INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 23, No. 4, p. 17-31, 2023
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Impact of Man-made hydroelectric dams in freshwater fish communities

Moussa Dosso*[1], Lassina Doumbia[1], Allassane Ouattara[1], Helguilé Shep[1,2], Germain Gourène[1]

[1]*Laboratory of Environment and Aquatic Biology, Environmental Sciences and Management Training and Research Unit, Nangui Abrogoua University, Abidjan, Côte d'Ivoire*

[2]*Department of Aquaculture and Fisheries (Ministry of Animal and Fisheries Resources), Treichville, Fishermen's Street, Abidjan, Côte d'Ivoire*

Article published on October 06, 2023

Key words: Fish community, Faé, Taabo, Kossou, Lake

Abstract

In tropical region, fish communities serve as crucial markers of the health of lake habitats. Based on experimental and commercial fishing, we investigated fish community structure of three tropical reservoirs Faé, Taabo and Kossou from October 2017 to October 2018. Fish species diversity, abundance and richness were assessed, and Focused Principal Component Analysis (FPCA) was used to evaluate the relationship between the fish communities and environmental variables. A total of 51 fish species belonging to 19 families and 9 orders were identified. Cichlids were most represented family in all lakes. Taabo Lake recorded the highest number of species (45) while Faé Lake was the low diversify with 30 species. Shannon's diversity index and equitability were highest in Kossou Lake; rarefied richness was highest in Faé Lake, while these three indices were lowest in Taabo. *Enteromius macrops* dominated at Taabo and Kossou lakes whereas *Pellonula leonensis* dominated in Faé. Similarity analyses showed that a distinct distribution of fish communities exists between Faé and Taabo lakes, Faé and Kossou lakes. However, between Taabo and Kossou lakes, composition did not change. High transparency and temperature and low conductivity greatly influenced the fish community structure.

***Corresponding Author:** Moussa Dosso ✉ dossomoussa204@yahoo.fr

Introduction

To address nation’s energy demands, Côte d'Ivoire’s government has been constructing hydroelectric dams since the end of 1950. Completion of these projects led to creation of lakes that are now important locations for fishing (Da Costa *et al.*, 2002; Da Costa and Dietoa, 2007), as well as for economic and social growth of areas around these lakes (Aboua *et al.*, 2010). Effects of human activities on watersheds of these various lakes pose a threat to survival of fish species in these habitats (Naigaga *et al.*, 2011; Vilizzi *et al.*, 2021).

These activities are as sources of annoyances that damage aquatic environment, which has an influence on biodiversity in general and fish community in particular (Carr and Neary, 2006). This has already caused diversity of fish species and fish stocks in numerous large African lakes, including Lake Victoria, to diminish (Balirwa *et al.*, 2003; Naigaga *et al.*, 2011). Although hydroelectric dams of Côte d'Ivoire have indeed been subjecting of impacts studies and sometimes harsh criticisms of their environmental effects (Diarra and Soumaguel, 1997; Gourène *et al.*, 1999); it is evident that the demand for fishery protein has resulted in increased fishing pressure on these lakes as the Ivorian population has grown over past few decades. These all represent significant environmental risks to fish populations living in these continental lakes (Da Costa and Dietoa, 2007; Endebu *et al.*, 2015).

Because of this, understanding water quality indicator organisms is crucial for preservation of fish populations and control of Lake Biodiversity loss. This study therefore assessed fish communities in lake environments threatened by biodiversity loss based on three lakes, of different sizes, the first of which was built in the 1970s (Traoré, 1996; Kouassi *et al.*, 2007). These are Faé lake: youngest and smallest of three lakes, it is a run-of-river dam where water is replenished almost daily; Taabo lake: a medium-sized lake with a water residence time of 45 days, which is emptied once a year and Kossou lake: oldest and largest of three lakes, has a very long water residence time and is never emptied. Objectives were (1) to determine composition of fish populations in lakes Faé, Taabo and Kossou using data from experimental and commercial fishing and (2) analyze structuring of ichthyofauna in relation to water quality on these three lakes according to abundance of fish species caught during experimental fishing.

Materials and methods

Study area

Three Côte d’Ivoire hydropower reservoirs have seen data collection. These lakes are Faé, Taabo and Kossou (Fig. 1). Faé dam reservoir is located in South-west region of Côte d’Ivoire (4°58’ - 5°0’ N and 6°38’ - 6°40’ W) with an area of 16.28 km² (Da Costa and Dietoa, 2007). According to Fadika *et al.* (2008), Faé lake dam was constructed in 1978 on the main course of "San pédro" river, to level of locality of which it carries the name "Faé".

Faé lake is a part of the Upper Guinea Ichthyological Province, which spans the entire coastline from Guinea’s Kogon river to Côte d'Ivoire’s and Liberia’s Nipoué river (Lévêque *et al.*, 1989; Paugy *et al.*, 1989, 1994). Taabo lake (06°10’ - 06°20’ N and 5° - 5°12’ W) was constructed in 1978 in Taabo city. It is implanted on mainstream course of Bandama river to about 110 km downstream of confluent of white Bandama (N’zi) and red Bandama (Marahoué) to about 120 km downstream Kossou lake (Kouassi *et al.*, 2007) and at 195 km from mouth of Bandama river (Traoré, 1996). Taabo lake covers an area of 69 km² (Kouassi *et al.*, 2007). Located in centre of Côte d’Ivoire, Kossou lake (6°58’ - 8°08’ N and 5°27’ - 5°45’ W) was built in 1971 on Bandama river, 296 km from mouth of this river (Traoré, 1996).

Kossou lake, with an area of 770 km², is located upstream (white Bandama) of Bandama river, which is 770 km long. Taabo and Kossou lakes belong to Nilo-Sudanese ichthyological province, more precisely to Eburneoghanean subprovince of West Africa, which is characterised by a few endemic species (Teugels *et al.*, 1988).

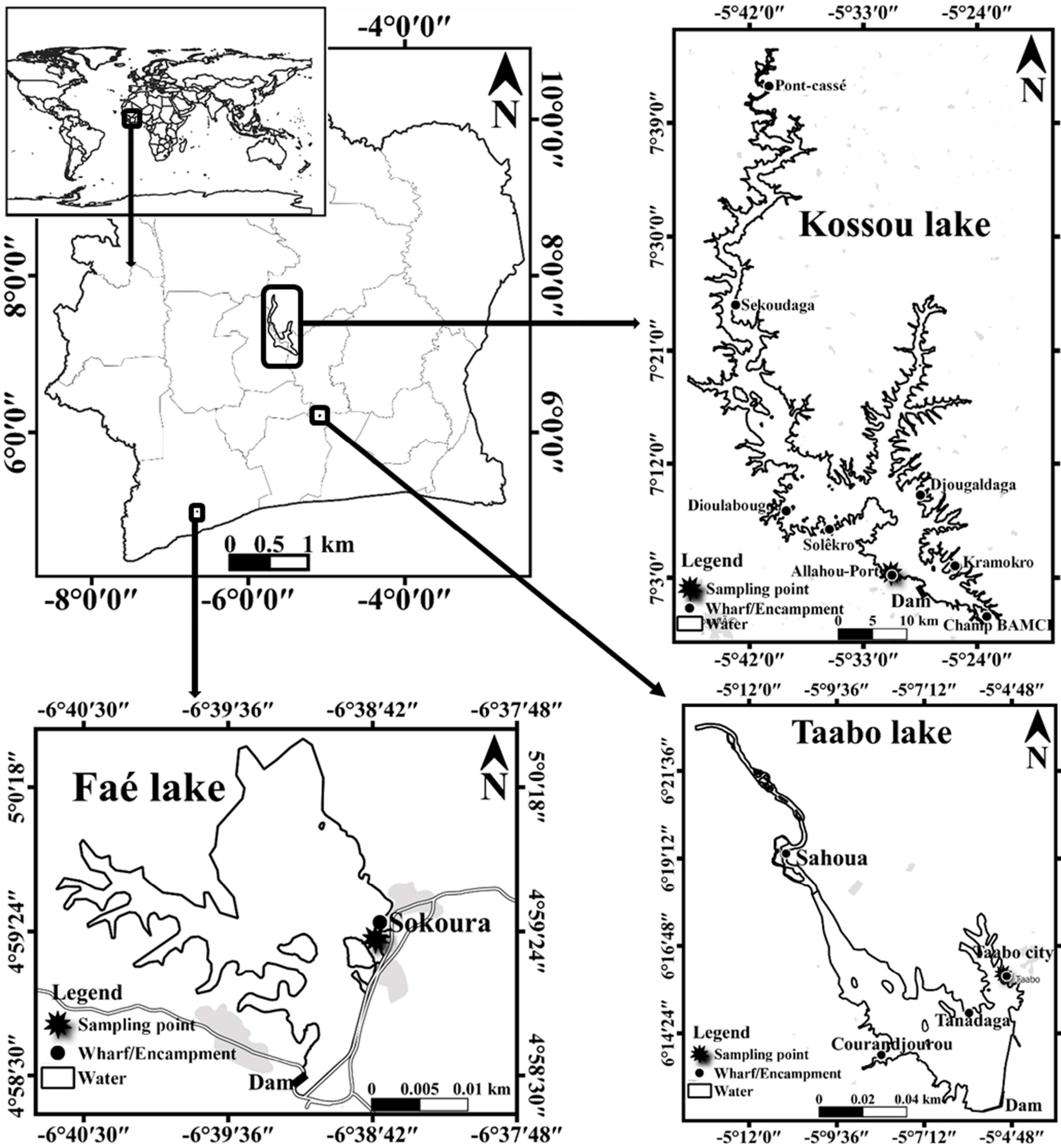

Fig. 1. Map showing locations of studies areas on Faé, Taabo and Kossou lakes.
(Côte d'Ivoire) [DOSSO, 2023 ©].

Sampling

We have collected experimental fishing samples every 45 days during nine (9) surveys from October 2017 to October 2018 at one site per lake (Sokoura, Taabo city and Allahou-Port in Faé, Taabo and Kossou lakes respectively) (Fig. 1). We have determined in situ at each sampling site temperature, pH, conductivity, dissolved oxygen and transparency before fishes sampling. We have measured temperature and dissolved oxygen by oxygen meter (HANNA HI 9146), electrical conductivity using a conductivity meter (HANNA HI 9835) and pH using pH meter (HANNA HI 991001) with specific probes. We used Seechi disk to measure transparency. We used analytical method described by Rodier *et al.* (2009) to determine these parameters. We collected fish sampling with one set of 5 multifilament gillnets (mesh sizes 13, 18, 30, 36 and 60 mm), one set of 8 monofilament gillnets (mesh sizes 15, 20, 21, 27, 35, 40, 50 and 70 mm) and two sets of 3 monofilament gillnets (mesh sizes 10, 25 and 60 mm) ((allowing capture of almost all fish longer than 40 mm total length)). These gillnet are 21.5 m-30 m long and 1.5 m-3.5 m high. At each sampling occasion, we have usually set gillnets during the overnight at about 17:00 PM (GMT) and lifted the following morning at about 07:00 AM (GMT).

We identified all specimens according to keys of Lévêque *et al.* (1990) and Lévêque *et al.* (1992) revised by Paugy *et al.* (2003); then counted.

We used commercial fishing data to establish specific richness of these lakes. We collected there data during two (2) main investigations (first took place in August and November 2017 and second in March-April 2018) and a prompt investigation (in November 2018). We visited during the two main investigations (August 2017 and April 2018) the only Wharf of Faé Lake, situated at Sokoura.

At Taabo lake, we visited several wharfs or encampments of fishers during these investigations; it is notably wharfs or encampments of Sahoua, Tanadaga, Taabo city (August 2017) and Courandjourou (March 2018) (Fig. 1). As for Kossou lake, during the two main investigations, we investigated the wharfs or encampments of Djougaldaga (August 2017 and March 2018) and Allahou-Port (November 2017). During the prompt investigation (November 2018), we visited wharfs or encampments of Pont-cassé, Sekoudaga, Kramokro, Champ BAMCI, Solêkro and Dioulabougou (Fig. 1).

Statistical analysis

We used Shannon-Weaver diversity index, equitability index of Piélou and rarefied richness to analysed species diversity. Most commonly used diversity index is Shannon-Weaver diversity index (Gray *et al.*, 1992). This index expresses diversity taking into account number of species and abundance of individuals within each species. Equitability index translates quality of population organisation (Zabi, 1993), it is a report between Shannon-Weaver diversity index of a community and its maximum diversity. Rarefied richness is the number of taxa for a given number of individuals (Grall and Coïc, 2005). In this study, we are calculated rarefied taxonomic richness per sample by using lowest abundance (20 individuals) recorded in samples as target number of individuals (Oksanen *et al.*, 2013). We calculated diversity indices by using "Vegan" package (Oksanen *et al.*, 2013) of R software.

We used Bray-Curtis similarity indices to highlighted similarity of fish composition and relationships among sampling lakes. We performed non-parametric multidimensional scaling (nMDS), analyses of similarities (ANOSIM) and similarity of percentage (SIMPER) using software Paleontological Statistic (PAST) version 2.15. nMDS analysis plotted sample units on two-dimensional ordination plane based on species composition similarities and dissimilarities (Hemery and Henkel, 2015). We discerned groups of species from nMDS plot and ANOSIM performed to test strengths of similarities within and differences between these species groups, using permutation and randomization methods on resemblance matrix. We used SIMPER to determine which species contributed to defining each group and percentage of contribution of each of these species (Hemery and Henkel, 2015).

We used Focused Principal Component Analysis (FPCA) (Falissard, 1999) to analyse main relationships between fish species and environmental variables. We selected species with an abundance greater than or equal to 5% per lake. We selected five parameters for analysis. Graphical output of FPCA analysis shows correlations in graphical format as concentric circles in which those with the lowest radius, represented the highest correlations (Fossi *et al.*, 2017). Center of these circles contains variables of interest on which analysis is “focused”. In a specific way, if a variable of set is closest to center of circle it is most correlated to target variable in correlation circle. Correlations among variables contained in set and target variable are plotted with different colors negative (yellow) and positive (green). Correlation is considered significative when p = 0.05 when a variable is placed inside red circle (Fossi *et al.*, 2017). We performed analyses with *psy* package (Legendre and Vaudor, 1991) of free sofware R 4.0.3 (R Core Team, 2020).

Results

Physical and chemical variables in lakes

Table 1 presents values of environmental variables measured in Faé, Taabo and Kossou lakes. Temperature and electrical conductivity were higher in Taabo Lake; those of pH were higher in Faé Lake and those of transparency and dissolved oxygen were higher in Kossou Lake. Temperature ranged from 27.04 °C to 31.28 °C in Taabo Lake, from 25.73 °C to 30.33 °C in Faé Lake and from 27.68 °C to 29.18 °C in Kossou Lake. Electrical conductivity varied between 74.07µs/cm and 110.68µs/cm in Taabo Lake, 46.57µs/cm and 76.85µs/cm in Faé Lake, 65.20µs/cm and 76.06µs/cm in Kossou Lake. Water pH ranged from 6.85 to 8.85 in Faé Lake, from 5.69 to 8.13 in Kossou Lake and from 7.33 to 8.11 in Taabo Lake. Transparency varied from 74.74cm to 108.21cm in Kossou Lake, from 44.30cm to 92.16cm in Taabo Lake and from 30.25cm to 48.96cm in Faé Lake. Dissolved oxygen was situated between 4.80mg/L and 6.85mg/L in Kossou Lake, 4.65mg/L and 6.72mg/L in Taabo Lake, 3.50mg/L and 4.60mg/L in Faé Lake.

Table 1. Environmental variables measured in Faé, Taabo and Kossou lakes from October 2017 to October 2018. [T = temperature; Cnd = electrical conductivity; Trans = transparency; DO = Dissolved Oxygen]

Lakes	Values	T (°C)	Cnd (µs/cm)	pH	Trans (cm)	DO (mg/L)
	min	25.73	46.57	6.85	30.25	3.50
Faé	med	28.24a	66.11a	7.39a	45.19a	4.11a
	max	30.33	76.85	8.85	48.96	4.59
	min	27.04	74.07	7.33	44.30	4.64
Taabo	med	29.56b	90.71b	7.70a	61.55b	5.89b
	max	31.28	110.68	8.11	92.16	6.72
	min	27.68	65.20	5.69	74.74	4.79
Kossou	med	28.42ab	68.23a	7.53a	92.60c	5.64b
	max	29.74	76.06	8.12	108.21	6.85

Different letters (a, b and c) on lakes refers significant difference between them (t-test, $p < 0.05$); min= minimum value, med = median value and max= maximum value.

Analysis showed significant differences in temperature, transparency, dissolved oxygen and electrical conductivity between Faé, Taabo and Kossou lakes (Mann-Withney test, $p < 0.05$). Concerning pH, statistical analysis did not show a significant difference between lakes (Kruskal-Wallis test, $p > 0.05$).

Composition and distribution of fishes in Faé, Taabo and Kossou lakes

A total of 51 fish species belonging to 34 genera, 19 families and 9 orders were recorded with 43 freshwater species, four estuarine/marines species (*Pellonula leonensis*, *Pelmatolapia mariae*, *Sarotherodon galilaeus* and *Sarotherodon melanotheron*), two introduced species (*Heterotis niloticus* and *Oreochromis niloticus*) and two hybrids (*Coptodon guineensis x Coptodon zillii* and *Oreochromis mossambicus x Oreochromis aureus*) (Table 2). Siluriformes (15 species belonging to five families), Perciformes (12 species belonging to three families), Osteoglossiformes and Characiformes (8 species belonging to three families for each two these orders) are orders containing highest number of families and species.

Cypriniformes present 4 species (one family) while Lepidosireniformes, Polypteriformes, Clupeiformes and Anabantiformes containing the weakest number of family and species (one species belonging to one family). Most species (31 species) belong to family Cichlidae (10 species), Mormyridae and Alestidae with six species each, Clariidae (5 species) and Cyprinidae (4 species). These families are followed by Claroteidae, Schilbeidae, Mochokidae with three species each. The other families are less diverse (with only one species). Taabo Lake, with 45 species, presents the most elevated specific richness. It is followed by Kossou Lake, which has 39 species.

Faé Lake (30 species) is least species-rich of three lakes. This fish distribution showed that 20 species were common to these three lakes. *Alestes baremoze*, *Hydrocynus forskalii*, *Labeo parvus*, *Labeobarbus waldroni*, *Malapterurus electricus* and *O. mossambicus x O. aureus* were met solely in Taabo Lake, while *Clarias buettikoferi* and *P. mariae* were present only in Faé lake (Table 2). Too signal that fish species *Protopterus annectens*, *Polypterus endlicheri*, *Papyrocranus afer*, *Marcusenius furcidens*, *Marcusenius senegalensis*, *Mormyrus rume*, *H. forskalii*, *L. parvus*, *Chrysichthys maurus*, *Clarias gariepinus*, *Heterobranchus isopterus*, *Heterobranchus longifilis*, *M. electricus*, *Synodontis bastiani*, *Synodontis punctifer*, *Synodontis schall*, *Parachanna obscura*, *Lates niloticus*, *O. mossambicus x O. aureus* and *P. mariae* sampled were found only in catches originating from commercial fishing.

Table 2. Fish species sampled in Faé, Taabo and Kossou Lakes [+= present; - = absent; 1 = estuarine/marine species; 2= introduced species; 3= hybrid; *= species sampled solely in captures descended of commercial fishing.]

Order	Family	Genus	Species	Codes	Faé Lake	Taabo Lake	Kossou Lake
Lepidosireniformes	Protopteridae	*Protopterus*	*P. annectens**	Pan	-	+	+
Polypteriformes	Polypteridae	*Polypterus*	*P. endlicheri**	Pen	-	+	+
Clupeiformes	Clupeidae	*Pellonula*	*P. leonensis*[1]	Ple	+	+	+
Osteoglossiformes	Arapaimidae	*Heterotis*	*H. niloticus*[2]	Hni	+	+	+
	Notopteridae	*Papyrocranus*	*P. afer**	Paf	+	-	+
	Mormyridae	*Marcusenius*	*M. furcidens**	Mfu	+	+	-
			*M. senegalensis**	Mse	+	-	+
			M. ussheri	Mus	+	+	+
		Mormyrus	*M. rume**	Mru	-	+	+
		Petrocephalus	*P. bovei*	Pbo	+	-	+
		Pollimyrus	*P. isidori*	Pis	-	+	+
Characiformes	Hepsetidae	*Hepsetus*	*H. odoe*	Hod	+	+	-
	Alestidae	*Alestes*	*A. baremoze*	Aba	-	+	-
		Brycinus	*B. imberi*	Bim	+	+	-
			B. longipinnis	Blo	+	+	+
			B. macrolepidotus	Bma	+	+	+
			B. nurse	Bnu	+	+	+
		Hydrocynus	*H. forskalii**	Hfo	-	+	-
	Distichodontidae	*Distichodus*	*D. rostratus*	Dro	-	+	+
Cypriniformes	Cyprinidae	*Enteromius*	*E. macrops*	Ema	+	+	+
		Labeo	*L. coubie*	Lco	-	+	+
			*L. parvus**	Lpa	-	+	-
		Labeobarbus	*L. waldroni*	Lwa	-	+	-
Siluriformes	Claroteidae	*Auchenoglanis*	*A. occidentalis*	Aoc	-	+	+
		Chrysichthys	*C. maurus**	Cma	+	+	+
			C. nigrodigitatus	Cni	+	+	+
	Schilbeidae	*Parailia*	*P. pellucida*	Ppe	-	+	+
		Schilbe	*S. intermedius*	Sin	+	+	+
			S. mandibularis	Sma	+	+	+
	Clariidae	*Clarias*	*C. anguillaris*	Can	+	+	+
			C. buettikoferi	Cbu	+	-	-
			*C. gariepinus**	Cga	-	+	+
		Heterobranchus	*H. isopterus**	His	+	-	+
			*H longifilis**	Hlo	+	+	+
	Malapteruridae	*Malapterurus*	*M. electricus**	Mel	-	+	-
	Mochokidae	*Synodontis*	*S. bastiani**	Sba	-	+	+
			*S. punctifer**	Spu	-	+	+
			*S. schall**	Ssc	-	+	+
Anabantiformes	Channidae	*Parachanna*	*P. obscura**	Pob	+	+	+
Perciformes	Centropomidae	*Lates*	*L. niloticus**	Lni	-	+	+
	Cichlidae	*Chromidocoptodon*	*C. guntheri*	Cgu	+	+	+
		Coptodon	*C. guineensis x C. zillii*[3]	Cgz	+	+	+
			C. zillii	Czi	+	+	+
		Hemichromis	*H. bimaculatus*	Hbi	-	+	+
			H. fasciatus	Hfa	+	+	+
		Oreochromis	*O. mossambicus x O. aureus*[3]*	Omo	-	+	-
			O. niloticus[2]	Oni	+	+	+
		Pelmatolapia	*P. mariae*[1]*	Pma	+	-	-
		Sarotherodon	*S. galilaeus*[1]	Sga	-	+	+
			S. melanotheron[1]	Sme	+	+	-
	Anabantidae	*Ctenopoma*	*C. petherici*	Cpe	+	+	+
9	19	34	51		30	45	39

Occurrence and relative abundance of experimental fishing species in Faé, Taabo and Kossou lakes

Among 16 fish species collected in Faé Lake, 62.5% (10 species) were constant while 47.05% (8 species) of 17 counted in Kossou Lake were constant. At Taabo lake 56% (14 species) among 25 fish species were accidental (Table 3). We found that family of Cyprinidae was most abundant in Taabo and Kossou lakes with 58.19% and 51.09% respectively, while Clupeidae (58.25%) dominated fish abundance in Faé Lake (Fig. 2a). At the species level, *Enteromius macrops* (58.04% and 51.09%) was most abundant in Taabo and Kossou lakes respectively (Fig. 2b). *P. leonensis* (58.25%) was more abundant in Faé Lake. *Marcusenius ussheri* (0.03%), *Hepsetus odoe* (0.03%) and *Brycinus nurse* (0.03%) in Taabo Lake; *Distichodus rostratus* (0.05%), *Auchenoglanis occidentalis* (0.05%), *Parailia pellucida* (0.05%) and *Schilbe intermedius* (0.05%) in Kossou lake; *H. niloticus* (0.06%) and *C. buettikoferi* (0.06%) in Faé lake showed the lowest abundances.

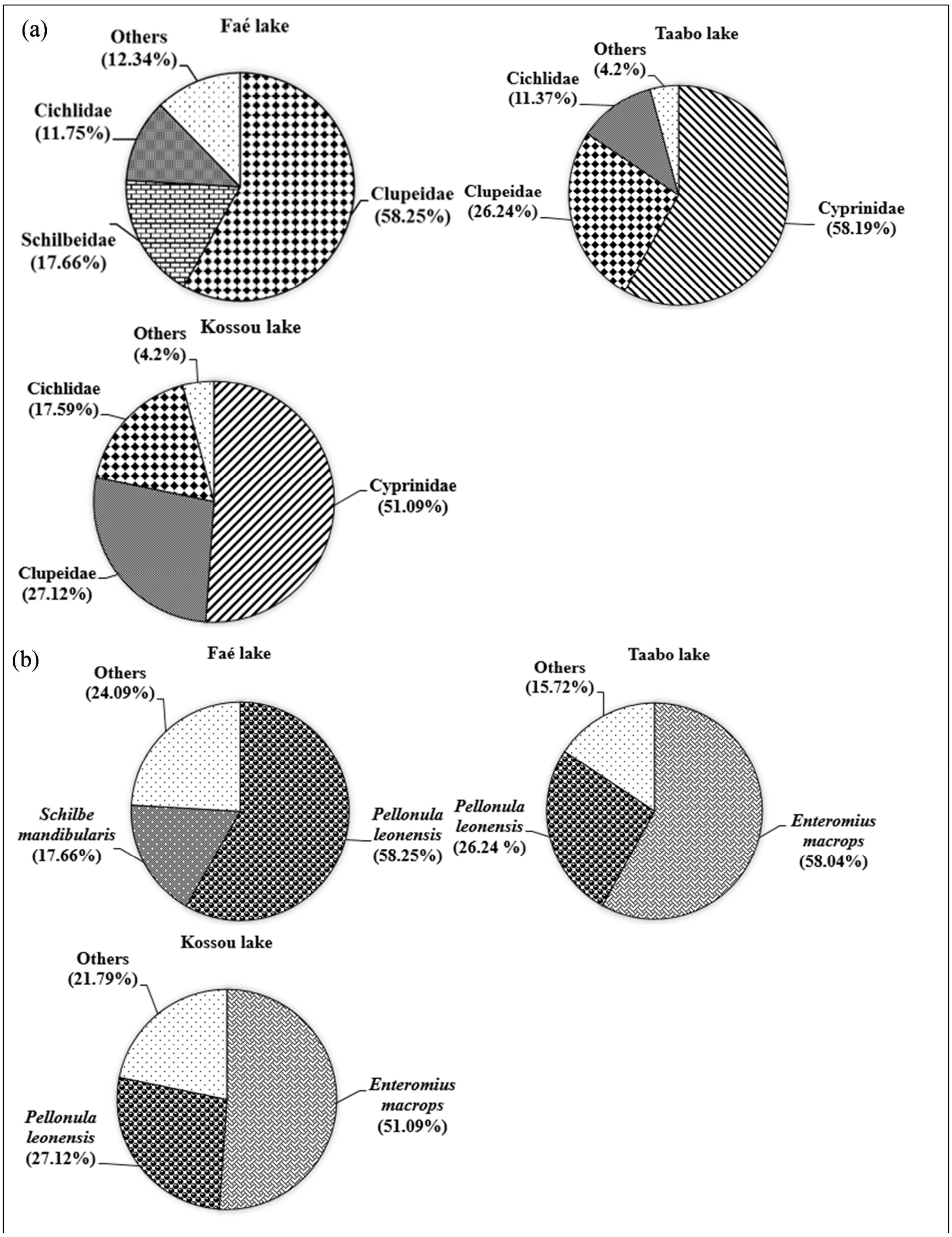

Fig. 2. Relative abundance of fish's families (a) and species (b) in Faé, Taabo and Kossou Lakes.

Table 3. Occurrence (Oc) and relative abundance (N) (percentages) of experimental fishing species in Faé, Taabo and Kossou lakes.

Family	Species	Faé lake		Taabo lake		Kossou lake	
		Oc%	N%	Oc%	N%	Oc%	N%
Clupeidae	*P. leonensis*	100	58.25	100	26.24	100	27.12
Osteoglossidae	*H. niloticus*	11.11	0.06	11.11	0.16	11.11	0.15
	M. ussheri	0	0	11.11	0.03	0	0
Mormyridae	*P. bovei*	55.56	0.90	0	0	0	0
	P. isidori	11.11	0.45	22.22	0.09	22.22	0.25
Hepsetidae	*H. odoe*	55.56	0.77	11.11	0.03	0	0
	A. baremoze	0	0	88.89	1.20	0	0
	B. imberi	11.11	0.26	55.56	0.32	0	0
Alestidae	*B. longipinnis*	66.67	0.77	22.22	0.06	0	0
	B. macrolepidotus	33.33	0.58	0	0	0	0
	B. nurse	0	0	11.11	0.03	0	0
Distichodontidae	*D. rostratus*	0	0	88.89	0.95	11.11	0.05
Cyprinidae	*E. macrops*	88.89	5.52	100	58.04	100	51.09
	L. coubie	0	0	22.22	0.16	0	0
Claroteidae	*A. occidentalis*	0	0	0	0	11.11	0.05
	C. nigrodigitatus	100	2.95	100	0.85	100	3.35
	P. pellucida	0	0	11.11	0.06	11.11	0.05
Schilbeidae	*S. intermedius*	0	0	22.22	0.09	11.11	0.05
	S. mandibularis	100	17.66	22.22	0.16	0	0
Clariidae	*C. anguillaris*	0	0	22.22	0.09	33.33	0.25
	C. buettikoferi	11.11	0.06	0	0	0	0
	C. guntheri	0	0	33.33	0.16	33.33	0.41
	C. guineensis x C. zillii	100	1.09	77.78	6.00	77.78	4.61
	C. zillii	11.11	4.69	88.89	3.35	77.78	0.76
Cichlidae	*H. bimaculatus*	0	0	100	0.06	100	5.22
	H. fasciatus	77.78	5.84	88.89	0.09	88.89	3.14
	O. niloticus	0	0	22.22	0.85	33.33	0.30
	S. galilaeus	0	0	22.22	0.85	66.67	3.14
	S. melanotheron	77.78	0.13	0	0	0	0
Anabantidae	*C. petherici*	0	0	11.11	0.06	0	0

Spatial diversity of experimental fishing species of Faé, Taabo and Kossou lakes

Although we did not find difference of Shannon-Weaver index (H') among lakes (Kruskal-Wallis test, p> 0.05), equitability index (E) and rarefied richness (Rr) varied between Faé and Taabo lakes. Lowest value was recorded at Taabo Lake. Kossou Lake did not differ significantly from those of Taabo and Faé (Fig. 3).

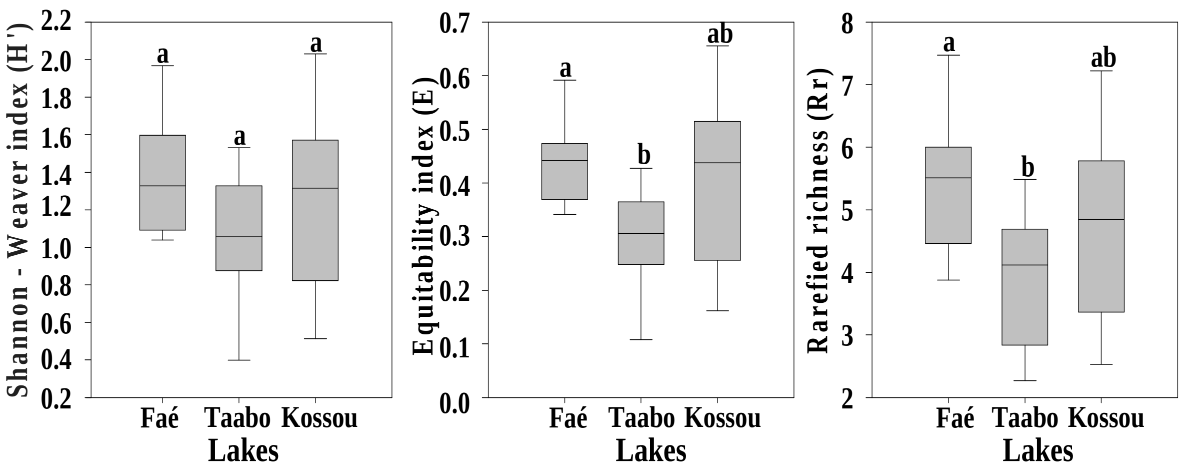

Fig. 3. Shannon - Weaver index (H'), equitability index (E) and rarefied richness (Rr) for experimental fishing species between Faé, Taabo and Kossou lakes. The boxplots having a joint letter are not different.

Compositional similarity

nMDS graphical representation (stress = 0.11) (Fig. 4) and ANOSIM analysis (Table 4) noted that compositions of fish communities were clearly separated and significantly different between Faé and Taabo lakes (global R ANOSIM = 0.6526, p -value = 0.0001), Faé and Kossou lakes (global R ANOSIM = 0.4925, p -value = 0.0002). According to SIMPER analysis (Table 5), species responsible for this segregation were characterized by dominance of *E. macrops*, *P. leonensis*, *Schilbe mandibularis*, *Hemichromis bimaculatus*, *Hemichromis fasciatus*, *C. guineensis x C. zillii* (hybrid) and *S. melanotheron* between Faé and Taabo lakes; *P. leonensis*, *E. macrops*, *S. mandibularis*, *H. bimaculatus*, *C. guineensis x C. zillii* (hybrid), *S. melanotheron*, *S. galilaeus*, *H. fasciatus* and *Chrysichthys nigrodigitatus* between Faé and Kossou lakes. Whereas, Taabo and Kossou lakes were not separated in nMDS biplot (stress = 0.11). ANOSIM result showed that there was no significant change in composition of fish community between Taabo and Kossou lakes (global R ANOSIM = 0.01715, P-value = 0.3283). Main species responsible for homogeneity and similitude between Taabo and Kossou lakes according to SIMPER analysis were characterized by dominance of *E. macrops*, *P. leonensis*, *H. bimaculatus*, *H. fasciatus*, *C. guineensis x C. zillii* (hybrid) and *S. galilaeus*.

Table 4. Statistic results of ANOSIM and their significance levels ($p < 0.05$) for pairwise comparisons of fish composition structure among Faé, Taabo and Kossou lakes (V = versus).

Localities	Comparison	R	p
Lakes	Global	0.4004	0.0001
	Faé lake V Taabo lake	0.6526	0.0001
	Faé lake V Kossou lake	0.4925	0.0002
	Taabo lake V Kossou lake	0.01715	0.3283

Table 5. Similarity Analysis Result (SIMPER) showing percentage of contribution [(Contrib.%) and cumulative percentage (Cum.%; 92% threshold) of main species to dissimilarity between different lakes: A. D. = Average dissimilarity (V = versus)]

Localities	Stations	A. D.	Species	Contrib.%	Cum.%
Lakes	Faé lake V Taabo lake	68.36	*E. macrops*	48.34	48.34
			P. leonensis	23.36	71.69
			S. mandibularis	7.665	79.36
			H. bimaculatus	6.193	85.55
			H. fasciatus	3.189	88.74
			C. guineensis x C. zillii (hybrid)	2.172	90.91
			S. melanotheron	2.009	92.92
	Faé lake V Kossou lake	70.25	*P. leonensis*	33.21	33.21
			E. macrops	32.63	65.85
			S. mandibularis	11.13	76.97
			H. bimaculatus	4.428	81.4
			C. guineensis x C. zillii (hybrid)	4.203	85.6
			S. melanotheron	2.722	88.33
			S. galilaeus	2.39	90.72
			H. fasciatus	2.161	92.88
			C. nigrodigitatus	1.586	94.46
	Taabo lake V Kossou lake	52.41	*E. macrops*	45.51	45.51
			P. leonensis	30.61	76.12
			H. bimaculatus	7.237	83.36
			H. fasciatus	4.117	87.47
			C. guineensis x C. zillii (hybrid)	2.835	90.31
			S. galilaeus	2.137	92.45

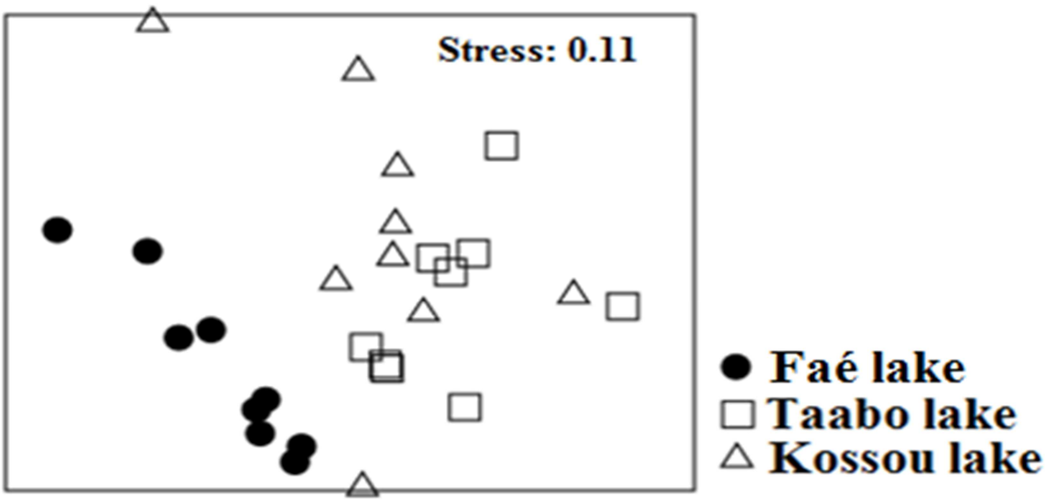

Fig. 4. Non-parametric multidimensional scaling (nMDS) ordinations of fish composition structure in Faé, Taabo and Kossou Lakes.

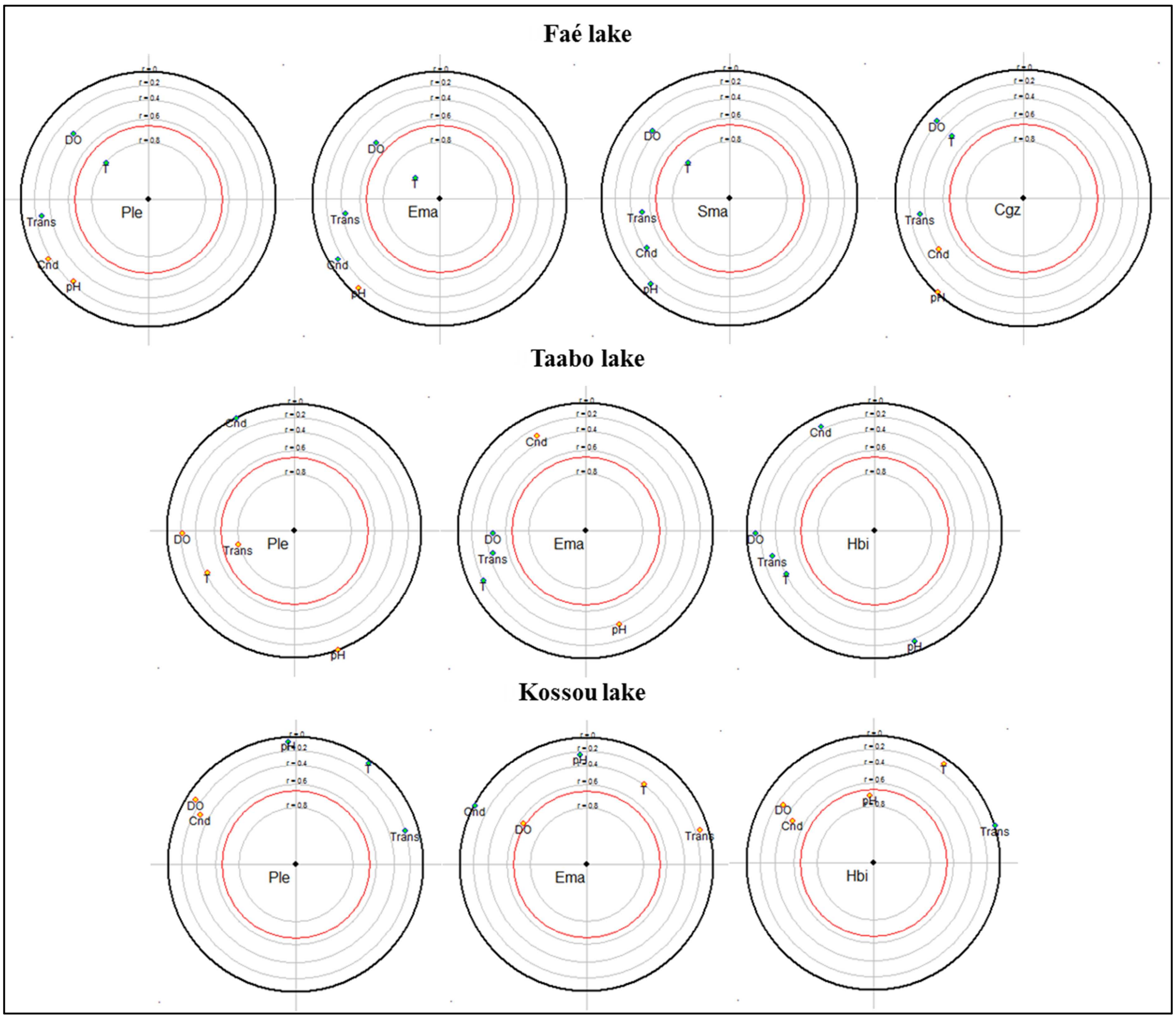

Fig. 5. Focused Principal Component Analysis (FPCA) showing relationships between environmental and biological variables in Faé, Taabo and Kossou lakes. Codes: Ple= *Pellonula leonensis*; Ema= *Enteromius macrops*; Sma= *Schilbe mandibularis*; Cgz= *Coptodon guineensis x Coptodon zillii*; Hbi= *Hemichromis bimaculatus*; T= Temperature; Trans= Transparency; Cnd= Electrical conductivity; DO= Dissolved oxygen.

Fish species relationships with environmental variables

We analyzed data using abundance of fish species as a variable. In Fig. 5 we report Focused Principal Component Analysis (FPCA) related to species' abundance and environmental variables. Correlation circle indicated that abundance of *P. leonensis*, *E. macrops*, *S. mandibularis* and *C. guineensis x C. zillii* to be positively correlated with dissolved oxygen, temperature, transparency and electrical conductivity (for *E. macrops* and *S. mandibularis*) in Faé lake. pH is correlated positively with *S. mandibularis* abundance. In Taabo Lake, correlation circle showed that there was a positive correlation between *H. bimaculatus* with all environmental variables. *E. macrops* is positively correlated with dissolved oxygen, temperature and transparency. Concerning *P. leonensis*, only electrical conductivity was positively correlated. Correlation circle, at Kossou Lake, indicated that abundance of *P. leonensis* was positively correlated with pH, temperature and transparency. Abundance of *E. macrops* was positively correlated with pH and electrical conductivity. Except for transparency that showed a positive correlation, there was a negative correlation between *H. bimaculatus* with the other environmental parameters.

Discussion

Composition and distribution of fishes in Faé, Taabo and Kossou lakes

Siluriformes, Perciformes, Osteoglossiformes and Characiformes were richest orders according to families and species while families who dominate population were Cichlidae, Mormyridae, Alestidae and Cyprinidae in lakes and other basins of Côte d'Ivoire and West Africa (Teugels *et al.*, 1988; Lévêque *et al.*, 1990, 1992; Lévêque and Paugy, 1999; Da Costa *et al.*, 2000; Konan *et al.*, 2006; Aboua *et al.*, 2010). Ten (10) fish species observed during this study were Cichlids. Cichlids were most dominant group in Faé, Taabo, Kossou lakes and other lacustrine environments in Côte d'Ivoire (Tah *et al.*, 2009; Aboua *et al.*, 2010; Tah *et al.*, 2012) as well as other lakes in East African great lakes (Lundberg *et al.*, 2000; Balirwa *et al.*, 2003; Darwall *et al.*, 2005; Witte *et al.*, 2007; Naigaga *et al.*, 2011).

Taabo Lake had highest number of species. This shows role of tributaries in enriching lake with fish. In fact, Taabo lake is fed by two main tributaries, white Bandama (N'zi) and red Bandama (Marahoue) whereas Faé and Kossou lakes each have only one main tributary, San pédro for Faé lake and white Bandama for Kossou lake. Overall, 20 common species were collected from all lakes. Two of these species (*O. niloticus* and *H. niloticus*) were introduced, while *P. leonensis*, *P. mariae*, *S. galilaeus* and *S. melanotheron* estuarines/marines species, *C. guineensis x C. zillii* and *O. mossambicus x O. aureus* hybrid species were present. These results support past research on fish populations in Taabo and Kossou lakes that made same observations (Aboua *et al.*, 2010). Presence in Faé lake of almost all species with estuarine or marines (*P. leonensis*, *P. mariae* and *S. melanotheron*), with exception *S. galilaeus*, encountered during this survey, is due to proximity of this lake to Atlantic Ocean. Indeed, Faé Lake belongs to ichthyological province of Upper Guinea, which includes all coastal basins (Lévêque *et al.*, 1989; Paugy *et al.*, 1989, 1994).

Relative abundance and spatio-temporal diversity of experimental fishing species in Faé, Taabo and Kossou lakes

Captures are dominated by *E. macrops* in abundance in Taabo and Kossou lakes whereas *P. leonensis* was more prolific in Faé Lake. *E. macrops* covers 58.04% of abundance in Taabo lake, 51.09% in Kossou lake while *P. leonensis* covers 58.25% of abundance in Faé lake. In addition, proportion of Mormyridae species, which are strictly freshwater fish (Lévêque *et al.*, 1991; Konan *et al.*, 2006), was low in these three lakes. Besides, Quality and degree of organisation of fish populations were analysed using Shannon - Weaver (H') diversity indices, equitability (E) and rarefied richness (Rr). Faé and Kossou lakes have highest values while Taabo lake has lowest values of these three indices (H': 0.39 to 1.53; E: 0.10 to 0.42; Rr: 2.26 to 5.48). These low values indicate that aquatic habitats are relatively unstable (Konan *et al.*, 2006). However, according to Zabi (1993) and Dajoz (2000), low indices values were characteristic of communities with weak diversity and low levels of organisation. After Thiennemann (1954), a balanced population is more stable, on contrary; any proliferation of a species reveals an imbalance due to a natural or anthropic cause. Low level of organization of fish communities in these three lakes could be related to high fishing pressure exerted by fishermen on these lakes (Yao *et al.*, 2015). More, Harmelin-Vivien (1992), Lévêque (1995) and Lemoalle (1999) point out that fish populations respond rapidly to disturbances in their environment, leading to changes in their specific composition, abundance and trophic structure.

Compositional similarity

Distinct distribution of fish communities was detected between Faé and Taabo lakes (global R ANOSIM= 0.6526, p-value= 0.0001), Faé and Kossou lakes (global R ANOSIM= 0.4925, p-value = 0.0002). Concerning Taabo and Kossou lakes, ANOSIM result showed that there was no significant change in composition of fish communities between these two lakes (global R ANOSIM= 0.01715, p-value = 0.3283). Species responsible for homogeneity and similarity between Taabo and Kossou lakes according to SIMPER analysis are characterised by dominance of *E. macrops*, *P. leonensis*, *H. bimaculatus*, *H. fasciatus*, *C. guineensis x C. zillii* (hybrid) and *S. galilaeus*. This similarity could be explained by the fact that Taabo and Kossou lakes belong to the Eburneoghanean ichthyological subprovince in West Africa, which is characterised by a few endemic species (Teugels *et al.*, 1988). Moreover, these two lakes are located on main course of Bandama River (Traoré, 1996 and Kouassi *et al.*, 2007).

Relationship between fish communities and environmental variables

Overall, environmental parameters measured to comply with surface water standards (except for dissolved oxygen in Faé Lake). Focused Principal Component Analysis (FPCA), reported in Fig. 5, shows that High transparency and temperature and low conductivity positively influence abundance of most fish species found in these three lakes. Other authors reported that abundance of fish species was influenced by water quality (Mrosso *et al.*, 2004; Carol *et al.*, 2006; Ye *et al.*, 2006; Mondal *et al.*, 2010; Naigaga *et al.*, 2011; Tape *et al.*, 2019; Vilizzi *et al.*, 2021).

Conclusion

In conclusion, distribution of fish species in lakes was influenced by ichthyological province in which lakes are located as well as rivers that feed them. Cichlids are most represented family in Faé, Taabo, Kossou lakes. Quality and degree of organization of fish populations in hydroelectric dams seems to be independent of lake size and age of these lake environments.

Acknowledgments

The authors acknowledge financial support received from Direction of Aquaculture and Fisheries (DAF), Côte d'Ivoire. This study would not have been able to achieve itself without support of agents of Ministry of the Animal and Fisheries Resources (MIAFR) and fishers of Faé, Taabo and Kossou lakes.

References

Aboua RDB, N'zi KG, Kouamélan EP, Berté S, Bamba M. 2010. Organisation spatiale du peuplement de poissons dans le Bandama. Int J Biol Chem Sci **4,** 1480-1493.

Balirwa JS, Chapman CA, Chapman LJ, Cowx IG, Geheb K, Kaufman L, Lowe-McConnell RH, Seehausen O, Wanink JH, Welcomme RL, Witte F. 2003. Biodiversity and fishery sustainability in the Lake Victoria basin: An unexpected marriage? Biosci **53,** 703-715.

Carol J, Benejam L, Alcaraj C, Vila-Gispert A, Zamora L, Navarro E, Armengol J, Garcia-Berthou E. 2006. The effects of limnological features on fish assemblages of 14 Spanish reservoirs. Ecol Freshwater Fish **15,** 66-77.

Carr GM, Neary JP. 2006. Water Quality for Ecosystem and Human Health. A Report by United Nations Environment Programme Global Environment Monitoring System (GEMS)/Water Programme. Ontario, Canada, 132.

Da Costa KS, Dietoa YM. 2007. Typologie de la pêche sur le lac Faé (Côte d'Ivoire) et implications pour une gestion rationnelle des ressources halieutiques. BFPP/Bull Fr Pêche Piscic **384,** 1-14.

Da Costa KS, Gourène G, Tito De Morais L, Thys Van Den Audenaerde DFE. 2000. Caractérisation des peuplements ichtyologiques de deux fleuves côtiers Ouest-Africains soumis à des aménagements hydroagricoles et hydroélectriques. Vie et Milieu **50,** 65-77.

Da Costa KS, Traore K, Yte W. 2002. Potential species for fishery enhancement in Lake Faé, Cote d'Ivoire. In: IG Cowx (ed) Management and Ecology of Lake and Reservoir Fisheries. Fishing News Books, Hull, United Kingdom 344-352.

Dajoz R. 2000. Précis d'écologie. 7ème Edition. Dunod, Paris, 615.

Darwall W, Smith K, Lowe T, Vié JC. 2005. The status and distribution of freshwater biodiversity in Eastern Africa. Occasional Paper of the IUCN Species Survival Commission No. 31. IUCN, Gland, Switzerland and Cambridge, UK, 36.

Diarra A, Soumaguel A. 1997. Influence du barrage Sélingué sur le régime hydrologique du fleuve Niger. Sustainability of Water Resources under Increasing uncertainly (Proceedings of the habitat symposium SI). IAHS **240,** 277-286.

Endebu M, Lema A, Genet T, Mitike A, Regassa B, Dejen E, Abegaz H. 2015. Fisheries Baseline Survey Describing Status of Fisheries in Lake Zeway, Ethiopia. J Fisheries Livest Prod, 3-129.

Fadika V, Goula BTA, Kouassi FW, Doumouya I, Koffi K, Kamagaté B, Savané I, Shrohourou B. 2008. Variabilité interannuelle et saisonnière de l'écoulement de quatre cours d'eau de l'Ouest côtier de la Côte d'Ivoire (Tabou, Dodo, Néro et San pédro) Dans un contexte de baisse de la pluviométrie en Afrique de l'Ouest. Eur J Sci Res **21,** 406-418.

Falissard B. 1999. Focused Principal Component Analysis: looking at a correlation matrix with a particular interest in a given variable. J Comput Graphical Stat **8,** 906-912.

Fossi MC, Baini M, Panti C, Galli M, Jiménez B, Muñoz-Arnanz J, Marsili L, Finoia MG, Ramírez-Macías D. 2017. Are whale sharks exposed to persistent organic pollutants and plastic pollution in the Gulf of California (Mexico)? First ecotoxicological investigation using skin biopsies. Comp Biochem Physiol Part C: Toxicol Pharmacol **199,** 48-58.

Gourène G, Teugels GG, Hugueny B, Thys Van den Audenaerde DFE. 1999. Evaluation de la diversité ichtyologique d'un bassin Ouest-Africain après la construction d'un barrage. Cybium **23,** 147-160.

Grall J, Coïc N. 2005. Synthèse des méthodes d'évaluation de la qualité du benthos en milieu côtier. Rebent, 48-90.

Gray JS, McIntyre AD, Stirn J. 1992. Manuel des méthodes de recherche sur l'environnement aquatique. Onzième partie. Evaluation biologique de la pollution marine, eu égard en particulier au benthos. FAO Document technique sur les pêches, 53-324.

Harmelin-Vivien M. 1992. Impacts des activités humaines sur les peuplements ichtyologiques des récifs coralliens de Polynésie française. Cybium **16,** 279-289.

Hemery GL, Henkel KS. 2015. Patterns of benthic mega-invertebrate habitat associations in the Pacific Northwest continental shelf waters. Biodivers Conserv **24,** 1691-1710.

Hugueny B, Camara S, Samoura B, Magassouba M. 1996. Applying an index of biotic integrity based on fish assemblage in West African river. Hydrobiologia **331,** 71-78.

Konan FK, Leprieur F, Ouattara A, Brosse S, Grenouillet G, Gourène G, Winterton P, Lek S. 2006. Spatio-temporal patterns of fish assemblages in coastal West African rivers: a self-organizing map approach. Aquat Living Resour **19,** 361-370.

Kouassi KL, Goné DL, Meledje NH, Wognin AV, Aka K. 2007. Hydrologie et évolution spatio-temporelle des charges solides en suspension dans le lac du barrage hydroélectrique de Taabo (Côte d'Ivoire). Eur J Sci Res **18,** 464-478.

Legendre P, Vaudor A. 1991. Le progiciel R. Analyse multidimensionnelle, analyse spatiale. Université de Montréal 144.

Lemoalle J. 1999. La diversité des milieux aquatiques. In: Lévêque C, Paugy D (ed) Les poissons des eaux continentales africaines. Diversité, écologie, utilisation par l'homme. Edition IRD, Paris 11-30.

Lévêque C, Paugy D, Teugels GG, Romand R. 1989. Inventaire taxonomique et distribution des poissons d'eau douce des bassins côtiers de Guinée et de Guinée-Bissau. Rev Hydrobiol trop **22,** 107-127.

Lévêque C, Paugy D, Teugels GG. 1990. Faune des Poissons d'Eaux Douces et Saumâtres de l'Afrique de l'Ouest (ed) Tome I. Faune tropicale, XXVIII, MRAC-Tervuren. ORSTOM, Paris, 1-384.

Lévêque C, Paugy D, Teugels GG. 1991. Annotated checklist of the freshwater fishes of the Nilo-Sudan river bassin in Africa. Rev Hydrobiol Trop **24,** 131-154.

Lévêque C, Paugy D, Teugels GG. 1992. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'ouest. (ed) Tome II. Faune tropicale, XXVIII, MRAC-Tervuren. ORSTOM, Paris 385-902.

Lévêque C, Paugy D. 1999. Impact des activités humaines. In: Les Poissons des Eaux Continentales Africaines: Diversité, Ecologie, Utilisation par l'Homme, Lévêque C, Paugy D (ed) IRD, Paris 365-383.

Lévêque C. 1995. L'habitat: être au bon endroit au bon moment ? Bull Fr Peche Piscic **337-339,** 9-20.

Lundberg JG, Kottelat M, Smith GR, Stiassny MLJ, Gill AC. 2000. So many fishes, so little time: an overview of recent ichthyological discovery in continental waters. Ann Mo Bot Gard **87,** 26-62.

Mondal DK, Kaviraj A, Saha S. 2010. Water quality parameters and fish biodiversity indices as measures of ecological degradation: a case study in two floodplain lakes of India. J Water Resour Protect **2,** 85-92.

Mrosso HDJ, Msuku BS, Seehausen O. 2004. Relationship between water transparency and species richness of surviving haplochromines in selectedhabitats in Mwanza gulf – Lake Victoria, Tanzania. J Sci **30,** 101-108.

Naigaga I, Kaiser H, Muller WJ, Ojok L, Mbabazi D, Magezi G, Muhumuza E. 2011. Fish as bioindicators in aquatic environmental pollution assessment: A case study in Lake Victoria wetlands, Uganda. Phys Chem Earth **36,** 918-928.

Oksanen Y, Blanchet F, Kindt G, Legendre P, Minchin PR, O'Hara RB, Gavin LS, Solymos P, Stevens MHH, Wagner H. 2013. "Vegan: Community Ecology Package", Librairie R on line. Url: http://CRAN.R-project.org/package=vegan.

Paugy D, Lévêque C, Teugels GG, Romand R. 1989. Freshwater fishes of Sierra Leone and Liberia: annotated checklist and distribution. Rev Hydrobiol Trop **23,** 329-350.

Paugy D, Lévêque C, Teugels GG. 2003. Poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest, édition complète. Tome I & II. (ed) IRD-MNHN-MRAC, Paris-Turvuren 815.

Paugy D, Traoré K, Diouf PS. 1994. « Faune ichtyologique des eaux douces d'Afrique de l'Ouest ». In: Teugels GG, Guégan JF, Albaret JJ (ed) Diversité biologique des poissons des eaux douces et saumâtres d'Afrique. Synthèses géographiques. Ann Mus r Afr centr Zool, Tervuren **275,** 35-66.

R Core Team. 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, Available online at: http:// www.R-project.org/

Rodier J, Legube B, Merlet N, Brunet R. 2009. Microbiological analysis of waters, In: The analysis of water (9th ed)., Enforcement of obstruction. Paris, France 717-869.

Tah L, Da Costa KS, Kouassi JN, Moreau J. 2009. Effort de pêche et production piscicole au lac d'Ayame I (bassin de la Bia; Côte d'Ivoire) après le départ des pêcheurs «bozos». Agron Afr **21,** 103-115.

Tah L, Goore Bi G, Da Costa KS. 2012. Length-weight relationships for 36 freshwater fish species from two tropical reservoirs: Ayamé I and Buyo, Côte d'Ivoire. Rev Biol Trop **60,** 1847-1856.

Tape LD, Nangoh KM, Edia OE, Niamien-Ebrottié JE, Ouattara A. 2019. Physicochemical characterization and organic pollution status of tropical urban man-made lakes (Yamoussoukro, Côte d'Ivoire). Int J Res Agr Vet Sci **1(1),** 15-24.

Teugels GG, Lévêque C, Paugy D, Traoré K. 1988. Etat des connaissances sur la faune ichtyologique des bassins côtiers de Côte d'Ivoire et de l'ouest du Ghana. Rev Hydrobiol Trop **21,** 221-237.

Thiennemann A. 1954. Ein drittes Biozonotishes Grundprincizip. Archiv Für Hydrobiol **49,** 421-422.

Traoré K. 1996. État des connaissances sur les pêcheries continentales ivoiriennes. Projet F.A.O. TCP/IVC/4553, Rapport de consultation, 135.

Vilizzi L, Tarkan AS, Yoğurtçuoğlu B. 2021. A standardised analytical framework for sampling fish communities: relevance toTurkish riverine ecosystems. Turk J Zool **45(3)**, 241-256.

Witte F, Wanink HJ, Kishe-Machumu M. 2007. Species distinction and biodiversity crisis in Lake Victoria. Trans Am Fisheries Soc **136,** 1146-1159.

Yao AA, Da Costa KS, Dietoa YM. 2015. Small pelagic fish Pellonula Leonensis Boulenger, 1916 (Pisces; Clupeidae) fishery in Taabo Lake: Typology, yield and socioeconomic characteristics. Int J Fisheries Aquat Stud **3,** 392-399.

Ye S, Li Z, Lek-Ang S, Feng G, Lel S, Cao W. 2006. Community structure of small fishes in a shallow macrophytic lake (Niushan Lake) along the middle reach of the Yangtze River, China. Aquat Living Resour **19,** 349-359.

Zabi SG. 1993. Organisation des peuplements de la macrofaune benthique de la lagune Ebrié (Côte d'Ivoire). Agron Afr **5,** 39-52.