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The spatio-temporal dynamics of the fish assemblage of the man-made Lake Buyo (Cote d'Ivoire, West Africa)

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This study aims to characterize the spatio-temporal variation of the fish assemblages in relation to the environmental variables of Buyo Dam Lake. Sampling was performed from July 2017 to June 2018 using experimental fishing and commercial fishing. Spatio-temporal analysis indicated a significant variation (p <0.05) in pH, electrical conductivity, total dissolved solids, and water transparency. A total of 45 species from 27 genus and 15 families were collected in the samples sites. Two species (*Chrysichthys johnelsis and Malapterurus barbatus*) are reported for the first time in the lake of Buyo. Among the fishes sampled, of Cichlidae (35.04%) and Claroteidae (16.43%) were the most abundants. The abundant species are *Oreochromis niloticus* (15.55%) and *Chrysichthys nigrodigitatus* (15.15%). The analysis of the structure of fish assemblages (H' from 2.28 to 2.75, E from 0.68 to 0.84) revealed a fairly diverse lake environment. The canonical correspondence analysis revealed the significant influence of water pH, electrical conductivity, dissolved solids content, water transparency and nitrite in the distribution of fish species in the lake of Buyo. This work constitute a baseline study for future investigations and will contribute to the implementation of a sustainable management plan for fisheries resources in the continental water.

Key words: Environmental parameters, fishes, settlement, Lake of Buyo, Côte d'Ivoire.

INTRODUCTION

Knowledge of the ichtyological fauna in African rivers and lakes is of concern to both scientists and development officials (Lalèyè et al., 2004). Indeed, the increasing intensification of the consumption of fish resources in continental environment in Africa associated with the processes of degradation of the natural environment pose real risks of regression and disappearance of species (Lalèyè et al., 2004). These anthropogenic pressures have led to conservation and rational management measures of fish stocks (Monchowui et al.,

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2008). For these authors, these measures concern the ecology, composition and level of exploitation of the ichtyological fauna of the water bodies. Therefore, any measure of conservation of ichtyological fauna requires a good knowledge of the fish species and the characterization of the factors that influence their distribution (Wu et al., 2011; Kamelan et al., 2013). In the preservation of natural resources for a sustainable and rational use, the systematic inventory and enumeration of living species must be performed before hand (N'Zi et al., 2003). Several works have been carried out on the lake of Buyo including those of Vanga et al. (2002), Vanga (2004), Ossey et al. (2008), and Kouamé et al. (2008). Their work focused on the impact of fishing on fish availability in the area surrounding the lake, the socio-economic consequences of the expulsion of the non-indigenouse fishermen, the analytical study of chemical characteristics and biological diversity and fish assemblage characterization of the lower Sassandra River. Apart from the work of Kouamé et al. (2008) which characterizes the fish assemblage of the lower Sassandra River, there are no available data concerning the fish assemblage of the lake of Buyo, nor on the environmental parameters that influence the distribution of these species. This lake plays a vital role in fish production in Côte d'Ivoire. Moreover, its ichtyological fauna is being exploited by the Ivorian and foreign population (Vanga et al., 2002). Therefore, preventive measures deserve to be taken for better management of fishery resource. It is within this framework that this study aims to characterize the ichthyological settlement in the lake of Buyo by a spatio-temporal approach while highlighting the environmental variables that influence the distribution of fish species of this lake.

MATERIALS AND METHODS

Study area

This study was conducted in the man-made lake Buyo (Figure 1). This lake is located between 06°14' and 07°03' North latitude and 07°31' West longitude and covers an area of 920 km^2 (Kouamé, 2010). It was built in 1981 on the edge of the Tai National Park, 4 km downstream from the confluence of the N'Zo River and the Sassandra River, drowning approximately 8400 ha of forest in the park (OIPR, 2006). This Lake of Buyo occupies a catchment area of 46 250 km^2 (Ossey et al., 2008). The hydrological regime of this lake depends on the Sassandra River, the N'Zo primary tributary and rainfall in the region (Traoré and Konan, 1989). It presents a hydrograph characterized by a period of high water from early October to mid-November with a maximum submerged area of 900 km^2 and a period of low water level from December to May with a minimum area of 230 km^2 (Traoré, 1996). Every year, the Lake of Buyo fills up completely by December and progressively empties until June of the following year. The depth of the lake varies on average from 9.2 to 20 m. Three study stations (Guessabo, Buyo city and PK15) have been outlined in this study area. The selection of these stations was made taking into consideration their closeness to the lake, the existence of commercial fishing, and their easy accessibility by road in all season.

Fish sampling

The fish were collected between July 2017 and June 2018 using a battery of 11 monofilaments gill nets (bar mesh size 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60 mm), each gill net measuring 30 m long by 1.5 m deep. Nets were set overnight (17-7 H) and during the following day (7-12 H). Experimental fishing data are added to the data from local fishermen captures. For the captures, the samples were collected from the fishermen as soon as they returned from fishing. All fishes were identified following Paugy et al. (2003a, b). The standard lengths (LS) of the fish were measured using a graduated ichtyometer and the total weight determined using precision scale (with ± 1 g).

Measurement of environmental variables

At each station, before each experimental fishing, the pH, dissolved oxygen level (in mg/l), conductivity (in µS/cm), total dissolved solids or TDS (in mg/L) and temperature of the water were measured using a multi-parameter Lovibond Senso Direct 150. The water transparency was measured in cm using a Secchi disk. Nitrite, total phosphorus and total chlorine levels were quantified using Hanna mini-photometers. The rates (%) of canopy closure, water cover by aquatic plants and substrate (sand, sand-gravel mixture, gravel, mud, rock, clay-mud mixture, deadwood-root-leaf mixture) were visually estimated (Arab et al., 2004; Rios and Bailey, 2006).

Data analysis

The data was analyzed for spatial and temporal variation using the Statistica 7.1 software. The descriptive analysis was applied to the physico-chemical data to highlight the central tendency (median, minimum and maximum). Before performing the comparison test, the normality of the data was verified by the Shapiro-Wilk test ($p > 0.05$ at all stations). The Kruskal-Wallis H test with Dunn's posterior multiple comparison test was used to verify the significant difference in spatio-temporal variations of physicochemical parameters (Zar, 1999). A level of significance of $p < 0.05$ was considered.

The descriptive analysis of the ichthyological settlement was carried out using the index below: Numeric percentage (N) or Abundance

$$N = \frac{n}{Nt} \times 100$$

Where n: Number of individuals in a taxonomic group (species, family or order) and Nt: Total number of individuals.

Also, Percentage weight (P) or Biomass.

$$P = \frac{p}{Pt} \times 100$$

Where p: Weight of individuals in a taxonomic group (species, family or order) and Pt: Total weight of individuals in a sample.

The numerical and weight percentages of the different species were determined according to N'Zi et al. (2008).

Diversity

Index of Shannon and Weaver (1963) (H ')

$$H' = \Sigma(\frac{Ni}{N}) \times \log_2(\frac{Ni}{N})$$

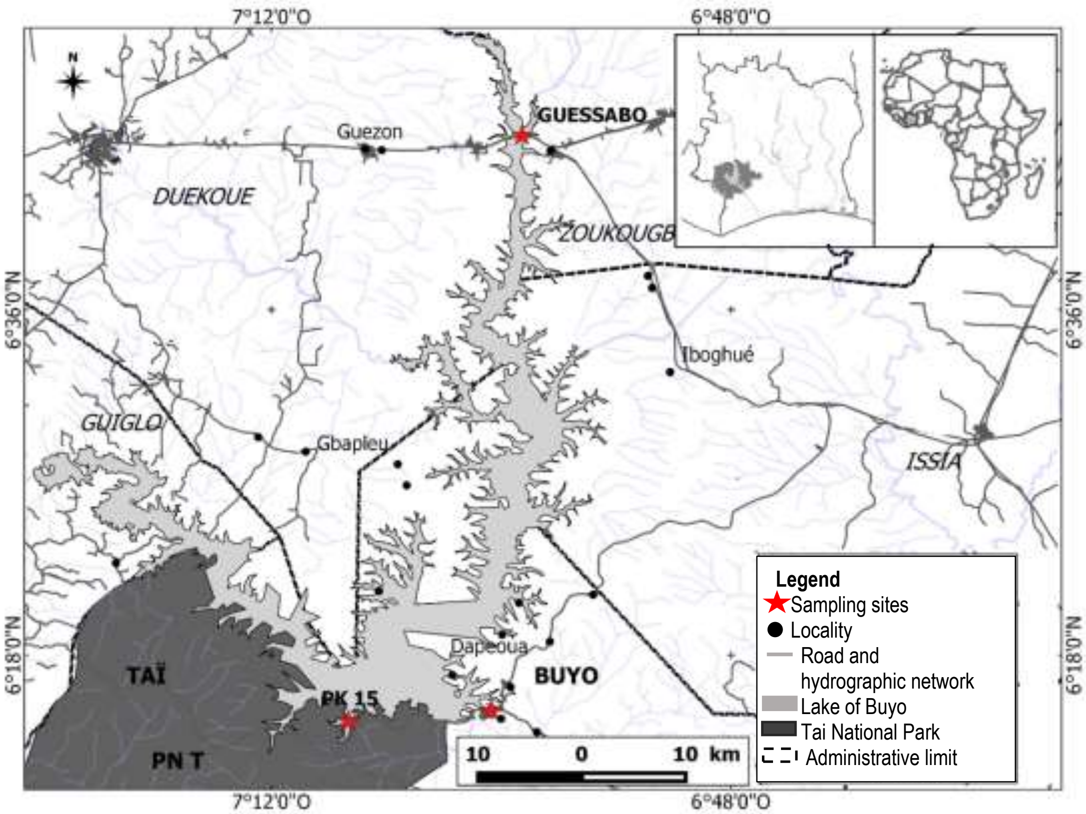

Figure 1. Location of the Lake of Buyo and location of the sampling stations (★) .

Where Ni: number of individuals of a given species, i ranging from 1 to S (total number of species) and N: total number of individuals. H' measures the degree of organization of the settlement (Amanieu and Lasserre, 1982).

H' is expressed in units of information per individual or bits / individual. It is nil if the sample is composed of a single species and maximal (in the order of 5) if all the species in the community are also represented in the sample (Ludwig and Renolds, 1988). Equality (E) of Piélou (1984).

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

Where H ': Shannon index and S: specific wealth.

E makes it possible to assess the quality of the settlement organization (Dajoz, 2000; Barbault, 2000). It varies between 0 and 1. It is maximal when the species have identical abundances in the settlement and minimal when a single species dominates the entire settlement. These indexs were made according to the program PAST.

Percentage of occurrence or frequency of species (%F)

Frequency of occurrence is the percentage of samples in which each taxon occurred (Gbenyedji et al., 2011):

$$F = \frac{Si}{St} \times 100$$

Where Si: number of stations where species i was captured and St: total number of stations examined. The classification of Djakou and Thanon (1988) was used for this study. It is established as follows: 80% ≤ F <100%: very frequent species; 60% ≤ F <79%: Frequent species; 40% ≤ F <59%: fairly frequent species; 20% ≤ F <39%: Ancillary species; F <20%: Accidental species.

Multivariate analysis

A canonical correspondence analysis (CCA) was used to identify possible correlations between fish assemblages and the environment variable (Ter Braak, 1988). The CCA was conducted using the Canoco Version 4.5 Software. This analysis has highlighted the main environmental variables that determine the distribution of fish (Ter Braak and Šmilauer, 2002). The CCA coupled with Monte Carlo permutation tests (499 permutations) was used to select the environmental variables that best explain the distribution pattern of fish species.

RESULTS

Environmental characteristics of the Lake of Buyo

The water variables in the Buyo Lake has been shown in Table 1. These results do not indicate any temporal variation within the same station. However, a significant spatio-temporal variation ($p < 0.05$) in water pH, electrical conductivity, total dissolved solids (TDS), and water

Table 1. Spatiotemporal variation of physico-chemical parameters measured at the Lake of Buyo from July 2017 to June 2018.

Physico-chemical parameter		Guessabo		Buyo ville		PK15	
		Rainy (a)	Dry (b)	Rainy (c)	Dry (d)	Rainy (e)	Dry (f)
pH	Median	5.47	5.64[ec]	5.38[b]	5.51	5.34[b]	5.57
	Max	5.75	5.72	5.5	5.62	5.61	5.63
	Min	5.10	5.62	4.91	5.41	5.24	5.55
Conductivity (µS/cm)	Median	74.55[e]	76[ef]	62.2	57.15	55.65[ab]	55.6[b]
	Max	88.7	91.95	65.8	59.95	63.7	63.85
	Min	63	73.45	54.15	54.6	45.55	50.05
Oxygen (mg/L)	Median	5.7	6.6	4.05	5.15	5.7	5.05
	Max	7.5	7.95	6.8	5.8	7	6.25
	Min	1	4.95	1.2	3.3	4	4.8
TDS (mg/L)	Median	49.2[ef]	50.05[ef]	40.5	38.75	37.8[ab]	35.85[ab]
	Max	57.55	61.7	44.55	40.15	40.7	38.15
	Min	44.7	49.25	37.35	37.55	30.35	33.25
Temperature (°C)	Median	30.75	31.2	29.9	30.85	29.2	30.9
	Max	31.85	31.85	31.95	31.75	31.85	31.2
	Min	27.9	29.1	28.05	30.8	27.4	30.2
Transparency (cm)	Median	84[f]	99.5	118	108	130.5	176[a]
	Max	154.5	140	132.5	130.5	180.5	188
	Min	58	70.5	70.5	57.5	77	115
Nitrite (mg/L)	Median	0.001	0.004	0.001	0.003	0.002	0.003
	Max	0.003	0.005	0.004	0.02	0.004	0.004
	Min	0	0.001	0	0.001	0	0.001
Total Phosphorus (mg/L)	Median	0.198	0.198	0.194	0.198	0.162	0.196
	Max	0.198	0.198	0.198	0.198	0.198	0.198
	Min	0.072	0.198	0.081	0.169	0.062	0.168
Total Chlorine (mg/L)	Median	0.04	0.06	0.07	0.02	0.06	0.06
	Max	0.21	0.07	0.12	0.02	0.41	0.11
	Min	0	0.03	0.01	0.01	0	0.01

GSB : Guessabo ; **BV** : Buyo ville ; **(a)** : Significant statistical difference compared to Guessabo in the rainy season; (**b**): significant statistical difference compared to Guessabo in the dry season; (**c**): significant statistical difference compared to Buyo Ville in rainy season; (**d**): significant statistical difference compared to Buyo Ville in the dry season; (**e**) significant statistical difference compared to PK15 in the rainy season; (**f**): significant statistical difference compared to PK15 in the dry season; (**ce**): significant statistical difference compared to Buyo Ville and PK15 in the rainy season; (**ef**): statistically significant difference compared to PK15 in rainy season and dry season; (**ab**): statistically significant difference compared to Guessabo in the rainy season and in the dry season.

transparency was observed for the three stations examined. Higher level of electrical conductivity and dissolved solids content were recorded at Guessabo (CND = 74.50 - 76 µS/cm, TDS = 49.20 - 50.05 mg/L) compared to those measured at PK15 (CND = 55.50 - 55.65 µS/cm, TDS = 35.85 - 37.80 mg/L). This trend was also observed in the dry season for the water pH for the three stations examined. However, during this same period transparency has the highest values at PK15 (130.5 - 176 cm) compared to the values obtained at Guessabo (95 cm).

Qualitative analysis of the fish settlement

A total of 45 species of fish composed of 27 genus, 15 families and 6 orders (Table 2) have been identified throughout the Lake of Buyo. These fish fauna contain four marine and/or brackish water species (*Pellonula leonensis, Sarotherodon galilaeus, Tilapia guineensis and Sarotherodon melanotheron*) and two introduced species (*Oreochromis niloticus* and *Heterotis niloticus*). The species richest orders are Siluriformes (14 species), Perciformes (10 species), Osteoglossiformes and Characiformes with 8 species each respectively. The richest family is Cichlidae with 8 species, followed by Mormyridae (7 species) and Alestidae (6 species).

The most represented families at the station Guessabo are Mormyridae (7 species), Cichlidae (6 species) and Alestidae (5 species). In Buyo town and PK15, Cichlidae dominate with 8 species, followed by Mormyridae (7 species) and Alestidae (5 species). The station at Guessabo is the richest station with 41 species, followed by PK15 with 32 species and Buyo city with 31 species. In general, the species richness is higher at upstream of the lake (Guessabo, n = 41 species) than downstream of the lake (Buyo zone, n = 31 species).

The spatio-temporal analysis of the settlement of the lake of Buyo showed that Cichlidae dominate the fish population of the lake followed by Mormyridae, Mochokidae and Cyprinidae in both dry and wet seasons. The predominance of these families is clearly observed at the stations with the particular case of Mormyridae which come first in terms of predominance at Guessabo. The species richness on the whole lake (Figure 2) is higher in the rainy season with 44 species and lower in the dry season with 34 species.

Quantitative analysis of the fish population

A total of 5265 individuals (or 0.483 tonnes) were captured in the Lake of Buyo during the study period. The best represented families in number of individuals (Figure 3) are Cichlidae (35.04%) followed by Claroteidae (16.43%) and Mochokidae (10.92%).

O. niloticus is preponderant in terms of numerical abundance with 15.55% (Figure 4). Next are *Chrysichthys nigrodigitatus* (15.15%), *Synodontis koensis* (9%), *Distichodus rostratus* (6.49%) and *Malapterurus electricus* (5.96%). These species alone accounted for 52.15% of the captures.

The spatio-temporal analysis shows a predominance of *C. nigrodigitatus* in the Guessabo captures during the rainy season and in the dry season, while in the same periods in Buyo City and at PK15, the *Cichlidae O. niloticus* and *Tilapia zillii* dominate the settlement.

In terms of biomass, Cichlidae and Claroteidae alone accounted for 58.62% of the total biomass captured at Lake of Buyo (Figure 5). The species *C. nigrodigitatus* and *O. niloticus* are the most represented with 48.63% of the total biomass of this lake (Figure 6). This trend remains unchanged in our three stations during the rainy season and in the dry season.

The Kruskal-Wallis H test shows no significant difference (p> 0.05) in abundance and biomass in space and time.

Structure of the fish settlement

The diversity index (H') and equitability (E) calculated in the study area on the basis of numerical abundance of species vary from one station to another and from one period to another. Diversity and fairness index values are higher in Buyo city (H'= 2.754 and E= 0.8454) and lower in PK15 (H'= 2.283 and E= 0.6853) in the rainy season. In the dry season, these values are higher at PK15 (H'= 2.447 and E= 0.7699) and lower at Buyo city (H'= 2.283 and E= 0.7752).

The Kruskal-Wallis H test shows that there is no significant variation (p> 0.05) in the Shannon and Weaver (H') diversity index and the Pielou (E) equitability in time as well as in space (Table 3).

Distribution of species in the Lake Buyo

The analysis of percentages of occurrence revealed twenty-three very frequent species. These are *P. leonensis*, *H. niloticus, Marcusenius ussheri, Mormyrus rume, Brycinus longipinnis, Brycinus macrolepidotus, D. rostratus, Labeo coubie, Labeo parvus, Chrysichthys maurus, C. nigrodigitatus, Schilbe mandibualris, Clarias anguillaris, M. electricus, S. koensis, Synodontis punctifer, Lates niloticus, T. zillii, Hemichromis bimaculatus, Hemichromis fasciatus, O. niloticus, S. melanotheron* and *Tilapia hybrid (Tilapia guineensis x T. zillii)*. All these species are present at all times with the exception of *B. longipinnis* which occurs only in the rainy season. The rare species (*Mormyrops anguilloïdes, Hepsetus odoe, Alestes baremoze, Chrysichthys johnelsis, Heterobranchus isopterus, Heterobranchus longifilis, Malapterurus barbatus, Synodontis schall* and *Parachanna obscura*) have, in most cases, been captured in the rainy season except for *H. odoe* and *P. obscura* that were captured in both seasons.

Determination of the ichthyological settlement

The influence of environmental variables on fish distribution has been demonstrated by the Canonical Correspondence Analysis (CCA) (Figure 7). Only the axes I (eigenvalue $\lambda 1 = 0.180$) and II (eigenvalue $\lambda 1 = 0.062$) that express 74.4% of the cumulative variance values for the species data were considered in the interpretation of the results. The Monte Carlo test made it possible to select, among the nine initial variables, five variables that express at 54.51% the observed species-

Table 2. List, occurrence and distribution of fish species sampled in the Lake of Buyo between July 2017 and June 2018.

Orders, families and genus	species	GSB	BV	PK15	PO	Character
Clupeiformes						
Clupeidae: *Pellonula*	*Pellonula leonensis**	+	+	+	100	**ETF**
Osteoglossiformes						
Arapaimidae: *Heterotis*	*Heterotis niloticus***	+	+	+	100	**ETF**
Mormyridae: *Marcusenius*	*Marcusenius furcidens*	+	+		66.66	**EF**
	Marcusenius senegalensis	+	+		66.66	**EF**
	Marcusenius ussheri	+	+	+	100	**ETF**
Mormyrops	*Mormyrops anguilloïdes*	+			33.33	**EAc**
	Mormyrus rume	+	+	+	100	**ETF**
Petrocephalus	*Petrocephalus bovei*	+	+		66.66	**EF**
Pollimyrus	*Pollimyrus isidori*	+		+	66.66	**EF**
Characiformes						
Hepsidae: *Hepsetus*	*Hepsetus odoe*	+			33.33	**EAc**
Alestidae: *Alestes*	*Alestes baremoze*		+		33.33	**EAc**
Brycinus	*Brycinus imberi*	+	+		66.66	**EF**
	Brycinus longipinnis	+	+	+	100	**ETF**
	Brycinus macrolepidotus	+	+	+	100	**ETF**
	Brycinus nurse	+		+	66.66	**EF**
Hydrocynus	*Hydrocynus forskalii*	+	+		66.66	**EF**
Distichodontidae: *Distichodus*	*Distichodus rostratus*	+	+	+	100	**ETF**
Cypriniformes						
Cyprinidae	*Barbus ablabes*	+		+	66.66	**EF**
Barbus	*Barbus macrops*	+		+	66.66	**EF**
Labeo	*Labeo coubie*	+	+	+	100	**ETF**
	Labeo parvus	+	+	+	100	**ETF**
Siluriformes						
Claroteidae : *Chrysichthys*	*Chrysichthys johnelsis*	+			33.33	**EAc**
	Chrysichthys maurus	+	+	+	100	**ETF**
	Chrysichthys nigrodigitatus	+	+	+	100	**ETF**
Schilbeidae: *Schilbe*	*Schilbe mandibularis*	+	+	+	100	**ETF**
	Schilbe intermedius	+		+	66.66	**EF**
Clariidae: *Clarias*	*Clarias anguillaris*	+	+	+	100	**ETF**
Heterobranchus	*Heterobranchus isopterus*	+			33.33	**EAc**
	Heterobranchus longifilis	+			33.33	**EAc**
Malapteruridae : *Malapterurus*	*Malapterurus barbatus*			+	33.33	**EAc**
	Malapterurus electricus	+	+	+	100	**ETF**
Mochokidae:*Synodontis*	*Synodontis bastiani*	+		+	66.66	**EF**
	Synodontis koensis	+	+	+	100	**ETF**
	Synodontis punctifer	+	+	+	100	**ETF**
	Synodontis schall	+			33.33	**EAc**
Perciformes						
Channidae: *Parachanna*	*Parachanna obscura*	+			33.33	**EAc**
Centropomidae : *Lates*	*Lates niloticus*	+	+	+	100	**ETF**
Cichlidae						
Hemichromis	*Hemichromis bimaculatus*	+	+	+	100	**ETF**
	Hemichromis fasciatus	+	+	+	100	**ETF**
Oreochromis	*Oreochromis niloticus***	+	+	+	100	**ETF**
Sarotherodon	*Sarotherodon galilaeus**		+	+	66.66	**EF**
	*Sarotherodon melanotheron**	+	+	+	100	**ETF**
Tilapia	*Tilapia guineensis**		+	+	66.66	**EF**
	Tilapia zillii	+	+	+	100	**ETF**

Table 2. Contd.

	Tilapia hybride *(T. guineensis X T. zillii)*	+	+	+	100	**ETF**
6 orders - 15 families - 27 genus		**41 species**	**31 species**	**32 species**		

ETF: Very Common Species; **EF**: Frequent Species; **EAc**: Species Accessory; +: Presence; *: species with marine and / or estuarine affinity; **: introduced species.

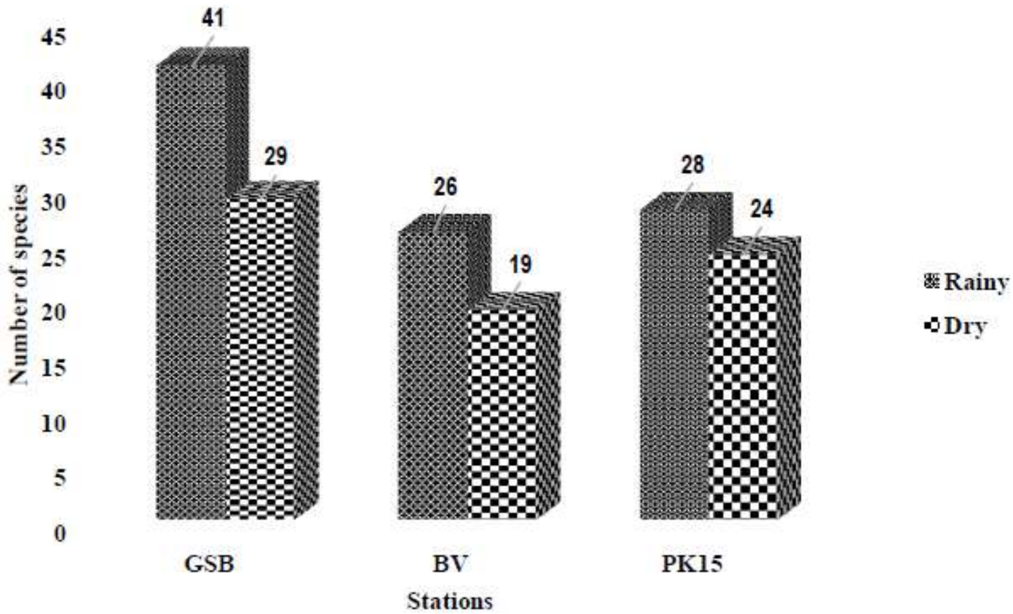

Figure 2. Spatio-temporal variation of species richness of the Lake of Buyo.
GSB: Guessabo; BV: Buyo Ville.

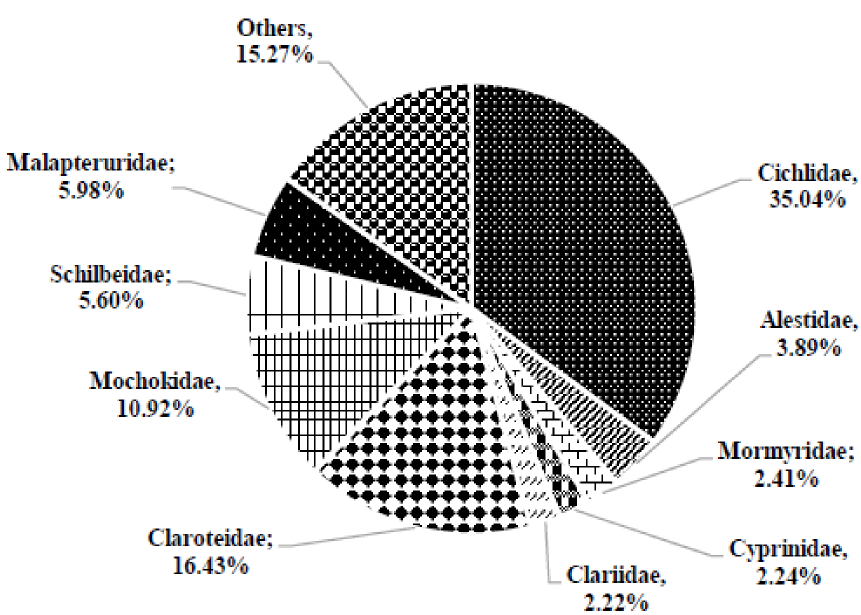

Figure 3. Numeric percentage of fish families captured in Lake of Buyo.

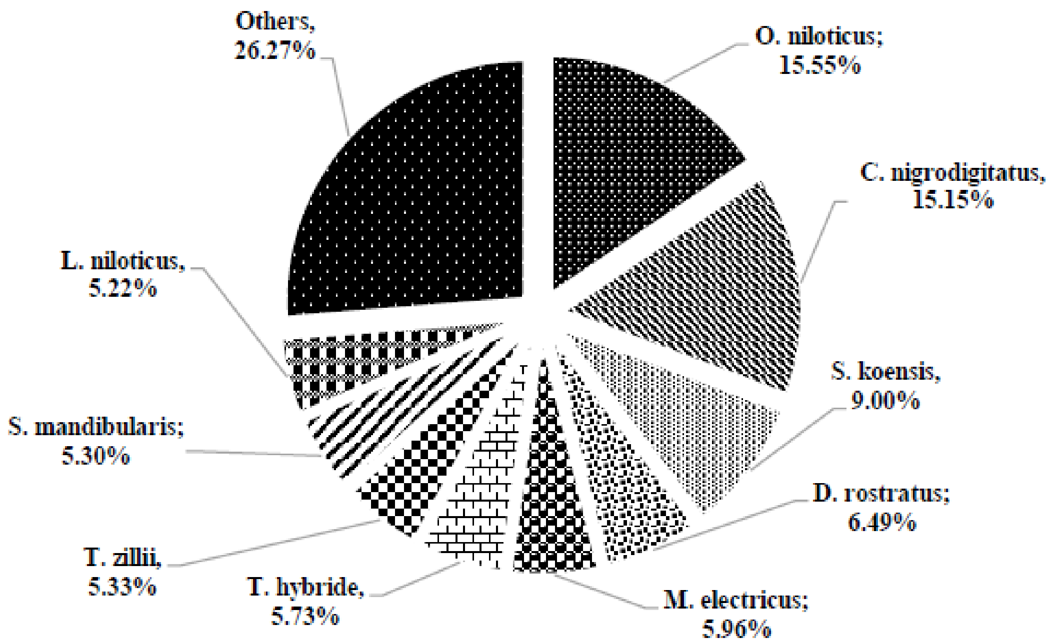

Figure 4. Percentage of fish species caught in Lake Buyo.

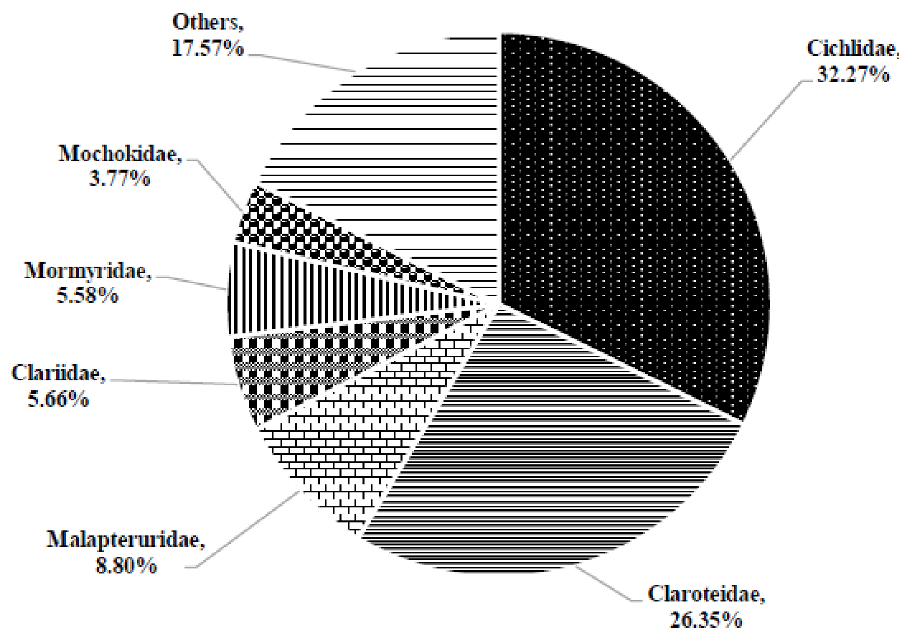

Figure 5. Percentage weight (biomass) of fish families captured in Lake of Buyo.

variable correlations. These variables are: Conductivity (12.65%), total dissolved solids (12.44%), pH (11.58%), nitrite (9.03%) and transparency (8.81%). Axis I makes it possible to separate the species into two groups A and B. The first group (A) of species consisting of *Marcusenius furcidens, Marcusenius senegalensis, Labeo coubie, Petrocephalus bovei, Hydrocynus forskalii, Brycinus imberi, P. leonensis, C. maurus, H. isopterus, H. longifilis, S. schall, C. johnelsis, M. anguilloïdes, B. macrolepidotus, L. parvus, D. rostratus, Brycinus nurse, H. odoe, P. obscura, Schilbe intermedius, M. rume, Barbus ablabes, Synodontis bastiani, Barbus macrops* and *Pollimyrus isidori* are associated to the station Guessabo and positively correlated with the variables like

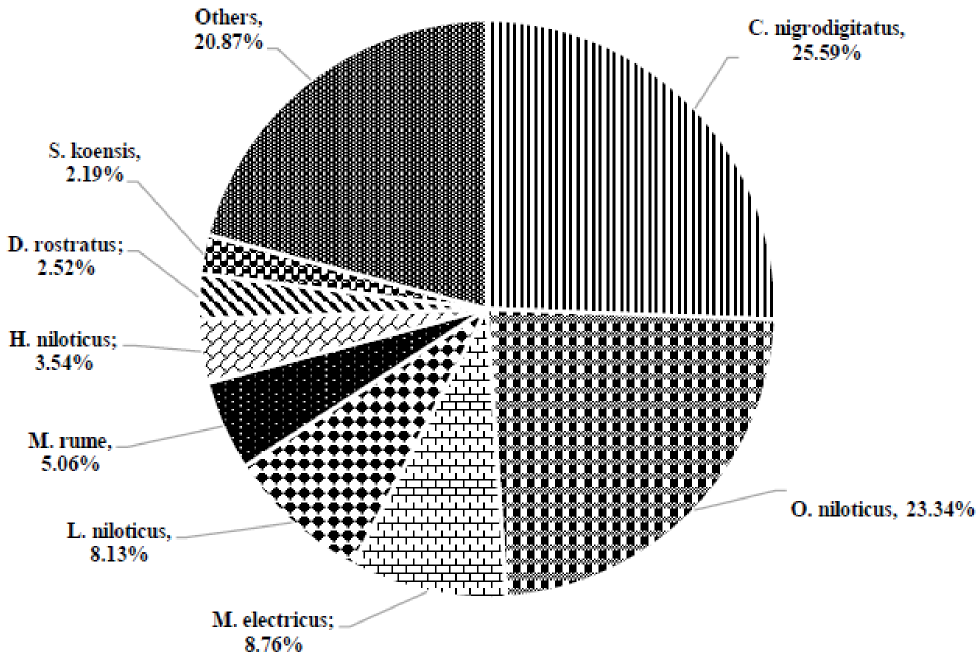

Figure 6. Percentage weight (biomass) of fish species caught in Lake of Buyo.

Table 3. Spatio-temporal variation of diversity (H') and equitability (E) index based on numerical abundance of species sampled in Lake of Buyo from July 2017 to June 2018.

Season	GUESSABO		BUYO VILLE		PK15		
	Shannon (H')	Equitability (E)	Shannon (H')	Equitability (E)	Shannon (H')	Equitability (E)	Variation
Rainy season	2.667	0.7182	2.754	0.8454	2.283	0.6853	NO
Dry season	2.403	0.7136	2.283	0.7752	2.447	0.7699	NO

conductivity, dissolved solids level and pH on the axis I. The second group (B) is composed of the species *A. baremoze, M. ussheri, S. mandibularis, B. longipinnis, H. bimaculatus, H. fasciatus, Lates niloticus, T. guineensis, Tilapia hybrid (T. guineensis x T. zillii), S. melanotheron, S. punctifer, T. zillii, O. niloticus, H. niloticus, C. nigrodigitatus, S. koensis, C. anguillaris, M. electricus, Sarotherodon galilaeus and M. barbatus* associated to Buyo City and PK15 stations. These species are negatively correlated to the nitrite and transparency variables on axis I. Axis II separates the second group (B) into two subgroups (B1 and B2). The first sub-group (B1) of species composed of *Baremoze alestes, M. ussheri, S. mandibularis, S. koensis, B. longipinnis, H. bimaculatus, H. fasciatus, L. niloticus, S. melanotheron, S. punctifer, T. guineensis, O. niloticus* and *Tilapia hybrid (T. guineensis X T. zillii*) is associated with the Buyo city station and is positively correlated to the nitrite variable along axis II. The second subgroup (B2) composed of the species *T. zillii, C. anguillaris, C. nigrodigitatus, M. electricus, S. galilaeus, H. niloticus* and *M. barbatus*, associated to the PK15 station is negatively correlated to the variable transparency.

DISCUSSION

Analysis of the environmental characteristics of the Lake of Buyo indicated a significant spatio-temporal variation in pH, electrical conductivity, total dissolved solids and water transparency of the various stations examined. This variation highlights the existence of different microhabitats on the lake whose ecological quality is closely related to surrounding human activities. Indeed, extreme values of water pH, conductivity and TDS were observed at the station of Guessabo located in urban area contrary to the values measured at the PK15 station located in forest zone closer to the Taï National Park and Buyo city near this park. Barakat et al. (2016) asserted that the deterioration of water quality in Guessabo would result mainly from anthropogenic activities such as the industrial and domestic wastewater discharge as well as

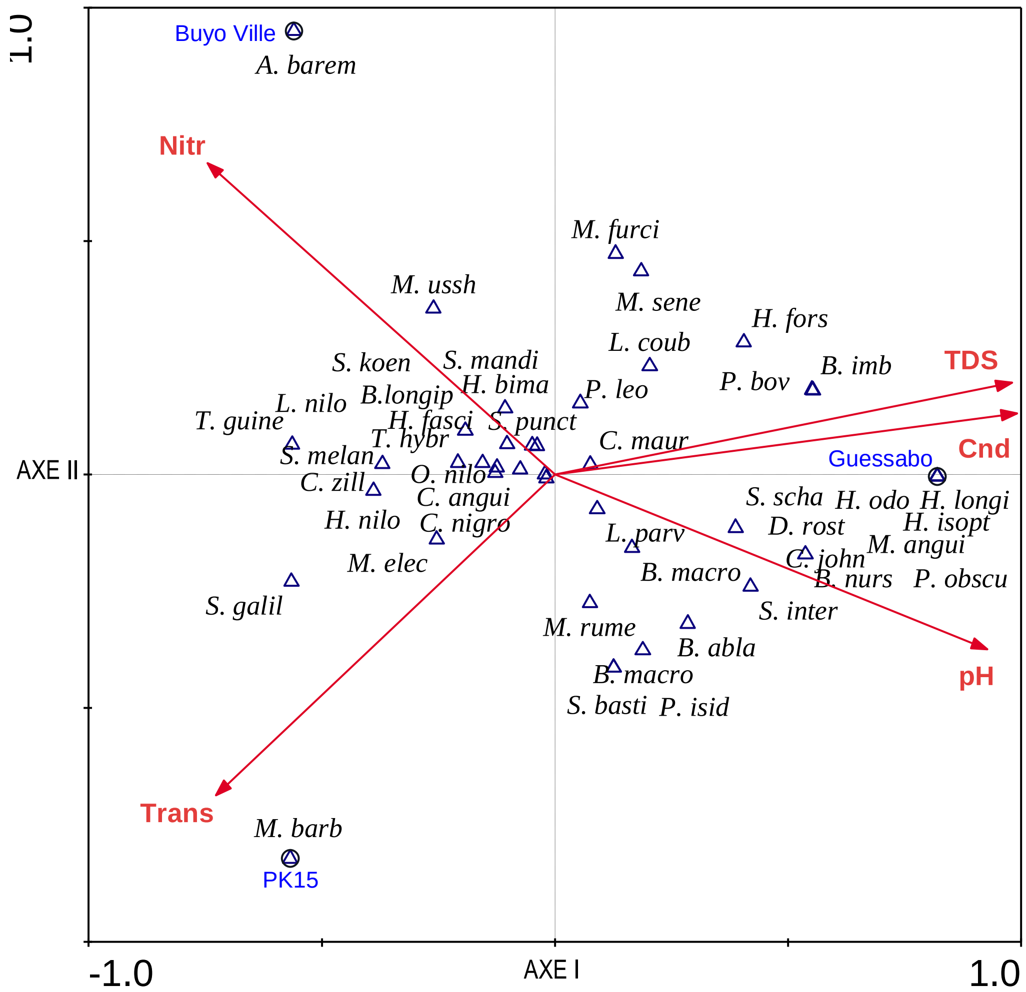

Figure 7. Canonical Correspondence Analysis (CCA) applied to environmental variables and fish species captured in Lake Buyo. The codes and the corresponding species are recorded in Table II. Cnd = conductivity; TDS = total dissolved solids; trans = transparency; pH = hydrogen potential; Nitr = nitrite.

agricultural drainage. This observation is confirmed by the work of Biggs et al. (2004) in the Amazon Basin, Martinelli et al. (2008) in the watersheds of the state of São Paulo, Salomão et al. (2008) in ten subtropical watersheds located in the State of São Paulo in Brazil, Germer et al. (2009) in the south-west of the Brazilian Amazon, and Andrade et al. (2011) in the small watersheds of the Atlantic coastal forest in south-eastern Brazil, which highlighted the impact of urbanization and agricultural practices on water quality. In addition, Silva et al. (2008) and Germer et al. (2009) reported in Amazonian rivers an increase in conductivity in relation to nutrient inputs (NO_3^-, PO_4^{3+}, K^+ and Mg^{2+}) in grazing watersheds relative to forest catchments. The results of this study indicated a spatio-temporal variation in transparency. This water parameter is affected by the amount of suspended sediment, the concentration of dissolved organic matter and the abundance of plankton present in the water column (Cherbi et al., 2008). The high value of transparency at PK15 in the dry season is related to the cumulative effect of the presence of forest that limits watershed erosion and the reduction of rainfall that allows the water body to settle fairly well. The external input of materials by runoff is also reduced (Cherbi et al., 2008).

The present study identified 45 species in Buyo. This specific richness is lower than that of Traoré's work (1996) but higher than that of Kouamé et al. (2008) who reported 56 species and 33 species respectively in the Lake of Buyo. The difference between our results and those of previous work is due to sampling methods and sampled habitats. The results of this study are obtained from sampling based mainly on gill net while the work of Kouamé et al. (2008), in addition utilized a battery of nets associated with electric fishing. This active fishing is more practical in shallow depths. This is not the case in the

Lake of Buyo. These differences could also be explained by (1) the sampling technique used by these authors, (2) the large number of sampling stations and (3) the extent of the study area. Indeed, Traore sampled on the Lake of Buyo in several stations: the zones of Buyo, 1er carrefour, PK28, Mossibougou, Liahinou, Badjan, Guessabo, Guiglo, Gbapleu, Beablo and Kéitadougou. As for Kouamé, his sampling took place only in two stations: the right bank and the left bank of the Lake of Buyo. However, the sampling of the present study considered three stations going from the upstream (Guessabo zone) to the downstream (Buyo city) and including a station located in the reserve part of the primary forest of the Tai National Park (PK15). According to N'Douba et al. (2003), the high number of sampling stations would be necessary because of the habitat diversity. This diversity of habitat positively influences the specific richness of the watercourse (Changeux, 1995). The presence of marine or estuarine species (*P. leonensis, S. galilaeus, S. melanotheron* and *T. guineensis*) shows that they migrate from the Atlantic Ocean to the Sassandra River, and then from the Sassandra River to Lake of Buyo in order to feed or for reproduction. Similar results were noted by Paugy et al. (2003a, b) in African freshwaters.

In the Lake of Buyo, the Cichlidae family dominates in the captures made. These results are similar to those reported by Traoré (1996), Tah et al. (2009), Adou et al. (2017), Montchowui et al. (2008), Ouedraogo et al. (2015) and Kouamé (2010) respectively in the Lakes of Buyo (Côte d'Ivoire), Ayamé 1 and Ayamé 2 (Côte d'Ivoire), Hlan (Benin), Sahelian of Higa (Burkina Faso) and on the lower Sassandra River (Côte d'Ivoire). According to Koné et al. (2003a), the creation of lakes caused by the installation of dam in general is followed by their colonization by Cichlidae species and certain fluvial species. Also, the high number of this family of fish in the captures could be explained by the dam built on the main river bed. Indeed, the Lake of Buyo, due to its stagnant water character, offers adequate ecological conditions that favor the proliferation of phytoplankton and zooplankton (Lévêque, 1997). The lake would be a preferred medium for these microphages who found a vacant trophic niche formed by the proliferation of plankton (Traoré, 1996). The spatio-temporal variation in species richness observed in the lake of Buyo is not a new phenomenon in open-type lacustrine environments (Lévêque, 1999). According to Bouchereau (1997), this variation is related either to the behavioral changes of individual fish, who becomes more or less vulnerable to fishing technique, or to migrations of populations. In the Lake of Buyo, spatio-temporal variations in species richness would be much more related to species migrations between the lake and its associated rivers during periods of low and high water. Indeed, the highest species richness on the lake is observed during the months of August-September which correspond to the rainy season. Fish migrate downstream from the N'zo and Lobo Rivers and the Sassandra River to Lake of Buyo at Guessabo and its flooding in search of suitable sites for spawning. In contrast, low specific richness is observed in December and March. It is the dry season and species that have come to reproduce in the shallow marginal areas of the lake migrate in the opposite direction. This situation was reported by Montchowui et al. (2008) in Lake Hlan in Benin where species richness would be higher during the rainy season because fish migrate from downstream of the Sô and Ouémé Rivers to Hlan Lake. The species *H. odoe, C. johnelsis, H. isopterus, H. longifilis, S. schall and P. obscura* were captured only at Guessabo station. The majority of these captures were made during the rainy season, the reproduction period for the majority of fish where the larvae and juveniles of the year's breeding are the most numerous with favorable feeding conditions for piscivorous species such as *H. odoe* and *P. obscura*. In addition, in this station, unlike the other two, is characterized by a muddy substrate, a preferred medium for species of the genus *Heterobranchus* and *Synodontis*. These fish search the mud in the bottom to extract plant debris, insect larvae, seeds and animal detritus. According to Yao et al. (2010), the muddy substrate plays an important role in feeding some *Synodontis* species that feed on benthic prey. Also, during the capture of these species in the rainy season, the station was largely covered with aquatic plants creating different types of habitats that could offer an availability of food resources due to the presence of floating vegetation, herbaceous and emergence and submergence of adjacent terrestrial vegetation. These habitats would also be suitable spawning grounds for these species and would encourage significant colonization by fish. *C. johnelsis* hitherto known from the Bia River is reported for the first time in the Lake of Buyo. Alestes baremoze, surface fish near the shoreline and essentially insectivorous according to Traoré (1996), was captured only at the Buyo Ville station, not far from the hydroelectric dam. This part of the station is characterized by a sandy and stony substrate constituting the preferential biotope of Chironomidae (Kouamélan, 1999). According to this author, these insects, which breed throughout the year, are an important source of food to these fishes. In addition, stony substrates are suitable for the development of insect larvae and other small organisms that are important food for fish (Morin, 2003). The species *M. barbatus* was captured only at PK15 station, the only station located in the Taï National Park. Kamelan (2014) for the first time reported this species in the Sassandra Basin, specifically in the Zakoué River, the only tributary of the river that irrigates the Taï National Park. For this author, anthropogenic actions would influence this species that would come to find refuge in the Park. Indeed, Lalèyè (2010a, b) indicated that *M. barbatus* and *M. punctatus* are threatened by agricultural activities, mining, urbanization and deforestation in Liberia, Sierra Leone and Guinea. This threat has also been observed in Nigeria where individuals of *Malapterurus beninensis* are threatened by oil exploration (Lalèyè et al., 2010). The species *H. isopterus* and *H. longifilis* were caught only in Guessabo during the rainy season. In fact, during the rainy season, this station is mostly covered with aquatic plants leading to a reduction in dissolved oxygen levels. However, species of the genus *Heterobranchus* also have an accessory respiratory organ that allows them to breathe oxygen from the air and thus to withstand the hypoxic conditions of the environment. During the dry season, the high dissolved oxygen level (6.56 ± 1.19 mg/l) causes Mormyridae *Marcusenius senegalensis* and *P. bovei*, to proliferate. According to Kamdem Toham and Teugels (1997), Mormyridae are very demanding fish in dissolved oxygen.

In terms of numerical abundance, Cichlidae (34.04%) are the most represented in the Buyo Dam. This trend resembles that observed by Traoré (1996), and Kouamé et al. (2008) in Lake of Buyo and Montchowui et al. (2008) in Lake Hlan in Benin. According to Balogun (2005), Cichlidae are important components of fish fauna in open-type African lakes such as Lakes Ihema (Rwanda), Kainji (Nigeria), Kangimi (Nigeria), Tiga (Nigeria), Georges (Uganda) and Toho-Todougba. The species *O. niloticu*s (15.55%) dominates the captures of Lake Buyo. This is due to the fact that *O. niloticus* is an all year-round reproducing species in the lake (Traoré, 1996) in addition to the appropriate ecological conditions that would favor the proliferation of phytoplankton and zooplankton that the lake would offer. The phytoplankton fraction constituting the diet of this species will favor its adaptation and its proliferation (Lévêque, 1997). This result is similar to those reported by Balogun (2005) in Kainji, Tiga and Bakolori lakes in Nigeria where *O. niloticus* is dominant in captures. The preponderance of *C. nigrodigitatus* in the captures in Guessabo, PK15 and Buyo Ville in the rainy season as well as in the dry season is due to the fact that this species would be benthic invertivore, which could explain its strong geographical distribution in the waterways of Côte d'Ivoire and Africa (Aboua et al., 2010).

In terms of abundance, Siluriformes (Claroteidae, Malapteruridae, Clariidae and Mochokidae) alone accounted for 44.58% of total biomass. This large proportion of Siluriformes fish could be explained by the fact that they are species that resist degrading ecological conditions (Tejerina-Garro et al., 2005). In the Lake of Buyo, for the species that dominate the settlement, their maximum numerical and maximum relative abundances were recorded during the rainy season. Indeed, when the water level rises, it invades the banks and is enriched with nutrients from the decomposition of organic matter and vegetation. This results in a rapid development of phytoplankton, zooplankton ... implying a rapid growth of fish correlated with a large biomass. In addition, the biomass is higher at the PK15 station compared to the Guessabo station, where the numerical abundance is high. This result would mean that the PK15 station in the Taï National Park, which is a reserved area, would offer adequate nutritional resources for the good development of the species found there, moreover, since these do not suffer from anthropic pressures (intense fishing activities, domestic and industrial pollution ...) as is the case in the Guessabo and Buyo Ville stations. Hugueny (1990) reported that the change in the vegetation cover due to agricultural and logging activities causes a reduction in the nutritional resources for species living in these environments. According to Kamelan (2014), the Taï National Park would be a good area for species development. The values of the diversity index (H' varying from 2.283 to 2.74) and of the equitability (E ranging from 0.685 to 0.845) in the three stations of the Lake of Buyo indicate a good settlement organization of studied stations. The results of this study indicate that the value of equitability in the different stations of the Lake of Buyo is above average. These results reflect a more or less balanced distribution of species.

The canonical correspondence analysis (CCA) indicates that the distribution of *M. furcidens* species, *M. senegalensis, L. coubie, P. bovei, H. forskalii, B. imberi, P. leonensis, C. maurus, H. isopterus, H. longifilis, S. schall, C. johnelsis, M. anguilloïdes, B. macrolepidotus, L. parvus, D. rostratus, B. nurse, H. odoe, P. obscura, S. intermedius, M. rume, B. ablabes, S. bastiani, B. macrops* and *P. isidori* at Guessabo station are significantly related to physico-chemical parameters such as pH, conductivity and total dissolved solids (TDS). In Côte d'Ivoire, several studies (Kouamé et al., 2008; Aboua et al., 2010 ; Kamelan et al., 2013, 2014) carried out on different rivers established relationships between species and environmental variables. Kouamé et al. (2008) showed the influence of dissolved solids levels on the species *H. forskalii, L. coubie* and *D. rostratus* in the main stream of the Sassandra River. Aboua et al. (2010) reported that dissolved solids, pH, and electrical conductivity significantly influence *B. ablabes, C. maurus, P. bovei,* and *B. imberi* species in the Bandama River. The importance of pH in the distribution of *M. senegalensis, B. macrolepidotus and M. anguilloides* species was also noted by Kamelan et al. (2013). The significant influence of these physicochemical parameters is related to the closeness of this station to human activities (cultivation, laundry, dishes, washing of vehicles). Indeed, the Guessabo station has the highest values of conductivity, pH and TDS in the zone Lake Buyo. These anthropogenic activities favor the variation of the parameters related to the mineralization of the waters (pH and conductivity). In addition, TDS is one of the discriminating factors influencing the distribution of fish communities in this study. Indeed, a high level of TDS is correlated to a strong accumulation of dissolved elements which influences the presence of fish species in

Guessabo. Similar results have been found in some rivers in Côte d'Ivoire. They are the Agnébi and Bia Rivers (Da Costa et al., 2000) and the Comoé River (Yao et al., 2005).

Nitrite is the only parameter influencing the distribution of *A. baremoze, M. ussheri, S. mandibularis, S. koensis, B. longipinnis, H. bimaculatus, H. fasciatus, L. niloticus, S. melanotheron, S. punctifer, T. guineensis, O. niloticus,* and *Tilapia hybrids (T. guineensis x T. zillii)* at Buyo Ville Station. In the Taï space hydrosystems in Ivory Coast, Kamelan (2014) found that the species *M. ussheri*, *S. mandibularis, B. longipinnis*, *H. fasciatus* and *S. melanotheron* had a preference for nitrite. The significant influence of nitrite in the distribution of species is linked to the strong agricultural activities in the vicinity of Buyo Ville Station. The nitrite level is higher (0.006 mg/l) in this station but does not exceed the threshold value (0.06 mg/l) above which nitrites becomes a threat to the development of aquatic fauna.

Transparency influences the distribution of *T. zillii, C. anguillaris, C. nigrodigitatus, M. electricus, S. galilaeus, H. niloticus and M. barbatus* at PK15. Aboua (2010) has highlighted the importance of transparency in the distribution of *C. nigrodigitatus* in the Bandama River. Kamelan (2014) argues that the transparency of water is affected by the amount of suspended elements, the dissolved organic matter concentration and the abundance of plankton (algae and microorganisms) in the water column. High transparency implies a small amount of these elements food source to these bhophophagous insectivorous species.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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