

Anthropogenic Impacts on Fish Populations in Lake Cayo (Republic of Congo, Central Africa)

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Abstract

Ichthyofaunal diversity and the impact of anthropogenic activities on fish population assemblages were studied in Lake Cayo, a small lake located in the coastal region of the Republic of Congo. Twelve stations were sampled twice over a two-year period. Fishing techniques following standardized methods utilizing monofilament gill nets, and nine environment variables were measured at each station. A total of 11,361 specimens comprising 30 species in 28 genera and 18 families were collected with the Cichlidae being the most diversified. Redundancy Analysis with forward selection coupled with Monte Carlo permutation tests identified depth, pH and substrate as accounting for 57.7% of the total variance among the nine variables sampled ($p < 0.05$). The low Shannon's diversity (1.16 ± 0.33) and Equitability (0.43 ± 0.12) indices at all sites, suggest that the Lake Cayo system is in poor ecological health.

Keywords

Fish, Diversity, Ecological Health, Lake Cayo, Lower Guinea

1. Introduction

Continental aquatic ecosystems are particularly affected by anthropogenic activities, including habitat modification, introduction of exotic species, pollution, sedimentation, and overfishing [1] [2]. The consequences of these activities, now amplified by population growth and increasing pressure on natural resources, potentially endanger ichthyofaunal diversity and the biological integrity of aquatic ecosystems. While long spared such impacts, continent-wide African fresh-

waters are now being increasingly impacted [2].

A small lake complex in the lower Loeme River basin includes two freshwater lakes, Cayo and Loufoualeba, both located in the coastal region of the Republic of Congo, about 30 km from the city of Pointe-Noire. Easily accessible via the Cabinda and Patra roads passing through extensive *Eucalyptus* plantations, this lacustrine complex is subject not only to intensive fishing pressure but is also located in a large on-shore oil exploitation area. Hence, establishing conservation and sustainable management measures for the fish populations in both lakes has become increasingly important. In an attempt to ameliorate these problems, since 2010 the lower Loeme lakes have been included as part of a Ramsar conservation site. However, ichthyological knowledge of coastal basins in the Republic of the Congo, including those in the Kouilou and Loeme drainages, is limited. Apart from data reported by [3] and in the recent compilation of [4] [5] on fish species richness across the lower Guinean ichthyofaunal province, no study of fish populations based on estimates of abundance or the drivers of fish community assemblages has previously been performed in the lower Loeme lake complex. Thus, the goal of the present study is to remedy this deficiency by more closely examining these neglected Ramsar ecosystems.

The present study provides the first report of the spatial distribution of fish species, the main environmental variables associated with species assemblages, and an assessment of the ecological health of the Lake Cayo ecosystem.

2. Material and Methods

2.1. Study Area

Fishes were collected in lake Cayo (Figure 1), which with an area of about 5.7 km² is the larger of the lakes in the lower Loémé River basin.

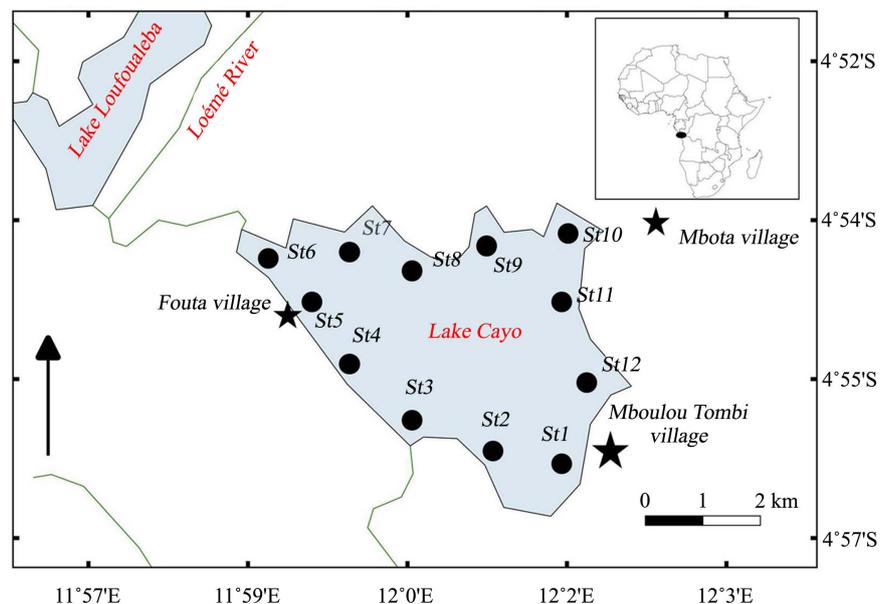


Figure 1. Lower Loémé River lake complex and sampling stations in lake Cayo.

2.2. Fish Sampling

The study area comprised 12 stations throughout the lake (**Figure 1**). Each station was sampled twice over a two-year period from February 2018 to January 2020, thereby including both the dry and rainy seasons. Standardized fishing techniques utilized four monofilament gill nets of 8, 10, 15 and 30 mm mesh sizes. At each station, gill nets were set overnight from 17 h to 7 h following [6]. Fish species were identified in the field, specimens were counted by species, measured to the nearest millimeter standard length (SL), weighed (fresh total weight) to the nearest 0.01 g, and tissue samples were taken from vouchered specimens for DNA extraction for use in subsequent studies. Samples for which field identification was uncertain were preserved in 10% formalin for subsequent identification in the laboratory of the Ichthyology Department of the American Museum of Natural History (AMNH). The classification of the families follows [7], with genera and species in alphabetical order.

2.3. Environmental Data

Prior to fish sampling nine environmental parameters were measured at each station (**Table 1**), with a sampling protocol following [6]. Variables included are: altitude (measured in m with a handheld Garmin GPSmap 64st); depth (in m, measured with an echo-sounder Echotest II Plastimo); pH, water temperature (in °C), salinity (in ppm), and conductivity ($\mu\text{S}/\text{cm}$) (all measured with an Am-tast multiparameter tester). The following substrate categories were identified and scored as %: sand, mud, or plant debris. Data for all nine parameters were collected at the beginning, middle, and end of each station, and all sampled stations were georeferenced using a GPSmap 64st. For each station, values given are mean values for 4 gill-nets, 2 seasons and 2 years (total $N=16$).

Table 1. Physico-chemical characteristics measured. * = Mean values for 4 gill-nets, 2 seasons and 2 years (total $N=16$).

Variables	Code	Stations											
		St1	St2	St3	St4	St5	St6	St7	St8	St9	St10	St11	St12
Altitude	Alt	3	3	4	4	5	4	4	5	3	4	4	3
Depth (m)*	Dep	1.08	1.00	1.10	0.99	1.05	1.51	1.43	1.23	1.71	0.73	1.10	0.76
pH*	pH	8.29	10.38	10.35	9.82	10.31	10.39	10.37	9.94	10.41	10.26	10.00	10.54
Conductivity ($\mu\text{S}/\text{cm}$)*	Cond	21.00	39.63	38.50	35.13	35.13	35.75	36.00	35.88	38.25	39.75	35.38	35.38
Salinity (ppm)*	Sal	36.75	39.63	35.63	37.75	36.75	39.00	39.13	39.50	41.63	43.38	38.75	39.13
<i>Substratum type (in %)</i>													
Sand	Sand	45	45	5	45	5	5	5	5	5	5	10	10
Plan debris	Pld	30	30	60	30	60	60	60	60	60	60	30	30
Mud	Mud	25	25	35	25	35	35	35	35	35	35	60	60

2.4. Statistical Analyses

Redundancy Analysis [8] was used to investigate possible correlations between environmental variables and fish community assemblages. Therefore, two matrices covering the 12 sampled stations were constructed, one containing numerical abundance of all species collected and another of the environmental variables. Monte Carlo tests (199 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 [9] using respectively $\log_{10}(x+1)$ and $\ln(x+1)$ or $\arcsin\sqrt{x}$ for percentages. In addition, the ecological health of the lake was evaluated, calculating three ecological diversity indices [10] [11]: Species richness S ; Shannon index H' with its Shannon maximum index H'_{\max} [12]; and Equitability R [13].

Species richness (S) is the number of species represented in the catches. Shannon diversity index (H') were calculated according the formula:

$$H' = \sum_{i=1}^S P_i \ln P_i \quad (1)$$

With $P_i = n_i/N$; N being the total number of individuals obtained for all species, n_i is the number of individuals of species i and P_i the relative abundance of species i in the sample. Shannon index varies between 0 and H' maximum, calculated according to the formula:

$$H'_{\max} = \ln S \quad (2)$$

The Equitability (R) indicates whether individuals are equally distributed among the species of the target area, and varies between 0 and 1. It tends towards 0 when the totality of catches is almost entirely of one species, and towards 1 when all species have the same abundance within given sample. It is calculated using the formula:

$$R = \frac{H'}{H'_{\max}} \quad (3)$$

The analysis was performed using CANOCO (Canonical Community Ordination, version 4.5) [8], for multivariate analysis (RDA); PRIMER version 5 [14] for univariate analysis (S , H' and R).

3. Results

3.1. Species Composition

Fish composition is provided in **Table 2**. A total of 11,361 specimens comprising 30 species belonging to 28 genera and 18 families were collected. Among families represented Cichlidae is the most species rich (5 species), with the remaining families represented by only 1 to 3 species. Among these is a putatively undescribed species of *Enteromius*, and a single introduced species (*Heterotis niloticus*).

Table 2. List of species collected, their code and relative abundance.

Families and species	Code	St1	St2	St3	St4	St5	St6	St7	St8	St9	St10	St11	St12
Arapaimidae													
<i>Heterotis niloticus</i> (Cuvier, 1829)	Hen	0.00	0.10	0.00	0.00	0.00	0.63	0.00	0.36	0.00	0.08	0.00	0.12
Mormyridae													
<i>Brienomyrus brachyistius</i> (Gill, 1862)	Brb	0.45	0.70	1.23	0.98	1.21	11.95	5.81	1.07	0.35	0.08	0.24	0.12
<i>Marcusenius moorii</i> (Günther, 1867)	Mam	0.45	0.90	1.09	0.28	1.69	1.89	0.81	2.25	1.24	0.08	0.12	0.23
<i>Pollimyrus pedunculatus</i> (David & Poll, 1937)	Pop	0.00	0.10	0.14	0.00	0.12	1.26	0.00	0.00	0.05	0.00	0.00	0.00
Clupeidae													
<i>Ethmalosa fimbriata</i> (Bowdich, 1825)	Ttf	0.00	0.00	0.00	0.00	0.00	0.00	2.70	0.00	0.00	0.00	0.00	0.12
Cyprinidae													
<i>Enteromius</i> sp	Esp	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.40	0.75	0.00	0.00
Distichodontidae													
<i>Neolebias spilotaenia</i> Boulenger, 1912	Nes	0.00	0.00	0.14	0.00	0.00	0.00	1.35	0.00	0.00	0.00	0.00	0.00
Alestidae													
<i>Brycinus kingsleyae</i> (Günther, 1896)	Brk	2.71	0.00	1.77	9.55	0.60	19.81	17.97	3.20	8.21	4.22	0.00	14.99
<i>Nannopetersius ansorgii</i> (Boulenger, 1910)	Naa	78.72	63.20	76.29	66.71	78.96	41.82	57.84	83.91	86.65	74.92	63.90	51.79
<i>Nannopetersius lamberti</i> Poll, 1967	Nal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	3.73	0.00
Clariidae													
<i>Clarias jaensis</i> Boulenger, 1909	Clj	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Clarias buthupogon</i> Sauvage, 1879	Csp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.08	0.00	0.00
Claroteidae													
<i>Chrysichthys dageti</i> Risch, 1992	Chd	8.66	18.70	3.95	2.53	3.75	7.23	0.81	3.08	0.25	4.59	7.70	7.73
Schilbeidae													
<i>Parailia occidentalis</i> (Pellegrin, 1901)	Pao	0.45	1.00	2.32	0.70	3.75	1.26	0.95	2.13	0.84	0.83	3.01	0.12
Eleotridae													
<i>Dormitator lebretonis</i> (Steindachner, 1870)	Dol	0.72	0.00	0.54	0.00	0.00	1.26	0.54	1.07	0.15	0.00	1.08	0.00
<i>Eleotris vittata</i> Duméril, 1861	Elv	0.54	0.00	0.41	0.00	0.00	4.09	0.68	0.00	0.35	0.00	0.84	0.81
Gobiidae													
<i>Ctenogobius lepturus</i> (Pfaff, 1933)	Ctl	0.36	1.30	2.59	1.97	0.00	1.26	6.35	0.36	0.45	0.75	1.93	5.77
<i>Gobionellus occidentalis</i> (Boulenger, 1909)	Goo	0.00	0.00	0.00	7.87	0.00	0.00	0.00	0.00	0.00	0.08	0.00	2.88
<i>Sicydium crenilabrum</i> Harrison, 1993	Sic	0.09	0.40	0.27	0.28	0.12	0.31	0.14	0.00	0.05	0.00	0.24	0.12
Anabantidae													
<i>Microctenopoma congicum</i> (Boulenger, 1887)	Mic	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Channidae													
<i>Parachanna insignis</i> (Sauvage, 1884)	Pob	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cichlidae													
<i>Chilochromis duponti</i> Boulenger, 1902	Cdu	0.00	0.00	0.00	0.00	0.48	0.31	0.00	0.00	0.00	0.00	0.00	0.00

Continued

<i>Hemichromis elongatus</i> (Guichenot, 1861)	<i>Hee</i>	4.06	5.90	5.18	3.51	3.87	2.83	2.84	1.30	0.94	6.25	9.99	3.11
<i>Oreochromis schwebischi</i> (Sauvage, 1884)	<i>Ors</i>	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.24	0.00	0.00	0.00	0.00
<i>Pelmatolapia cabrae</i> (Boulenger, 1899)	<i>Pec</i>	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
<i>Coptodon guineensis</i> (Günther, 1862)	<i>Cog</i>	2.43	7.20	3.95	4.92	4.47	3.46	1.22	0.47	0.05	4.59	7.10	12.00
Mugilidae													
<i>Neochelon falcipinnis</i> (Valenciennes, 1836)	<i>Nef</i>	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00
Carangidae													
<i>Trachinotus teraia</i> Cuvier, 1832	<i>Trt</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00
Gerreidae													
<i>Eucinostomus melanopterus</i> (Bleeker, 1863)	<i>Eum</i>	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.45	0.00	0.00
Haemulidae													
<i>Pomadasys jubelini</i> (Cuvier, 1830)	<i>Poj</i>	0.00	0.10	0.14	0.56	0.36	0.00	0.00	0.00	0.00	2.11	0.00	0.12

3.2. Fish Communities, Stations, and Environmental Variables

Results of the Redundancy Analysis (**Figure 2(a)** and **Figure 2(b)**) indicate that the first two axes (22.3% and 13.1% respectively) express 35.4% of the cumulative variance in the fish data. Species and environmental variable correlations for both axes are high, respectively 0.95 and 0.82. Monte Carlo permutation tests (999 iterations) also indicate that the contributions of the two first axes are significant ($F = 1.79$; $p = 0.009$). Consequently, only these two axes were considered for data analysis. Redundancy Analysis with forward selection identified three environmental variables as accounting for 57.7% of the total variance among nine variables ($p < 0.05$): Depth, pH and substrate (mud). Based on these results, it appears that the three selected environmental variables have a significant ($p < 0.05$) influence on fish community assemblages in Lake Cayo.

Three groups of sampling sites are distinguished in relation to both RDA Axes 1 and 2 (**Figure 2(a)**): Group 1, represented by stations (St 1, 10, 11 and 12) described as across the lake from the affluent inlet of the Loeme; Group 2, composed of stations (St 6, 7, 8 and 9) described as adjacent to the affluent inlet of the Loeme; and Group 3, composed of stations (St 2, 3, 4 and 5) described as adjacent to the effluent outlet into the Loeme.

The eleven fish species found at Group 1 sites, negatively correlated with Axis 1 and positively with Axis 2, include *Chrysichthys dageti*, *Clarias buthupogon*, *C. jaensis*, *Enteromius* sp, *Eucinostomus melanopterus*, *Hemichromis elongatus*, *Pomadasys jubelini*, *Gobionellus occidentalis*, *Nannopetersius ansorgii* and *N. lamberti*. Those at Group 2 sites, positively correlated with Axis 1, are distinguished by an assemblage including 12 species (*Brienomyrus brachyistius*, *Dormitator lebretonis*, *Eleotris vittata*, *Ethmalosa fimbriata*, *Marcusenius moorii*, *Microctenopoma congium*, *Neolebias spilotaenia*, *Parailia occidentalis*, *Pelmatolapia cabrae*, *Pollimyrus pedunculatus*, *Oreochromis schwebischi* and *Trachinotus teraia*). And those at Group 3 sites, negatively correlated with Axis 1 and

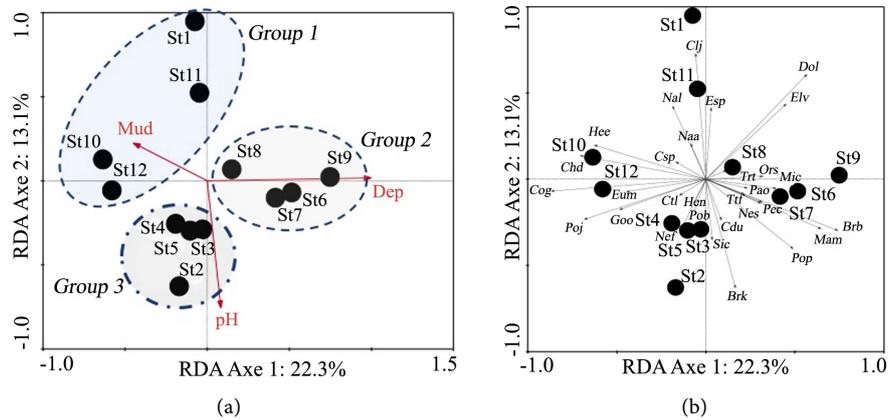


Figure 2. RDA ordination of species, stations and the two forward selected environmental variables. (a): biplot of stations and environmental variables; (b): biplot of stations and species.

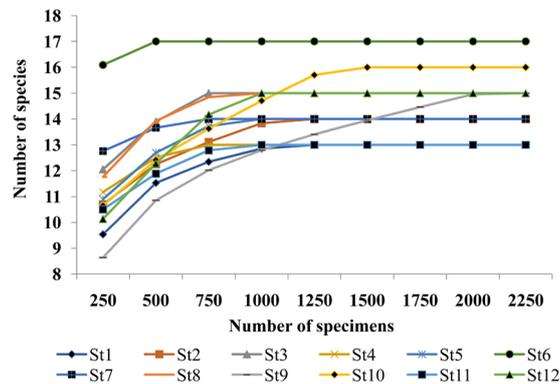


Figure 3. Rarefaction of the specific richness in each station studied (12) according to the number of specimens.

2, are composed of 7 species (*Brycinus kingsleyae*, *Chilochromis duponti*, *Ctenogobius lepturus*, *Heterotis niloticus*, *Neochelon falcipinnis*, *Parachanna insignis*, and *Sicydium crenilabrum*).

3.3. Rarefaction of Species Richness

Rarefaction curves of the species richness at each station (Figure 3) indicate that an increase in the number of specimens collected does not necessarily lead to an increase in the species richness. Thus, a sample of 318 specimens was needed to reach the maximum number of 17 species in the most diversified station (St2). While in the least diversified stations (St1, St4 and St11, with 13 species each), respectively 712, 1079 and 831 specimens were reported.

3.4. Ecological Diversity Indices

Ecological diversity indices, including species richness (S), Shannon index (H), Shannon maximum index (H'_{max}) and Equitability (R) were calculated for each of the 12 stations (Table 3). Values of Equitability were highest 0.59 in station 6 and lowest 0.21 in station 9.

Table 3. Ecological diversity indices. N : number of specimens; S : Species richness; H' : Shannon index; H'_{\max} : Shannon maximum index; R : Equitability.

Stations	S	N	H'	H'_{\max}	R
St1	13	1079	0.80	2.56	0.31
St2	14	1058	1.35	2.63	0.51
St3	15	734	1.07	2.70	0.39
St4	13	712	1.28	2.56	0.49
St5	14	827	0.95	2.64	0.35
St6	17	318	1.66	2.83	0.59
St7	14	740	1.47	2.64	0.55
St8	15	845	0.80	2,71	0.29
St9	15	2022	0.59	2.71	0.21
St10	16	1328	1.06	2.77	0.38
St11	13	831	1.34	2.57	0.52
St12	15	867	1.55	2.71	0.57

4. Discussion

4.1. Fish Diversity and Distribution

In their study of fishes caught in brackish or freshwater biotopes from coastal regions of the Republic of Congo, [3] reported only six species (*Eleotris vittata*, *Ethmalosa fimbria*, *Eucinostomus melanopterus*, *Neochelon falcipinnis*, *Pelmatolapia cabrae* and *Pomadasys jubelini*) present in Lake Cayo. However, in the present study a total of 30 species is reported for the lake and this ichthyofauna is dominated by Cichlidae, despite only a single species, *Pelmatolapia cabrae*, being reported by [3]. All species recorded from Lake Cayo are typical of the lower Guinean ichthyofaunal province, with the exception of *Heterotis niloticus*, which has been widely introduced within the area for aquaculture purposes [15].

The present study represents the first ecological investigation of fishes performed in a coastal basin of the Republic of Congo, and compliments a short list of the similar studies recently undertaken in the lower Guinean ichthyofaunal province [16] [17]. Given the small size and seeming homogeneity of habitat space within Lake Cayo, a total of 30 species unevenly distributed across sites within the lake is unexpected. Yet, according to the RDA (**Figure 2(b)**), water depth (22.3%) is the most important variable for fish distribution in the system, followed by pH (20.1%) and a mud substrate (15.3%). Several authors have already shown the importance of these environmental variables in structuring fish populations in both riverine and lacustrine ecosystems in Africa [6] [16] [17] [18] [19] [20].

4.2. Ecological Health of the Lake Cayo

The Southwestern Coastal Equatorial ecoregion, in which Lake Cayo is located,

has been identified as being highly vulnerable to human impacts [21]. Among these oil exploitation and logging are the main activities identified as polluting aquatic systems in the ecoregion. To these must be added increasing over exploitation of fish stocks (pers. obs.).

The three ecological diversity indices (S , H' and R), calculated based on species abundance, revealed that in all habitat groups in the Cayo (see **Figure 2(a)**), the H' (Group 1: mean = 1.19; Group 2: mean = 1.13; Group 3: mean = 1.16) and R (Group 1: mean = 0.45; Group 2: mean = 0.41; Group 3: mean = 0.43) indices are far from approaching their maximum values, respectively H' maximum (2.65; 2.72; 2.63) for H' and 1 for R . Even if analysis of fish communities using diversity indices does not reflect the complete organizational modalities of populations within a system, it is however known that these indices are of utility in the diagnosis of aquatic ecosystem health [22] [23]. In addition, it is well known that when all species of a community are in abundance and the environment in good ecological health, H' and R indices approach their maximum values [23] [10]. This situation is not the case in the lake Cayo where *Nannopetersius ansorgii* dominates significantly (72.1%) in all the stations sampled. Based on these results, it is now clear that the Lake Cayo is not in good ecological health, and as discussed below this probably reflects increasing anthropogenic activities around the lake.

5. Conclusion

The present study provides data on fish diversity and imbalance in terms of abundance on fish species in the lake Cayo, one of the lakes of the Lower Loeme lake complex. An imbalance which could be explained by the species *Nannopetersius ansorgii*, well adapted to this environment. With 30, a total of fish species reported, including a putatively undescribed species of *Enteromius* and a single introduced species (*Heterotis niloticus*), this database contributes to a better understanding of fish communities in the lower Guinean ichthyofaunal province. Water depth, pH and Mud are shown to have a significant influence on fish assemblages. The low values of the Shannon and Equitability indices in all the habitats sampled could indicate the negative impacts mainly from overfishing and oil pollution on the ecological health of Lake Cayo.

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Conflicts of Interest

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

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