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Trophic status and phytoplankton diversity of two dam ponds in Eastern Cameroon (Central Africa)

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***Abstract*— A study aimed to determine the level of water pollution and phytoplankton diversity of two dam ponds (Ngaikada and Kpokolota) in Bertoua city was conducted from March 2016 to April 2017 using a monthly sampling frequency. Water samples were collected at surface directly using a 1L polyethylene vials and at 1.5 m depth using a 6L Van Dorn bottle. Physicochemicals analyzes were carried out according to the standard methods of APHA and Rodier, while the harvesting of phytoplankton organisms was done by direct sampling and analyzed by the Utermôhl method. The results of the physicochemicals analyzes reveal no significant difference ($P > 0.05$*) from surface to depth, high temperature (26.18 ± 1.40°C; 26.29 ± 1.01°C), low transparency (48.57 ± 17.15 cm; 51.43 ± 11.51 cm), high levels of orthophosphates (4.05 ± 3.38 mg/L; 4.15 ± 3.52 mg/L) and oxidability (8.49 ± 6.40 mg/L; 8.10 ± 6.68 mg/L) and high levels of chlorophyll 'a' (33.65 ± 24.66 µg/L; 43.67 ± 22.97 µg/L) respectively for Ngaikada and Kpokolota ponds. These characteristics classify these water bodies as hypereutrophics. Biological analyzes have shown that these ponds are quite diversified with 136 and 143 species identified in Kpokolota and Ngaikada respectively. The specific richness, the abundance and the density of phytoplankton organisms recorded at the surface were significantly higher ($P < 0.05$*) than those at 1.5 m depth. Rehabilitation processes such as control of nitrogen compound flows by purifying waste water from plantations and households, cutting aquatic plants and cleaning mud from ponds should be quickly put in place for a resumption of aquaculture activities.*

***Keywords*— Anthropogenic, Bertoua, hypereutrophics, phytoplankton, ponds, rehabilitation.**

I. INTRODUCTION

In recent decades, rapid urbanization transformed human ecosystem in a disorderly manner, causing a disruption of some major ecological balances with disastrous consequences on the environment and strong repercussions on hydrosystems. These anthropogenic pressures lead from year to year to an increase in the emission of pollutants of all kinds, most of which reach the aquatic ecosystems that constitute the major biospher receptacle (**Colas *et al.*, 2014**). Eutrophication has become a growing phenomenon in most developing countries due to the excess of nutrients (nitrogen and phosphorus) released into the environment that are transported to hydrosystems without prior treatment (Kengne Tenkeu *et al.*, 2020). This eutrophication phenomenon undermines the ecological integrity of ponds making fish farming difficult, or even impossible, yet it covers huge animal protein needs by reducing the massive outflow of foreign exchange (**Agadjihouèdé *et al.*, 2011**). Ponds contain many phytoplankton organisms that are primary producers at the base of the food chain of the freshwater food web. These phytoplankton organisms are considered the first biological community to respond to anthropogenic pressures and are the most direct indicator of nutrient concentrations in the water column of all quality biological elements (**Solimini *et al.*, 2006**).

In Cameroon, the environmental profile of fish farming ponds shows multiple and complex problems, including the degradation of water quality and biodiversity (**Kramkimel *et al.*, 2004; Mikolasek *et al.*, 2009; Efole Ewoukem *et al.*, 2017**). Studies based on phytoplankton biodiversity have focused mainly on large metropolitan areas (**Kemka *et al.*, 2006; Ebang Menye *et al.*, 2012**), neglecting some regional capitals such as the city of Bertoua, which has experienced a rapid population growth that has led to an increase in animal protein needs and consequently a proliferation of ponds that are strongly impacted by human activities making fish farming impractical. Very little data are available on water quality and planktonic fauna in these ponds. The aim of this work is therefore to study the physicochemical quality of water and phytoplankton dynamics of two dam ponds (Ngaikada and Kpokolota) in the city of Bertoua in order to propose measures to rehabilitate these ponds for resumption of fish farming activities. To achieve this objective, it will act to: (1) analyze the physicochemical quality of pond waters in order to determine their trophy status; (2) identify and count phytoplankton organisms in the different pond strata; (3) establish the links between the physicochemical quality of water and phytoplankton abundance.

II. MATERIAL AND METHODS

1.Description of the study site

The city of Bertoua is located in the Department of Lom-and-Djérem, Eastern Cameroon Region (Figure 1). This locality is a vast peneplain whose altitude varies between 400 and 900 m. The temperature is high throughout the year and oscillates between 18 and 30°C. Precipitation is relatively abundant (1500 to 2000 mm of rainfall per year) and its climate is subtropical with two seasons (**Olivry, 1986; Sighomnou, 2004**).

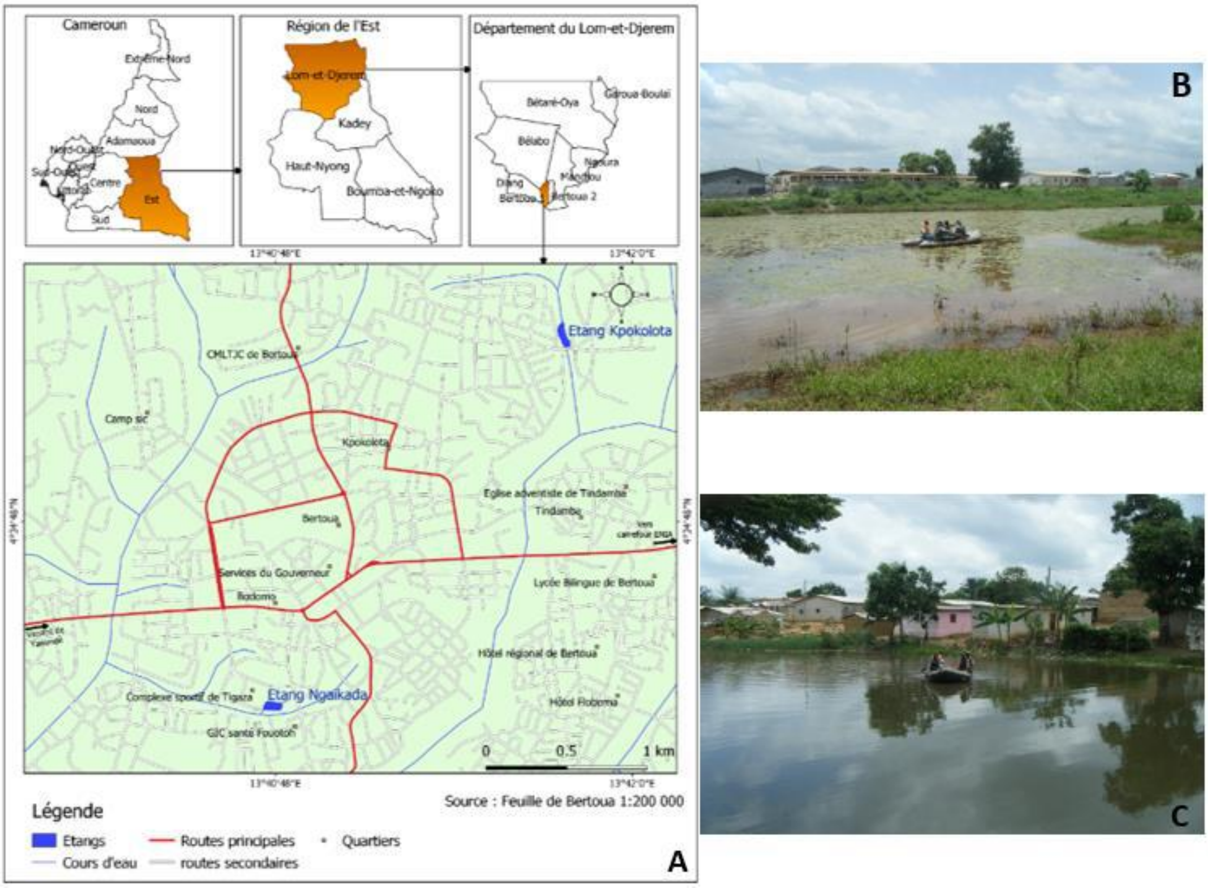

Fig.1: Geographical location of the two study ponds in Bertoua: A -General situation; B- Ngaikada Pond; C - Kpokolota Pond.

1.1. Ngaikada Pond

Ngaikada Pond is a wild, unmaintained and highly anthropized dam pond in an advanced state of decay with a fairly pronounced siltation. The geographical coordinates of this body of water are: 04°34'175" North latitude, 013°40'759" East longitude with an altitude of 655 m (Figure 1). This pond has an average depth of about 1.5 m, a perimeter of 420 m, an area of 10800 m^2 and a water volume of about 10692 m^3. The water from this pond is used by the local population for agriculture and for watering animals. This pond is mainly characterized by a strong vegetation consisting of plants and higher plants (*Nymphaea lotus, Pistia stratiotes*...), that cover the surface of the pond making navigation difficult. The main sources of pollution come from dead plants, numerous dwellings and plantations located in the watershed.

1.2. Kpokolota Pond

Kpokolota Pond is a very poorly maintained, wild and highly anthropophized dam pond. Its geographical coordinates are: 04°35'432" North latitude, 013°41'770" East longitude and an altitude of 654 m (Figure 1). The average depth is about 151.43 m, with a perimeter of 630 m, an area of 14300 m^2 and a water volume of about 21450 m^3. The main sources of pollution come from household wastewater located in the catchment area, from garbage dumps near the pond and especially from bottom-less latrines whose waste is dumped directly into the pond.

2. Sampling

The movements on the ponds were made using an inflatable Zodiac MR II. Sampling was carried out from March 2016 to April 2017 during a monthly frequency with surface and 1.5 m depth sampling for physicochemistry and biology.

2.1. Physicochemical analysis

Samples for surface physicochemical analyzes were collected directly at the surface using polyethylene vials, while at 1.5 m depth, these samples were collected using a 6 L Van Dorn bottle. Some parameters were measured directly in the field. In fact, the temperature was measured using a mercury column thermometer graduated to 1/100th of a degree, the transparency (Zs) measured using a 30 cm diameter black and white Secchi disc, the depth measured using a weighted and graduated string, the percentage of dissolved oxygen saturation using a HACH HQ14d Oxymeter, electrical conductivity and Total Dissolved Solids (TDS) using a HANNA Hi 99300 portable TDS/Conductimeter. Other parameters such as turbidity, suspended solids (SS) and nutrients (NO_3^-, NO_2^-, NH_4^+, and PO_4^{3-}) were measured in the laboratory using the colorimetric method with the HACH/DR 2010 spectrophotometer; oxidizable materials were measured by volumetric method and chlorophyll 'a' content measured using the Lorenzen colorimetric method. These analyzes were carried out according to the technical and recommendations of **APHA (1998)** and **Rodier *et al.* (2009)**.

The stoichiometric ratio[N]/[P] (nitrogen concentration/phosphorus concentration) was calculated for each pond and compared to the **Redfield *et al.* (1963)** standard ratio value ([N]/[P] = 16) according to the following formulas:

$$[N] = [NO_3^-] + [NO_2^-] + [NH_4^+]$$

$$[P] = [PO_4^{3-}]$$

Nitrogen, phosphorus or the two elements will be limiting if the ratio[N]/[P] is less than, greater than or equal to 16, respectively. The principal component analysis (PCA) will be used to establish the abiotic typology of sampling stations based on all environmental parameters measured at the surface and at depth. The Trophic State Index (TSI) of **Carlson (1977)** is a mathematical model based on three variables: transparency (t), chlorophyll 'a' (chl 'a') and orthophosphates (PO_4^{3-}) calculated from the following three equations:

$$TSI\ (t) = 60 - 14{,}41 \times \ln (t)$$

$$TSI\ (chl\ 'a') = 30{,}6 + 9{,}81 \times \ln (chl\ 'a')$$

$$TSI\ (PO_4^{3-}) = 4{,}15 + 14{,}42 \times \ln (PO_4^{3-})$$

The average of the indices from the three variables indicates a precise position of the trophic status of the ponds. It is calculated as follows:

$$TSI = [TSI\ (t) + TSI\ (chl\ 'a') + TSI\ (PO_4^{3-})] / 3$$

The Carlson scale used to determine the trophic level of each pond is a set of indices ranging from 0 to 100 (Table I).

Table 1 Limit values of the Trophic State Index (TSI) of Carlson (1977).

TSI	Trophic state
[0-40[	Oligotrophic
[40 -50[	Mesotrophic
[50 -70[	Eutrophic
[70-100]	Hypereutrophic

2.2. Biological analysis

Phytoplankton organism was collected by direct sampling at the surface and using a Van Dorn bottle at depth and then transferred to clean, transparent 500 ml glass vials and fixed with 2.5 ml of a Lugol solution. After 48 hours of sedimentation, the supernatant was gently removed and the sub-sample of approximately 15 ml denser was preserved.

After homogenization, 1 ml of the sub-sample was pipetted and observed in a Sedgewick-Rafter counting cell with an inverted microscope (Olympus CK2). The count was duplicated to minimize the risk of error and the identification of at least 400 individuals per sample was recommended for an accuracy of +/- 95% (**APHA, 1998**). Due to the richness of some samples in particles and organisms, a dilution to 1/10th or 1/20th with distilled water was essential to facilitate enumeration. The count was carried out using an OLYMPUS CK2 inverted microscope with enlargement of 400x, with scans from left to right of the surface of the counting cell with alternating transects. Taxa have been identified through the specialized literature of: **Bourrelly (1985 & 1990)**; **Branco & Senna (1991)**, as well as books and publications on phytoplankton taxonomy from **Couté & Iltis (1981)**; **Kemka (2000)** and **Couté & Perrette (2011)**.

The density was calculated using the formula:D= Ni x S x 1000/ (v x s) with D = density (ind/L); S = area of the counting cell (1000 mm^2); Ni = number of individuals counted; 1000 = conversion factor in liters; s = area of the total counted field and v = volume of sedimented sample (5 ml). The transformation of chlorophyll 'a' (chl 'a') contents into carbon (C) following the works of **Reimann *et al*., (1982)**, **Dessery *et al*.**, (1984) and **Aleya & Devaux (1989)** was done by the formula: C = [chlorophyll 'a'] x 30. Since carbon represents 12% of the fresh weight of a cell (**Hamilton & Holm-Hansen, 1967**; **Pridmore & Hewitt, 1984**), the phytoplankton biomass was calculated using the formula given below:

$$\text{Biomasse } (\mu g/L) = \frac{C \times 100}{12} = [\text{chl } 'a'] \times 250$$

With C = phytoplankton carbon mass and 250 = Conversion coefficient. The Shannon and Weaver (1963) diversity index has been used to highlight the overall stands diversity and their degree of organization (**Tonkin *et al.*, 2013**). The Piélou regularity index (E) was used to reflects the quality of organization of the stands and varies from 0 to 1. It is close to 1 when all species tend to have the same abundance and close to 0 when one or a few species dominate the stand (**Dajoz, 2000**).

III. RESULTS

1. Physicals parameters

The transparency values recorded in Ngaikada pond (A) fluctuate at the surface from 20 cm to 80 cm with an average of 48.57 ± 17.15 cm and the depth values range from 70 cm to 130 cm with an average of 98.93 ± 21.23 cm (Figure 2A). In Kpokolota pond (B), the transparency varies at the surface from 30 cm to 65 cm with an average of 51.43 ± 11.51 cm and the depth values oscillates from 130 cm to 170 cm with an average of 151.43 ± 11.17 cm (Figure 2B). The student t-test shows a significant difference (P < 0.05*) between the different depths of the Ngaikada and Kpokolota Ponds.

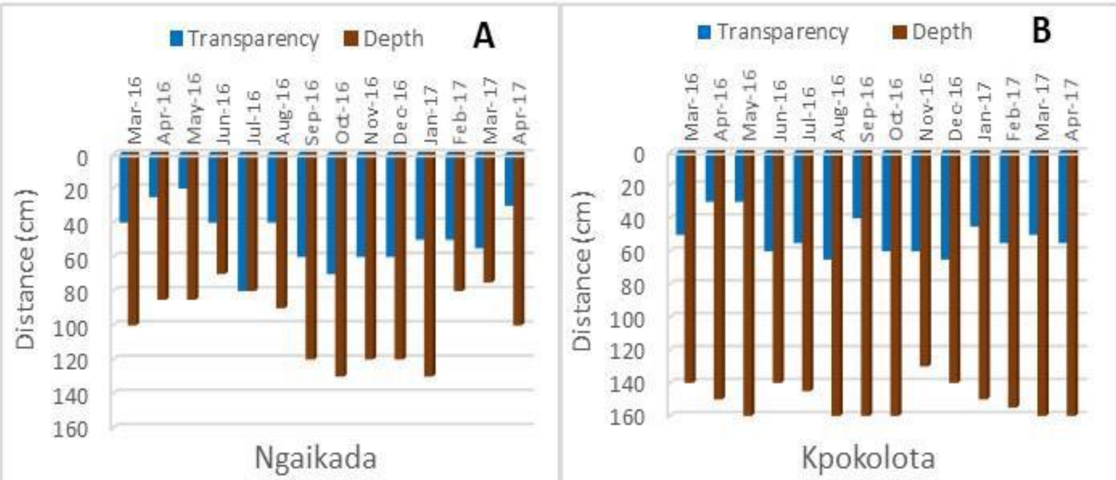

Fig.2: Spatiotemporal variations of the transparency and the depth in Ngaikada (A) and Kpokolota (B) ponds.

Water temperatures were relatively high in the ponds studied. In Ngaikada pond, it varies at the surface from 24°C to 30°C with an average of 26.57 ± 1.6°C and at depth from 24°C to 28°C with an average of 25.79 ± 1.19°C. In Kpokolota pond, the surface temperature fluctuates from 25°C to 29°C with an average of 26.43 ± 1.16°C and at depth from 24°C to 27°C with an average of 26.14 ± 0.86°C (Figure 3A). The suspended solids values recorded in Ngaikada pond range at the surface from 1 mg/L to 173 mg/L with an average of 27.07 ± 44.37 mg/L and at depth these values range from 1 mg/L to 235 mg/L with an average of 53.43 ± 63.55 mg/L. In Kpokolota pond, suspended solids values at the surface range from 4 mg/L to 117 mg/L with an average of 28.07 ± 29.63 mg/L and at depth these values range from 4 mg/L to 230 mg/L with an average of 54.29 ± 75.72 mg/L (Figure 3B). In Ngaikada pond, Total Dissolved Solids (TDS) values fluctuate at the surface from 25 mg/L to 51 mg/L with an average of 35.5 ± 7.5 mg/L and at depth from 25 mg/L to 52 mg/L with an average of 35.86 ± 7.61 mg/L. These TDS values range in Kpokolota pond at the surface from 28 mg/L to 52 mg/L with an average of 35 ± 7.27 mg/L and at depth from 28 mg/L to 51 mg/L with an average of 35.71 ± 6.63 mg/L (Figure 3C). Turbidity varies in Ngaikada pond at the surface from 2 FTU to 173 FTU with an average of 38.43 ± 46.37 FTU and at depth these values fluctuate from 5 FTU to 258 FTU with an average of 52.18 ± 69.06 FTU. In Kpokolota pond, Turbidity fluctuates at the surface from 8 FTU to 84 FTU with an average of 36.64 ± 22.27 FTU and at depth these values vary from 0 FTU to 97 FTU with an average of 39.79 ± 27.9 FTU (Figure 3D).

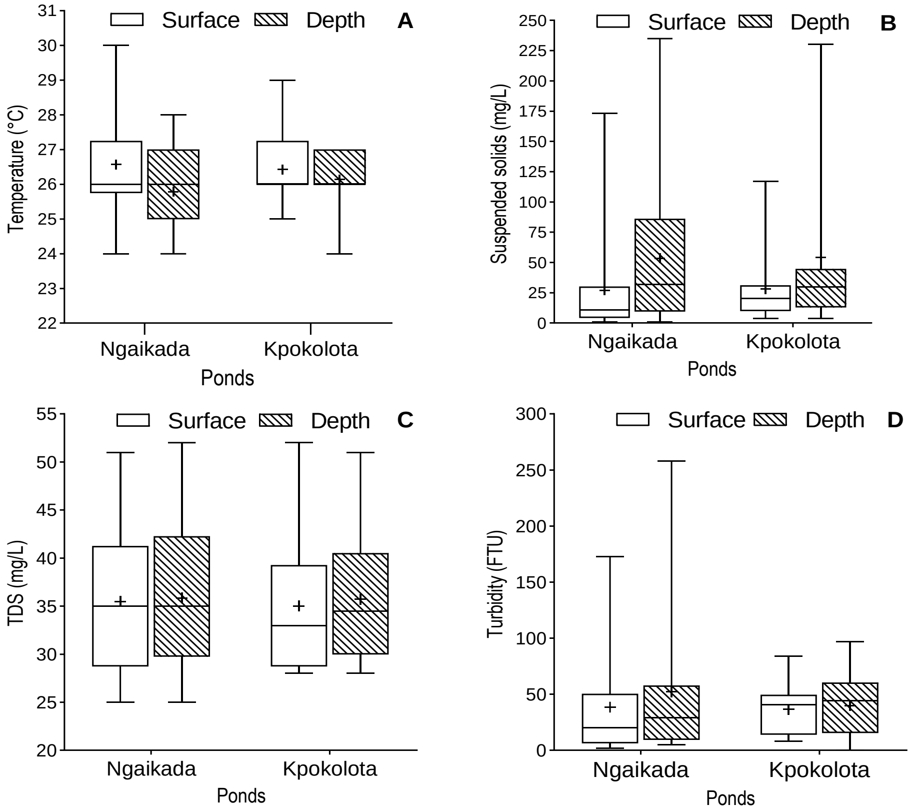

Fig.3: Spatial variations of temperature (A), Suspended Solids (B), TDS (C) and turbidity (E) in Ngaikada and Kpokolota ponds.

2. Chemicals parameters

The potential Hydrogen (pH) values obtained in Ngaikada pond range at the surface from 5.31 to 7.46 with an average of 6.4 ± 0.71 and at depth, these values range from 5.22 to 7.54 with an average of 6.28 ± 0.68. In Kpokolota pond, these pH values range at the surface from 5.16 to 7.51 with an average of 6.41 ± 0.7 and at depth from 5.13 to 7.5 with an average of 6.37 ± 0.64 (Figure 4A). Electrical conductivity values vary in Ngaikada pond from 48 µS/cm to 103 µS/cm at the surface with an average of 69.74 ± 15.46 µS/cm and at depth from 49 µS/cm to 104 µS/cm with an average of 69.74 ± 15.76 µS/cm. These electrical conductivity values fluctuate in Kpokolota pond at the surface from 53.6 µS/cm to 103 µS/cm with an average of 68.64 ± 14.66 µS/cm and at depth from 54.8 µS/cm to 103 µS/cm with an average of 71.2 ± 14.23 µS/cm (Figure 4B). Dissolved oxygen (O_2) levels in Ngaikada pond at the surface range from 33.9% to 83.9% with an average of 58.81 ± 12.32% and at depth from 34.4% to 70.7% with an average of 54.64 ± 10.13%. In Kpokolota pond, surface oxygen levels range from 35.3% to 84.7% with an average of 60.09 ± 11.12% and at depth from 36% to 69.4% with an average of 56.62 ± 8.45% (Figure 4C). Dissolved carbon dioxide (CO_2) levels in Ngaikada pond range from 0.66 mg/L to 10.56 mg/L at the surface with an average of 3.32 ± 2.95 mg/L and at depth from 0.66 mg/L to 7.04 mg/L with an average of 3.25 ± 2.13 mg/L. These CO_2levels change in Kpokolota pond from 0.76 mg/L to 15.84 mg/L at the surface with an average of 3.95 ± 4.34 mg/L and at depth from 0.66 mg/L to 15.84 mg/L with an average of 3.8 ± 5.02 mg/L (Figure 4D).

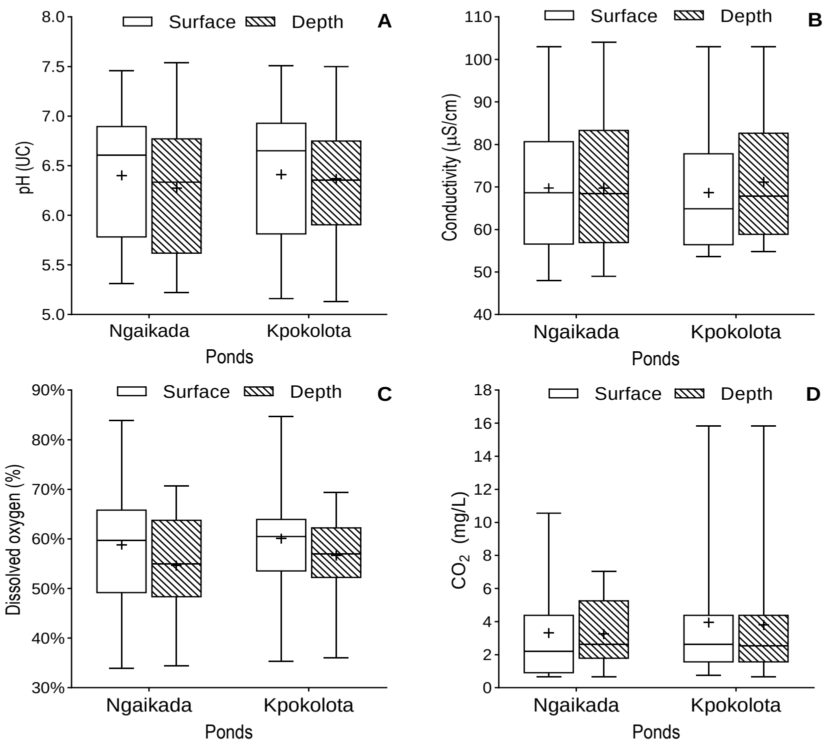

Fig.4: Spatial variations of potential Hydrogen (A), conductivity (B), dissolved oxygen (C) and dissolved carbon dioxide (D) in Ngaikada and Kpokolota ponds.

Nitrate (NO_3^-) contents in Ngaikada pond range at the surface from 0 mg/L to 4.1 mg/L with an average of 1.81 ± 1.13 mg/L and at depth from 0 mg/L to 5.5 mg/L with an average of 1.8 ± 1.63 mg/L. These nitrates content change in Kpokolota pond from 0 mg/L to 1.7 mg/L at the surface with an average of 0.78 ± 0.43 mg/L and at depth from 0 mg/L to 1.7 mg/L with an average of 0.66 ± 0.48 mg/L (Figure 5A).

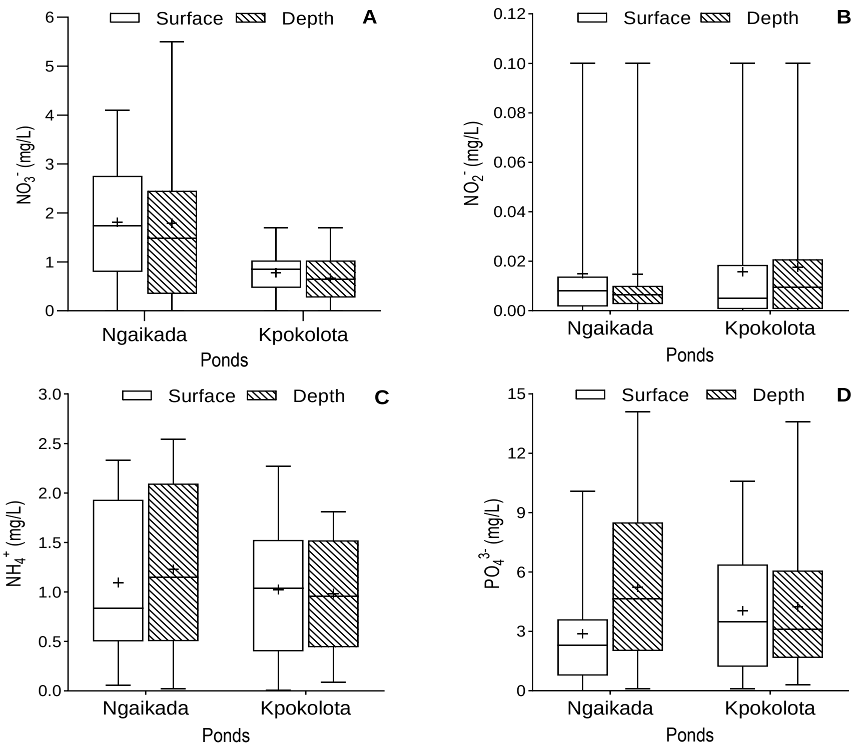

Fig.5: Spatial variations of nitrate (A), nitrite (B), ammoniacal nitrogen (C) and orthophosphate (D) in Ngaikada and Kpokolota ponds.

Nitrite (NO_2^-) contents fluctuate in Ngaikada pond from 0 mg/L to 0.1 mg/L at the surface with an average of 0.01 ± 0.03 mg/L and at depth from 0 mg/L to 0.1 mg/L with an average of 0.01 ± 0.03 mg/L. These nitrates levels change in Kpokolota pond from 0 mg/L to 0.1 mg/L at the surface with an average of 0.02 ± 0.03 mg/L and at depth from 0 mg/L to 0.1 mg/L with an average of 0.02 ± 0.03 mg/L (Figure 5B). Ammoniacal nitrogen (NH_4^+) levels fluctuate in Ngaikada pond from 0.06 mg/L to 2.23 mg/L at the surface with an average of 1.09 ± 0.76 mg/L and at depth from 0.02 mg/L to 2.54 mg/L with an average of 1.23 ± 0.82 mg/L. These ammoniacal levels change in Kpokolota pond from 0.01 mg/L to 2.27 mg/L at the surface with an average of 1.03 ± 0.72 mg/L and at depth from 0.09 mg/L to 1.81 mg/L with an average of 0.981 ± 0.6 mg/L (Figure 5C). Orthophosphate (PO_4^{3-}) levels fluctuate in Ngaikada pond from 0 mg/L to 10.1 mg/L at the surface with an average of 2.88 ± 2.77 mg/L and at depth from 0.1 mg/L to 14.1 mg/L with an average of 5.23 ± 3.98 mg/L. These orthophosphate levels change in Kpokolota pond from 0.1 mg/L to 1.6 mg/L at the surface with an average of 4.05 ± 3.33 mg/L and at depth from 0.3 mg/L to 13.6 mg/L with an average of 4.25 ± 3.71 mg/L (Figure 5D).

Oxydability levels in Ngaikada pond range from 0.59 mg/L to 22.91 mg/L at the surface with an average of 9.24 ± 7.15 mg/L and from 0.19 mg/L to 20.34 mg/L at depth with an average of 7.74 ± 5.64 mg/L. These oxydability levels change in Kpokolota pond from 0.4 mg/L to 21.33 mg/L at the surface with an average of 7.76 ± 6.63 mg/L and at depth from 0.2 mg/L to 24.12 mg/L with an average of 8.44 ± 7.03 mg/L (Figure 6A). The chlorophyll 'a' (chl 'a') contents in Ngaikada Pond range from 0.6 µg/L to 80.3 µg/L at the surface with an average of 30.1 ± 24.88 µg/L and from 0.6 µg/L to 96.2 µg/L at depth with an average of 37.19 ± 24.44 µg/L. These chl 'a' level change in Kpokolota pond at the surface from 3.1 mg/L to 83.1 mg/L with an average of 37.79 ± 19.45 mg/L and at depth from 13 mg/L to 108.3 mg/L with an average of 49.56 ± 26.49 mg/L (Figure 6B). The stoichiometric ratio of dissolved inorganic nitrogen to orthophosphate in Ngaikada pond at the surface range from 0 to 9.61 with an average of 1.75 ± 2.36 and at depth from 0.15 to 13.8 with an average of 2.04 ± 3.94. This ratio fluctuates in Kpokolota pond at the surface from 0.07 to 31.71 with an average of 3.03 ± 8.31 and at depth from 0.09 to 2.46 with an average of 0.72 ± 0.64 (Figure 6C).

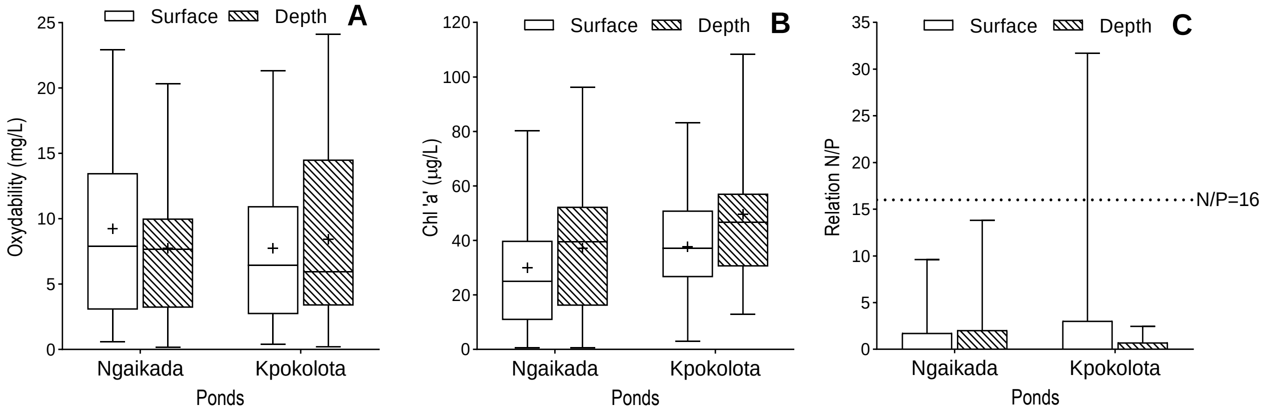

Fig.6: Spatial variations of oxydability (A), Chlorophyll 'a' (B) and N/P ratio (C) in Ngaikada and Kpokolota ponds.

3. Abiotic typology of sampling stations

The Principal Component Analysis (PCA) of the ponds is provided by the first two factor axes F1 (55.85%) and F2 (33.87%) which together account for 89.72% of the total inertia. The factor map shows a distribution of the four stations in relation to their physicochemicals characteristics. Two main groups emerge in this factorial design (Figure 6):

- Group I, whose F2 axe discriminates in positive coordinates between the Ngaikada surface (Ngai surf) and Kpokolota surface (Kpo surf) stations, characterized by good transparency of water, good oxygenation and high temperatures.

- Group II, whose F2 axe discriminates in its negative part, the Ngaikada depth (Ngai depth) and Kpokolota depth (Kpo depth) stations characterized by turbid water, rich in nutrients, with high chlorophyll 'a' contents and strong mineralization of water.

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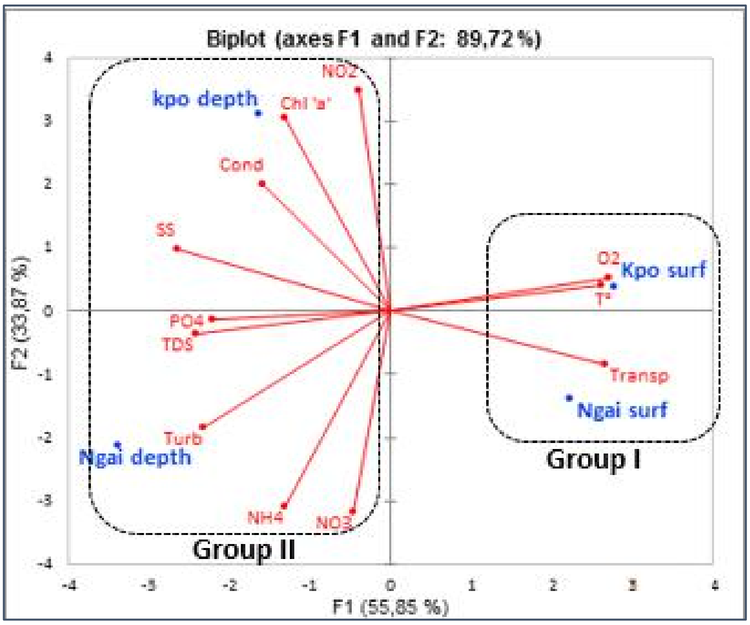

Fig.7: Principal Component Analysis (PCA) performed on the environmental variables of the station's studies. Chl 'a': Chlorophyll 'a', Cond: Electrical conductivity, SS: Suspended Solids, NH4: Ammonium, NO2: Nitrite, NO3: Nitrate, O2: Dissolved Oxygen, PO4: Orthophosphate, T°: Temperature, TDS: Total Dissolved Solid, Trans: Transparency and Turb: Turbidity.

4. Trophic level of the ponds studied

Ngaikada pond shown a TSI (t) = 70.28, TSI (PO_4^{3-}) = 123.94 and TSI (chl 'a') = 65.09. The Trophic State Index (TSI) of Ngaikada pond was 86.44. Kpokolota pond presented a TSI (t) = 69.7, TSI (PO_4^{3-}) = 124.27 and TSI (chl 'a') = 67.65. The Trophic State Index (TSI) of Kpokolota pond was 87.21.

5. Distribution of phytoplankton taxonomic units in ponds

During this study, 143 species of phytoplankton were identified in Ngaikada pond belonging to 62 genus, 54 families, 28 orders and 9 classes while in Kpokolota pond, the diversity was 136 species of phytoplankton grouped into 54 genus, 49 families, 28 orders and 14 classes (Tableau 2).

Table 2 Taxonomic units of phytoplankton in ponds

Ponds	Classes	Orders	Families	Genus	Species
Ngaikada	9	28	54	62	143
Kpokolota	14	28	49	54	136

6. Phytoplankton structure of the ponds

The specific richness in Ngaikada pond at the surface varied from 5 species to 26 species with an average of 15 ± 6 species and at depth from 5 species to 21 species with an average of 11 ± 4 species. In Kpokolota Pond, this diversity evolved at the surface from 11 species to 20 species for an average of about 15 ± 3 species and at depth from 7 species to 16 species with an average of about 11 ± 3 species. The specific richness of surface in Ngaikada (P=0.03*) and Kpokolota (P=0.001**) ponds were significantly higher than those at depth (Figure 8A). The abundance in Ngaikada pond at the surface varies from 40 ind. to 431 ind. with an average of 236 ± 125 ind. and at depth from 21 ind. to 285 ind. with an average of 120 ± 77 ind.. In Kpokolota Pond, this surface abundance fluctuates from 61 ind. to 701 ind. with an average of 317 ± 169 ind. and at depth from 28 ind. to 330 ind. with an average of 178 ± 80 ind.. The phytoplankton abundances of surface in Ngaikada (P=0.006**) and Kpokolota (P=0.009**) ponds are significantly higher than those at depth (Figure 8B). The phytoplankton density in Ngaikada pond at the surface ranges from 4000 ind./L to 43100 ind./L with an average of 23600 ± 12500 ind./L and at depth from 2100 ind./L to 28500 ind./L with an average of 12000 ± 7700 ind./L. In Kpokolota Pond, surface density fluctuates from 6100 ind./L to 70100 ind./L with an average of 31700 ± 16900 ind./L and at depth from 2800 ind./L to 33000 ind./L with an average of 17800 ± 8000 ind./L. The phytoplankton densities of surface in Ngaikada (P=0.006**) and Kpokolota (P=0.009**) ponds are significantly higher than those at depth (Figure 8C). The phytoplankton biomass in Ngaikada Pond at the surface ranges from 18 µgC/L to 2409 µgC/L with an average of 903 ± 746.4 µgC/L and at depth from 18 µgC/L to 2886 µgC/L with an average of 1115.79 ± 733.25 µgC/L. In Kpokolota Pond, this biomass changes

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at the surface from 93 µgC/L to 2493 µgC/L with an average of 1133.57 ± 583.54 µgC/L and at depth from 390 µgC/L to 3249 µgC/L with an average of 1486.71 ± 794.72 µgC/L (Figure 8D).

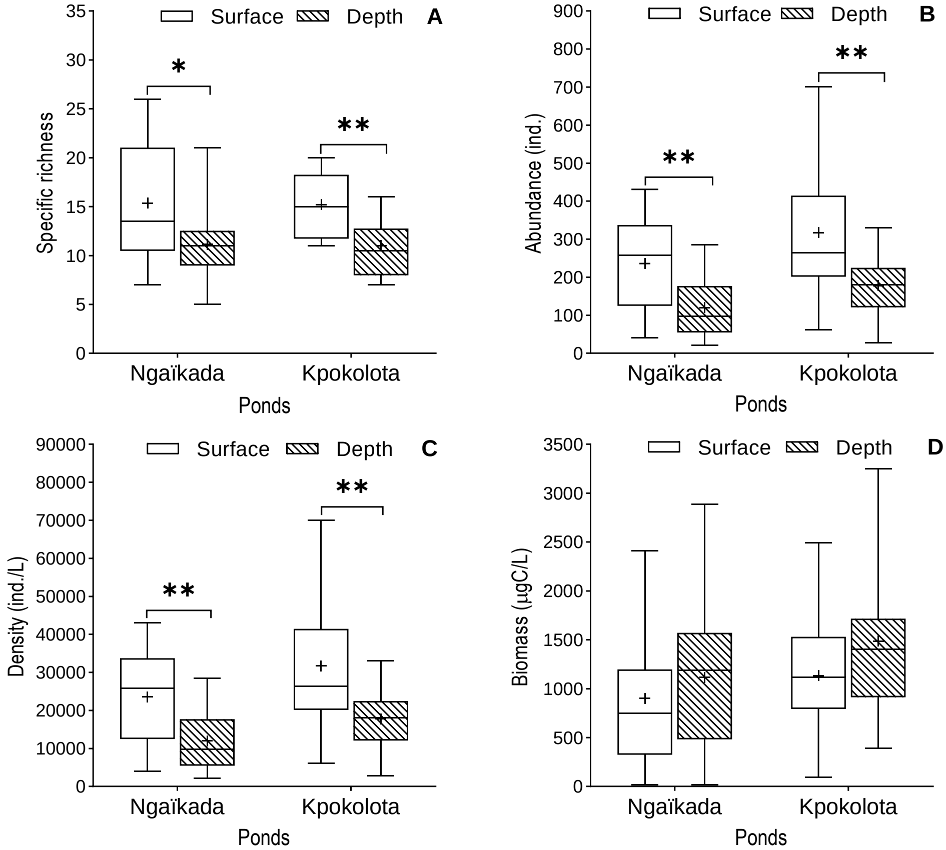

Fig.8: Spatial variations of specific richness (A), abundance (B), density (C) and biomass (D) in Ngaikada and Kpokolota ponds.

The diversity index of Shannon and Weaver (1963) varied in the Ngaikada pond at the surface from 2.23 bits/ind. to 4.12 bits/ind. with an average of 3.42 ± 0.53 bits/ind. (H'max = 3.83 bits/ind.) and at depth from 2.26 bits/ind. to 4.05 bits/ind. with an average of 3.05 ± 0.49 bits/ind. (H'max = 3.39 bits/ind.).

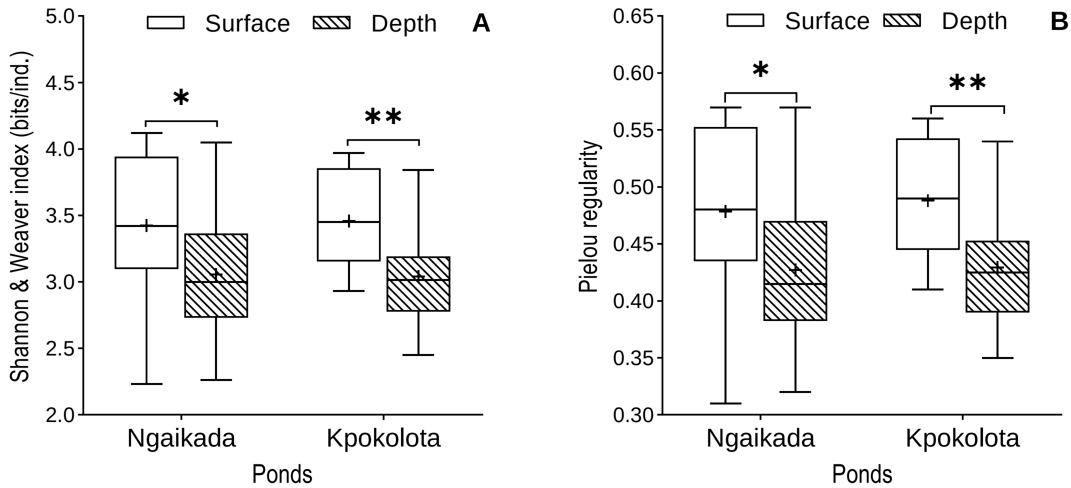

Fig.9: Spatial variations of Shannon and Weaver diversity index (A) and Piélou regularity (B) in Ngaikada and Kpokolota ponds.

This index varies in Kpokolota pond at the surface from 2.93 bits/ind. to 3.97 bits/ind. with an average of 3.46 ± 0.36 bits/ind. (H'max = 3.89 bits/ind.) and at depth from 2.45 bits/ind. to 3.84 bits/ind. with an average of 3.04 ± 0.34 bits/ind. (H'max = 3.41 bits/ind.). The diversity index of surface in Ngaikada (P=0.003*) and Kpokolota (P=0.005**) ponds are significantly higher than those at depth (Figure 9A). The Piélou regularity index varies in Ngaikada pond from 0.31 to 0.57 at the surface with an average of 0.48 ± 0.07 and at depth from 0.32 to 0.57 with an average of 0.43 ± 0.06. In Kpokolota Pond, this regularity fluctuates at the surface from 0.41 to 0.56 with an average of 0.49 ± 0.05 and at depth from 0.35 to 0.54 with an average of 0.43 ± 0.04. The Piélou regularity of surface in Ngaikada (P=0.003*) and Kpokolota (P=0.004**) ponds are significantly higher than those at depth (Figure 9B).

IV. DISCUSSION

1. Physicochemical variables

The low transparency values obtained in the ponds studied can be attributed to the action of winds combined with their shallow depths. Winds cause turbulence that, coupled with the shallow depth of the ponds, constantly suspend particles matter and phytoplankton that reduce the transparency of the pond water (**Cunha *et al.*, 2019**). In addition, these ponds are dam ponds, which are therefore located on the bed of the watercourses and subject to sedimentary inputs carried by the tributaries from the catchment area. The temperature average values recorded in Ngaikada (26.18°C) and Kpokolota (26.29°C) ponds are relatively high and depend strongly on the amount of sunlight and the degree of mineralization of the organic matter that produces energy that can increase the water temperature. In this connection, **Antalé (2012)** affirms that the temperature of surface waters depends closely on the amount of sunshine and exchanges with the atmosphere. The high values of suspended solid well above the threshold (25 mg/L) are due to untimely and irregular rainfall in the study area that transported particular matter into the ponds by erosion. High levels of suspended solids have resulted in high turbidity values with averages above the 35 mg/L threshold. **Al-Aubadi*et al.* (2019)** point out that rainfall favors the erosion of mineral and organic particles from the catchment area, which are transported by runoff water to the ponds where they cause the mix of water, increasing the suspended solids content of the environment and consequently its transparency and turbidity. The electrical conductivity and Total Dissolved Solids have been elevated in ponds, reflecting high anthropogenic activity and high organic pollution (Kengne Tenkeu *et al.*, 2020). The high average of electrical conductivity values in ponds would be justified by leaching from agricultural land and the input of domestic wastewater into the ponds. On this subject, **Zébazé Togouet *et al* (2007)** confirm that the supply of wastewater to the aquatic environment increases its content of ionizable salts and consequently its electrical conductivity. The percentage of dissolved oxygen saturation was high in the pond, characteristic of a strong photosynthetic activity of algae and aquatic plants that release oxygen into the environment (**Ramade, 2005**). Dissolved carbon dioxide evolves in the opposite of oxygenation and the observed fluctuations in levels are undoubtedly linked to CO_2 using for photosynthesis and to the activity of aerobic bacteria that degrade fermentable organic matter, consuming dissolved oxygen while releasing carbon dioxide. In this regard, **Boyd (2020)** points out that in water, breathing has the effect of reducing O_2 while increasing CO_2. Nutrient levels were high and sometimes well above the standards prescribed for fish farm ponds, reflecting overall richness organic matter in the ponds. The high levels of nitrogen elements in ponds are due to non-native inputs of organic matter and nitrogenous metabolic waste from human activity, mainly from agricultural activities in the pond catchment area (**Moss *et al.*, 2013**) or from residential areas (**Wang *et al.*, 2014**). The high levels of ammonium are explained by the significant decomposition of organic matter accompanied by a high consumption of dissolved oxygen, favoring its production by ammonification. High levels of orthophosphates show advanced trophic status of the ponds and would come from runoff from the watershed. **Dunnette (1992)** rightly argues that the phosphorus content of a biotope is a predictor of the degree of eutrophication of its waters. The high levels of chlorophyll 'a' reflect a high phytoplankton biomass, reflecting high photosynthetic activity and therefore high productivity (**Lu *et al.*, 2016**).

The ponds studied show a homogeneous physicochemical quality of water from surface to depth (P > 0.05), making it possible to recommend a single sampling for future studies. In the ponds studied and compared to **Redfield's (1963)** standard ratio, only one N/P ratio data is greater than 16 in Kpokolota Pond (31.71) at the surface showing a limitation of eutrophication by phosphorus at that month. However, the overall surveys are all lower than the Redfield ratio (N/P = 16), showing that nitrogen is the limiting factor of eutrophication in these two ponds. The ponds studied with a low transparency and a high level of orthophosphates and chlorophyll ‘a’, have high TSI values in Ngaikada (86.44) and Kpokolota (87.21) allowing to characterize these two ponds as being hypereutrophic. The hypereutrophic state of the ponds can explain the abandonment of fish farming activities and could lead to their disappearance in the near future. The measures to be

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implemented for the rehabilitation and the management of eutrophication in these ponds should therefore focus on mowing aquatic plants, cleaning pond mud and controlling the flow of nitrogen compounds, which appear to be the factor whose absence or low content would limit algal growth. However, other factors such as light intensity, transparency or water temperature also control the increase in algal biomass (**Beck and Hall, 2018**).

2. Phytoplankton structure

Taxonomic analysis of phytoplankton in Bertoua ponds identified 143 species in Ngaikada and 136 species in Kpokolota. The diversity observed in the ponds is higher than 103 taxa obtained by **Kemka (2000)** in Yaounde municipal lake, but smaller than the 152 taxa obtained by **Djiogo Kingfack (2007)** in Mefou dam lake, 237 taxa obtained by **Ebang Menye *et al.* (2012)** in Mfoundi rivers and 162 taxa obtained by **Koda (2015)** in CAPFORT fish farm in Mbalmayo. This relatively high taxonomic richness recorded in the Bertoua ponds compared to other studies is due to the strong anthropization of the catchment area of the ponds with organic and mineral materials containing high levels of nutrients that promote the rapid and continuous growth of algae and aquatic plants. These organic pollutants, which have a high nitrogen and phosphorus load, offer favourable conditions for the development of different phytoplankton species. In this regard, **Aboim *et al.* (2020)** point out that the low water volume associated with high nutrient levels is favourable to the development of phytoplankton organisms. Spatial variations of phytoplankton abundances and densities are logical responses to changes and physicochemical conditions in the environment. The relatively low taxonomic richness compared to other studies is due to the hypereutrophic character of the ponds studied because, productivity is maximal in all groups of living beings at the eutrophic stage (**Zébazé Togouet, 2008**). The higher abundances and densities of phytoplankton at the surface than at depth ($P < 0.05$) are believed to the high temperatures and high light intensities offered by solar energy for phytoplankton photosynthesis. **Azhikodan and Yokoyama (2016)** confirm these observations by stating that light intensity is the main environmental factor likely to vary with depth and probably plays a very important role in the observed taxonomic differences between the surface and depth of water bodies. The differences of abundance and densities lower in Ngaikada than in Kpokolota ($P < 0.05$) are due to the high presence of aquatic plants on the surface of Ngaikada pond, which prevents better light penetration, an essential condition for photosynthesis. The high phytoplankton biomass is due to high nutrient concentration in the ponds absorbed by phytoplankton organisms and reflect high photosynthetic activity and consequently high primary productivity in ponds (**Lu *et al.*, 2016**). The high phytoplankton biomass recorded in Kpokolota than in Ngaikada ($P < 0.05$) is due to the high levels of chlorophyll 'a' and nutrients recorded in this pond that promoted phytoplankton growth.

The Shannon and Weaver Diversity Index is higher at the surface than at depth in Ngaikada ($P < 0.05^*$) and Kpokolota ($P < 0.01^{**}$) Ponds. This high diversity of surface organisms could be explained by the high light intensities in this stratum in both ponds, which provides essential conditions for photosynthesis, and playing an important role in the observed differences of diversity (**Azhikodan and Yokoyama, 2016**). The regularity of Piélou is low in the ponds, but shallower in depth than on the surface in the Ngaikada ($P < 0.05^*$) and Kpokolota ($P < 0.01^{**}$) ponds. This low regularity shows populations that are not in equilibrium, due to the strong dominance of a small group of species to the detriment of the others (**Djego *et al.*, 2012**) mainly represented in the Ngaikada pond by *Pinnularia gibba* and *Stauroneis phoenicenteron*species and in the Kpokolota pond by *Azpeitia africana* and *phacus orbicularis* species. Some species such as *Azpeitia africana*, *Microcystis aeruginosa*, *Surirella capronii*, *Rhizolenia* sp., *Cymatopleura solea* and *Closterium aciculare* are positively correlated with ammoniacal nitrogen. Nitrate are correlated with the species *Rhizolenia* sp. and *Trachelomonas hispida*. The taxa *Trachelomonas armata*, *Volvox dissipathrix*, *Phacus orbicularis* and *Pleurotaenium trabecula* are positively correlated with nitrite while *Pinnularia cardinalis*, *Pleurotaenium subcornulatum* and *Pleurotaenium trabecula* are positively correlated with orthophosphate in the pond's studies. The preference of some taxa for various nutrients is due to the fact that nutrients promote phytoplankton growth. For this purpose, **Lapointe *et al.* (2004)** claims that nutrient inputs from urban or agricultural effluents are a cause of the great richness and phytoplankton abundance of some water bodies.

V. CONCLUSION

The results of this study show that the Ngaikada and Kpokolota ponds are both hypereutrophic with nitrogen as the limiting factor of eutrophication. These ponds have a homogeneous physicochemical quality of water column from the surface to the depth, allowing a single sampling point to be recommended for future studies. specific richness, abundance and density are higher at the surface than at depth in all ponds, mainly due to the ever-increasing light intensity in the upper layers of the ponds. These ponds are quite diversified, but not in balance because of the dominance of a small group of species. The correlations observed between some organisms and nutrients support the idea that these nutrients are responsible for phytoplankton growth. The hypereutrophication of these ponds due to strong anthropization is incompatible with fish farming and restoration measures must be quickly put in place at the risk of seeing them disappear in the very near future. These rehabilitation measures will have to focus on controlling the flow of nitrogen compounds, mowing aquatic plants and cleaning the mud from ponds.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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