Environmental Influences on Fish Species Distribution in the Musolo River System, Congo River Basin (Democratic Republic of the Congo, Central Africa)

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Abstract

Ichthyofaunal distribution was studied in the Musolo River system, a small affluent tributary of the Congo River flowing into Pool Malebo (Democratic Republic of the Congo). Twelve ecological stations were sampled, of which eight were located in the Musolo main-channel and four in the Fushi River, a principal tributary of the Musolo. Each station was sampled four times over a two-year period, with fishing techniques following standardized methods utilizing dip and cast nets, and nine environment variables were measured at each station. Fifty-three fish species belonging to 36 genera and 16 families were collected with the Alestidae, Distichodontidae, Cichlidae, Cyprinidae, Mormyridae, and Mochokidae being the most diversified. Redundancy Analysis with forward selection coupled with Monte Carlo permutation tests (499 permutations) identified total dissolved solid (25.8%) and altitude (24.4%) as accounting for 50.2% of total variance ($p < 0.05$). The contribution of the two first axes was significant ($F = 3.41$; $p = 0.004$). Species richness increases from upstream to downstream. In general, the high value of Shannon's diversity (1.07-2.67) and Equitability

(0.62-0.96) indices at all sites, indicates that the examined stretch of the Musolo River system is in good ecological health, despite its location adjacent to the megacity of Kinshasa

Keywords: Fish, Ecology, Musolo River, Pool Malebo, Middle Congo, Africa

Introduction

Aquatic ecosystems throughout the African continent are increasingly impacted by human activities, such as over fishing and destructive fishing practices, charcoal production, industrial deforestation, dam construction for irrigation and hydropower, and pollution (Kamdem Toham & Teugels, 1999; Mbimbi & Stiassny, 2011; Aboua et al., 2015; Monsembula et al., 2013; Paugy & Lévêque, 2017). The consequences of such activities potentially endanger the biological integrity of these ecosystems and the diversity of their ichthyofaunas. With almost 3.7 million km^2 of drained surface, 40,200 m^3s^{-1} annual average discharge, and over 1250 valid fish species (Snoeks et al., 2011) the Congo basin, second only to the Amazon River in discharge (Lee et al., 2011), is not spared from human pressure, mainly amplified by rapid demographic growth and economic development. This huge area and its different aquatic habitats harbor the world's second most diversified freshwater fish community after that of the Amazon River basin (Winemiller et al., 2016).

Within the Congo Basin, Pool Malebo, which harbors about 316 fish species, forms the boundary between the lower and middle Congo ichthyofaunal regions and is one of the most species-rich areas currently known throughout the Congo catchment, exclusive of Lake Tanganyika (Snoeks et al., 2011). However, this species richness likely reflects the result of collection efforts mainly concentrated in the main channel of the Congo River and in some of its larger tributaries while smaller tributaries, such as the Musolo River, remain unexplored. Moreover, because of the demographic growth of the megacity of Kinshasa, smaller tributaries in the vicinity have undergone profound habitat alteration due to farming, deforestation, charcoal production, and overexploitation pressure. Thus, it is necessary to survey these smaller systems before species or populations go extinct because knowing how many and what species inhabit an ecosystem is fundamental for any ecological study and for effective management of biodiversity (Lalèyé 2006; Olds et al., 2016).

To contribute to the knowledge of *diversity and ecology of the Congo basin ichthyofauna*, the present study was conducted in the Musolo River basin where diversity and spatial distribution of fish species was investigated, and the main environmental variables associated with species assemblages were assessed.

Material and Methods

Study area

Fishes were collected in the Musolo River system, including the main-channel and Fushi River, its principal tributary (Figure 1). With a main-channel length of around 20 km, and a basin area of about 120 km^2, the Musolo River is a small left bank tributary of the Congo River flowing into Pool Malebo in the Democratic Republic of the Congo. The Musolo River system is located in N'sele, a peripheral municipality of the megacity of Kinshasa, at about 25 km from the center of Kinshasa. Nowadays, about 15 percent of the Musolo drainage is located within the heavily populated port town of Kinkole in the northeast part of the city.

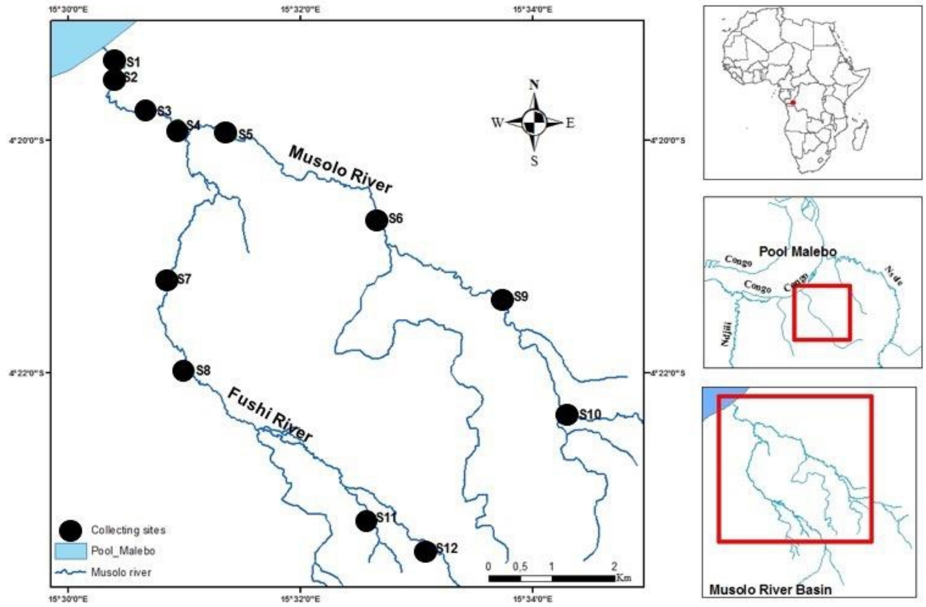

Figure 1: Musolo River basin and sampling stations

Fish sampling

A total of 12 ecological stations were sampled (Figure 1) eight of which (S 1, 2, 3, 4, 5, 6, 9 and 10) located in the main-channel and four (S 7, 8, 11 and 12) located in a major tributary (Figure 1). Stations were sampled four times over a two-year period from February 2015 through September 2016, including both the dry and rainy seasons. Standardized fishing techniques utilized dip nets and cast nets of 12 mm mesh size and 3 m in diameter. At each station of about 100 m, three dip nets were used (Figure 2a) simultaneously during 30 min before making 20 cast net jets along the length of each station (Figure 2b).

All samples were identified in the field, specimens counted by species and tissue samples were taken from vouchered specimens for DNA extraction to be analyzed in subsequent studies. Fishes for which field identification was not certain 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 Van Der Laan et al (2019), with genera and species in alphabetical order.

Figure 2: Fishing technics. a: search with dip nets (station 4); b: cast nets (station 1).

Environmental data

Prior to fish sampling, nine environmental parameters were collected at each station (Table 1). The variables included are: depth (in m, measured with a Norcross Hawkeye H22PX echo-sounder); pH, water temperature (in °C), total dissolved solid (in ppm), and conductivity (µS/cm) (all measured with a Hanna Combo tester HI 98129); altitude (measured in m with a GPSmap 64st). The following substrate categories were identified and scored as %: sand; mud; and gravel. Data for all nine parameters were collected at the beginning, middle, and end of each station. Therefore, for each station, values given are mean values for 3 sampling points, 2 seasons and 2 years (total N= 12).

Table 1: *Physico-chemical characteristics measured. *: 3 sampling points, 2 seasons and 2 years (total N= 12).*

Environmental variables	**Code**	**Stations**											
		S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
Temperature (°C)*	Temp	27.6	30	27.3	26.2	27.5	30.1	28.1	28.4	26	26	24	24.2
pH*	PH	5.9	5.75	6.09	6.1	6.75	6.18	5.9	6	6.2	6.1	5.93	6.25
Conductivity (µS/cm)*	Con	6.0	4.0	5.0	5.0	3.0	1.0	1.0	2.0	2.0	2.0	6.0	5.0
Total Dissolved Solids (ppm)*	TDS	3.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	3.0	2.0
Altitude (m)	Alt	280	281	282	287	289	313	300	309	328	359	327	338
Depth (m)*	Dep	0.7	1.3	1.1	1.2	0.9	0.8	1.2	1	0.5	0.5	0.5	0.8
Substrate types (%)													
Sand	San	80	100	100	100	80	100	100	100	100	100	60	80
Mud	Mud	20	0	0	0	20	0	0	0	0	0	40	0
Gravel	Gra	0	0	0	0	0	0	0	0	0	0	0	20

Data analysis

In the present study, Redundancy Analysis (RDA), using CANOCO (Canonical Community Ordination, version 4.5) (Ter Braak & 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 (499 permutations, $p < 0.05$) were used to select environmental variables explaining variation in the fish species data. Prior to ordination, fish abundance and environmental data were transformed to better meet the assumptions of normality (Fischer & Paukert, 2008) using respectively $\log_{10}(x+1)$ and ln (x+1) or ArcSin$\sqrt{x}$ for percentages.

The ecological health of the Musolo River was evaluated at each station by calculating three ecological diversity indices (Lobry et al., 2003; Lande, 1996), using PRIMER version 5 (Clarke & Gorley, 2001): Species richness S, Shannon index H’, and Equitability R. Species richness S is the number of species represented in the catches. Shannon diversity index H’ (Shannon, 1948) was calculated according to the following formula:

$$H' = -\sum_{i=1}^{S} P_i \ln P_i$$

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:

$$H'max.. = lnS.$$

The Equitability R (Pielou, 1966) indicates whether individuals are equally distributed among the species of the studied site, 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:

$$R = H'/H'max.$$

Results

Species composition

The composition of the ichthyofauna of the Musolo River system collected during this study is presented in Table 2. A total of 602 specimens, including 53 species belonging to 36 genera and 16 families, were collected. The species reported, include two *Clariallabes* unassignable to currently known species and one introduced species (*Oreochromis niloticus*). Among the fish families sampled, Alestidae (n = 8 species), Distichodontidae (n = 7), Cichlidae, Cyprinidae, and Mormyridae (n = 6 each), Mochokidae (n = 4) are the six most represented. The remaining families are poorly represented ($1 \leq n \leq 3$).

Table 2: List of species collected, their code and relative abundance. (*) Introduced species.

Families and species	Code	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Notopteridae													
Xenomystus nigri (Günther, 1868)	Xen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0
Mormyridae													
Gnathonemus petersii (Günther, 1862)	Gnp	1.2	0.0	1.8	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marcusenius aff. macrolepidotus (Peters, 1852)	Mam	5.8	3.4	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marcusenius monteiri (Günther, 1873)	Mamo	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marcusenius stanleyanus	Mas	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petrocephalus christyi Boulenger, 1920	Pec	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petrocephalus microphthalmus Pellegrin,1908	Pem	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clupeidae													
Microthrissa congicus (Regan, 1917)	Mic	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyprinidae													
Clypeobarbus pleuropholis (Boulenger, 1899)	Clp	15.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Labeo lineatus Boulenger, 1898	Lali	2.5	0.0	3.6	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Labeo longipinnis Boulenger, 1898	Lalo	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Labeo cf. *parvus* Boulenger, 1902	Lap	0.0	0.0	0.0	1.7	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Labeo weeksii Boulenger, 1909	Law	1.2	0.0	1.8	5.2	4.5	21.1	9.1	0.0	0.0	0.0	0.0	0.0
Raiamas christyi (Boulenger, 1920)	Rac	0.8	12.1	7.3	3.4	54.5	42.1	72.7	23.1	46.9	0.0	0.0	24.0
Distichodontidae													
Distichodus affinis Günther, 1873	Diaf	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distichodus antonii Schilthuis, 1891	Dian	0.4	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distichodus atroventralis Boulenger,1898	Diat	0.0	1.7	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distichodus sexfasciatus Worthington & Ricardo, 1937	Dis	0.4	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mesoborus crocodilus Pellegrin, 1900	Mec	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nannocharax cf. *gracilis* Poll, 1939	Nag	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nannocharax cf. *schoutedeni* Poll, 1939	Nas	0.4	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 2: *Continued.*

Families and species	Code	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Alestidae													
Alestopetersius tumbensis Hoedeman, 1951	**Alt**	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brycinus comptus (Roberts & Stewart, 1976)	Brc	22.8	8.6	30.9	12.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brycinus imberi (Peters, 1852)	Bri	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bryconaethiops boulengeri Pellegrin, 1900	Brb	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.0	18.8	0.0	0.0	12.0
Hydrocynus goliath Boulenger, 1898	Hyg	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrocynus vittatus Castelnau, 1861	Hyv	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Micralestes acutidens (Peters, 1852)	Mia	19.5	3.4	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phenacogrammus interruptus (Boulenger, 1899)	Phi	3.7	22.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clariidae													
Clariallabes sp1	Clsp1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.0	2.2	0.0
Clariallabes sp2	Clsp2	0.4	0.0	0.0	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clarias gabonensis Günther, 1867	Clg	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphiliidae													
Belonoglanis tenuis Boulenger, 1902	Beb	1.7	8.6	43.6	36.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phractura scaphyrhynchura (Vaillant, 1886)	Phs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0
Mochokidae													
Microsynodontis christyi Boulenger, 1920	Mich	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synodontis congica Poll, 1971	Syc	0.0	6.9	0.0	8.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synodontis notatus Vaillant, 1893	Syn	0.8	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synodontis schoutedeni David, 1936	Sys	0.8	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Clroteidae													
Auchenoglanis occidentalis (Valenciennes, 1840)	Auo	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Parauchenoglanis monkei (Keilhack, 1910)	Pam	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0

Table 2: *Continued.*

Families and species	Code	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Schilbeidae													
Parailia congica Boulenger, 1899	Pac	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Schilbe intermedius Rüppell, 1832	Sci	2.5	1.7	1.8	12.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Schilbe marmoratus Boulenger, 1911	Scm	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mastacembelidae													
Mastacembelus niger (Sauvage, 1879)	Man	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0
Channidae													
Parachanna obscura (Günther, 1861)	Pao	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0
Cichlidae													
Coptodon tholloni (Sauvage, 1884)	Cot	2.1	5.2	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	40.0	52.0
Ctenochromis polli (Thys van den Audenaerde, 1964)	Ctp	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemichromis elongatus (Guichenot, 1861)	Hee	1.2	1.7	0.0	0.0	4.5	5.3	0.0	0.0	0.0	50.0	6.7	0.0
Hemichromis stellifer Loiselle. 1979	Hes	1.7	0.0	0.0	0.0	31.8	26.3	13.6	23.1	6.3	16.7	28.9	8.0
Oreochromis niloticus (Linneaus, 1758)*	Orn	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tylochromis lateralis (Boulenger, 1898)	Tyl	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nothobranchiidae													
Epiplatys chevalieri (Pellegrin, 1904)	Epc	0.0	0.0	0.0	0.0	0.0	5.3	0.0	15.4	12.5	33.3	15.6	0.0
Epiplatys spilargyreius (Duméril,1861)	Eps	0.0	0.0	0.0	3.4	0.0	0.0	0.0	38.5	0.0	0.0	0.0	0.0

Fish communities, stations and environmental variables

Results of the Redundancy Analysis (Figure 3) indicate that the first two axes (33.3% and 9.8% respectively) express 43.1% of the cumulative variance in the fish data. Species and environmental variable correlations for both axes are high, respectively 0.88 and 0.84. Monte Carlo permutation tests (499 iterations) also indicate that the contributions of the two first axes are significant ($F = 3.41$; $p = 0.004$). Redundancy Analysis with forward selection identified two environmental variables as accounting for 50.2% of the total variance among five variables ($p < 0.05$): total dissolved solids (TDS, 25.8%) and altitude (24.4%). Our results indicate that these two environmental variables have a significant ($p < 0.05$) influence on fish community assemblages in the Musolo River basin.

Three habitat types of sampling sites are distinguished in relation to both RDA Axes 1 and 2 (see Figure 3a): Upstream, represented by sites located upstream close to the source (S9, S10, S11 and S12); Middle, sites composed of intermediate stations (S5, S6, S7and S8); and downstream, composed of sites (S1, S2, S3 and S4) situated downstream from the confluence of the Musolo River main-channel with the Fushi River.

The main fish species found upstream, positively correlated with Axis 2 are *Bryconaethiops boulengeri*, *Clariallabes* sp1, *Coptodon tholloni*, *Epiplatys chevalieri*, *E. spilargyreius*, *Hemichromis elongatus*, *H. stellifer*, *Parauchenoglanis monkei*, and *Xenomystus nigri*. Intermediate habitats, positively correlated with Axe 1 and negatively correlated with Axis 2, are mainly composed of *Brycinus comptus*, *Clarias gabonensis*, *Labeo longipinnis*, *Mastacembelus niger*, *Phractura scaphyrhynchura*, *Raiamas christyi*. Downstream habitats, negatively correlated with Axis 1, are distinguished by an assemblage including *Alestopetersius tumbensis*, *Auchenoglanis occidentalis*, *Belonoglanis tenuis*, *Brycinus imberi*, *Clariallabes* sp2, *Clypeobarbus pleuropholis*, *Ctenochromis polli*, *Distichodus affinis*, *Distichodus antonii*, *D. atroventralis*, *D. sexfasciatus*, *Gnathonemus petersii*, *Hydrocynus goliath*, *H. vittatus*, *Labeo lineatus*, *L.* cf. *parvus*, *L. weeksii*, *Marcusenius* aff. *macrolepidotus*, *M. monteiri*, *M. stanleyanus*, *Mesoborus crocodilus*, *Micralestes acutidens*, *Microthrissa congicus*, *Microsynodontis christyi*, *Nannocharax* cf. *schoutedeni*, *N.* cf. *gracilis*, *Oreochromis niloticus*, *Parachanna obscura*, *Parailia congica*, *Petrocephalus christyi*, *P. microphthalmus*, *Phenacogrammus interruptus*, *Schilbe intermedius*, *S. marmoratus*, *Synodontis congica*, *S. notatus*, *S. schoutedeni* and *Tylochromis lateralis*.

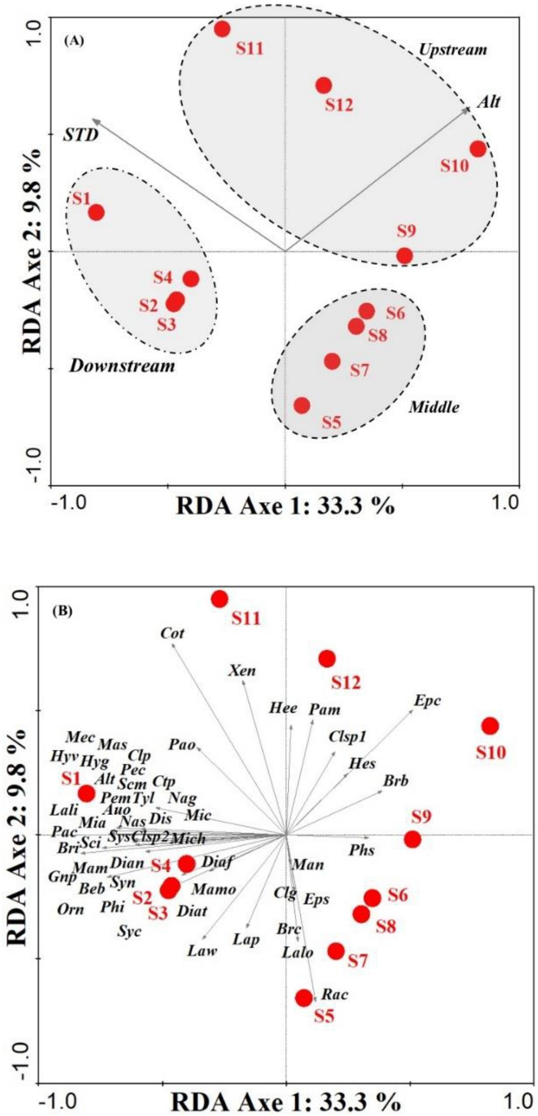

Figure 3: *Redundancy Analysis ordination of species, stations, and the two forward selected environmental variables.* ***A****: biplot of stations and environment variables;* ***B:*** *biplot of stations and species.*

Spatial variation of ecological diversity indices

For each of the twelve sampling stations, diversity indices, including species richness (S), Shannon index (H'), Shannon maximum index (H' max.), and Equitability (R) were calculated (Table 3). With 12 specimens and three species, station 10 was the least diversified, whereas station 1 was the most diversified with 241 specimens and 36 species. However, values of Equitability were highest 0.96 in station 8 and lowest 0.62 in station 7.

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	R	H'	H'max
S1	36	241	0.74	2.66	3.58
S2	21	58	0.88	2.67	3.04
S5	6	23	0.70	1.25	1.79
S6	5	19	0.84	1.35	1.61
S7	4	22	0.62	0.86	1.39
S8	4	13	0.96	1.33	1.39
S4	14	58	0.81	2.13	2.64
S3	10	55	0.70	1.57	2.30
S9	7	32	0.80	1.56	1.95
S10	3	12	0.92	1.01	1.10
S11	8	46	0.76	1.57	2.08
S12	5	25	0.79	1.27	1.61

Discussion

Considering the small size of the Musolo River catchment (c. 120 km^2) and sampling following standardized methods utilizing only dip nets and cast nets, a total of 53 species is unexpectedly high, particularly in comparison with the considerably larger nearby Congo tributaries such as N'sele (6 000 Km^2), Inkisi (13 500 Km^2) and Lefini (13 500 Km^2) with respectively 148 species (Monsembula et al., 2013), 140 species (Ibala Zamba, 2010) and 61 species (Wamuini et al., 2010). The outflow of the Musolo River into Pool Malebo and the absence of rapids or waterfalls, which can act as barriers between these two ecosystems, likely accounts for the high species richness of the Musolo fish fauna by providing many opportunities for colonization to and from the Pool. That argument is supported by the fact that 98 % of species reported from the Musolo River are also found in Pool Malebo (Brooks et al., 2011). Interestingly, *Phractura scaphyrhynchura* which was reported for the first time in the Kinshasa region by Monsembula et al. (2013) in a leftbank tributary of N'sele River (Mayi Mpembe River 4°21'49.57''S-15°42'36.47"E) the headwaters of which arise near headwaters of the Musolo River. The fact that *Phractura scaphyrhynchura* is present in both the Musolo River and the Mayi-Mpembe River but absent in the Pool Malebo provides additional support for faunal exchange between neighbor catchments during periods of flooding or past stream capture in the Congo basin (Stiassny et al., 2016). The fish species reported in the present study are characteristic of the Congolese province (Lévêque, 1997), except for *Orechromis nilotucus,* which was introduced into this part of the Congo basin in 1957 for fish farming (Welcomme, 1988). In addition, a species composition dominated by Alestidae, Distichodontidae, Cichlidae, Cyprinidae, Mormyridae, and Mochokidae is in accord with the findings of Lévêque & Paugy (2017a) for the Congo basin as a whole.

The present study is one of the few ecological investigations of fishes performed within the Congo basin and complements a short list of the similar studies recently undertaken in the Inkisi River (Wamuini et al., 2010), a left bank affluent of the Congo River in the Democratic Republic of the Congo (DRC) and Lefini (Ibala Zamba et al., 2019), and Loua Rivers (Batiabo et al., 2019), respectively, a large and a small right bank affluent in the Republic of the Congo (RC). Indeed, investigations of the drivers of fish community assemblages, in general, are rarely performed in Africa (Kouamélan et al., 2003; Kouadio et al., 2006; Ibanez et al., 2007) and 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 in the Lower Guinean ichthyofaunal province (Kamdem Toham & Teugels, 1997, 1998; Mbega, 2004; Ibaňez et al., 2007).

The standard observation of species richness increasing downstream (Hugueny, 1989, 1990; Paugy & Bénech, 1989; Pouilly, 1993; Hay et al., 1996; Kamdem Toham & Teugels, 1997, 1998; Kouamé et al., 2008) is reported here for the Musolo River system (see Figure 3b), even if, certainly because of the short length of the river (± 20 km) and human activities impacts, species numbers correlated with Upstream sites (9 species) is not significantly different from that reported in Middle sites (6). Indeed, according to Lévêque & Paugy (2017b), the physical conditions found throughout a watercourse, from upstream to downstream, induces a response from biological communities, with a progressive change according to the capacities of species to adapt to environmental conditions and available food resources. This longitudinal zonation is accompanied by an increase in species richness through increasing habitat heterogeneity and volume (Hugueny, 1990).

Based on the RDA (Figure 3a), TDS (25.8%) and slope (24.4%) are the two most important variables for fish distribution in the Musolo basin. TDS, which is a measure of the combined dissolved content of all inorganic and organic inputs present in the water (Weber-Scannell & Duffi, 2007), represents a variable strongly correlated with habitats downstream, likely explained by the fact that downstream sites are loaded with inputs from waters flowing from upstream. Therefore, in addition to the proximity to the Pool, elevated TDS probably also contributes to the high fish diversity of downstream sites (S = 38 species vs. 9 and 6, respectively in upstream and middle sites). However, the high slope (about 79 m) between the most distant stations from upstream and those downstream, represented in the present study by the altitude, is also positively correlated with habitats situated upstream in the basin. In addition to this particularity, habitat homogeneity due to the proximity of these upstream habitats to the source would also undoubtedly contribute to their low fish diversity.

Even if, studying fish communities using diversity indices does not reflect the organizational modalities of populations in a system (Barbault, 1992; Korkmaz & Zencir, 2009), it is however known that these indices are of utility in the diagnosis of the ecological health of an aquatic ecosystem (Lobry et al., 2003; Daly et al., 2018). In the present study, three ecological diversity indices (S, H' and R) calculated based on species abundance, reveal that in all site as provided by the RDA (Figure 3a), the H' (Upstream: 1.98; Middle: mean = 1.47; Downstream: 1.35) and R (Upstream: 0.79; Middle: mean = 0.77; Downstream: 0.82) indices are approaching their maximum values, respectively H' maximum (2.50; 1.93; 1.69) for H' and 1 for R. This reflects an excellent distribution of species abundance in the Musolo River basin, despite a weak evenness observed at station 7 (H' = 0.86; H' max. = 1.39. R = 0.62), principally explained by the slight dominance of *Raiamas christyi* in the catches. Once again, this could likely be the result of the development of intense human activities around that habitat such as gardens, sand extraction, and charcoal production. According to Ludwig & Reynolds (1988) and Lobry et al., (2003), when all species of the community have a good distribution of abundance and the environmental in good ecological health, H' and R indices approach their maximum values.

Conclusion

The present study contributes to a better understanding of fish communities in the Congo basin, by providing data on fish diversity and distribution in the Musolo River, one of its small left bank tributaries in the Democratic Republic of Congo. As in most of the Congo basin the ichthyofauna of Musolo River is diverse and Alestidae, Distichodontidae, Cichlidae, Cyprinidae, Mormyridae, and Mochokidae are the most represented families.

Total dissolved solids and altitude are shown to have a significant influence on the distribution of fish assemblages, and richness increases from upstream to downstream. The high value of Shannon and Equitability indices in all habitats sampled indicates that the Musolo basin is in good ecological health.

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