Original Research Article

Influence of environmental variables on fish distribution in the flooded swamp forest of the Lake Tumba micro-basin on the Mbandaka- Research Center in Ecology and Forestry of Mabali (CREF Mabali) road axis in Bikoro, Equateur Province (DR Congo)

Abstract

Background and objective: The majority of aquatic ecosystems in the Democratic Republic of Congo are highly anthropized, which could negatively influence biodiversity. The overall objective of this study is to evaluate the influence of environmental variables on fish distribution in the flooded swamp forest of the Lake Tumba micro-basin on the Mbandaka-Research Center in Ecology and Forestry of Mabali road.

Study area: This study took place in ponds, swamps, marigots and small streams in relation to Lake Tumba in the flooded forest zone of the Mbandaka-Mabali road axis in the territory of Bikoro, Equateur Province in the Democratic Republic of Congo.

Methods: Fish were collected using different fishing techniques and gears. Physico-chemical parameters were sampled using a multi-parameter Combo pH probe of the brand Hanna pH/ORP/EC/DO N° HI 9828, dissolved oxygen was measured using the Brand Voltcraft DO-100 oximeter and depth was determined using a graduated board. Several ecological indices of fish communities were determined as well as Hierarchical Ascending and Principal Component Classification analyses.

Results: Twenty-two fish species belonging to ten orders, thirteen families and fifteen genera were identified. The average values of the abiotic variables show that the waters of the study area are characterized by low values of physico-chemical parameters within the ranges compatible with the survival of the local fish fauna. The canonical correspondence analyses reveal that five environmental variables (temperature, depth, dissolved oxygen, sandy bottom and sandy-muddy or gravelly bottom) would explain the abundance and distribution of fourteen fish species in the Longonye site. In contrast, turbidity, conductivity, pH, muddy bottom, and bottom littered with plant debris influenced the abundance and distribution of eight fish species at the Hongo, Ilungu, Lotende and Membe sites. Scoop fishing, stump removal, and the use of ichthyotoxic plants were the main anthropogenic activities that could compromise the fish fauna in the study area.

Conclusion and outlook: Limiting anthropogenic activities that may cause deterioration of fish habitats and alter water quality and promoting sustainable local fishing methods would help preserve the fish fauna studied.

Key words: Abiotic variables, Distribution, Ichthyological fauna, Flooded swamp forest, Bikoro

1. INTRODUCTION

Among the organisms living in aquatic ecosystems, fish are the best known because of their size, abundance and biodiversity. A source of natural animal protein important in the diet, this fishery resource is very rich in mineral elements as well as vitamins A and D, approximately the same as meat in terms of protein content (17 to 20%) and nutritional value [1]. It is the main source of animal protein most accessible to populations in some countries in Africa [2] and mainly in the Democratic Republic of Congo [3,4].

In addition, fish play a considerable role in the ecological process of aquatic ecosystems, acting at different tropical levels as herbivores, detritivores, predators and prey [5]. In addition, the life history of several species is characterized by migrations between environments with different abiotic parameters [6].

Contemporary anthropological studies of primitive societies have confirmed the importance of fishing as a means of subsistence [7,8]. According to Yao et al, [8], human settlements are often established in areas with relatively good fish catch.

The majority of the aquatic ecosystems of the Democratic Republic of Congo are highly anthropized where agricultural exploitation [9,10], mining activities [11,12,13], garbage dumps [14,15], etc., invade the aquatic environment; this could negatively influence biodiversity [116,17].

The fishery resources of the Congo Basin show a clear tendency to overexploitation due to the large number of artisanal fishermen, illegal fishing practices with nets with too small a mesh, the absence of biological rest [18]. According to Boika et al. [19], given the disturbances and threats that these ecosystems are currently undergoing, a good taxonomic knowledge of the species, their living environment, their biology and the relationships that link them to the environment can encourage effective measures for their conservation and rational use.

In the Congo Basin, studies related to the biology, ecology, systematics as well as the influence of abiotic variables on fish are fragmentary [19]. Few studies have been carried out on fish in the flooded swamp forest of Lake Tumba, except for the one carried out by Boika et al. [19], and those that exist deal with the systematics of fish in Lake Tumba and the Ikela region [20].

This study proposes to evaluate the influence of environmental variables on the distribution of fish in the micro basin of the flooded swamp forest of the Lake Tumba micro basin on the road axis Mbandaka-Research Center in Ecology and Forestry of Mabali (CREF Mabali) in Bikoro in the Equateur Province in the Democratic Republic of Congo in order to determine the parameters responsible for the distribution of fish in the different habitats of this ecosystem.

2. STUDY ENVIRONMENT, MATERIALS AND METHODS

2.1. Study environment

This study took place in the flooded forest zone of the Mbandaka-Mabali road axis in the Equateur province of the Democratic Republic of Congo, where there are ponds, swamps, marigots and small streams, in connection with Lake Tumba (Figure 1).

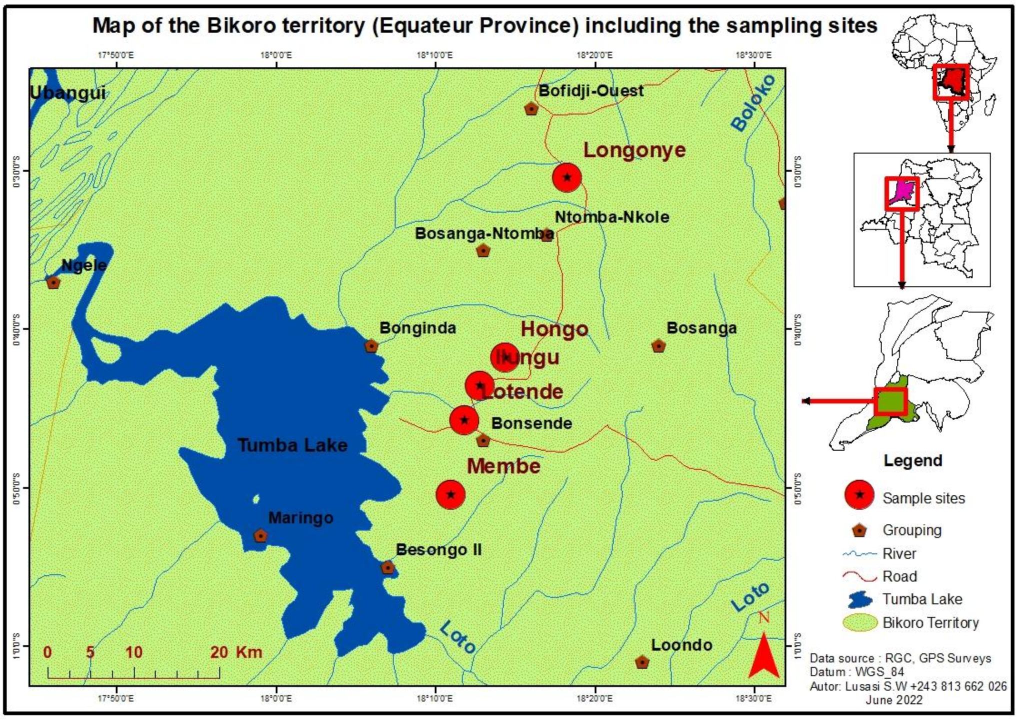

Figure 1. Map of the Lake Tumba region showing the floodplain forest area of the Mbandaka-Mabali road in Equateur Province

In the study area, the following five sampling sites (Table 1) were selected:

Table 1. Sites surveyed on the Mbandaka-Mabali axis

Sites	Geographic coordinates	Location along the road
Site I (Longonye)	00°30’ 23.8’’ S 18° 18’ 14’’ E	Between Elanga and Nsimba villages
Site II (Hongo)	00° 41’ 43.6’’ S 18° 14’ 21.2’’ E	Between villages Iyembe Monene and Iyembe Moke
Site III (Ilungu)	00° 43’ 30.7’’ S 18° 12’ 45.3’’ E	Between Iyembe Monene and Mpenda villages
Site IV (Lotende)	00° 45’ 41.5’’S 18° 11’ 49.5’’E	After the crossroads Mabali - Bikoro
Site V (Membe)	00° 50’ 24.5’’ S 18° 10’ 15.9’’ E	Mpaha-Bolia

The Lake Tumba region is bathed in a humid tropical climate of the equatorial type, characterized by almost constant temperatures, low temperature variations and abundant and regular rainfall [20]. There is a period of low rainfall from mid-June to mid-September characterized by a drop in temperature, open skies, rare and very low rainfall, resulting in a decrease in plant growth activity, limited leaf fall and a drop in water levels; This is a period conducive to fishing; a period of heavy rainfall from mid-September to mid-December, characterized by the resumption of plant life; this is the hottest season; a period of recession, with less rainfall, from mid-December to the end of February and a second rainy season from March to mid-June.

2.2. Biological material

The biological material consists of different species of fish and ichthyotoxic plants collected in the flooded swamp forest of the Lake Tumba micro-basin on the Mbandaka-CREF Mabali road axis in the Democratic Republic of Congo.

2.3. Methods

2.3.1. Collection of fish samples

Fish were collected using different techniques and gears. These include traditional creel fishing, line fishing, longline fishing, spear fishing, scooping (emptying of ponds) and fishing with ichthyotoxic plants. In the case of the latter technique, extracts of bark, leaves, roots and/or fruits of the different plant species were used.

2.3.2. Conservation of specimens

The different fish specimens collected were sorted and then fixed in a 10% formalin solution and kept in plastic jars. On each batch of specimens, the date and the site of harvest were indicated. The samples thus conditioned were sent to the laboratory for the appropriate manipulations.

2.3.3. Systematic identification of fish

In the laboratory, the different fish specimens were first of all removed from their formalin through several successive baths in tap water, then kept in jars containing 95% ethanol. Fish were identified to species level using systematic fish identification keys proposed by Poll and Gosse [21]; Lévêque et al, [22]; Mbega and Teugels [23]; Stiassny et al, [24] at the Laboratory of Limnology, Hydrobiology and Aquaculture of the Department of Biology of the Faculty of Sciences of the University of Kinshasa.

2.3.4. Collection and systematic identification of ichthyotoxic plants

The different ichthyotoxic plant species used by fishermen in the area to catch fish were collected in the flooded swamp forest of the Lake Tumba micro-basin on the Mbadaka-CREF Mabali road axis. After harvesting, plant samples were preserved in herbarium form for later identification. The species were identified according to the APG III botanical classification system [25] at the Plant Systematics Laboratory of the Centre for Research in Ecology and Forestry of CREF/Mabali.

2.3.5. Statistical analysis and data processing

The data from the different analyses and observations were encoded on the Excel 2013 spreadsheet. The results obtained after the treatments were expressed in the form of tables, graphs and figures to make them interpretable. The Origin 6.1 software was used to draw the relative abundance diagrams of the orders, families and genera of the identified fishes. Mapping of the fishing stations was generated using ArcGIS 10.8 software using geographic coordinates (latitude and longitude) collected in the field with a Gamin Etrex GPS.

In order to understand the influence of environmental variables on the distribution of fish species in the swampy forest located on the Mbandaka Cref Mabali road axis, multivariate analyses were carried out on the basis of data relating to the ichthyological fauna and abiotic variables in relation to the different sampling sites. Hierarchical Ascending Classification (HAC) and Principal Component Analysis (PCA) were performed with the PaSt software (Paleontological Statistics, Version 2.16).

The Ascending Hierarchical Classification analysis consisted of grouping ecological entities or sampling units with similar characteristics based on the list of fish species caught as well as abiotic parameters in order to estimate the closeness of the fish catching sites. It is based on the measurement of similarity distances between ecological entities [30], the different sampling sites in this case.

Principal Component Analysis (PCA), a descriptive and exploratory method, was used in order to extract, in the most synthetic way possible, information on the influence of abiotic variables on biotic parameters (fish fauna) of the study area. This analysis allows an arrangement of the ecological entities along two or more dimensional axes based on the data on the specific composition [31]. The angle between the arrows indicates the correlations between the variables, the ecological entities as well as the biotic variables in this case, the different fish species identified.

3. RESULTS

3.1. List of fish inventoried in the flooded forest located on the Mbandaka-Mabali road axis

Table 2 lists the orders, families, genera and species of fish identified in the flooded forest along the Mbandaka-CREF Mabali road.

Table 2. Fish species identified in the flooded forest of the Mbandaka-CREF Mabali road axis

N°	Taxa recorded	Vernacular name (Lotomba)
I	**Order of *Lepidosireniformes***	
	1° Family of *Protopteridae*	
	a) *Protopterus dolloi* Boulenger, 1900	Nsembe
II	**Order of *Cyprinodontiformes***	
	2° Familly of *Aplocheilidae*	
	b) *Aphyosemion elegans* Boulenger, 1899	Moningo
III	**Order of *Cypriniformes***	
	3° Familly of *Hepsetidae*	
	c) *Hepsetus odoe* Bloch, 1794	Mwenge
IV	**Order of *Gonorhynchiformes***	
	4° Familly of *Phractolaemidae*	
	d) *Phractolaemus ansorgi*i Boulenger, 1901	Mobili
V	**Order of *Mormyriformes***	
	5° Familly of *Mormyridae*	
	e) *Petrocephalus microphtalmus* Pellegrin, 1908	Mbeyi, Ntoku
	f) *Petrocephalus pellegrini* Poll, 1941	Mbeyi, Ntoku
VI	**Order of *Osteoglossiformes***	
	6° Familly of *Notopteridae*	
	g) *Xenomystus nigri* Günther, 1868	Ilembe
	7° Familly of *Pantodontidae*	
	h) *Pantodon buccholzi* Peters, 1877	Ihanzoli
VII	**Order of *Perciformes***	
	8° Familly of *Anabantidae*	
	i) *Ctenopoma ansorgii* Boulenger, 1912	Lokaka
	j) *Ctenopoma kingsleyae* Günther, 1896	Molombe
	k) *Ctenopoma lineatum* Nichols, 1923	Lokaka
	l) *Ctenopoma nanum* Günther, 1923	Lokaka

	m) *Ctenopoma pellegrini* Boulenger, 1902	Mwende
	9° Familly of *Cichlidae*	
	n) *Hemichromis fasciatus* Peters, 1852	Ebindi, Mokeke
	o) *Hemichromis elongatus* Guichenot, 1861	Ebindi, Mokeke
VIII	**Order of *Channiformes***	
	10° Familly of *Channidae*	
	p) *Parachanna obscura* Günther, 1861	Nsinga, Mongusu
IX	**Order of *Polypteriformes***	
	11° Familly of *Polypteridae*	
	q) *Polypterus ansorgii* Boulenger, 1910	Monkonga
X	**Order of *Siluriformes***	
	12° Familly of *Clariidae*	
	r) *Channallabes apus* Gunther, 1873	Mohombi
	s) *Clariallabes brevibarbis* Pellegrin, 1913	Lokamba
	t) *Clarias anguillaris* Linné, 1758	Ngolo
	u) *Clarias sp*	Ngolo
	13° Familly of *Malapteruridae*	
	v) *Malapterurus electricus* Gmelin, 1789	Nina, Ntula

The results of Table 2 above show that 22 species of fish grouped in ten (10) orders, 13 families and 15 genera have been recorded in the flooded forest of the Mbandaka-Cref Mabali road axis.

3.1.1. Relative abundance of the identified orders of fish

The orders *Perciformes*, *Osteoglossiformes* and *Siluriformes* are each represented by two families, or 15.4%. They are followed by *Cypriniformes*, *Polypteriformes*, *Mormyriformes*, *Gonorhynchiformes*, *Channiformes*, *Cyprinodontiformes*, *Lepidosireniformes* with one family each (Figure 2).

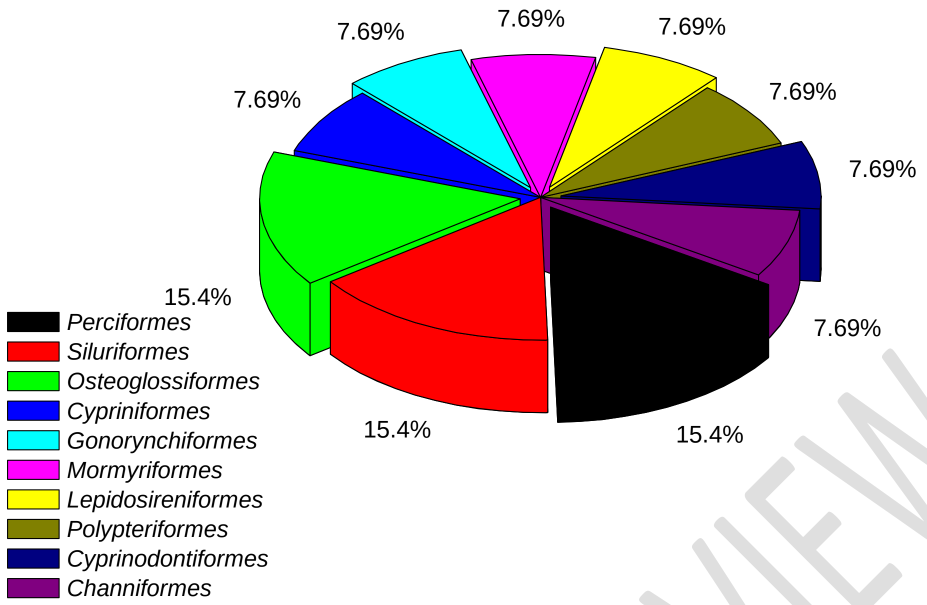

Figure 2. Relative abundance (%) of the orders of fishes surveyed.

3.1.2. Relative abundance of families of identified fishes

Of all the fish identified, those of the family *Anabantidae* are the most representative with five species or 22.7% followed by the *Clariidae* with four species or 18.2%. They are followed by the families *Mormyridae* and *Cichlidae* which are represented by two species each or 9.09%. The other families are represented by only one species each (4.55%) (Figure 3).

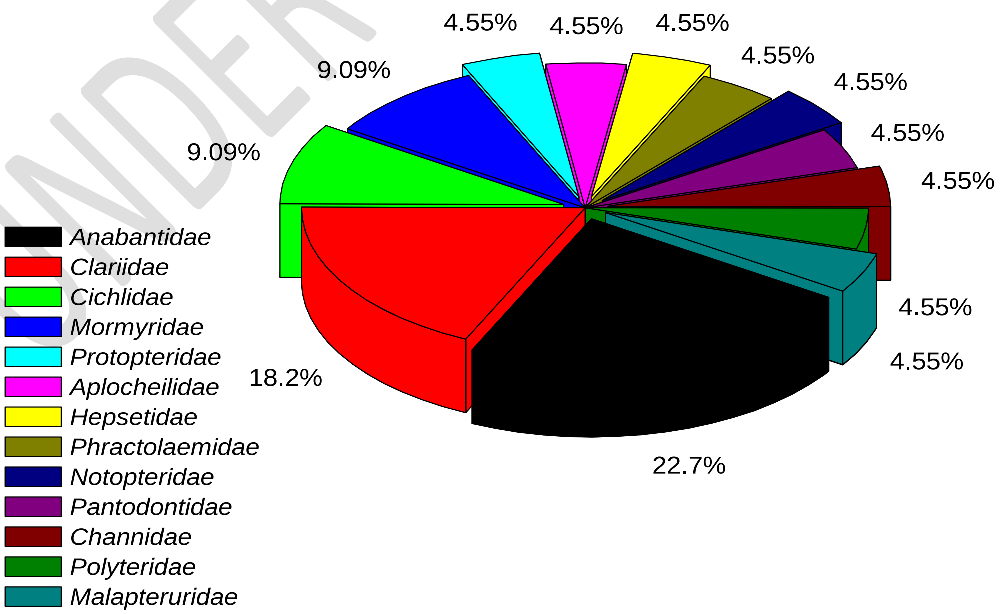

Figure 3. Relative abundance (%) of identified fish families

3.1.3. Relative abundance of identified fish genera

Of all the genera of fish identified, the genera *Ctenopoma* with 5 species or 22.7 %, *Clarias*, *Petrocephalus* and *Hemichromis* with 2 species or 9.09 % respectively are the most represented. *Protopterus*, *Aphyosemion*, *Hepsetus*, *Phractolaemus*, *Xenomystus*, *Pantodon*, *Clariallabes*, *Chanallabes*, *Malapterurus*, *Parachanna* and *Polypterus* are represented by only one species or 4.55 % (Figure 4).

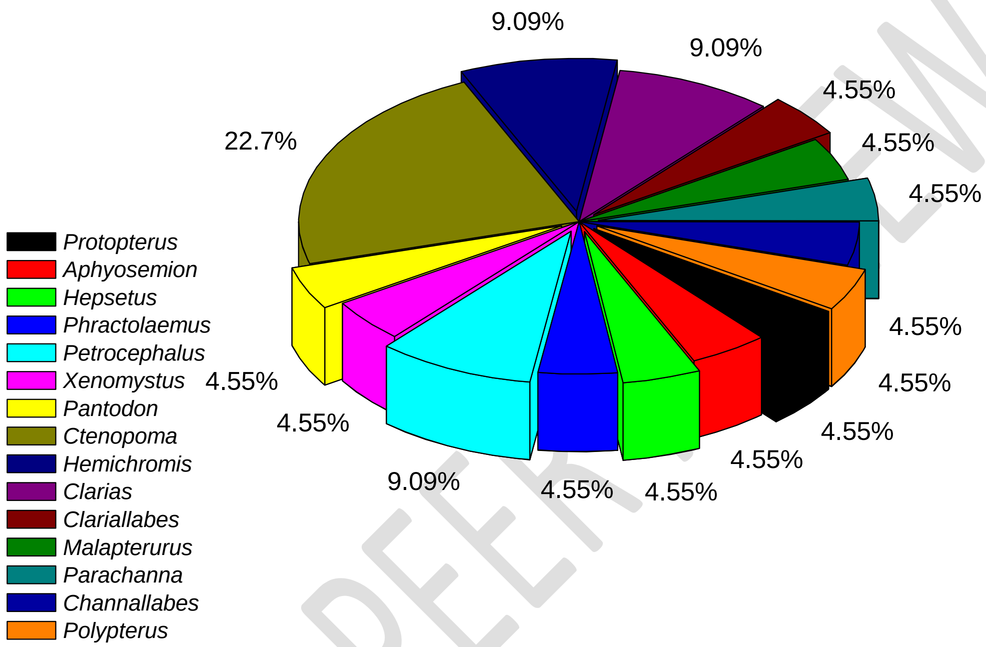

Figure 4. Relative abundance (%) of the genera of the inventoried fishes

3.1.4. Numerical frequency of inventoried species

The results visualized in figure 5 below inform that the numerical frequency of the identified fish species varies from one species to another. The species most collected are: *Clariallabes brevibarbis* with 88 individuals or 7.46%, *Clarias anguillaris* with 82 specimens or 6.95%, *Channallabes apus* with 78 individuals or 6.61%, *Clarias spp* with 76 individuals or 6.44%, *Ctenopoma kingsleyae* with 74 specimens or 6.27%, *Ctenopoma pellegrini* with 72 individuals or 6, 1%, *Ctenopoma ansorgii* with 68 specimens or 5.76%, *Ctenopoma lineatum* with 64 specimens or 5.42%, *Petrocephalus pellegrini* with 64 individuals or 5.42%, *Parachanna obscura* with 62 individuals or 5.25% and *Ctenopoma nanum* with 60 specimens or 5.08%. The remains of the species are less representative with a percentage of capture of less than 5%.

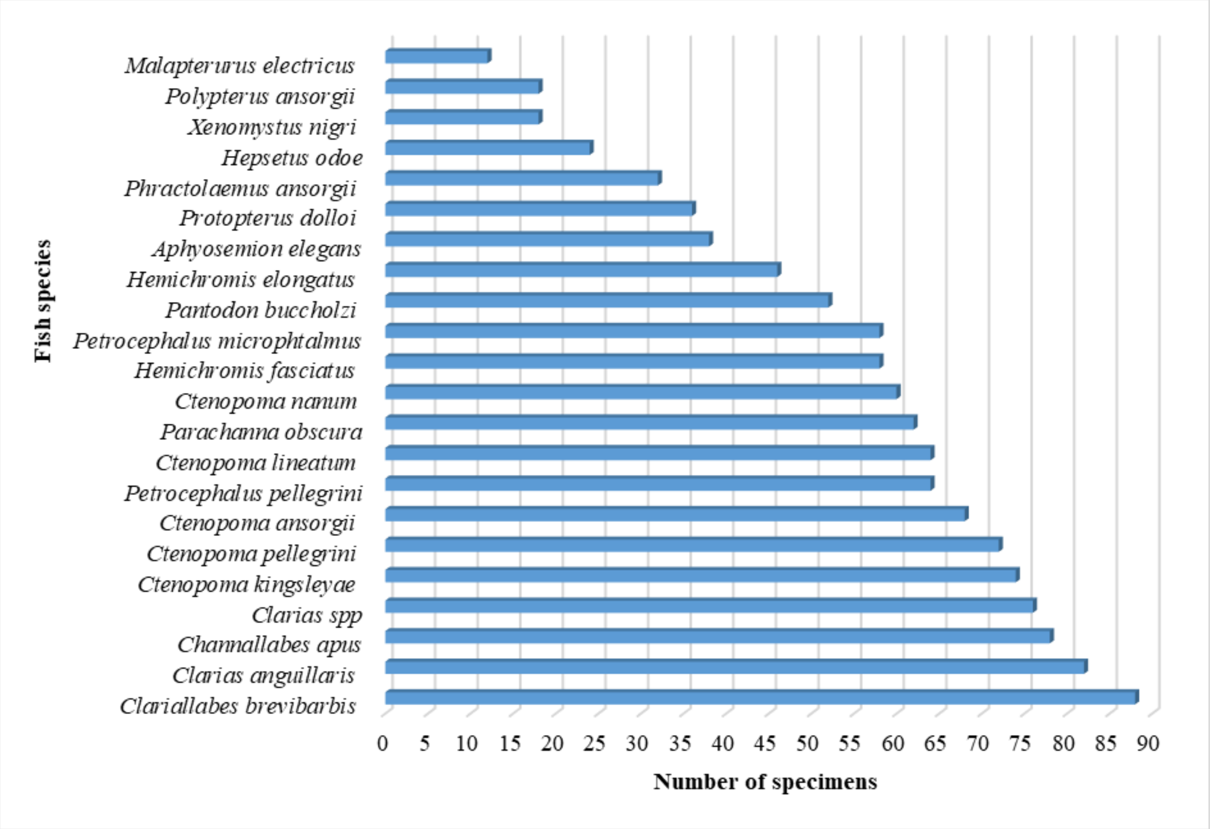

Figure 5. Numerical frequency of fish species caught

3.1.5. Proportion of fish caught according to the fishing stations

The variation in the catch of the different fish species identified in this study according to the study sites is recorded in Table 3.

Table 3: Catch proportion of the different fish species identified

Fish species	Study sites					Total
	Longonye	Hongo	Ilungu	Lotende	Membe	
Aphyosemion elegans	8	5	9	9	7	**38**
Hepsetus odoe	9	0	0	15	0	**24**
Phractolaemus ansorgii	6	4	9	5	8	**32**
Protopterus dolloi	7	6	8	5	10	**36**
Petrocephalus pellegrini	12	14	16	12	10	**64**
P. microphtalmus	13	15	11	10	9	**58**
Xenomystus nigri	18	0	0	0	0	**18**
Pantodon buccholzi	10	11	12	8	11	**52**
Ctenopoma ansorgii	8	13	10	17	20	**68**
C. kingsleyae	14	15	16	15	14	**74**

C. lineatum	8	10	10	16	20	**64**
C. nanum	10	8	8	15	19	**60**
C. pellegrini	14	13	16	15	14	**72**
Parachanna obscura	8	8	12	16	18	**62**
Hemichromis fasciatus	12	13	12	10	11	**58**
H. elongatus	10	8	11	9	8	**46**
Polypterus ansorgii	6	0	0	8	4	**18**
Channallabes apus	16	14	16	16	16	**78**
Clariallabes brevibarbis	20	17	18	15	18	**88**
Clarias anguillaris	18	13	18	16	17	**82**
C. spp	16	15	14	15	16	**76**
Malapterurus electricus	7	0	0	0	5	**12**
22	**250**	**202**	**226**	**247**	**255**	**1180**

The proportion of fish captured varied from site to site and also from species to species. All fish species were captured in the five sampling sites except for *Hepsetus odoe*, *Xenomystus nigri*, *Polypterus ansorgii* and *Malapterurus electricus* which were captured either in one site (*Xenomystus nigri*) or two sites (*Hepsetus odoe* and *Malapterurus electricus*). In terms of number of individuals, the Membe site with 255 specimens, Longonye with 250 specimens and Lotende with 247 individuals are those where fish were collected in large quantities.

3.2. Evaluation of ecological indices

3.2.1. Biological diversity indices

The values of the different indices of biological diversity evaluated on the basis of the ichthyological fauna inventoried in the flooded forest located on the Mbandaka-CREF Mabali road axis are shown in Table 4.

Table 4. Values of biological diversity indices

Calculated indices	**Sample sites**				
	Longonye	**Hongo**	**Ilungu**	**Lotende**	**Membe**
Taxa_S	22	18	18	20	20
Simpson_1-D	0.9485	0.9382	0.9406	0.9451	0.9424
Shannon_H	3.027	2.828	2.856	2.942	2.915
Equitability_E	0.9792	0.9785	0.9882	0.9821	0.9731

According to the results in the table above, all sites show a high species richness that varies between 18 taxa (Hongo and Ilungu) and 22 taxa (Longonye). Simpson's index varies between

0.9382 (Hongo) and 0.9485 (Longonye) and shows that there is a codominance of species across the five sites. The Shannon-Weaver indices for all sites are greater than 1.5 and indicate that the fish fauna is rich and varied. The Longonye site appears to be the most diverse (H'=3.027) and contains 22 species, followed by the Lotende (H'=2.942), Membe (H'=2.915), and the Hongo and Ilungu sites have 2.828 and 2.856 species respectively. In general, the sites studied indicate a certain balance between the numbers of the different species of fish sampled; the Piélou equitability index varies from 97.31% (Membe) to 98.82% (Ilungu).

3.2.2. Jaccard similarity index

The similarity values of the study sites obtained in relation to fish richness are shown in Table 5.

Table 5. Jaccard's similarity matrix based on the fish fauna of the study sites

	Longonye	Hongo	Ilungu	Lotende	Membe
Longonye	100	82	82	82	91
Hongo		100	100	90	90
Ilungu			100	90	90
Lotende				100	90
Membe					100

The similarity matrix established between the five sites studied according to the biological diversity of the fish fauna shows that all these sites are more than 80% similar. The Hongo and Ilungu sites are 100% similar and the Longonye, Ilungu and Lotende sites are 82% similar. The Membe site is 91% similar to the Longonye site and 90% similar to the other three sites.

3.3. Ichthyotoxic plant species identified

The following plants (Table 6) were identified in the study area and are often used by the local population to capture fish.

Table 6. Piscivorous plants used for fish capture

Family	Species	Vernacular name (Lontomba)	Part used
Acanthaceae	*Duvernoya dewevrei* De Wild et ThDur	Lwenzeli	Leaves (paste)
Commeliaceae	*Palisota barteri* Hook	Itétéle	Leaves (dough) and fruit

Liliaceae	*Sansiviera trifasciata* Prain	Mwela mo nkoy	Leaves (paste)
Loganiaceae	*Antocleista schweinfurthii* Gild	Ilobo i mai	Crushed bark (paste)
Mimosaceae	*Cathorniion altissimum* Hutch et Danay	Elele	Bark and leaves
	Tephrosia vogelii Hook	Booha	Seedling (sap), leaves, fruits and flowers (sap)
	Pentaclethra eetveldeana De Wild et Th. Dur	Ehili	Trunk bark (crushed)
Sapindaceae	*Blighia welwitchii* (Hiern) Radl	Booho	Fruits
	Tetrapleura tetraptera (Thonn) Taub	Boléhé	Fruits
Urticaceae	*Fleurya podocarpa* Weed	Lohambiya	Whole plant (paste)
7	**10**		**5**

Ten (10) plant species grouped in seven (7) botanical families are used for fishing fish. For some plant species, the whole plant is used while for others it is either the leaves, fruits, barks, roots and/or flowers that are used.

3.4. Environmental variables

3.4.1. Physical parameters

The average values of the physical parameters of the water collected at the sampling sites are shown in Table 7.

Table 7. Average values of physical parameters of water at the sampling sites

Sites	Physical parameters			
	Temperature (°C)	Turbidity (NTU)	Conductivity (µS/cm)	Depth (cm)
Longonye	26.3±1.2	3.8±0.3	3.18±0.115	113.75±46.25
Hongo	25.9±0.6	4.25±0.25	3.1±0.2	108±41.6
Ilungu	26.1±1.5	5.05±0.35	3.32±0.475	101.5±43.5
Lotende	24.5±0.7	5.2±0.3	3.45±0.25	102±48
Membe	25.5±1.1	5.65±0.05	2.82±0.17	84.5±38.5

The results in the table above show that the waters are warm with average temperatures ranging from 24.5±0.7°C (Lotende) to 26.3±1.2°C (Longonye). The waters are less turbid with average values ranging from 3.8±0.3 (Longonye) to 5.65±0.05 NTU (Membe). These waters are low in ions with average conductivity values between 2.825±0.17 µS/cm (Membe) and 3.45±0.25 µS/cm (Lotende). The depth of the water column remained shallow across the different study sites; it ranged from 84.5±38.5 cm (Membe) to 113.75±46.25 cm (Longonye).

3.4.2. Type of bottom substrate

The composition of the bottom substrate at the sampling sites as visualized in Figure 6 shows that, at each site, the muddy bottom is dominant and the sandy bottom is very poorly represented. The bottom littered with plant debris comes after the mud and sandy-muddy.

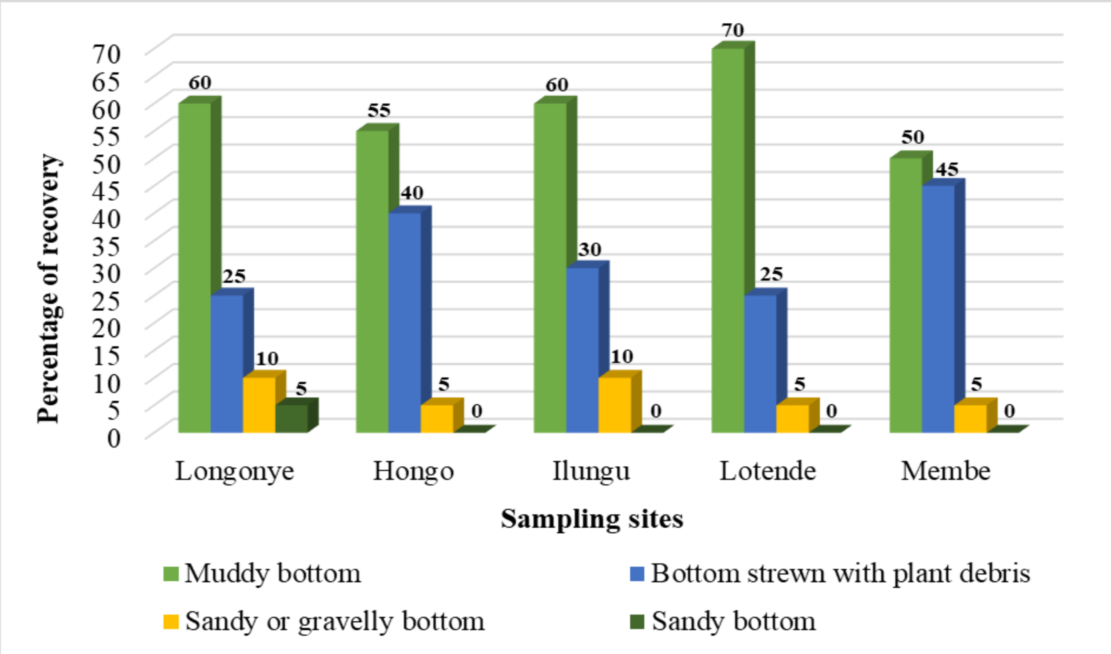

Figure 6. Composition of the bottom substrate at the sampling sites

3.4.3. Chemical parameters

The mean values of the chemical parameters of the water at the sampling sites are shown in Table 8.

Table 8. Average values of chemical parameters of the water at the study sites

Sampling sites	Chemical Parameters	
	pH	Dissolved oxygen (mg/L)
Longonye	4.13±0.33	3.18±0.18
Hongo	4.5±0.6	3.45±0.35
Ilungu	4.45±0.25	6.5±0.05
Lotende	4.5±0.4	3.02±0.22
Membe	4.32±0.72	2.85±0.12

The waters at the various sampling sites have an acidic hydrogen potential; mean pH concentrations range from 4.135±0.33 (Longonye) to 4.5±0.6 (Hongo). The waters are poorly oxygenated; dissolved oxygen content ranges from 2.852±0.12 mg/L (Membe) to 6.5±0.05 mg/L (Ilungu).

3.5. Anthropogenic activities in the study area

The different human activities identified in the flooded swamp forest along the Mbandaka - Cref Mabali road axis are summarized in Table 9.

Table 9. Human activities identified at the study sites

N°	Nature of the activity	Corporate purpose	Probable impacts on humans and ichthyofauna
1	Slash and burn agriculture	Production of food crops for consumption and sale. Source of income for the local population.	During low water, large dry portions of the swamp forest are cut down for food crops, resulting in : - Disappearance of important portions of the swamp forest; - Organic pollution: increased turbidity and acidity threaten fish habitat.
2	Search for building materials: *Eremospatha macrocarpa* lianas, *Raphia sese* and *Raphia laurentii* main veins, and *Sclerosperma manii* leaves	Housing construction and source of income	Organic pollution
3	Felling of trees	Commercial exploitation of wood: timber, firewood and charcoal: source of income for the impoverished population.	Deforestation: disappearance of large areas of swamp forest.
4	Artisanal fishing	Capture of fish for consumption and incidentally for sale in case of abundant fishing.	Water pollution by ichthyotoxics, exposure of the population to the harmful effects of toxic products, destruction of fish habitats by inappropriate fishing techniques, such as stumping (destroys spawning grounds and in the long run can lead to the scarcity or disappearance of certain species) and scooping which captures fish of all ages, adults, juveniles and fry.
5	Housework (Bathing, Laundry, Dishwashing, Excreta disposal, Car, bike and motorcycle washing)	Housework and personal hygiene.	Water pollution by the contribution of organic and chemical pollutants, Exposure of the population to water-borne diseases.

From the results recorded in the table above, it appears that several anthropogenic activities are carried out in the study area with possible negative impacts on the aquatic ecosystem and on the health of the population.

3.6. Analysis of the groupings of fishing sites according to physico-chemical parameters and fish fauna

The similarity dendrogram of the sampling sites established according to the environmental variables as well as the inventoried ichthyological fauna highlights two large groups of sites (Figure 7) separated by a Euclidean distance of 38 with a very significant difference (r = 0.8711). The Membe site alone forms the first group, while the second is made up of the Hongo, Ilungu, Lotende and Longonye sites. The second group is in turn divided into two subgroups where the Hongo, Ilungu and Lotende sites form the first subgroup (29 away) and the Longonye site forms the second subgroup (30 away).

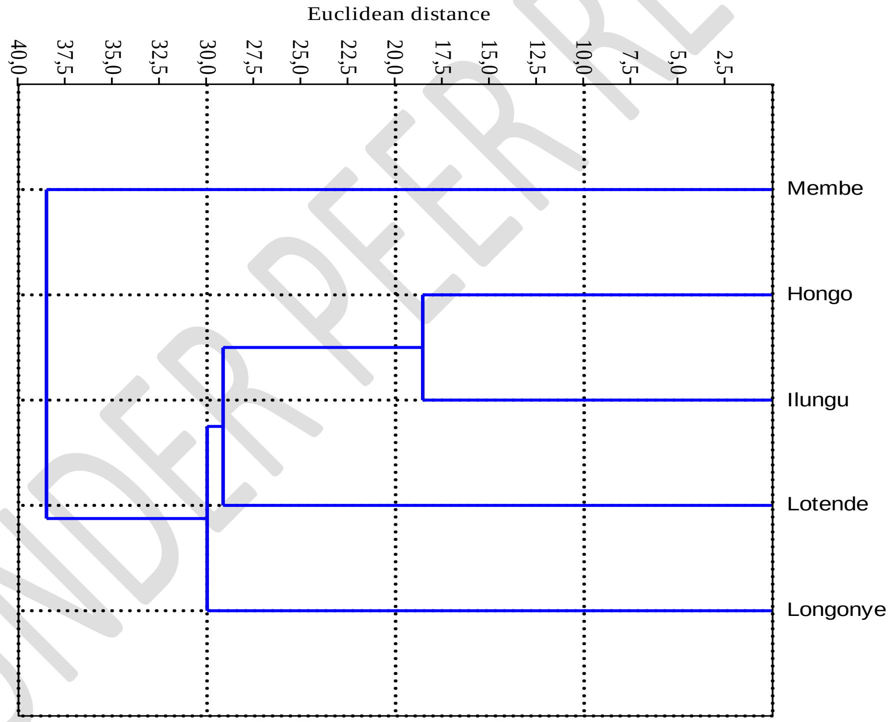

Figure 7. Ascending Hierarchical Classification Dendrogram of fishing sites according to abiotic variables and fish fauna

3.7. Correlation between environmental variables and fish species

The results visualized in figure 8 below show that four of the five sites (Hongo, Ilungu, Lotende and Membe) are positively correlated on axis two associated with the fish species

Aphyosemion elegans, *Hepsetus odoe*, *Ctenopoma ansorgii*, *C. lineatum*, *C. nanum*, *C. pellegrini* and *Polypterus ansorgii* under the influence of four environmental variables: turbidity, conductivity, pH, muddy bottom and a bottom littered with plant debris. The Longonye site is positively correlated with axis 1 where five environmental variables (temperature, depth, dissolved oxygen, sandy bottom and sandy-muddy or gravelly bottom) positively influence the distribution of fourteen fish species (*Phractolaemus ansorgii, Protopterus dolloi, Petrocephalus pellegrini, P. microphtalmus, Xenomystus nigri, Pantodon buccholzi, Ctenopoma kingsleyae, Hemichromis fasciatus, H. elongatus, Channallabes apus, Clariallabes brevibarbis, Clarias anguillaris, C. spp* and *Malapterurus electricus*).

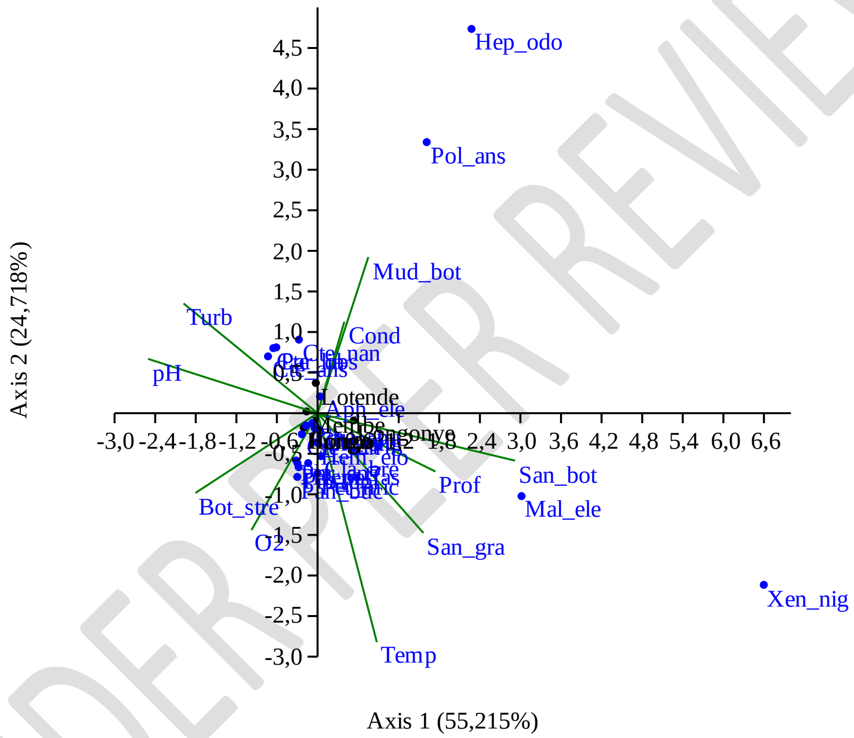

Figure 8. Diagram of the Canonical Correspondence Analysis between the fishing sites, the abiotic variables and the inventoried fish fauna

Legend: Temp = Temperature, Turb = Turbidity, Cond = Conductivity, Prof = Depth, pH = Hydrogen potential, Fon_vas = Muddy bottom, Fon_sab = Sandy bottom, Fon_grav = Sandy-muddy or gravelly bottom, Fon_veg = Bottom littered with debris, vegetation, Aph_ele = *Aphyosemion elegans*, Hep_odo = *Hepsetus odoe*, Phr_ans = *Phractolaemus ansorgii*, Pro_dol = *Protopterus dolloi*, Pet_pel = *Petrocephalus pellegrini*, Pet_mic = *Petrocephalus microphtalmus*, Xen_nig = *Xenomystus nigri*, Pan_buc = *Pantodon buccholzi*, Cte_ans = *Ctenopoma ansorgii*, Cte_kin =

Ctenopoma kingsleyae, Cte_lin = *Ctenopoma lineatum*, Cte_nan = *Ctenopoma nanum*, Cte_pel = *Ctenopoma pellegrini*, Par_obs = *Parachanna obscura*, Hem_fas = *Hemichromis fasciatus*, Hem_elo = *H. elongatus*, Pol_ans = *Polypterus ansorgii*, Cha_apu = *Channallabes apus*, Cla_bre = *Clariallabes brevibarbis*, Cla_ang = *Clarias anguillaris*, Cla_spp = *Clarias spp* and Mal_ele = *Malapterurus electricus*.

4. DISCUSSION

This study allowed the collection of twenty-two (22) species of fish divided into 15 genera, 13 families and 10 orders. This environment has a fairly diverse fish fauna which can be explained by the adaptation of these species to the environmental conditions. As stated by Lévêque and Paugy [32], the ichthyological communities of African rivers are very rich because many species adapt to adverse conditions. In terms of species, the catches are dominated in terms of abundance by : *Clariallabes brevibarbis* (7.46%), *Clarias anguillaris* (6.95%), *Channallabes apus* (6.61%), *Clarias spp* (6.44%), *Ctenopoma kingsleyae* (6.27%), *Ctenopoma pellegrini* (6, 1%), *Ctenopoma ansorgii* (5.76%), *Ctenopoma lineatum* (5.42%), *Petrocephalus pellegrini* (5.42%), *Parachanna obscura* (5.25%) and *Ctenopoma nanum* (5.08%). These results are close to the observations made by Boika et al, [19]; Bila-Isia and Zanga [33]; Snoek et al, [34]. The *Perciformes* and *Siluriformes* are among the most represented orders in the ichthyological province of Congo and in other forest ecosystems of Central Africa [19].

These observations are similar to those reported by Matthes [20] in the flooded forest and marshes of Lake Tumba. The latter reports thirty-one (31) species inventoried during his study in the flooded forest and ponds, while twenty-two (22) species constitute the sample of this study in the same biotope. Matthes [20] collected fifteen (15) species that were not recorded in the present study and nine (9) species recorded in this study were not reported by Matthes [20]. The difference in these results could be explained by the fishing techniques used, the extent exploited as well as the duration of the sampling.

Regarding the evaluation of diversity indices, all sites showed a high specific richness that varied between 18 taxa (Hongo and Ilungu sites) and 22 taxa (Longonye site). This richness is thought to be related to the availability of varied food resources in the study area. According to Pwema [35], the diversity of ecological niches has the potential to provide rich biological diversity. Simpson's index showed that there is a codominance of species across the five sites [27], the value of this index ranged from 0.9382 (Hongo site) to 0.9485 (Longonye site). The

Shannon-Weaver indices for all sites indicated that the fish fauna is rich and varied. The Longonye site with 22 species was the most diverse (H'=3.027), followed by the Lotende (H'=2.942), Membe (H'=2.915) and the Hongo and Ilungu sites had 2.828 and 2.856 respectively. In general, the sites studied indicated a certain balance between the numbers of the different fish species sampled; the Piélou Equitability Index varied from 97.31% (Membe) to 98.82% (Ilungu). These results corroborate with those reported by Boika et al, [19]; Wamuini [26]; Hermi and Aissa [29].

Jaccard's similarity matrix established between the five sites studied according to the biological diversity of the fish fauna showed that all the sites are more than 80% similar and contain almost the same fish species. The Hongo and Ilungu sites are 100% similar and the Longonye, Ilungu and Lotende sites are 82% similar. The Membe site is 91% similar to the Longonye site and 90% similar to the other three sites. These observations are also confirmed by the ascending hierarchical classification of sites. This analysis showed that the Membe site alone forms the first group, while the second group was formed by the Hongo, Ilungu, Lotende and Longonye sites. This rapprochement of the groups shows a similarity linked to the very close abiotic and biotic characteristics between the different sites [36]. The equitable occupation of the fish species can be justified by the complexity of the food web, which gives the possibility to the different species to exploit different areas without competing [35,37].

The results obtained from the physico-chemical parameters showed that the waters were warm with mean temperatures ranging from 24.5±0.7°C (Lotende) to 26.3±1.2°C (Longonye); they were less turbid with mean values ranging from 3.8±0.3 NTU (Longonye) to 5.65±0.05 NTU (Membe). According to Lévêque and Paugy [32], throughout intertropical Africa, average water temperatures are high and most often above 20°C and follow that of the ambient air. Matthes [20] reports that forest shading has a significant effect on the average temperature of rivers and stagnant waters, where the temperature is generally very high (28 to 38 °C), even under vegetation cover [19]. The turbidity averages obtained would be related to precipitation, which has the effect of increasing suspended matter inputs through runoff [19], which in turn increases turbidity and decreases the transparency of the water [26]. The waters were low in ionic load with average conductivity values ranging from 2.825±0.17 µS/cm (Membe) to 3.45±0.25 µS/cm (Lotende). The conductivity values are closer to those obtained by Boika et al, [19]. The prevalence of muddy and sandy bottoms justifies the abundance of capture of fish species of the genera *Petrocephalus*, *Hemichromis*, *Clarias*, *Ctenopoma* and

Clariallabes that would have a preference for these types of mud. The waters at the different sampling sites showed an acidic hydrogen potential; with average pH values ranging from 4.135±0.33 (Longonye site) to 4.5±0.6 (Hongo site). The acidic pH values found are close to those obtained by Boika et al, [19] and would therefore be caused by dissolved thermostable humic matter, originating from the decomposition of organic matter; this even gives the waters of the study area a black hue [19]. The waters are poorly oxygenated; dissolved oxygen content ranges from 2.852±0.12 mg/L (Membe) to 6.5±0.05 mg/L (Ilungu). The low levels of dissolved oxygen obtained would be a function of the acidity of the water due to the abundance of organic matter in the water [19], which decreases the level of dissolved oxygen through the reduction and release of ferrous oxides that absorb a significant portion of the dissolved oxygen [20].

Various environmental parameters and site characteristics influence the distribution and abundance of a large number of ichthyological species in the flooded swamp forest of the Mbandaka - CREF Mabali road axis. The canonical correspondence analyses showed that the Longonye site was positively correlated with axis 1 where five environmental variables including temperature, depth, dissolved oxygen, sandy bottom as well as sandy-muddy or gravelly bottom would explain the abundance and distribution of fourteen fish species including: *Phractolaemus ansorgii*, *Protopterus dolloi*, *Petrocephalus pellegrini*, *P. microphtalmus*, *Xenomystus nigri*, *Pantodon buccholzi*, *Ctenopoma kingsleyae*, *Hemichromis fasciatus*, *H. elongatus*, *Channallabes apus*, *Clariallabes brevibarbis*, *Clarias anguillaris*, *C. spp* and *Malapterurus electricus*. On the other hand, the Hongo, Ilungu, Lotende and Membe sites were positively correlated with axis two associated with the fish species *Aphyosemion elegans, Hepsetus odoe, Ctenopoma ansorgii, C. lineatum, C. nanum, C. pellegrini* and *Polypterus ansorgii* whose distribution was influenced by four environmental variables: turbidity, conductivity, pH, muddy bottom as well as the bottom littered with plant debris. Several researchers have also demonstrated the influence of environmental variables on the abundance and distribution of aquatic species: shrimp [31,38], fish [36,39] and benthic macroinvertebrates [40,41].

5. CONCLUSION AND PERSPECTIVES

The objective of this study was to evaluate the influence of physico-chemical parameters on the abundance and distribution of fish species that inhabit the flooded swamp forest of the

Lake Tumba micro-basin located on the Mbandaka-CREF-Mabali road axis in the territory of Bikoro, Equateur province in the Democratic Republic of Congo.

The results obtained showed that the ichthyological fauna of this environment is quite diversified. Twenty-two species of fish were caught during the sampling period. These fishes belong to 10 orders, 13 families and 15 genera. The evaluation of abiotic variables showed that the waters of the study area are characterized by low values of physico-chemical parameters within the ranges compatible with the survival of the local fish fauna. Five environmental variables, including temperature, depth, dissolved oxygen, sandy bottom and sandy-muddy or gravelly bottom, explain the abundance and distribution of fourteen species of fish at the Longonye site, while turbidity, conductivity, pH, muddy bottom and bottom strewn with plant debris influence the abundance and distribution of fish at the Hongo, Ilungu, Lotende and Membe sites. Scoop fishing, stump removal, and the use of ichthyotoxic plants have been the main anthropogenic activities that have the potential to compromise the natural capital of the local ichthyofauna and negatively affect fish habitats and the hydrosystem. Promoting sustainable local fishing methods and prohibiting anthropogenic activities that may cause deterioration of fish habitats and alter water quality would help preserve the fish fauna of the study area.

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