Fish community assemblages in relation to environmental variables in the Lefini River, middle Congo River basin (Republic of Congo)

by

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Abstract. – This study, one of the few ecological investigations of fishes recently performed in Africa, was undertaken in the Lefini River basin, a large right bank affluent of the Congo River in the Republic of Congo. The study area comprised 12 ecological stations, spread along 103 km of the river. Each station was sampled eight times over a two-year period, with fishing following standardized methods utilizing five monofilament gill nets of 10, 12, 15, 20 and 30 mm mesh size. Eighteen environment variables were also measured at each station. A total of 8,698 specimens, including 84 species belonging to 51 genera, 21 families, was reported. Redundancy Analysis with forward selection coupled with Monte Carlo permutation tests identified three variables (temperature, canopy closure, and canopy height) as accounting for 36.9% of the total variance ($p < 0.05$). The contribution of the two first axes was significant ($F = 1{,}56$; $p = 0.02$). Fish populations are distributed according to five habitat types: pool with fringing grasses; river bank with grass; forest with high canopy coverage 60.0-67.0%; forest with mean canopy coverage 33.0-48.0%; and forest with low canopy coverage 24.0%. The index of species richness "S" showed the grassy habitat to be the least diversified but overall, the high value of H' (2.64-3.24) and R (0.73-0.83) indices in all stations, indicates that the examined stretch of the Lefini basin is in good ecological health.

Key words
Fish
Ecology
Lefini River
Middle Congo
Africa

Résumé. – Distribution des communautés des poissons en relation avec les variables de l'environnement dans la rivière Léfini, bassin du Moyen Congo (République du Congo).

La présente étude, l'une des rares investigations sur l'écologie des poissons entreprises en Afrique, a été réalisée dans le bassin de la rivière Léfini, un grand affluent de la rive droite du fleuve Congo en République du Congo. L'étude a été menée dans 12 stations écologiques, réparties sur 103 km le long de la rivière. Chaque station a été échantillonnée huit fois en deux ans, suivant une méthode de pêches standardisées à l'aide des filets maillants monofilaments de 10, 12, 15, 20 et 30 mm de côté de maille. Dix-huit variables de l'environnement ont été mesurées au niveau de chaque station prospectée. Un total de 8698 spécimens, appartenant à 84 espèces, 51 genres et 21 familles, ont été reportés. L'Analyse Canonique de Redondance avec sélection préalable, couplée au test de permutation de Monte Carlo (999 itérations) a identifié 3 variables (température, couverture de la canopée et hauteur de la canopée) exprimant à elles seules 36,9% de la variance totale ($p < 0{,}05$). La contribution des deux premiers axes a été significative ($F = 1{,}56$; $p = 0{,}02$). Les populations de poissons sont distribuées suivant cinq types d'habitats : vasque bordée d'herbes ; rive bordée d'herbes ; forestier à grande couverture de la canopée 60,0-67,0% ; forestier à moyenne couverture de la canopée 33,0-48,0% et forestier à faible couverture de la canopée 24,0%. Les indices de la richesse spécifique "S" ont montré la faible diversification des stations herbeuses. Cependant, les valeurs élevées des indices de Shannon H' (2,64-3,24) et d'équitabilité R (0,73-0,83), dans l'ensemble des stations, indiquent que le tronçon examiné dans le bassin de la rivière Léfini est en bonne santé écologique.

Understanding fish-habitat relationships is essential for the sustainable management and conservation of riverine fishes (Wildhaber *et al.*, 2000; Fischer and Paukert, 2008; Paugy and Lévêque, 2017). Aquatic ecosystems throughout the African continent are increasingly being impacted by human activities, such as industrial deforestation, dam-construction for irrigation and hydropower, overfishing, and pollution (Kamdem Toham and Teugels, 1999; Aboua *et al.*, 2015; Paugy and Lévêque, 2017). The consequences of such activities potentially endanger the biological integrity of these ecosystems and the diversity of their ichthyofaunas.

The main goal of fish community ecology is to understand the mechanisms and the processes responsible for differences and similarities between the fish assemblages (Angermeier and Karr, 1983). One of the most important functions of such ecological studies is to gain an understanding of the spatial and temporal patterns in both the structure of communities and the size and distribution of popula-

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tions (Ornellas and Coutinho, 1998). Thus, the monitoring of populations is an essential step for informing management of aquatic ecosystems (Baumgartner *et al*., 2010). The study of fish populations based on estimates of abundance has been the subject of many ecological studies (*e.g*. Paugy and Bénech, 1989; Laë, 1994; Blanchard, 2001; Lobry *et al*., 2003; Munyandorero, 2006; Tejerina-Garro *et al*., 2006). However, investigations of the drivers of fish community assemblages are rarely performed in Africa (Kouamélan *et al*., 2003; Kouadio *et al*., 2006). The few available studies have mostly been undertaken in West Africa (Mérona, 1981; Hugueny, 1989, 1990; Pouilly, 1993; Kouamélan *et al*., 2003; Yao *et al*., 2005; Kouadio *et al*., 2006, Aboua *et al*., 2015), South Africa (Hay *et al*., 1996) and Central Africa in the Lower Guinean ichthyofaunal province (Kamdem Toham and Teugels, 1997, 1998; Mbega, 2004; Ibanez *et al*., 2007) and recently in the Congo Basin (Ibala Zamba, 2010; Wamuini LunkayiLakio *et al*., 2010).

In order to contribute to the knowledge of community structure and diversity of the Congo Basin ichthyofauna, the present study was undertaken in the Lefini River basin. In this study, the spatial distribution of the Lefini fish community was investigated, the main environmental variables associated with species assemblages was determined and the ecological health of the river highlighted.

MATERIAL AND METHODS

Study area

Fish samples were collected in the Lefini River, a large right bank affluent of the Congo River, entirely located within the Republic of Congo. The Lefini River Basin is situated approximately at 200 km to the north of Brazzaville, on the Bateke plateau, in the heart of the Republic of Congo. With a main-channel total length of around 290 km, the Lefini River basin covers an area of 13000 km^2 and drains both the Lefini Faunal Reserve and the Lesio-Louna Gorilla Natural Reserve.

Fish sampling

A total of 12 ecological stations were sampled, six of which were of a grass bank type (stations 1, 4, 5, 6, 10 and 11) and the other six of a forest bank type (stations 2, 3, 7, 8, 9 and 12) (Appendix I). These extended along a stretch of 103 km of the Lefini River and were distributed over three zones, situated respectively upstream, within, and downstream of the Lesio-Louna Gorilla Natural Reserve (Fig. 1). Each station was sampled eight times over a two-year period from March 2007 to August 2008 (see details in appendix I), in a standardized way using five monofilament gill nets, each 30 m long and 1.5 m deep, with 10, 12, 15, 20 and 30 mm mesh size. At each sampling station, gill nets were

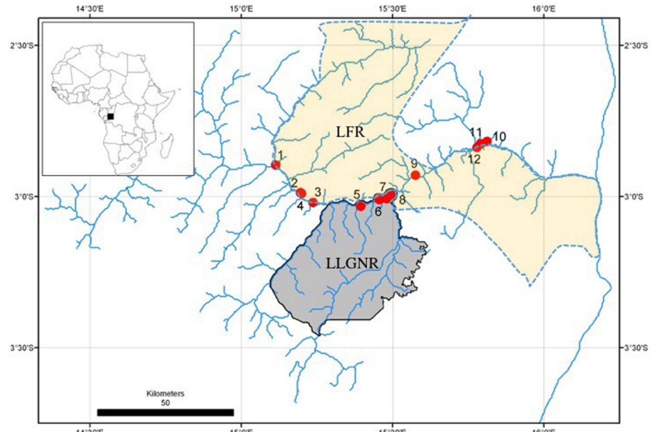

Figure 1. – Sampling stations (1-12). Grass bank stations: 1, 4, 5, 6, 10 and 11; Forest bank stations: 2, 3, 7, 8, 9 and 12; LFR: Lefini Faunal Reserve; LLGNR: the Lesio-Louna Gorilla Natural Reserve.

Figure 2. – Set of gill nets. **A**: Station 1 (Ah1); **B**: Station 10 (Avh1).

set (Fig. 2A, B) overnight from 17 h to 7 h (see Ibala Zamba, 2010). All samples were identified in the field, the specimens counted by species, measured to the nearest millimetre standard length, and weighed (fresh total weight) to the nearest 0.01 g. Fishes for which field identification was not certain were preserved in 10% formalin for subsequent identification in the laboratory of the Royal Museum for Central Africa (RMCA-Tervuren). The taxonomic order of the families follows that adopted by Eschmeyer *et al*. (2018), while the genera and species follow an alphabetical order.

Measurement of environmental variables

A total of 18 environmental variables (Tab. I) were measured at each sampling station. Sampling protocol followed Ibala Zamba (2010). Data for all 18 parameters were collected at the middle of each of the five nets, after they were set. Therefore, for each station, values given are mean values for 5 gill-nets, 2 days, 2 seasons and 2 years (total n = 40).

The variables included are: current speed (measured using the time taken by a float dropped between two fixed locations spaced 5m apart, and then converted into $m.s^{-1}$); depth (in m, measured with an echo-sounder ECHOTEST II PLASTIMO); pH, water temperature and conductivity (all measured with a WTW pH 330i/SET meter); oxygen (measured in mg/l with an oxymeter WTW Oxi 315i/SET); water transparency (in m, measured with a Secchi disk); distance from river bank (measured in m with a decameter); canopy closure (visually estimated, expressed in %); canopy height (visually estimated, expressed in m); altitude (measured in m with a GPS GARMIN geko 201); distance from the source (in km, calculated from a scaled map of the Lefini river). The following substrate categories were identified and scored as %: sand, mud (without wood and aquatic plants), dead leaves, aquatic plants, dead wood, mixture of dead wood, dead leaves and mud.

Data analyses

In the present study, a nonsignificant difference ($p > 0.05$) in water depth between dry (0.5-1.8 m; mean = 0.9) and rainy (0.6-2.1 m; mean = 1.1) seasons was reported for all sampling stations. Consequently, season effects were not considered in data analyses. Redundancy Analysis (RDA) (Ter Braak and Šmilauer, 2003) was used to investigate possible correlations between environmental variables and fish community assemblages. Therefore, two matrices covering the 12 sampling stations were constructed: (1) numerical abundance of all species collected and (2) environmental variables. Monte Carlo tests (999 permutations, $p < 0.05$) were used to select environmental variables explaining variation in fish species data. Prior to ordination, fish abundance and environmental data were transformed to better meet the assumptions of normality (Fischer and Paukert, 2008) using respectively $\log_{10}(x + 1)$ and $\ln(x + 1)$ or $\mathrm{ArcSin}\sqrt{x}$ for percentages. In addition, the ecological health of the Lefini River basin was evaluated, calculating three ecological diversity indices (Lande, 1996; Lobry *et al*., 2003): Species richness S; Shannon index H' with its Shannon maximum index H'max (Shannon, 1948); and Equitability R (Pielou,

Table I. – Physico-chemical characteristics measured. Values in habitat: Minimum-Maximum or mean (Minimum-Maximum). *: Mean values for 5 gill-nets, 2 days, 2 seasons and 2 years (total n = 40)

Environmental variables	Code	Grass bank	Forest bank	t-test	
		n = 6	n = 6	t-value	p
Distance of source (km)	Diss	135.7-238.3	154.3-235.4	–0.116	0.909
Altitude (m)	Alt	303.0-336.0	308.0-328.0	0.216	0.833
Canopy height (m)	Hauc	0	14.0 (10.2-20)	–29.714	**< 0.001**
Depth (m)*	Pro	1.0 (0.6-1.8)	1.1 (0.7-1.7)	–0.661	0.654
Oxygen (mg/l)*	Oxy	3.7 (2.2-6.2)	4.0 (2.4-5.1)	–0.408	0.691
Conductivity (µS/cm)*	Cond	6.8 (6.1-7.3)	7.3 (6.2-9.9)	–0.756	0.466
Transparency (m)*	Tra	1.0 (0.6-1.8)	1.0 (0.7-1.3)	–0.726	0.483
Distance from river bank (m)*	Disb	5.1 (1.1-15)	6.1 (3.2-14)	–0.879	0.399
pH*	pH	5.8 (5.5-6.1)	5.2 (5.1-5.4)	3.817	**0.003**
Temperature (°C)*	T°	26.9 (25.5-29.8)	25.6 (25.1-26.5)	1.829	0.097
Velocity (m/s)*	Vit	0.2 (0.0-0.3)	(0.1 (0-0.4)	0.356	0.729
Substrate types and canopy closure (in %)					
Canopy closure	Couc	0	46.7 (24.0-67.0)	–11.549	**< 0.001**
Sand	Sab	47.3 (38.0-76.0)	31.0 (10.0-50.0)	1.894	0.087
Mud	Boue	29.2 (13.0-41.0)	21.8 (12.0-29.0)	1.349	0.206
Dead leaves	Feum	0	17.0 (11.0-30.0)	–11.458	**< 0.001**
Aquatic plants	Plaa	20.7 (2.0-41.0)	9.5 (4.0-15.0)	1.737	0.113
Dead wood	Boim	0	12.0 (5-23)	–7.903	**< 0.001**
Mixture of dead wood, dead leaves and mud	Bbf	2.8 (2.0-4.0)	8.7 (6.0-13.0)	–6.227	**0.001**

1966). The Student t-test was used to evaluate statistical differences ($p \leq 0.05$) between environmental variables in forest and grass bank stations.

The analysis was performed using CANOCO (Canonical Community Ordination, version 4.5) (ter Braak and Šmilauer, 2003), for multivariate analysis (RDA); PRIMER version 5 (Clarke and Gorley, 2001), for univariate analysis (S, H' and R); and STATISTICA version 8, for Student t-test.

RESULTS

Species composition

The composition of the fish diversity is shown in table II. A total of 8,698 specimens, including 84 species belonging to 51 genera and 20 families, were collected. Among the fish families sampled, Mormyridae (n = 17 species), Alestidae (n = 13), Distichodontidae (n = 12), Cichlidae (n = 7) and Anabantidae (n = 6) are the five most represented. The remaining families are poorly represented ($1 \leq n \leq 3$).

Eleven species were recorded only in forest bank type stations (*Marcusenius monteiri*, *Mormyrops furcidens*, *M. sirenoides*, *Micralestes acutidens, Distichodus lusosso*, *Nannocharax taenia*, *Citharinus macrolepis*, *Malapterurus microstoma*, *Channallabes apus*, *Ctenopoma weeksii* and *Microctenopoma nanum*) and three species only in grass bank type stations (*Mormyrops zanclirostris*, *Pelmatochromis nigrofasciatus* and *Tetraodon miurus*) (see Appendix II).

Stations and environmental variables

Results of the t-tests between environmental variables in forest and grass bank type stations are reported in table I. Variables related to the canopy (canopy closure, canopy height) and substrate (percentages of dead leaves, dead wood, and the mixture of dead wood, dead leaves and mud) are significantly different ($p < 0.001$) between the two habitat categories, as is pH ($p = 0.003$).

Fish communities, stations and environmental variables

Results of the Redundancy Analysis (Fig. 3) indicate that the first two axes (20.6% and 9.3%, respectively) express 29.9% of the cumulative variance in the fish data. Species and environmental variable correlations for both axes are high, 0.94 and 0.88, respectively. Monte Carlo permutation tests (999 iterations) showed also that the contributions of the two first axes are significant ($F = 1.56$; $p = 0.02$). Redundancy Analysis with forward selection identified three environmental variables as accounting for 36.9% of the total variance among 18 variables ($p < 0.05$): temperature (16.5%), canopy closure (9.8%) and canopy height (9.5%). The remainder (1.1 %) represented the variation shared between the three variables selected. Our results indicate that these

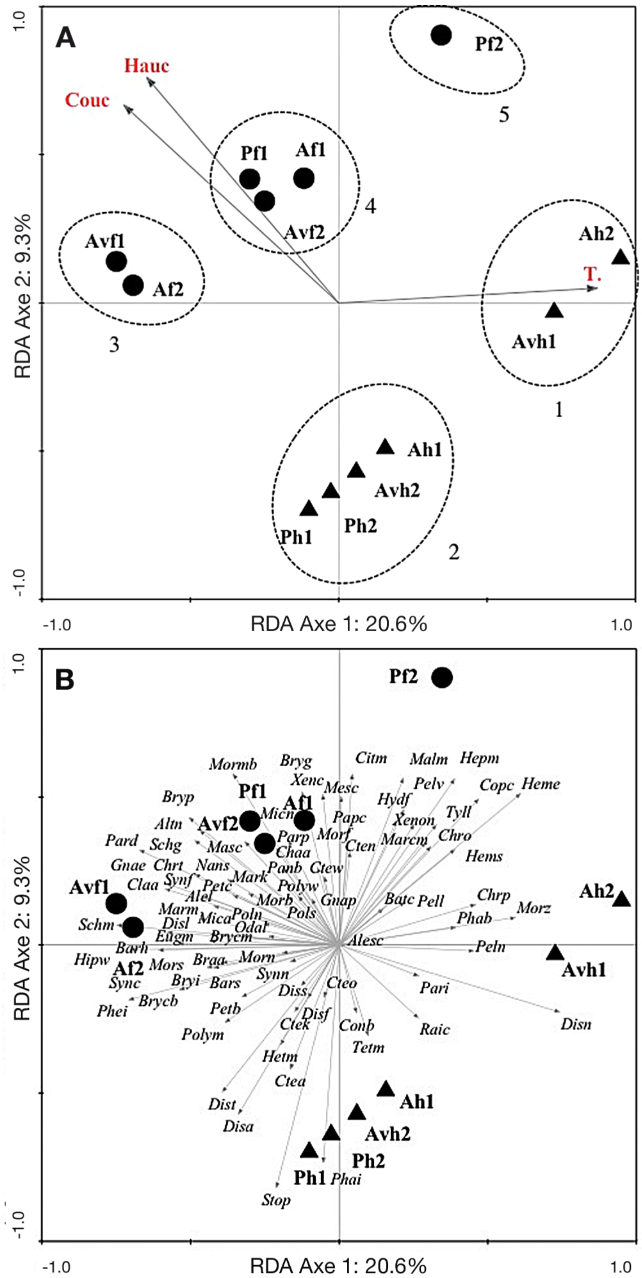

Figure 3. – RDA ordination of species, stations and the three forward selected environmental variables. **A**: Biplot of stations and environment variables (1-5: habitats 1-5); **B**: Biplot of stations and species. ▲: grass bank stations; ●: forest bank stations.

three environmental variables have a significant ($p < 0.05$) influence on fish community assemblages.

Five habitat types are distinguished in relation to both RDA axes 1 and 2 (Fig. 3A): habitat (1) pool with fringing grasses (Ah2 and Avh1), habitat (2) banks with grass (Ah1, Avh2, Ph2 and Ph1), habitat (3) forest with high canopy coverage 60.0-67.0% (Af2 and Avf1), habitat (4) forest with average canopy coverage 33.0-48.0% (Pf1, Avf2 and Af1)

Table II. – List of species collected, their code and relative abundance: Values in habitat: mean (Minimum-Maximum).

Family/species	Code	Habitat 1	Habitat 2	Habitat 3	Habitat 4	Habitat 5
Polypteridae						
Polypterus mokelembembe Schliewen & Schäfer, 2006	Polym	0.0	0.5 (0.0-1.5)	0.5 (0.0-1.0)	0.1 (0.1-0.2)	0.0
Polypterus weeksii Boulenger, 1898	Polyw	0.0	0.0 (0.0-0.2)	0.0	0.1 (0.0-0.1)	0.0
Pantodontidae						
Pantodon buchholzi Peters, 1877	Panb	0.2 (0.0-0.5)	0.2 (0.1-0.3)	0.1 (0.0-0.2)	0.8 (0.5-1.1)	0.0
Notopteridae						
Papyrocranus congoensis (Nichols & La Monte, 1932)	Papc	0.4 (0-0.7)	0.0	0.0	0.3 (0.1-0.4)	0.0
Xenomystus nigri (Günther, 1868)	Xenon	11.6 (7.9-15.2)	4.9 (3.0-5.8)	3.6 (2.9-4.2)	7.4 (4.0-10.4)	7.1
Mormyridae						
Gnathonemus echidnorhynchus Pellegrin, 1924	Gnae	0.0	0.0 (0.0-0.1)	0.5 (0.4-0.6)	0.3 (0.0-0.8)	0.0
Gnathonemus petersii (Güther, 1862)	Gnap	0.1 (0.0-0.2)	0.4 (0.0-0.8)	0.1 (0.0-0.2)	0.5 (0.1-1.0)	0.7
Hippopotamyrus weeksii (Boulenger, 1902)	Hipw	0.0	0.4 (0.0-1.1)	1.3 (1.0-1.5)	0.1 (0.0-0.3)	0.5
Marcusenius kutuensis (Boulenger, 1899)	Mark	0.0	0.0 (0.0-0.1)	0.1 (0.0-0.2)	0.2 (0.0-0.5)	0.0
Marcusenius monteiri (Günther, 1873)	Marm	0.0	0.0	0.1 (0.0-0.2)	0.0	0.0
Marcusenius moorii (Günther, 1867)	Marcm	7.3 (7.0-7.7)	3.4 (1.4-4.5)	1.7 (1.6-1.9)	5.9 (3.6-8.2)	3.7
Mormyrops boulengeri Pellegrin, 1900	Morb	0.0	0.0 (0.0-0.1)	0.0	0.1 (0.0-0.2)	0.0
Mormyrops furcidens Pellegrin, 1900	Morf	0.0	0.0	0.0	0.0 (0.0-0.1)	0.0
Mormyrops nigricans Bonlenger, 1899	Morn	0.0	0.2 (0.0-0.6)	0.0	0.2 (0.0-0.4)	0.0
Mormyrops sirenoides Boulenger, 1898	Mors	0.0	0.0	0.1 (0.0-0.2)	0.0	0.0
Mormyrops zanclirostris (Günther, 1867)	Morz	0.1 (0.0-0.2)	0.0	0.0	0.0	0.0
Mormyrus caballus Boulenger, 1898	Mormb	0.0	0.1 (0.0-0.3)	0.3 (0.2-0.3)	0.2 (0.0-0.4)	0.8
Petrocephalus balayi Sauvage, 1883	Petb	2.5 (0.2-4.8)	2.1 (0.9-3.0)	3.9 (2.2-5.6)	0.9 (0.7-1.3)	0.7
Petrocephalus christyi Boulenger, 1920	Petc	0.9 (0.7-1.1)	3.1 (1.7-4.6)	2.1 (1.3-2.9)	2.9 (1.6-4.6)	4.7
Pollimyrus nigripinnis (Boulenger, 1899)	Poln	0.1 (0.0-0.2)	0.3 (0.0-0.8)	0.2 (0.0-0.4)	0.2 (0.0-0.4)	0.2
Pollimyrus schreyeni Poll, 1972	Pols	0.1 (0.0-0.2)	0.3 (0.5-0.7)	0.2 (0.0-0.4)	0.2 (0.0-0.5)	0.7
Stomatorhinus patrizii Vinciguerra, 1928	Stop	0.0	0.2 (0.1-0.2)	0.1 (0.0-0.2)	0.0	0.0
Clupeidae						
Odaxothrissa losera Bonlenger, 1899	Odal	0.1 (0.0-0.2)	0.1 (0.1-0.2)	0.1 (0.0-0.2)	0.1 (0.0-0.2)	0.0
Pellonula leonensis Bonlenger, 1916	Pell	0.1 (0.0-0.2)	0.0	0.0	0.1 (0.0-0.1)	0.0
Pellonula vorax Günther, 1868	Pelv	0.1 (0.0-0.2)	0.0	0.0	0.1 (0.0-0.2)	0.2
Cyprinidae						
Enteromius cf. *holotaenia* (Boulenger, 1904)	Barh	0.0	1.1 (0.0-2.3)	3.3 (1.5-5.1)	0.7 (0.4-1.5)	0.2
Enteromius validus (Stiassny Liyandja & Monsembula Iyaba, 2016)	Bars	0.0	0.1 (0.0-0.4)	0.2 (0.0-0.3)	0.1 (0.0-0.4)	0.0
Raiamas christyi (Boulenger, 1920)	Raic	0.1 (0.0-0.2)	0.6 (0.0-1.8)	0.0	0.1 (0.0-0.2)	0.3
Hepsetidae						
Hepsetus microlepis (Boulenger, 1901)	Hepm	2.6 (1.2-4.1)	0.9 (0.3-1.5)	0.7 (0.3-0.8)	1.5 (0.6-1.7)	3.1
Alestidae						
Alestes liebrechtsii Boulenger, 1898	Alel	1.8 (0.7-2.9)	2.5 (0.1-4.8)	2.3 (2.1-2.5)	4.0 (0.6-7.3)	1.1
Alestopetersius caudalis (Boulenger, 1899)	Alesc	0.9 (0.7-1.1)	1.5 (0.2-2.8)	0.3 (0.2-0.4)	2.7 (0.4-4.7)	0.2

Table II. – Continued.

Family/species	Code	Habitat 1	Habitat 2	Habitat 3	Habitat 4	Habitat 5
Alestopetersius nigropterus Poll, 1967	Altn	1.5 (1.3-1.9)	1.5 (0.2-3.8)	5.5 (3.3-7.6)	5.1 (1.9-8.6)	0.8
Bathyaethiops caudomaculatus (Pellegrin, 1925)	Batc	0.0	0.0 (0.0-0.1)	0.0	0.0	0.2
Brachypetersius altus (Boulenger, 1899)	Braa	4.4 (3.2-5.5)	9.9 (2.8-18.9)	8.4 (5.4-11.3)	7.8 (1.7-17.4)	6.0
Brycinus grandisquamis (Boulenger, 1899)	Bryg	1.4 (0.2-2.5)	0.8 (0.5-1.5)	1.0 (0.6-1.3)	1.6 (0.5-3.5)	2.3
Brycinus imberi (Peters, 1852)	Bryi	0.0	0.1 (0.0-0.3)	0.7 (0.0-1.3)	0.0	0.0
Brycinus poptae (Pellegrin, 1906)	Bryp	0.0	0.1 (0.0-0.1)	1.8 (0.0-3.6)	0.7 (0.6-0.8)	0.2
Bryconaethiops boulengeri Pellegrin, 1900	Brycb	0.1 (0.0-0.2)	1.4 (0.1-2.4)	2.4 (1.7-3.1)	0.4 (0.0-1.0)	1.0
Bryconaethiops microstoma Günther, 1873	Brycm	0.0	1.5 (0.9-3.2)	3.6 (3.3-3.8)	1.0 (0.0-2.9)	2.8
Hydrocynus forskahlii (Cuvier, 1819)	Hydf	0.0	0.1 (0.0-0.2)	0.0	0.0 (0.0-0.1)	1.0
Micralestes acutidens (Peters, 1852)	Mica	0.0	0.0	0.1 (0.0-0.2)	0.0	0.0
Phenacogrammus interruptus (Boulenger, 1899)	Phei	1.0 (0.2-1.8)	9.0 (1.5-16.1)	13.8 (10.5-17.1)	5.8 (2.1-10.5)	1.0
Citharinidae						
Citharinus macrolepis Boulenger, 1899	Citm	0.0	0.0	0.0	0.0 (0.0-0.1)	0.2
Distichodontidae						
Distichodus affinis Günther, 1873	Disa	0.0	1.3 (0.3-3.6)	0.3 (0.2-0.4)	0.2 (0.0-0.4)	0.2
Distichodus fasciolatus Boulenger, 1898	Disf	0.0	0.2 (0.0-0.7	0.0	0.2 (0.0-0.7)	0.0
Distichodus lusosso Schilthuis, 1891	Disl	0.0	0.0	0.1 (0.0-0.2)	0.0	0.0
Distichodus noboli Boulenger, 1899	Disn	18.2 (10.9-25.5)	7.9 (1.1-19.2)	0.0	1.9 (0.2-4.1)	2.9
Distichodus sexfasciatus Boulenger, 1897	Diss	0.0	0.0 (0.0-0.1)	0.0	0.0 (0.0-0.1)	0.0
Distichodus teugelsi Mamonekene & Vreven, 2008	Dist	0.0	3.1 (0.9-6.1)	1.0 (0.2-1.9)	0.5 (0.1-1.2)	0.2
Eugnathichthys macroterolepis Boulenger, 1899	Eugm	0.1 (0.0-0.2)	0.3 (0.2-0.5)	0.3 (0.2-0.3)	0.2 (0.1-0.4)	0.5
Mesoborus crocodilus Pellegrin, 1900	Mesc	1.7 (0.5-2.9)	1.2 (0.5-1.5)	1.0 (1.0-1.1)	1.8 (0.5-2.6)	4.5
Nannocharax taenia Boulenger, 1902	Nant	0.0	0.0	0.1 (0.0-0.0)	0.0 (0.0-0.1)	0.0
Phago boulengeri Schilthuis, 1891	Phab	0.9 (0.5-1.4)	0.4 (0.1-0.5)	0.0	0.5 (0.2-0.8)	0.2
Phago intermedius Boulenger, 1899	Phai	0.0	0.2 (0.1-0.3)	0.0	0.0 (0.0-0.1)	0.0
Xenocharax crassus Pellegrin, 1900	Xenc	6.4 (3.4-9.5)	3.0 (0.8-5.9)	4.1 (2.7-5.4)	8.0 (2.4-12.4)	5.3
Claroteidae						
Chrysichthys ornatus Boulenger, 1902	Chro	1.2 (0.4-1.8)	0.7 (0.4-1.1)	0.4 (0.0-0.9)	0.7 (0.4-1.0)	1.8
Chrysichthys punctatus Boulenger, 1899	Chrp	4.4 (3.4-5.3)	3.7 (0.4-5.0)	0.6 (0.4-0.9)	2.5 (0.7-4.4)	5.5
Chrysichthys thonneri Steindachner, 1912	Chrt	0.1 (0.0-0.2)	0.6 (0.2-0.9)	1.1 (0.3-1.9)	0.5 (0.1-0.7)	1.5
Parauchenoglanis punctatus (Boulenger, 1902)	Parp	0.0	0.1 (0.0-0.2)	0.0	0.4 (0.1-0.6)	0.2
Schilbeidae						
Pareutropius debauwi (Boulenger, 1900)	Pard	0.2 (0.0-0.5)	0.06 (0.0-0.2)	3.7 (1.7-5.7)	0.8 (0.7-0.9)	0.7
Schilbe grenfelli (Boulenger, 1900)	Schg	0.1 (0.0-0.2)	0.1 (0.0-0.2)	0.9 (0.6-1.6)	0.2 (0.0-0.5)	0.3
Schilbe marmoratus Boulenger, 1911	Schm	5.8 (4.8-6.7)	13.5 (7.9-17.6)	17.4 (15.1-19.6)	13.5 (12.1-15.0)	9.2
Clariidae						
Channallabes apus (Günther, 1873)	Chaa	0.0	0.0	0.0	0.0 (0.0-0.1)	0.0
Clarias angolensis Steindachner, 1866	Claa	0.1 (0.0-0.2)	0.1 (0.0-0.2)	0.5 (0.2-0.9)	0.2 (0.1-0.3)	0.0

Table II. – Continued.

Family/species	Code	Habitat 1	Habitat 2	Habitat 3	Habitat 4	Habitat 5
Malapteruridae						
Malapterurus microstoma Poll & Gosse, 1969	Malm	0.0	0.0	0.0	0.0	0.2
Mochokidae						
Synodontis contractus Vinciguerra, 1928	Sync	0.0	0.4 (0.0-0.6)	0.8 (0.3-1.3)	0.8 (0.1-1.7)	0.2
Synodontis flavitaeniatus Boulenger, 1919	Synf	0.0	0.3 (0.0-1.1)	0.2 (0.1-0.2)	0.5 (0.1-1.0)	0.2
Synodontis nigriventris David, 1936	Synn	0.2 (0.0-0.5)	0.4 (0.0-0.9)	0.2 (0.1-0.2)	0.3 (0.1-0.6)	0.2
Mastacembelidae						
Mastacembelus congicus Boulenger, 1896	Masc	0.2 (0.0-0.5)	0.1 (0.0-0.2)	0.5 (0.4-0.6)	0.1 (0.0-0.3)	0.2
Cichlidae						
Congolapia bilineata (Pellegrin, 1900)	Conb	4.9 (1.0-8.8)	5.5 (1.8-10.0)	2.3 (1.5-3.1)	2.5 (1.0-4.1)	2.3
Coptodon congica (Poll & Thys van den Audenaerde, 1960)	Copc	2.2 (1.2-3.2)	0.1 (0.0-2.1)	0.0	1.1 (0.4-1.6)	3.1
Hemichromis elongatus (Guichenot, 1861)	Heme	7.2 (5.4-8.9)	1.7 (0.9-3.0)	0.9 (0.8-0.9)	2.0 (1.5-2.6)	4.7
Hemichromis stellifer Loiselle, 1979	Hems	1.2 (0.7-1.6)	0.6 (0.0-1.5)	0.2 (0.0-0.2)	0.5 (0.3-0.6)	0.8
Heterochromis multidens (Pellegrin, 1900)	Hetm	0.0	0.2 (0.0-0.2)	0.1 (0.0-0.2)	0.0 (0.0-0.1)	0.0
Pelmatochromis nigrofasciatus (Pellegrin, 1900)	Peln	0.1 (0.0-0.2)	0.0	0.0	0.0	0.0
Tylochromis lateralis (Boulenger, 1898)	Tyll	5.7 (5.0-6.5)	4.1 (1.7-5.6)	1.9 (1.5-2.3)	4.7 (2.6-8.0)	10.3
Anabantidae						
Ctenopoma acutirostre Pellegrin, 1899	Ctea	0.2 (0-0.5)	0.5 (0.3-0.9)	0.3 (0.2-0.4)	0.2 (0.1-0.3)	0.2
Ctenopoma kingsleyae Günther, 1896	Ctek	0.0	0.2 (0.0-0.8)	0.1 (0.0-0.2)	0.0 (0.0-0.1)	0.0
Ctenopoma nigropannosum Reichenow, 1875	Cten	0.2 (0.0-0.5)	0.1 (0.0-0.2)	0.1 (0.0-0.1)	0.1 (0.1-0.2)	0.2
Ctenopoma ocellatum Pellegrin, 1899	Cteo	0.4 (0.0-0.7)	0.2 (0.0-0.5)	0.1 (0.0-0.2)	0.2 (0.0-0.3)	0.0
Ctenopoma weeksii Boulenger, 1896	Ctew	0.0	0.0	0.0	0.0 (0.0-0.1)	0.0
Microctenopoma nanum (Günther, 1896)	Micn	0.0	0.0	0.0	0.1 (0.0-0.1)	0.0
Channidae						
Parachanna insignis (Sauvage, 1884)	Pari	0.2 (0.0.2-0.3)	0.2 (0.0-0.2)	0.0	0.1 (0.0-0.3)	0.0
Tetraodontidae						
Tetraodon miurus Boulenger, 1902	Tetm	0.0	0.0 (0.0-0.1)	0.0	0.0	0.0

and habitat (5) forest with low canopy coverage 24.0% (Pf2). Based on the RDA analysis (Fig. 3B), it is clear that some species can be considered as characteristic for certain habitats.

The main fish species found in Habitat (1), positively correlated with axe 1, are *Distichodus noboli*, *Mormyrops zanclirostris*, *Chrysichthys punctatus*, *Pelmatochromis nigrofasciatus* and *Phago boulengeri*. Habitat 2, negatively correlated with axe 2, is mainly characterised by *Stomatorhinus patrizii*, *Phago intermedius*, *Distichodus affinis*, *D. teugelsi*, *Ctenopoma acutirostre*, *Heterochromis multidens* and *Tetraodon miurus*. Habitat 3, negatively correlated with axe 1, included *Schilbe marmoratus*, *Phenacogrammus interruptus*, *Hippopotamyrus weeksii*, *Gnathonemus echidnorhynchus*, *Clarias angolensis*, *Bryconaethiops microstoma*, *Marcusenius monteiri*, *Micralestes acutidens* and *Distichodus lusosso*. Habitat 4, positively correlated with axe 2, included *Mormyrus caballus*, *Brycinus grandisquamis*, *B. poptae*, *Alestopetersius nigropterus*, *Schilbe grenfelli*, *Microctenopoma nanum*, *Mastacembelus congicus*, *Parauchenoglanis punctatus*, *Ctenopoma weeksii*, *Mormyrops furcidens*, *Channallabes apus* and *Pantodon bucholzi*. Finally, habitat 5 correlated positively with axe 2, is mainly characterised by *Citharinus macrolepis*, *Malapterurus microstoma*, *Hepsetus microlepis*, *Pellonula vorax*, *Hydrocinus forskahlii* and *Xenomystus nigri*.

Spatial variation of ecological diversity indices

For each of the five habitats provided by the RDA, the species richness S, Shannon index

Table III. – Ecological diversity indices. Values in habitat: mean (Minimum-Maximum). N: number of specimens; S: Species richness; H': Shannon index; H'max.: Shannon maximum index; R: Equitability.

Habitats	N	S	R	H'	H'max.
Habitat 1	427 (415-439)	35 (32-38)	0.79 (0.73-0.86)	2.82 (2.64-3)	3.56 (3.47-3.64)
Habitat 2	672 (473-849)	50 (45-55)	0.78 (0.76-0.79)	3.04 (2.93-3.15)	3.91 (3.81-4.01)
Habitat 3	567 (469-665)	47 (44-50)	0.79 (0.78-0.79)	3.02 (2.98-3.06)	3.85 (3.78-3.91)
Habitat 4	1146 (863-1441)	56 (52-58)	0.77 (0.75-0.79)	3.09 (3.01-3.21)	4.02 (3.95-4.6)
Habitat 5	583	51	0.82	3.24	3.93

H', Shannon maximum index H'max. and Equitability R were calculated. For habitats 1, 2, 3 and 4, these values are represented by the mean of its values obtained in the stations, which constitute the habitat. In habitat 5, consisting of a single station Pf2, values were reported as such (Tab. III). With averages of 427 specimens (415-439) and 35 species (32-38), habitat 1 was the least diversified, whereas habitat 4 was most diversified with 1146 specimens (863-1441) and 56 species (52-58). However, mean values of Equitability were highest in habitats 1 and 3 respectively 0.79 (0.73-0.86) and 0.79 (0.78-0.79) and low 0.77 (0.75-0.79) in habitat 4.

DISCUSSION

The fish diversity study of the Lefini River basin provided by Ibala Zamba (2010) reported 140 species belonging to 76 genera, 27 families. In that study, 110 stations were sampled using a variety of collecting methods to sample as much of the available habitat diversity as possible. The present study investigates the spatial distribution of fish communities in relation to environmental variables; 84 species are reported from 12 stations sampled following standardized methods utilizing monofilament gill nets.

Unlike the standard observation of species richness increasing downstream (Hugueny, 1989, 1990; Paugy and Bénech, 1989; Pouilly, 1993; Hay *et al.*, 1996; Kamdem Toham and Teugels, 1997, 1998; Kouamé *et al.* 2008), or the opposing observation in some cases (Kouadio *et al.*, 2006), richness did not change in a upstream-downstream gradient in the Lefini River basin, in the 103 km section studied. This result corroborates that of Mérona (1981) in the Bandama in Ivory Coast, and could be explained by the low human impacts along the Lefini River and also certainly by the low slope (33 m) between the most distant stations; from upstream to downstream Ah1 situated about 135 km from the source and Avh1.

According to Chapman and Chapman (2003), forest rivers are often characterized by ion-poor waters, acidity (pH < 7) and low conductivity. Waters of the Lefini River basin, bordered by an important gallery forest, are in general acidic ($5.1 \leq pH \leq 6.1$) with a low conductivity (5.9-9.9 µS/cm). However, significant differences ($p = 0.003$) were found between forest and grass bank type stations with respectively low (5.1-5.4) and high pH (5.5-6.1) (Tab. I). The presence of organic matter (dead leaves, dead wood and mixture of dead wood, dead leaves and mud) in forest bank type stations is likely responsible for these significant differences in pH.

According to the RDA (Fig. 3A), temperature (16.5%) is the most important variable for fish distribution in the Lefini River. This variable is strongly correlated with habitat 1, pool with fringing grasses, where the average temperature is 29.3°C, significantly different from the other four habitats ($p < 0.001$). These high temperatures and low oxygen levels (mean = 2.5 mg/l), which are also significantly different from the other four habitats ($p = 0.03$), probably contribute to the fact that low fish diversity of habitat 1 (mean S = 35 vs. 47-56). Species with the most important relative abundance values in this habitat are *Distichodus noboli*, *Xenomystus nigri*, *Marcusenius moorii* and *Hemichromis elongatus* (see Tab II). In some West Africa rivers, several authors have mentioned the importance of temperature on fish distribution (Kouamélan *et al.*, 2003; Yao *et al.*, 2005; Kouadio *et al.*, 2006; Aboua *et al.*, 2015). In addition, according to Lowe-McConnell (1987), still waters are characterized by high temperatures.

The canopy closure (9.8%) and canopy height (9.5%), characteristic for forest habitats type (habitat 3, 4 and 5), are the two other most important variables for fish distribution in the Lefini River. Several authors have noted the importance of the canopy closure or height on fish distribution (Kamdem Toham and Teugels, 1997, 1998; Kouamélan *et al.*, 2003; Yao *et al.*, 2005; Kouadio *et al.*, 2006; Esteves *et al.*, 2008; Kouamé *et al.*, 2008). The structure, as well as the functional importance of overhanging vegetation in determining the temperature, physical chemistry, hydraulic regime, and the distributions of organisms in aquatic environments have been well-documented by Lowe-McConnell (1975) and Brosset (1982) for African aquatic ecosystems.

According to Barbault (1992) and Korkmaz and Zencir (2009), studying fish communities using diversity indices does not reflect the organisational modalities of populations in a system. However, these indices are of great importance for the diagnosis of the ecological health of an aquatic ecosystem (Lobry *et al.*, 2003). In the present study, the three ecological diversity indices (S, H' and R), calculated based on species abundance revealed that in all habitats, the H' and R indices are approaching their maximum values, respectively H' maximum for H' and 1 for R (Tab. III), even in the least diverse habitat 1. This reflects an excellent distribution of species abundance in the Lefini river basin. Indeed, according to Ludwig and Reynolds (1988) and Lobry *et al.*

(2003), when all species of the community are an excellent distribution of abundance and the environmental in good ecological health, H' and R indices calculated are approaching their maximum values.

CONCLUSION

Our results contribute to a better understanding of fish distribution in the Lefini River basin. Specifically, the study indicates that in the Lefini River basin, fish populations are distributed according five habitat types: pool with fringing grasses, banks grass fringed, forest with high canopy coverage, forest with mean canopy coverage and forest with low canopy coverage. The index of species richness showed that grassy habitats are the least diversified. In addition, the high value of Shannon and Equitability indices in all habitats indicates that the examined stretch of the Lefini basin is in good ecological health.

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REFERENCES

ABOUA B.R.D., N'ZI K.G., BAMBA M. & KOUAMELAN E.P., 2015. – Ichthyologic diversity of Bandama River basin (Côte d'Ivoire): an update and environmental influence on fish distribution. *Eur. Sci. J.*, 11(12): 99-116.

ANGERMEIER P.L. & KARR J.R., 1983. – Fish community along environmental gradients in a system of tropical stream. *Environ. Biol. Fish.*, 9: 117-135.

BARBAULT R., 1992. – Écologie des Peuplements, Structure, Dynamique et Évolution. 273 p. Masson, Paris.

BAUMGARTNER G., GUBIANI E.A., DELARIVA R.L. & SANCHES P.V., 2010. – Spatial patterns in fish assemblages of ILha Grande National Park, Brazil. *Wetlands*, 9: 309-320.

BLANCHARD F., 2001. – Une approche de la dynamique des peuplements de poissons démersaux exploités : analyse comparée de la diversité spécifique dans le golfe de Gascogne (océan Atlantique) et dans le golfe du Lion (mer Méditerranée). *Aquat. Living Resour.*, 14: 29-40.

BROSSET A., 1982. – Le peuplement de cyprinodontes du bassin de l'Ivindo, Gabon. *Rev. Ecol. Terre Vie*, 36: 233-292.

CHAPMAN C.A. & CHAPMAN L.J., 2003. – Deforestation in tropical Africa. In: Conservation, Ecology, and Management of African Fresh Waters (Crisman T.L., Chapman L.J., Chapman C.A. & Kaufman L.S., eds), pp. 229-246. University Press of Florida.

CLARKE K.R. & GORLEY R. N., 2001. – Primer v5: user manual/tutorial. 91 p. Primer-E Ltd, Plymouth, UK.

ESCHMEYER W.N., FRICKE R. & VAN DER LAAN R., 2018. – Catalog of Fishes: Classification. (http://www.calacademy.org/scientists/catalog-of-fishes-classification/). Electronic version accessed 20.06.2018.

ESTEVES K.E., LOBO A.V.P. & FARIA M.D.R., 2008. – Trophic structure of fish community along environmental gradient of subtropical River (Paraitinga River, Upper Tietê River Basin, Brazil). *Hydrobiologia*, 598: 373-387.

FISCHER J.R. & PAUKERT C.P., 2008. – Habitat relationships with assemblages in minimally disturbed Great Plains regions. *Ecol. Freshw. Fish*, 17: 597-609.

HAY C.J., VAN ZYL B.J. & STEYN G.J., 1996. – A quantitative assessment of biotic integrity of the Okavango River, Namibia based on fish. *Water SA.*, 22: 263-284.

HUGUENY B., 1989. – Biogéographie et structure des peuplements de poissons d'eau douce de l'Afrique de l'Ouest : approches quantitatives. 295 p. Thèse Université Paris 7.

HUGUENY B., 1990. – Richesse des peuplements de poissons dans le Niandan (haut Niger, Afrique) en fonction de la taille de la rivière. *Rev. Hydrobiol. Trop.*, 23(4): 351-364.

IBALA ZAMBA A., 2010. – Faune des poissons des rivières Luki et Léfini (Bassin du Congo) : diversité et écologie. 452 p. PhD thesis, KU Leuven.

IBANEZ C., OBERDORFF T., TEUGELS G.G, MAMONONEKENE V., LAVOUE S., FERMON Y., PAUGY D. & KAMDEM TOHAM A., 2007. – Fish assemblages structure and function along environmental gradients in rivers of Gabon (Africa). *Ecol. Freshw. Fish*, 16: 315-334.

KAMDEM TOHAM A. & TEUGELS G.G., 1997. – Patterns of microhabitat use among fourteen abundant fishes of the lower Ntem River Basin (Cameroon). *Aquat. Living Resour.*, 10: 289-298.

KAMDEM TOHAM A. & TEUGELS G.G., 1998. – Diversity patterns of fish assemblages in the Lower Ntem River Basin (Cameroon), with notes on potential effects of deforestation. *Arch. Hydrobiol.*, 141: 421-446.

KAMDEM TOHAM A. & TEUGELS G.G., 1999. – First data on an index of biotic integrity (IBI) based on first assemblages for the assessment of the impact of the deforestation in a tropical West African river system. *Hydrobiologia*, 397: 29-38.

KORKMAZ A.S. & ZENCIR O., 2009. – Fish community structure in Suveri stream, Central Antolia, Turkey. *J. Anim. Vet. Adv.*, 8(11): 2305-2310.

KOUADIO N.F., KOUAMELAN E.P., N'DOUBA V., KONE T., SNOEKS J. & OLLEVIER F., 2006. – Update of fish biodiversity and impact of human activities on the community structure, Mé River (Ivory Coast). *J. Biol. Sci.*, 6(5): 805-814.

KOUAMÉ K.A., YAO S.S., GOORE BI G., KOUAMELAN E.P., N'DOUBA V. & KOUASSI N.J., 2008. – Influential environmental gradients and patterns of fish assemblages in a West African basin. *Hydrobiologia*, 603: 159-169

KOUAMÉLAN E.P., TEUGELS G.G., N'DOUBA V., GOORE BI G. & KONE T., 2003. – Fish diversity and its relationships with environmental variables in a West African basin. *Hydrobiologia*, 505: 139-146.

LAË R., 1994. – Évolution des peuplements (poissons et crustacés) dans une lagune tropicale, le lac Togo, soumise à un régime alternatif de fermeture et d'ouverture du cordon lagunaire. *Aquat. Living Resour.*, 7: 165-179.

LANDE R., 1996. – Statistics and partitioning of species diversity, and similarity among multiple communities. *Oikos*, 76: 5-13.

LOBRY J., GASCUEL D. & DOMAIN F., 2003. – La biodiversité spécifique des ressources démersales du plateau continental guinéen: utilisation d'indice classique pour un diagnostic sur l'évolution des écosystèmes. *Aquat. Living Resour*., 16: 59-68.

LOWE-McCONNELL R.H., 1975. – Fish Communities in Tropical Freshwater: their Distribution, Ecology and Evolution. 337 p. Longman, London.

LOWE-McCONNELL R.H., 1987. – Ecological Studies in Tropical Fish Communities. 382 p. Cambridge University Press.

LUDWIG J.A. & REYNOLDS J.F., 1988. – Statistical Ecology: A Primer on Methods and Computing. John Wiley & Sons, New York.

MBEGA J.D., 2004. – Biodiversité des poissons du basin inférieur de l'Ogooué (Gabon). 614 p. Presses Universitaires de Namur.

MÉRONA B.D., 1981. – Zonation ichtyologique du bassin du Bandama (Côte d'Ivoire). *Rev. Hydrobiol. Trop*., 14: 63-75.

MUNYANDORERO J., 2006. – Size, diversity, dominance and trophic structures of the fish community in a tropical lake: a case study for the Sinazongwe area, Lake Kariba, Zambia. *Aquat. Living Resour*., 19: 123-136.

ORNELLAS A.B. & COUTINHO R., 1998. – Spatial and temporal patterns of distribution and abundance of a tropical fish assemblage in a seasonal Sargassum bed, Cabo Frio Island, Brazil. *J. Fish Biol*., 53: 198-208.

PAUGY D. & BENECH V., 1989. – Poissons d'eau douce des bassins côtiers du Togo (Afrique de l'Ouest). *Rev. Hydrobiol. Trop*., 22: 295-316.

PAUGY D. & LEVEQUE C., 2017. – Impacts of human activities. *In*: The Inland Water Fishes of Africa: Diversity, Ecology and Human use (Paugy D., Leveque C. & Otero O., eds), pp. 459-478. Institut de Recherche pour le Développement (IRD), Royal Museum for Central Africa (RMCA).

PIELOU E.C., 1966. – The measurement of diversity in different types of biological collections. *J. Theor. Biol*., 13: 131-144.

POUILLY M., 1993. – Habitat, écomorphologie et structure des peuplements de poissons dans trois petits cours d'eau tropicaux de Guinée. *Rev. Hydrobiol. Trop*., 26: 319-332.

SHANNON C.E., 1948. – A mathematical theory for communication. *Bell. Syst. Tech. J*., 27: 379-423 and 623-656.

TEJERINA-GARRO F.L., MERONA B.D., OBERDORFF T. & HUGUENY B., 2006. – A fish-base index of large river for French Guiana (South America): method and preliminary results. *Aquat. Living Resour*., 19: 31-46.

TER BRAAK C.J.F. & ŠMILAUER P., 2003. – Canoco 4. 242 p. Cambridge University Press, USA.

WAMUINI LUNKAYILAKIO S., VREVEN E., VADEWALLE P., MUTAMBUE S. & SNOEKS J., 2010. – Contribution à la connaissance de l'ichtyofaune de l'Inkisi au Bas-Congo (RD du Congo). *Cybium*, 34(1): 83-91.

WILDHABER M.L., ALBERT A.L., SCHIMITT C.J., TABOR V.M. MULHERN D., POWELL K.L. & SOWA S.P., 2000. – Natural and anthropogenic influences on the distribution of the threatened Neosho madtom in a midwestern warmwater stream. *Trans. Am. Fish. Soc*., 129: 243-261.

YAO S.S., KOUAMELAN E.P., KONE T., N'DOUBA V., GOORE BI G., OLLEVIER F. & THYS VAN DEN AUDENAERDE D.F.E., 2005. – Fish communities along environment gradients within the Comoé River basin, Côte d'Ivoire. *Afr. J. Aquat. Sci*., 30: 195-204.

Appendix I. – Sampling stations (1-12), their location, coordinates and date of the sampling periods. Forest bank stations in grey.

Station	Description	Code	Coordinates	Date of the sampling periods			
				Dry season		Rainy season	
				2007	2008	2007	2008
1	Lefini River, confluent Lefini-Nambouli, left bank	Ah1	2°53,764'S-15°06,846'E	28-29/08	5-6/08	22-23/04	24-25/03
2	Lefini River at 2.4 km downstream of camp Malina, right bank	Af1	2°59,231'S-15°11,755'E	25-26/08	1-2/08	25-26/04	20-21/03
3	Lefini River, ± 3 km upstream of confluent Léfini-Loubilika, right bank	Af2	3°01,155'S-15°14,239'E	23-24/08	30-31/07	27-28/04	18-19/03
4	Lefini River, ± 4 km down- stream of camp Malina, right bank	Ah2	2°59,447'S-15°11,988'E	18-19/08	3-4/08	14-15/04	22-23/03
5	Lefini River, ± 3 km upstream of mount Epopé, left bank	Ph1	3°01,971'S-15°23,707'E	7-8/08	26-27/07	30/04-1/05	28-29/03
6	Lefini River at 600 m upstream of camp Oteni, left bank	Ph2	3°00,625'S-15°27,359'E	9-10/08	28-29/07	28-29/03	30-31/03
7	Lefini River, downstream of mount Epopé, right bank	Pf1	3°00,484'S-15°28,869'E	11-12/08	22-23/07	25-26/03	1-2/04
8	Lefini River, in front of Lesio-Louna Gorilla Natural Reserve	Pf2	2°59,649'S-15°29,751'E	13-14/08	24-25/07	22-23/03	26-27/03
9	Lefini River, at Mondo camp, left bank	Avf1	2°55,789'S-15°34,570'E	15-16/08	7-8/08	19-20/03	13-14/04
10	Lefini River upstream of Obanga camp, right bank	Avh1	2°49,084'S-15°48,770'E	20-21/08	13-14/08	17-18/03	19-20/04
11	Lefini River, ± 3 km upstream of Oteni camp, left bank	Avh2	2°49,480'S-15°47,507'E	18-19/08	11-12/08	14-15/03	17-18/04
12	Lefini River, second channel, ± 500 m upstream of camp Oteni, left bank. Lesio-Louna Gorilla Natural Reserve	Avf2	2°50,251'S-15°46,787'E	22-23/08	9-10/08	11-12/03	14-15/04

Appendix II. – List of species collected with their abundance in sampling stations.

Family/species	Stations											
	1	2	3	4	5	6	7	8	9	10	11	12
Polypteridae												
Polypterus mokelembembe	1	2	0	0	0	2	1	0	5	0	9	1
Polypterus weeksii	0	2	0	0	0	0	1	0	0	0	1	0
Pantodontidae												
Pantodon buchholzi	1	10	0	2	1	1	13	0	1	0	2	4
Notopteridae												
Papyrocranus congoensis	0	3	0	0	0	0	5	0	0	3	0	1
Xenomystus nigri	50	156	14	35	26	24	91	44	29	63	33	35
Mormyridae												
Gnathonemus echidnorhynchus	1	0	2	0	0	0	9	0	4	0	0	0
Gnathonemus petersii	7	3	0	1	2	2	12	4	1	0	0	1
Hippopotamyrus weeksii	0	0	5	0	5	3	1	3	10	0	1	3
Marcusenius kutuensis	1	0	0	0	0	0	6	0	1	0	0	0
Marcusenius monteiri	0	0	0	0	0	0	0	0	1	0	0	0
Marcusenius moorii	36	124	9	34	7	28	67	23	11	29	27	32
Mormyrops boulengeri	0	1	0	0	0	0	2	0	0	0	1	0
Mormyrops furcidens	0	1	0	0	0	0	0	0	0	0	0	0
Mormyrops nigricans	1	2	0	0	3	0	5	0	0	0	0	0
Mormyrops sirenoides	0	0	1	0	0	0	0	0	0	0	0	0
Mormyrops zanclirostris	0	0	0	1	0	0	0	0	0	0	0	0

Appendix II. – Continued.

Family/species	Stations											
	1	2	3	4	5	6	7	8	9	10	11	12
Mormyrus caballus	0	0	1	0	0	0	4	5	2	0	2	2
Petrocephalus balayi	23	19	27	21	4	24	10	4	15	1	11	5
Petrocephalus christyi	40	35	14	5	8	25	19	29	9	3	17	41
Pollimyrus nigripinnis	0	0	0	0	1	0	5	1	3	1	5	1
Pollimyrus schreyeni	0	0	0	1	0	4	1	4	3	0	4	4
Stomatorhinus patrizii	1	0	1	0	1	1	0	0	0	0	1	0
Clupeidae												
Odaxothrissa losera	0	0	0	0	0	1	2	0	1	1	1	2
Pellonula leonensis	0	0	0	0	0	0	0	0	0	1	0	1
Pellonula vorax	0	0	0	0	0	0	0	1	0	1	0	2
Cyprinidae												
Enteromius cf. *holotaenia*	24	22	7	0	0	9	5	1	35	0	2	1
Enteromius validus	1	0	0	0	2	0	5	0	2	0	0	0
Raiamas christyi	3	3	0	1	0	2	0	2	0	0	11	0
Hepsetidae												
Hepsetus microlepis	13	31	4	18	4	2	20	19	2	5	5	5
Alestidae												
Alestes liebrechtsii	1	9	10	3	6	29	46	7	17	12	29	65
Alestopetersius caudalis	24	43	2	5	1	20	5	1	1	3	2	42
Alestopetersius nigropterus	33	129	16	5	4	8	56	5	52	8	1	17
Bathyaethiops caudomaculatus	0	0	0	0	0	1	0	1	0	0	0	0
Brachypetersius altus	24	25	26	14	21	150	50	37	78	23	81	154
Brycinus grandisquamis	5	7	3	11	3	4	11	14	9	1	9	31
Brycinus imberi	0	0	0	0	0	0	0	0	9	0	2	0
Brycinus poptae	1	12	17	0	0	1	7	1	0	0	0	6
Bryconaethiops boulengeri	19	4	15	0	4	19	11	6	12	1	1	0
Bryconaethiops microstoma	28	0	18	0	4	14	33	17	23	0	1	1
Hydrocynus forskahlii	2	0	0	0	0	0	0	6	0	0	0	1
Micralestes acutidens	0	0	1	0	0	0	0	0	0	0	0	0
Phenacogrammus interruptus	139	71	82	8	49	64	121	6	72	1	9	19
Citharinidae												
Citharinus macrolepis	0	0	0	0	0	0	0	1	0	0	0	1
Distichodontidae												
Distichodus affinis	6	0	2	0	17	2	5	1	1	0	4	1
Distichodus fasciolatus	0	0	0	0	0	1	0	0	0	0	4	6
Distichodus lusosso	0	0	1	0	0	0	0	0	0	0	0	0
Distichodus noboli	68	62	0	48	91	9	15	18	0	106	20	2
Distichodus sexfasciatus	0	0	0	0	0	1	0	0	0	0	0	1
Distichodus teugelsi	2	18	9	0	29	7	1	1	1	0	30	2
Eugnathichthys macroterolepis	2	1	1	0	2	4	4	3	2	1	1	2
Mesoborus crocodilus	13	37	5	13	7	9	30	28	7	2	3	4
Nannocharax taenia	0	1	1	0	0	0	0	0	0	0	0	0
Phago boulengeri	1	9	0	6	2	4	9	1	0	2	3	2
Phago intermedius	1	0	0	0	1	2	0	0	0	0	1	1
Xenocharax crassus	28	187	13	42	10	47	105	33	37	14	5	21
Claroteidae												
Chrysichthys ornatus	9	8	0	8	2	5	5	11	6	2	4	9
Chrysichthys punctatus	36	11	2	15	2	28	14	34	6	22	30	48
Chrysichthys thonneri	4	2	9	1	1	7	8	9	2	0	4	6

Appendix II. – Continued.

Family/species	Stations											
	1	2	3	4	5	6	7	8	9	10	11	12
Parauchenoglanis punctatus	1	2	0	0	1	0	7	1	0	0	1	3
Schilbeidae												
Pareutropius debauwi	2	14	8	0	0	17	9	4	39	2	1	6
Schilbe grenfelli	0	0	3	0	0	0	0	2	8	1	1	4
Schilbe marmoratus	68	203	94	30	70	140	173	57	104	20	83	107
Clariidae												
Channallabes apus	0	0	0	0	0	0	1	0	0	0	0	0
Clarias angolensis	1	5	1	0	0	1	3	0	6	1	1	1
Malapteruridae												
Malapterurus microstoma	0	0	0	0	0	0	0	1	0	0	0	0
Mochokidae												
Synodontis contractus	5	7	6	0	2	5	1	1	2	0	0	15
Synodontis flavitaeniatus	1	4	1	0	5	1	12	1	1	0	0	1
Synodontis nigriventris	3	9	1	0	4	0	2	1	1	2	3	1
Mastacembelidae												
Mastacembelus congicus	1	1	3	2	0	0	0	1	3	0	1	3
Cichlidae												
Congolapia bilineata	44	36	15	39	24	14	12	14	10	4	60	36
Coptodon congica	5	6	0	14	10	0	19	19	0	5	0	10
Hemichromis elongatus	12	31	4	24	14	7	30	29	6	37	6	13
Hemichromis stellifer	5	9	0	7	7	0	7	5	2	3	2	3
Heterochromis multidens	2	2	0	0	1	0	0	0	1	0	1	0
Pelmatochromis nigrofasciatus	0	0	0	0	0	0	0	0	0	1	0	0
Tylochromis lateralis	44	52	11	22	8	30	30	64	10	27	34	71
Anabantidae												
Ctenopoma acutirostre	3	5	2	2	4	2	1	1	1	0	4	1
Ctenopoma kingsleyae	0	1	1	0	0	0	0	0	0	0	5	0
Ctenopoma nigropannosum	0	1	0	0	0	1	1	1	1	2	1	1
Ctenopoma ocellatum	0	0	1	0	2	0	2	0	0	3	3	3
Ctenopoma weeksii	0	0	0	0	0	0	1	0	0	0	0	0
Microctenopoma nanum	0	1	0	0	0	0	0	0	0	0	0	1
Channidae												
Parachanna insignis)	2	2	0	1	1	0	3	0	0	1	1	0
Tetraodontidae												
Tetraodon miurus	1	0	0	0	0	0	0	0	0	0	0	0