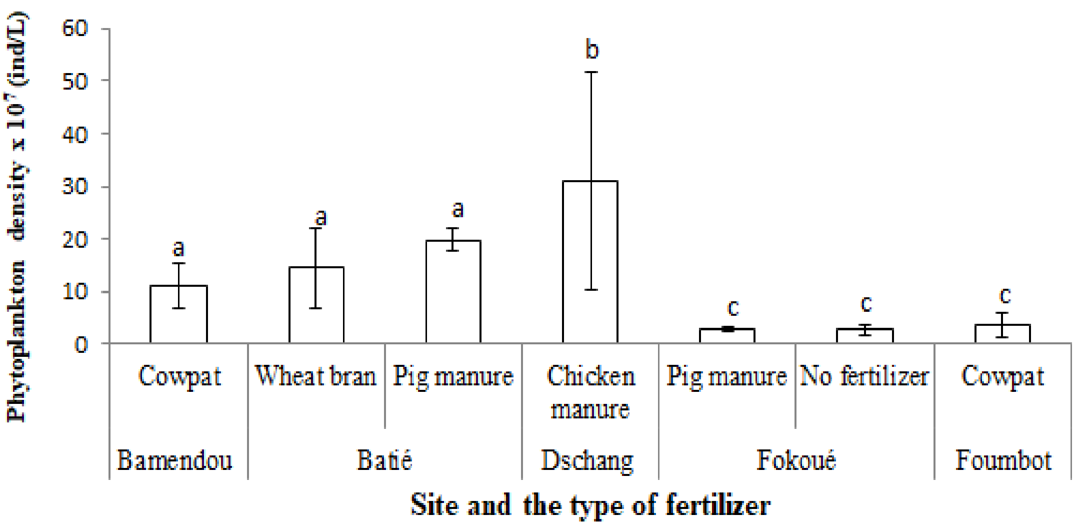
When comparing sites with the identical type of fertiliser, the families Merimopediaceae, Oscillatoriaceae, Gomphosphaeriaceae, Zynemataceae, Surirellaceae and Nitzechiaceae represented in the Batié ponds fertilised with pig manure were absent in Fokoué. However, all the families (Chlorophyceae, Chrocococaceae, Hydrodyctyaceae, Scenedesmaceae, Ulothricheaceae, Chrysophyceae, Surirellaceae, Naviculaceae and Euglenophyceae) listed in the ponds of Fokoué fertilised with pig manure were also identified in the ponds fertilized with pig manure in Batié. Relative to cow dung, the Merimopediaceae, Naviculaceae, Fragilariaceae and Aulacoseinaceae were listed in Bamendou and Foumbot. However, the families Colaciaceae, Chrysophyceae, Oscillatoriaceae and Nastoccaceae identified in Bamendou were absent in Foumbot. Additionally, only the Chrocococaceae present in Foumbot was absent in Bamendou. When comparing sites with equal type of fertiliser, the Merimopediaceae, Chlorophyceae, Hydrodyctyaceae, Scenedesmaceae, Ulothricheaceae, Naviculaceae, Fragilariaceae, Euglenophyceae and Aulacoseinaceae were recognised in the ponds of Bamendou and Foumbot fertilised with cow dung.

3.5. Phytoplankton density according to site and type of fertilizer

The average phytoplankton densities according to sampling site and the type of fertiliser are illustrated in Figure 2. The ponds of Dschang fertilised with chicken manure had significantly higher densities ($p<0.05$) as compared to Foumbot and Fokoué regardless of the type of fertiliser.

The phytoplankton mass was significantly ($p<0.05$) higher in Bamendou as matched with Foumbot (cow dung). In pond fertilised with pig manure, phytoplankton density was significantly higher in Batié compared to Fokoué.

At the same site, at Batié as well as at Fokoué, densities were comparable regardless of the type of fertilizer administered.



a, b, c: bars carrying the same letters are not pas significantly different (p>0,05)

Figure 2: Phytoplankton density according to sampling site and type of fertiliser

3.6. Effect of site and type of fertiliser on phytoplankton species frequency

The influence of the site and the type of fertiliser on the phytoplankton species frequency is illustrated in Figures 3-8. None of the three phytoplankton species common to all ponds was dominant in all the ponds. Nevertheless, *Microcystis robusta* presented the highest frequency, i.e. 53.36% of the total percentage of species in Foumbot ponds (fertilised with cow dung) as compared to the frequency of all the species listed in all the types of ponds. *Kirchneriela obesa* was more foremost in the unfertilised ponds in Fokoué.

In the same sampling site, in Batié, *Microcystis aeruginosa* was more recurrent in ponds fertilised with pig manure while *Microcystis incerta* was more abundant in ponds fertilised with animal feed. In Fokoué, the species *Ulothrix bypirenoida* was more frequent in ponds fertilised with pig manure, yet *Kirchneriela obesa* was more prevailing in unfertilized ponds.

When comparing the sites with equal type of fertiliser, *M. aeruginosa* was more frequent in Batié *whereas U. bypirenoida* was more represented in Fokoué (pig manure). Relative to cow dung, *Nostoc parmeloides* was more represented in Bamendou while *Microcystis robusta* was more frequent in Foumbot.

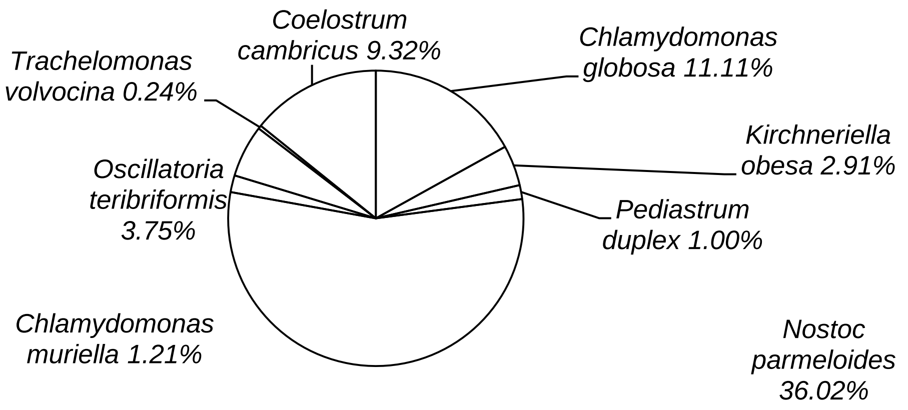


Figure 3: Phytoplankton relative frequency in Bamendou (cow dung**)**

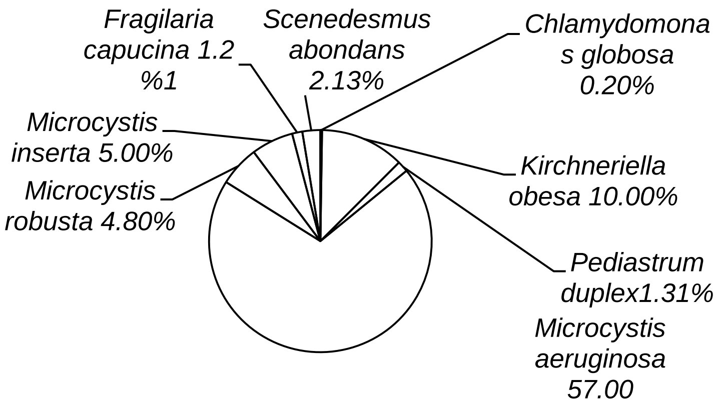


Figure 4: Phytoplankton relative frequency in Batié (pig manure)

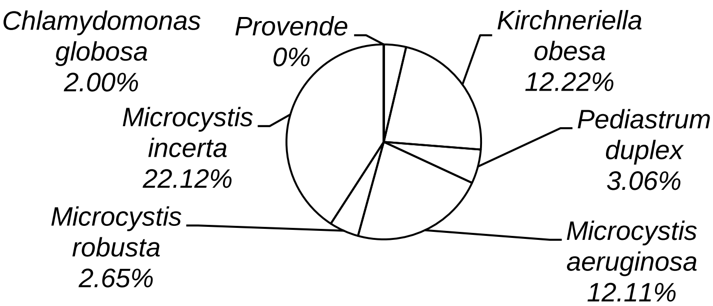


Figure 5: Phytoplankton relative frequency in Batié (Wheat bran**)**

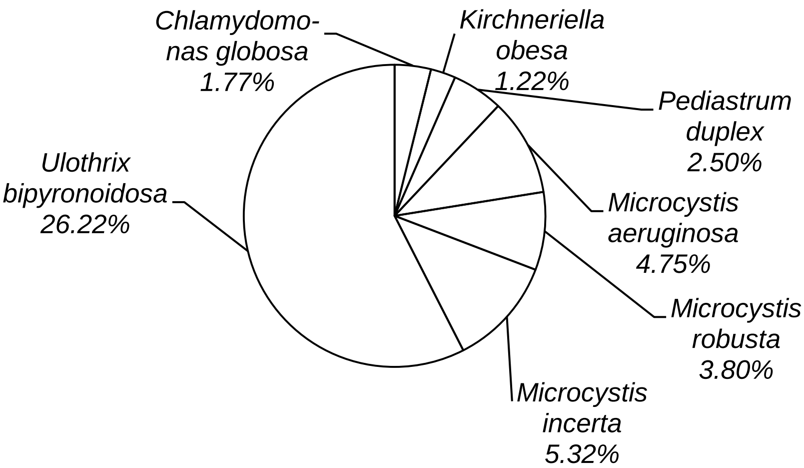


Figure 6: Phytoplankton relative frequency in Fokoué (pig manure**)**

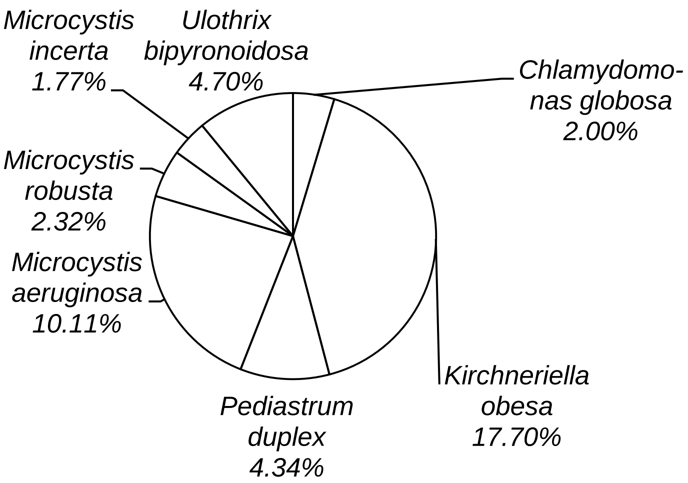


Figure 7: Phytoplankton relative frequency in Fokoué (Not fertilised**)**

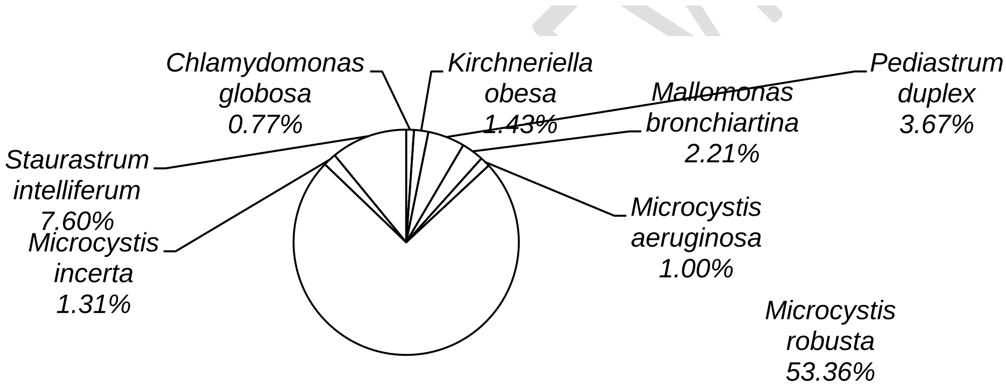


Figure 8: Phytoplankton relative frequency in Foumbot (cow dung)

3.7. Phytoplankton diversity indices according to sampling site and type of fertiliser

The impact of site and type of fertiliser on diversity indices is summarized in Table 3.

Table 3: Phytoplankton diversity index according to sampling site and type of fertiliser

Diversity index (Bit/ ind)	**Sampling sites and types of fertilisers**						
	Bamendou	**Batié**		**Dschang**	**Fokoué**		**Foumbot**
	Cow dung	Pig manure	Wheat bran	Chicken manure	Pig manure	Not fertilised	Cow dung
Shannon - Weaver (H')	2.27	2.37	2.15	1.34	1.09	1.14	1.99

Piélou Evenness (J)	0.42	0.57	0.44	0.22	0.12	0.10	0.31

Table 3 displays that independently of the site and the type of fertiliser, the highest values of the Shannon-Weaver, and the Piélou evenness indices were observed in the Batié ponds enriched with pig manure while the lowest value occurred in unfertilized ponds of Fokoué.

Sampling site being equal, in Batié, the values of these diversity indices were higher in the ponds fertilized with pig manure and lower in the ponds enriched with animal feed. In Fokoué, the highest Shannon-Weaver index was recorded in unfertilized ponds as compared to ponds fertilised with pig manure. However, the highest Piélou evenness index value was observed in ponds enriched with pig manure compared to those receiving no fertiliser.

In relation to sites with the same type of fertiliser, the highest Shannon-Weaver and Piélou equitability indices were recorded in Bamendou compared to Foumbot for cow dung. For pig manure, these values were higher in the ponds of Batié compared to those of Fokoué.

3.8. Correlation between water physicochemical characteristics and phytoplankton density according to sampling site and type of fertiliser

The correlations between the physicochemical characteristics of water and the phytoplankton densities (Table 4) showed that, with the exception of the relationship between the density of phytoplankton and phosphates, on the one hand and the transparency on the other hand, which were not significant, they were significant (*p* < 0.01), negative and strong for all the other physicochemical characteristics of the water in the unfertilised ponds of Fokoué. Likewise, phytoplankton density was negatively and strongly correlated with dissolved oxygen in Dschang ponds fertilised with chicken droppings. Conversely, the density of phytoplankton was positively and very strongly correlated (*p* < 0.01) with pH in ponds fertilised with cow dung regardless of the site.

Table 4: Correlation between physicochemical characteristics of water and phytoplankton densities

Physicochemical characteristics of water	**Phytoplankton density**						
	Bamendou	**Batié**		**Dschang**	**Fokoué**		**Foumbot**
	Cow dung	Pig manure	Wheat bran	Chicken droppings	Pig manure	Not fertilized	Cow dung
Nitrates (NO_3^-)	0.03	-0.11	-0.17	0,13	-0.22	-0.85**	0.29
Nitrites (NO_2^-)	0.22	-0.01	-0.10	0,29	-0.22	-0.68**	-0.47
Dissolved Oxygen (O_2)	0.16	0.18	0.14	-0,99*	0.45	-0.99**	0.31
pH	0.99**	0.23	-0.22	0,18	0.22	-0.93**	0.99**

Orthophosphates (PO_4^{3-})	-0.56	-0.21	-0.52	-0,12	-0.52	0.22	-0.52
Temperature	0.26	0.14	0.12	0,08	-0.22	-0.77**	-0.18
Transparency	-0.32	0.19	-0.41	0.13	-0.22	0.28	0.23

****:** significant correlation at $p < 0.01$ (bilateral)

4. DISCUSSION

Phytoplankton species and genus richness was highest in unfertilised Fokoué ponds and animal feed enriched ponds of Batié respectively. This observation supports the findings of Nana et al. [31] in unfertilised ponds and may be linked to the influence of the use of fertilisers on the physicochemical characteristics of the water. In fact, Patrick [32] revealed a decline in biodiversity from unpolluted to polluted backgrounds. Furthermore, Moss [33] suggested that only species capable of adapting to a high nutrient enrichment of the environment and to an environment presenting ostensible extreme will have an advantage in eutrophic conditions; this ensures an uneven distribution of taxa. The population of taxa unable to adapt decreases and that of taxa able to adapt amplifies, and the proportions of taxa according to the trophic level are thus modified according to the populations of these taxa. Radji et al. [34] similarly reported that the physicochemical characteristics of the water influenced the dynamics of phytoplankton populations. The highest species richness in unfertilised ponds showed the great variability of species living in a pure or dystrophic environment. The imbalance observed in the fertilised environments may be related to the effect of the fertilisers brought continuously which modifies the physicochemical characteristics of the water.

The distribution of species showed that of the 220 species identified, 3 species (*Chlamydomonas globosa, Kirchneriella obesa* and *Pediastrum duplex*) are registered in all sites regardless the type of fertiliser. *Kirchneriella obesa, Pediastrum duplex* and *Microcystis aeruginosa* were the most represented in unfertilised ponds. This result is similar to that reported by Nana et al. [16] who observed the majority of *Merismopedia elegans, Mycrocystis aeruginosa* and *Nostoc entophytum* in unfertilised ponds compared to ponds fertilised with different doses of chicken manures. This tendency to mainly have the species *M. aeruginosa* may be explained by the fact that it constitutes the most to common toxic cyanobacterial blooms in freshwaters.

The distribution of phytoplankton genera disclosed that among the genera identified in all sites regardless of the nature of the fertiliser dispensed, *Chlamydomonas* and *Pediastrum* were listed. This result is explained by their ability to encyst and remain immobile in bodies of water respectively.

The highest richness of phytoplankton families was recorded in the Dschang ponds fertilised with chicken droppings. This result is similar to that reported by Nana et al. [31] in ponds fertilised with chicken manures and pig manure and may be related to the high organic load of this enricher.

The highest density was recorded in the ponds of Dschang fertilised with chicken droppings. These results are contradictory to those observed by Nana et al. [31] and may be linked to the production conditions of phytoplankton organisms and the impact of collection sites. Indeed, the highest densities in the ponds of Dschang might be linked to the henhouse on stilts which would offer higher concentrations of nutrient salts, the basis of phytoplankton production.

The diversity indices were relatively low in the unfertilised ponds, as compared to the ponds fertilised with pig manure in Fokoué and chicken droppings in Dschang. This result could be elucidated by a high specific frequency of *Kirchneriella obesa* (17.70%), *Ulothrix bipyronoidosa* (26.22%) and

Microcystis incerta (41.02%) respectively in these ponds. The low values of the diversity indices in these ponds are similar to those testified by Kemta et al. [13] in the Yaoundé Municipal Lake and may be related to a young population with a high potential of multiplication with a predominance of one species or a small number of species.

5. CONCLUSION

All in all, phytoplankton community structure was upset by the sampling sites and types of fertilisers. The richness of phytoplankton species and genera was higher in the unfertilised ponds of Fokoué and the ponds of Batié fertilised with animal feed respectively. The highest values of phytoplankton phyla richness were detected in Dschang, Fokoué, Foumbot and in the ponds receiving animal feed from Batié. Phytoplankton density, Shannon-Weaver and Piélou evenness indices, were significantly disturbed by sampling sites and type of fertiliser. Temperature, dissolved oxygen and nitrogenous compounds significantly affect phytoplankton density. Phytoplankton taxa may then be exploited as potential bioindicators of water abiotic variables in fertilised ponds of the western highlands agro-ecological zone of Cameroon.

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