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Diversity and Distribution of Fish Species in the Upper Loémé Basin in Mayombe (Republic of Congo, Central Africa)

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Abstract

This study was initiated to document fish species richness and distribution in the upper reaches of the Loémé basin. Carried out between February 2020 and September 2021, sampling targeted eight stations using a standardized gillnetting approach and collected 1356 specimens distributed across 24 species, 18 genera, 9 families, and 5 orders, with the Cyprinidae family (8 species) being the most represented. Species diversity through diversity indices was found to be low, with an unequal distribution of species ($H' = 1.54$; $D' = 0.47$; $J' = 0.46$) at the Bidounzi in Tsessi (TSBI) station where only two species, *Enteromius camptacanthus* and *E. martorelli*, dominate; and average in the remaining stations where species are equally distributed ($H' > 2$; $D' < 0.47$; $J' > 0.5$). The Loufouyou gorges constitute a geographic barrier to species dispersal. *Brachyalestes kingsleyae*, *Bryconalestes longipinnis*, *Chrysichthys auratus*, *Hemichromis elongatus*, *Hepsetus lineata* and *Marcusenius moorii* were only sampled in Loémé station in Bilinga (BILO) and Bilinga station downstream from the bridge (BAPO), two stations located downstream of the gorges. This study provides basic knowledge on both species diversity of the upper course of the Loémé basin and the influence of the Loufouyou gorges on their distribution. It also opens up perspectives for future studies of the ichthyological fauna of the latter.

Keywords

Ichthyofauna, Gillnet, Ecology, Loémé Basin, Africa

1. Introduction

Lotic aquatic environments are particularly fragile ecological systems [1], insofar as they are nowadays affected by increasing human activities (e.g. gravel extraction at quarries, hydroelectric dam development, gold panning, overexploitation of fish resources) which led to the modification or disappearance of habitats, pollution of various origins, chronic water turbidity, and the reduction and extinction of resources. The consequences of these activities, currently exacerbated by human population growth and increasing pressure on natural resources, endanger aquatic fauna in a global scale [2] [3]. The need to know the initial species composition, biology, and interrelationships is therefore at the heart of scientific concerns. Thus, numerous research has shown higher interest in investigating species distribution and community structure [4]-[9]. Fish can be used as an indicator to assess the general state of watercourses [10] [11]. Following this observation, it is therefore increasingly important for resource managers to improve their knowledge of ichthyological populations across hydrographic network of countries worldwide. The Loémé, a river flowing almost entirely in Congo Brazzaville, arises in the Mayombe mountains near the border with Cabinda and crosses the Mayombe before reaching the coastal plain where it forms numerous meanders in the marshes. It is characteristic of those rivers which reach the ocean with difficulty after crossing coastal lagoons. With a surface area of approximately 3250 km^2, this basin drains a large part of the Mayombe. Works carried out in the Loémé basin in its lower and middle course [12]-[14], only report on the systematics of its ichthyofauna, as is the case for most fresh and brackish water systems in the Republic of Congo. The other aspects are not or only barely addressed [15]. The present work is part of efforts to supplement knowledge on the fish communities in this basin, precisely in its upper reaches.

2. Materials and Methods

2.1. Study Area

The portion of the Loémé basin concerned by this study is located in Mayombe, Kouilou Department and extends from the locality of Mvoungouti to that of Bilinga following the railway line of the realignment of the Congo-Ocean Railway (CFCO). The Loémé basin, located south of the Kouilou basin, has a total surface area of approximately 3250 km^2. The Congolese Mayombe is located between latitude 3˚30' and 4˚50'S and latitude 11˚30' and 13˚12'E. It is located between 40 and 80 km from the Atlantic Ocean with a width of 50 to 80 km. It is an orogeographic and floristic entity, part of which in Congo Brazzaville is preserved by the Dimonika Biosphere Reserve established in March 1988 [16]. Overall, eight sta-

tions were prospected in the upper reaches of the Loémé basin, including its different size tributaries (Figure 1). These stations included the Loémé stations in Bilinga (BILO), Bilinga downstream of the bridge (BAPO), Loufouyou in Nemba (NELO), Loémé in Nemba (LONE), Bidounzi in Tsessi (TSBI), Loémé in Tsessi (TSLO), Mvougounti forested banks (MVBF) and Mvougounti grassy banks (MVBH). The stations were chosen based on: 1) their proximity to the various CFCO stations, making them easily of access, and 2) their various environmental aspects, including the habitat type, canopy, riverbank type, and the presence or absence of human activities. The sampling campaigns were spread over two years at the rate of two campaigns per year, one in the dry season and a second one in the rainy season.

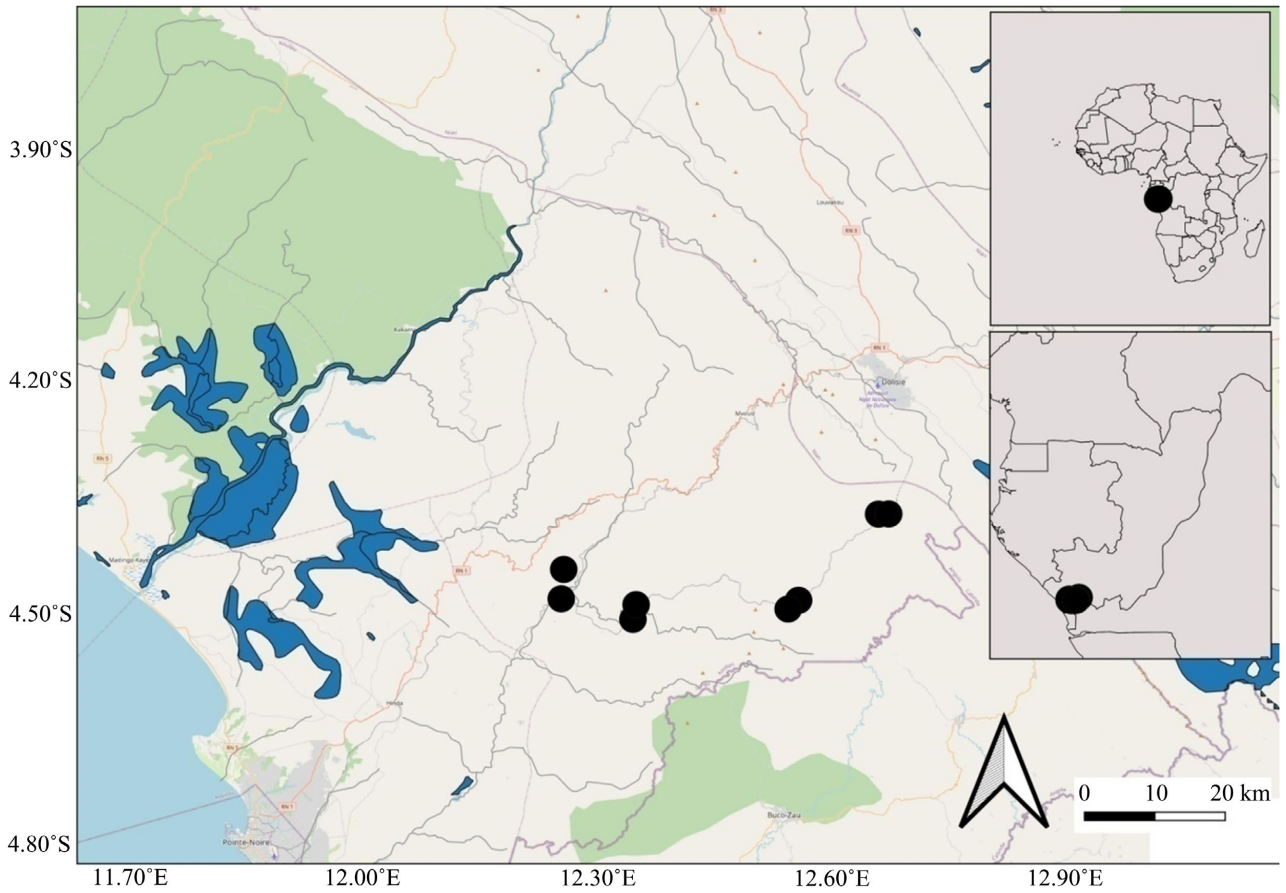


Figure 1. Study area and sampling stations.

2.2. Fish Sampling

For each campaign, stations were sampled using a standardized fishing method using four gillnets of 10, 12, 15 and 25 mm mesh size, 30 m long and 1.5 m drop. The nets were set for approximately 14 hours overnight, between 5 p.m. and at 7 a.m., following [17]-[19]. Species were identified and counted (individuals per species) in the field. The Standard Length of each fish was measured to the nearest 0.01 millimeter and the weight to the nearest 0.01 g. Fish whose identifications

were uncertain in the field were preserved in 10% formalin for further identification at the ichthyological laboratory of the National Institute for Research in Exact and Natural Sciences (IRSEN). The classification of families was done according to [20] and that of species of the same family, in alphabetical order.

2.3. Environmental Data

At each station and during every campaign, the water physicochemical variables were recorded. These include the temperature (˚C), conductivity (μS/cm), TDS (mg/l), and pH. The measurements were carried out *in-situ* using the *HANNA* and YSI multi-parameter probes. For each measurement, the electrodes are immersed in water and the value of the parameter displayed is read on the screen after stabilization. Turbidity (m) and depth (m) were measured respectively using a Secchi disk and a depth gauge. Water velocity (m/s), distance to the bank (m), canopy height (m), average width (m), and net shading (%) were also recorded. The nature of the substrate was estimated in percentage of sand, gravel, pebbles, mud, dead wood, dead leaves, boulders and large rocks. In addition to these habitat characteristic variables, the presence or absence of agricultural activities in the vicinity of the station, a non-quantifiable variable, was also recorded. A water sample was taken per station. These water samples were each taken using a 0.5 litre plastic bottle at a depth of 20 cm, stored in a cooler and brought back to the laboratory in these same bottles. The dosage of Calcium, Magnesium, Potassium, Ammonium, Aluminum, Phosphates, Sulfates, Chlorides, Carbonates, Nitrates, Nitrites ions and the alkalinity titer was carried out ex-situ at the hydrology laboratory of the National Institute for Research in Exact and Natural Sciences.

2.4. Statistical Analyses

Based on the non-significant seasonal differences ($p > 0.05$) found on more than 70% of the environmental parameters recorded (**Table 1**), with the student's t test, using STATISTICA version 8 software, the treatments were carried out without taking into account the seasonal variations. Diversity indices provide more information about community composition than just species richness; they also take into account the relative abundance of different species [21]. Four types of indices, classic in ecology were calculated using PRIMER software, version 5 [22]. These included the Specific richness S corresponding to the simple counting of the number of species present in the sample; the Shannon H' index [23], used in ecology as a measure of specific diversity [24]-[26]. The following expression was used to calculate H':

Table 1. Minimum, maximum, mean and standard deviation values of environmental parameters. Min: minimum, Max: maximum, Avg: mean, SD: standard deviation.

Environmental variables	Codes	Min - Max (Avg ± SD)	T-test	
			t-value	p
pH	pH	7.31 - 7.70 (7.56 ± 0.13)	1.86	0.016

Continued

Temperature (˚C)	T ˚C	23.8 - 27.4 (25.88 ± 1.2)	1.76	0.011
Conductivity (*uS*/cm)	CE	20 - 138 (83.63 ± 37.80)	1.76	0.137
Total dissolved solids (mg/l)	TDS	9.5 - 60 (37.25 ± 16.52)	1.76	0.131
Speed (m/s)	Vit	0 - 0.67 (0.36 ± 0.23)	1.80	0.197
Turbidity (m)	Turb	0.45 - 1 (0.69 ± 0.22)	1.77	0.097
Depth (m)	Prof	0.65 - 1 (0.82 ± 0.13)	1.77	0.274
Distance to shore (m)	Dibe	0.5 - 3 (1.78 ± 0.92)	1.76	0.454
Canopy Size (m)	Taca	0 - 22.5 (6.72 ± 8.26)	1.76	0.363
Averagewidth (m)	Lamo	3.5 - 45 (19.81 ± 13.01)	1.76	0.171
Measures estimated in percentage				
Sand	Sab	5 - 32.5 (20.94 ± 11.72)	1.89	0.001
Gravel	Grav	5 - 70 (26.25 ± 23.26)	1.76	0.366
Pebbles	Cail	0 - 25 (5.94 ± 8.44)	1.86	0.078
Mud	Boue	0 - 20 (7.13 ± 6.98)	1.76	0.219
Dead wood	Bomo	0 - 15 (5.94 ± 5.33)	1.77	0.115
deadleaves	Femo	0 - 10 (4.00 ± 4.13)	1.76	0.262
Mud-dead wood-dead leaves	Bbm	0 - 10 (3.25 ± 3.08)	1.76	0.060
Boulders	Pepi	0 - 10 (3.75 ± 3.72)	1.76	0.325
Large rocks	Grpi	0 - 20 (9.38 ± 7.65)	1.76	0.179
Net shading	Omfi	0 - 60 (23.13 ± 26.58)	1.76	0.333
Laboratory measurement				
Calcium	Ca^{2+}	3.11 - 16 (10.31 ± 4.23)	1.76	0.31
Magnesium	Mg^{2+}	0.90 - 8.21 (4.03 ± 2.85)	1.81	0.02
Potassium	K^{+}	0.5 - 5.26 (3.08 ± 1.83)	1.76	0.27
Ammonium	NH_4^{+}	0.03 - 0.07 (0.04 ± 0.01)	1.76	0.30
Aluminium	Al^{3+}	0.04 - 0.09 (0.07 ± 0.02)	1.76	0.05
Phosphates	PO_4^{3-}	0.01 - 0.34 (0.10 ± 0.13)	1.76	0.43
Sulfates	SO_4^{2-}	1.06 - 5.36 (2.16 ± 1.42)	1.89	0.05
Chloride	Cl^{-}	1.29 - 13.12 (4.76 ± 3.96)	1.89	0.03
Alkalimetrictiter	TAC	4.1 - 10.19 (5.98 ± 2.05)	1.76	0.15
Carbonates	HCO_3^{-}	5 - 12.43 (7.25 ± 2.53)	1.76	0.14
Nitrates	NO_3^{-}	0.3 - 11.45 (3.43 ± 4.00)	1.81	0.34
Nitrites	NO_2^{-}	0.001 - 0.01 (0.0043 ± 0.0041)	1.76	0.50

$$H' = -\sum_{i=1}^{S} (n_i/N) \log (n_i/N) \quad (1)$$

With S: the total number of species present in the station; n_i: number of species individuals in the sample; N: total number sampled individuals. H' varying from 0 to H'_{max} and $H'_{max} = \log S$.

Pielou's R equitability index makes it possible to measure the distribution of individuals within species, independently from specific richness.

$$R = H'/H'_{max} \quad \text{with} \quad H'_{max} = \log S \quad (2)$$

Its value varies from 0 (dominance of one of the species) to 1 (equidistributional of individuals in the species);

The Simpson index for measuring diversity. It measures the probability that two randomly selected individuals belong to the same species [27].

$$D = \sum n_i (n_i - 1)/N(N-1) \quad (3)$$

n_i: represents the number of individuals of species i in the sample and N the total number of individuals. D varies between 0 (maximum diversity) and 1 (minimum diversity).

To identify the relationships between stations, fish communities and different environmental variables, multivariate analyses were performed [28]. These analyses were used to determine the correlation between species richness and environmental variables that influence environmental conditions, using CANOCO 4.5 software for Windows [29]. Numerical abundance matrices of species and environmental variables were used. Data were normalized before ordination, species abundances were transformed into $\log(x+1)$, while environmental variables were transformed into $\ln(x+1)$, or into $\arcsin\sqrt{x}$ for percentage data [18] [30]. Principal Component Analysis (PCA) was chosen, on the one hand, with a gradient length ($3 < LG < 4$) for the distribution of stations according to species abundances; on the other hand, with $LG < 3$ for the distribution of stations according to environmental variables [31]. The Monte Carlo test (999 permutations $p < 0.05$) was performed with variable selection, to retain those that best explain the variations in the fish species data. Only three variables (9.38%) out of 32 were significant at the 0.05 probability threshold (see **Table 1**).

3. Results

3.1. Species Composition

Out of one thousand three hundred and fifty-six specimens captured during this work, 24 species distributed in 18 genera, 9 families and 5 orders were identified. Cyprinids were the most diverse with 8 species, followed by mormyrids, alestids, claroteids, and cichlids with 3 species each. The Distichodontidae, Hepsetidae, Clariidae and Malapteruridae were the least represented families with only one species each (**Table 2**).

Table 2. Species collected, their code and their relative abundances in the stations.

Family	Genus and species	Species code	Station codes							
			BILO	BAPO	NELO	LONE	TSBI	TSLO	MVBF	MVBH
Mormyridae	*Brienomyrus brachyistus* (Gill, 1863)	*Bbra*	0	33.33	0	66.67	0	0	0	0
	Marcusenius moorii Günther, 1863	*Mmoo*	0	100	0	0	0	0	0	0
	Paramormyrops kingsleyae (Günther, 1896)	*Pkin*	0	0	8.79	3.30	23.08	12.09	23.08	29.67
Cyprinidae	*Enteromius camptacanthus* (Bleeker, 1863)	*Ecam*	0	0	0	0	71.75	0	16.14	12.11
	Enteromius holotaenia (Boulenger, 1904)	*Ehol*	8.33	85.42	0	0	2.08	4.17	0	0
	Enteromius martorelli (Roman, 1971)	*Emar*	0	1.96	12.42	5.88	34.64	10.46	16.34	18.30
	Garra ornata (Nichols and Griscom, 1917)	*Gorn*	0	0	0	0	0	25	45	30
	Labeo lukulae Boulenger, 1902	*Lluk*	2.70	24.32	21.62	37.84	0.00	13.51	0	0
	Labeobarbus compiniei (Sauvage, 1879)	*Lcom*	2.94	0	26.47	19.12	2.94	25	10.29	13.24
	Labeobarbus roylii (Boulenger, 1912)	*Lroy*	0	0	0	100	0	0	0	0
	Labeobarbus sandersi (Boulenger, 1912)	*Lsan*	0	0	3.64	23.03	3.03	21.82	24.85	23.64
Distichodontidae	*Distichodus notospilus* Günther, 1867	*Dnot*	0	0	29.33	29.33	0	38.67	2.67	0
Alestidae	*Brachyalestes kingsleyae* (Günther, 1896)	*Bkin*	5.26	94.74	0	0	0	0	0	0
	Brycinus macrolepidotus Valenciennes, 1849	*Bmac*	0	0	38.71	45.16	3.23	12.90	0	0
	Bryconalestes longipinnis (Günther, 1864)	*Blon*	0	100	0	0	0	0	0	0
Hepsetidae	*Hepsetus lineata* (Bloch, 1794)	*Hodo*	0	100	0	0	0	0	0	0
Clariidae	*Clarias camerunensis* Lönnberg, 1895	*Ccam*	0	0	0	0	33.33	0	16.67	50
Malapteruridae	*Malapterurus beninensis* Murray, 1855	*Mben*	0	0	0	0	0	50	0	50

Continued

Claroteidae	*Chrysichthys auratus* (Geoffroy Saint-Hilaire, 1808)	*Caur*	10	90	0	0	0	0	0	0
	Parauchenoglanis balayi (Sauvage, 1879)	*Pbal*	0	0	11.90	4.76	0	4.76	23.81	54.76
	Parauchenoglanis punctatus (Boulenger, 1902)	*Ppun*	0	0	25	0	0	25	50	0
Cichlidae	*Chromidotilapia mamonekenei* Lamboj, 1999	*Cmam*	0	0	3.06	3.06	0.44	15.28	15.72	62.45
	Chromidotilapia melaniae Lamboj, 2003	*Cmel*	0	0	0	0	5	25	65	5
	Hemichromis elongatus (Guichenot, 1861)	*Helo*	0	100	0	0	0	0	0	0

3.2. Diversity Indices

Specific richness (*S*), Shannon (*H'*), equitability (*R*) and Simpson (*D*) indices were calculated based on the numerical abundances of species per station (see Table 3). The highest value of each index is in bold and the lowest is underlined.

Table 3. Ecological diversity indices. *N*: number of specimens; *S*: Specific richness; *R*: equitability; *H'*: Shannon; *D*: Simpson; H'_{max} : Shannon maximum.

Stations	*N*	*S*	*H'*	H'_{max}	*R*	*D*
BILO	13	5	2.04	2.32	0.88	0.22
BAPO	166	10	2.03	3.32	0.61	0.36
NELO	106	10	3.03	3.32	0.91	0.13
LONE	125	11	2.89	3.46	0.84	0.16
TSBI	247	10	1.54	3.32	0.46	0.47
TSLO	174	14	3.15	3.81	0.83	0.13
MVBF	212	12	3.10	3.58	0.87	0.13
MVBH	313	11	2.53	3.46	0.73	0.25
Min	13	5	1.54	2.32	0.46	0.13
Max	313	14	3.15	3.81	0.91	0.47
Avg	169.5	10.38	2.54	3.32	0.77	0.23

Figure 2(a) and Figure 2(b) show the distribution of diversity in 8 stations through the diversity indices *H'*, H'_{max} and *R*. From this graph, equitability is high when the gap between H_{max} and *H'* is low. Five stations (NELO, BILO, LONE, TSLO and MVBH) present, for species found within each of them, an equitable distribution in abundance, the BAPO and TSBI stations have respectively an averagely balanced and unbalanced distribution.

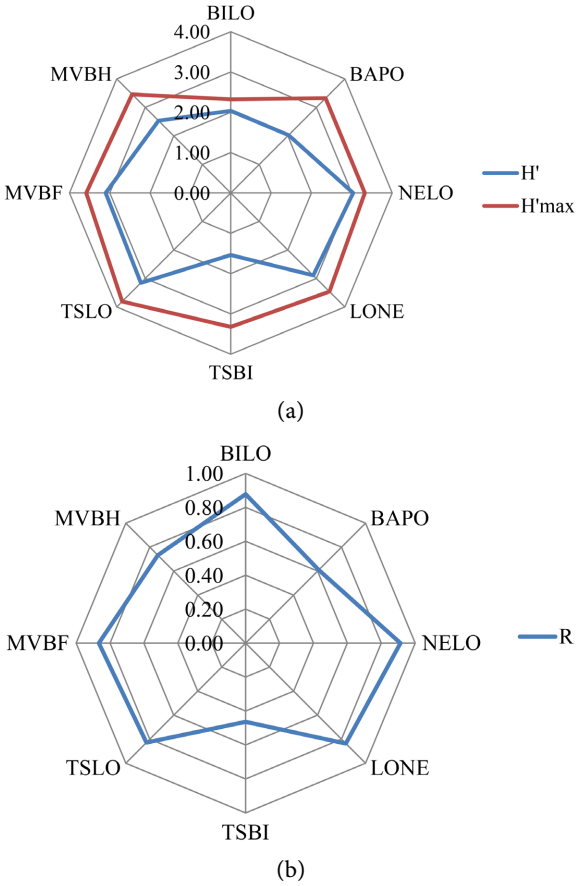
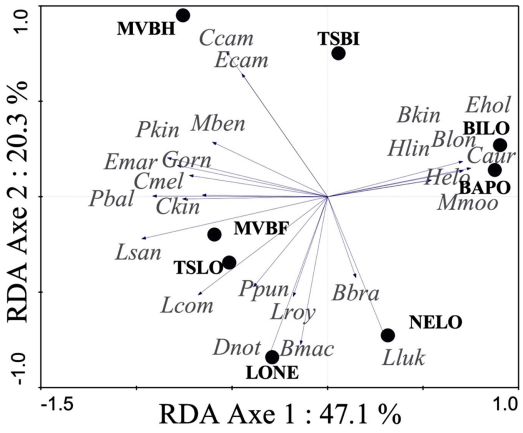


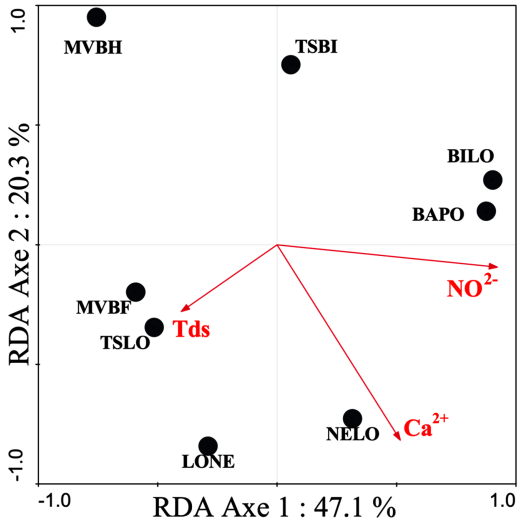
Figure 2. Distribution of diversity in stations across diversity indices. (a): H' and H'_{max}; (b): R.

3.3. Fish Communities, Stations and Environmental Variables

The results of the Canonical Redundancy Analysis (RDA) (**Figure 3(a)** and **Figure 3(b)**) indicate that the first two axes (respectively 47.1% and 20.3%) express 67.4% of the cumulative variance of the fish data. The Monte Carlo test (with 999 permutations) also showed that the contributions of the first two axes are significant ($F = 3.974$; $p = 0.003$). The BAPO and BILO stations are very well represented on axis 1 (47.1%) in its positive part, the TSBI and LONE stations are very well represented on axis 2 (20.3%), respectively on the positive and negative sides. The species *Brachyalestes kingsleyae*, *Bryconalestes longipinnis*, *Chrysichthys auratus*, *Enteromius holotaenia*, *Hemichromis elongatus*, *Hepsetus lineata* and *Marcusenius moorii* are highly correlated with each other and are grouped together in the BAPO and BILO stations. *Clarias camerunensis* and *Enteromius camptacanthus*, which are highly correlated, are present in both the MVBF and MVBH stations and the TSBI station. *Enteromius martoelli*, *Garra ornata* and *Paramormyrops kingsleyae* are also highly correlated and characteristic of the MVBF and MVBH stations. *Brycinus macrolepidotus* and *Distichodus notospilus* are still correlated but to a lesser extent, the former being more present in the TSLO station and the latter in the LONE and NELO stations (**Figure 3(a)**).



(a)



(b)

Figure 3. ARD of species, stations and the three environmental variables selected upstream. (a): species-stations biplot; (b): environmental variables-stations biplot.

4. Discussion

In their study of fishes caught in brackish or freshwater biotopes from coastal regions of the Republic of Congo, [12] reported 62 species from the Loémé River system. [13] published results of an inventory of material collected from the Kouilou and the Loémé at Mayombe, indicating 24 species for the Loémé. Most recently, [14] have identified 41 species from the middle course of the Loémé Rivers system. However, in the present study, the collection of fish carried out in the upper reaches of the Loémé basin allowed to identify 24 species. The Cyprinidae family is the most diversified. It is well known that species richness is a function of habitat diversity. In other words, environments with a wide range of habitats are likely to host a greater number of species [32]. The Loémé basin is characterized, in its upper reaches, by almost uniform habitats that the number of species is not large enough, but characteristic of Lower Guinea. According to [33], the Lower Guinean ichthyofaunal province comprises approximately 680,000 square

kilometers of territory along the west coast of central Africa, following the arc of the Gulf of Guinea from the Cross River in eastern Nigeria, to the Chiloango River in the Angolan province of Cabinda. Extending from 7.4˚E - 7.4˚N to 14.8˚E - 5.4˚S, it includes the mainly coastal rivers draining much of eastern Nigeria, southern Cameroon, Equatorial Guinea, Gabon, south-western Republic of Congo, and Cabinda, all of which flow into the Atlantic Ocean north of the Congo River mouth.

The absence of grass beds which certainly play a role in slowing down currents, which can serve as a brake on erosion, but above all, represent a very important oxygen resource favorable to the presence of a rich and diverse fauna [34] would explain this relatively low diversity.

The study of community structure carried out through the diversity indices (S, H', J'and D) expresses a low specific diversity in the TSBI station where H' is less than 2. This situation can be explained by the very reduced width and depth, the type of vegetation, including the exposure of the station to agricultural activities, giving rise to species adapted to such situations. The equitability of 0.46 (less than 0.5) is the consequence of the codominance of two species (*Enteromius camptacanthus* and *E. martorelli*) in that station. This is corroborated by the findings of [35] who stated that in an environment subjected to difficult conditions, the expected number of species decreases, while the number of individuals per species increases. Similarly, according to [36], the dominance of a species or the strong presence of a few species at a site indicates an increase in the influence of human activities. This diversity is average in the BILO, BAPO, NELO, LONE, TSLO, MVBF, and MVBH stations where H' is between 2 and 3. These are relatively intact stations with regard to anthropogenic activities. For these stations with average specific diversity, a relatively equitable distribution of species abundances is noted within each of them for J' values greater than 0.5. According to [37], the biological communities reflect the conditions of the watershed because they are sensitive to changes in many environmental factors. The regularity of species distribution is an important element of diversity. A species represented abundantly or by a single individual does not make the same contribution to the ecosystem. Maximum diversity is achieved when species have a very regular distribution [38]. This result corroborates the work of [39] on biodiversity and forestry, lessons from the *Sylvipaca* study plots. Regarding the Simpson index, specific diversity is highest in stations where its value is low (0.13), particularly in NELO, TSLO, and MVBF; 0.16 in the LONE station. These stations are characterized by the presence of at least one completely forested bank, therefore with a canopy cover greater than or equal to 50%. However, in the TSBI, BAPO, MVBH, and BILO stations where the values of this index are respectively 0.47; 0.36; 0.25 and 0.22, the banks are characterized by herbaceous facies. This index shows that habitats consisting of grassy banks are less diverse than those consisting of forest banks. The result of the multivariate analyses across axis 1, which alone represents 47.1% showed two trends: that of the species present in the stations located on the negative side and

that of the stations on the positive side of the same axis, notably *Brachyalestes kingsleyae*, *B. longipinnis*, *Chrysichthys auratus*, *Hemichromis elongatus*, *Hepsetus lineata*, and *Marcusenius moorii* which were captured only in the stations located in the locality of Bilinga. These are separated from the other stations by the Loufouyou gorges which constitute a major topographical feature in the locality of Nemba. These gorges make species migrations impossible. According to [40] Depending their size, waterfalls can present impassable barriers for fishes, such that isolated populations upstream remain protected from any competitors. The proximity of the BAPO and BILO stations to each other on the positive side of axis 1, as well as the TSBI and LONE stations, on the negative side of axis 2 in the redundancy analysis (RDA) for both physicochemical parameters and species, could be explained by the quantity of Nitrites as well as by the species that were captured only in these stations. The selection of the microhabitat (station) depends on environmental factors [41].

5. Conclusion

This study provides basic data on the ichthyofaunal diversity and distribution in these upper reaches of the Loémé basin. The fauna sampled, characteristic of the ichthyological province of Lower Guinea, was found to be moderately diverse and distributed with a dominance of species from the Cyprinidae family. This diversity is attributed to the torrential nature of this basin in the study area, the lack of diversification of habitat types, added to this the Loufouyou gorges which constitute a factor limiting the migrations of species. This work opens a door for further studies on the ichthyofauna of the Loufouyou caves.

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Conflicts of Interest

All authors confirm that they have read and approved the content of the submitted article. They also declare that there are no conflicts of interest among the authors or with the publication ethics of the journal.

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