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Contribution to the study of the sustainable exploitation of the ichthyofauna of Lake Mai-Ndombe in the Democratic Republic of Congo

[Contribution à l'exploitation durable des ressources halieutiques du lac Mai-Ndombe en République démocratique du Congo]

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Abtract

In this aquatic ecosystem, fishing is carried out by the local population and is considered an important activity. The demographic growth estimated at 3.8%, the lack of employment, the increase in the number of fishermen on the one hand, and the subsidy to socio-economic needs on the other hand push the majority population to invest massively in fishing. This study was initiated with the aim of knowing the aspects of the exploitation of the halieutic resources in Lake Mai-Ndombe.Data on the fishing gear used, the catches obtained and the after-market yield of the fish were obtained from eleven fishing stations located along the lake from November 2014 to December 2015. Two types of fishing gear (net and longline) are mainly used to catch fish in the Lake.The large species are *Chrysichthys punctatus* Boulenger, 1899, *Parachanna obscura* Günther, 1861 LC, *Clarias pachynema* Boulenger, 1903 and *Clarias platycephalus* Boulenger, 1873. The small spece is the *Nannothrisa stewarti*. 13,245 kg of fish were caught with longlines and sold at 5,245,278 FC (5,828 USD) while for nets, 14,675 kg of fish were caught and sold at 5,044,315 FC (5,605 USD). Four species were considered to be dominant with a percentage of dominance of species: *Chrysichthys punctatus* 0.826, *Parachanna obscura* 0.230; *Clarias pachynema* 0.180 and *Clarias platycephalus* 0.151.The family Claroteidae had a high occurrence (17.48%).These gears were less selective i.e. they caught species of all kinds. These results underscore the urgent need for a comprehensive conservation management plan to halt the ongoing decline in species and CPUE in this valuable and vulnerable ecosystem.Given these practices regarding the exploitation of Lake Mai-Ndombe's resources, we call for monitoring of mesh sizes; the establishment of biological closure periods; revitalizing fisheries and aquaculture policy. As for social aspects, it is necessary to implement community-based education and adopt co-management of fishery resources.

Keywords : Lake Mai-Ndombe; Exploitation; Ichthyology; Fish diversity; Fish Occurrence; Monetary cost; CPU

Résumé

Dans l'écosystème aquatique du lac Mai-Ndombe, la pêche est exercée par la population locale et est considéré comme une importante activité. La croissance démographique de la contrée est estimée à 3,8%. Le manque d'emploi, l'augmentation de nombre de pêcheurs d'une part et d'autres parts les besoins socio-économiques poussent la majeure partie de population d'investir massivement dans la pêche. Le but de cette étude était d'initier les recherches pour avoir les connaissances sur l'aspect d'exploitation des ressources halieutiques du Lac Mai-Ndombe. Les données sont collectées par l'usage des outils de pêche. Les poissons sont capturés sur les onze stations de pêche situées dans le lac pour la période allant de Novembre 2014 à décembre 2015. Deux types d'outils de pêche ont été utilisé (filet maillant et filet moustiquaire). Ces outils sont principalement utiliser pour capturer les poissons dans le lac. Les espèces de grande taille capturées sont notamment les *Chrysichthys punctatus* Boulenger, 1899, *Parachanna obscura* Günther, 1861 LC, *Clarias pachynema* Boulenger, 1903 and *Clarias platycephalus* Boulenger, 1873. Dans cette pêche la petite espèce capturée est constituée de *Nannothrisa stewarti*. L'ensemble de sa capture par le filet moustiquaire a constitué 13.245 kg de poissons capturés et est vendu à une somme de 5.245.278 FC (5,828 USD), alors que le filet maillant qui avait produit 14.675 kg de poissons et est vendu à 5044,315 FC (5605 USD). Quatre espèces étaient considérées comme dominantes notamment : *Chrysichthys punctatus* 0.826, *Parachanna obscura* 0.230; *Clarias pachynema* 0.180 et *Clarias platycephalus* 0.151. La famille de Claroteidae avait une haute fréquence (17,48%). Les matériels de pêche utilisés étaient moins sélectifs, par exemple ils capturaient toutes sortes d'espèces. Les résultats prouvent qu'il y a urgence d'initier la meilleure gestion et la bonne façon de conserver les ressources pour stopper si non diminuer l'épuisement de ressource et de la diminution de Capture Par Unité Effort 'CPUE) de poissons dans notre précieuse écosystème qui est à la fois vulnérable. Telles pratiques selon l'exploitation des ressources halieutiques du Lac Mai-Ndombe, nous rappelons aux communautés qu'il soit initié les activités de contrôle de maille, les dimensions des engins de pêche, observation de période de reproduction de poissons, leurs milieux de reproduction, redynamiser la pêche moderne proposer les règlements sur l'aquaculture. En ce qui concer.

Mots-clés: Lac Mai-Ndombe; Exploitation; Ichtyologie; Diversité de poissons; Occurrence de poissons; Prix monétaire cout; CPU

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1. Introduction

Fisheries contribute to the prosperity of various stakeholders as a source of income for the population (Fondo et al., 2025). However, in most parts of Africa, fisheries production and yields have declined considerably and catch per unit effort (CPUE) has become low in natural water bodies such as rivers, streams and lakes (Gbaguidi et al., 2016, Mali et al., 2026). The main threats are overfishing caused by the increase in the fishing population, poverty of local populations, use of sophisticated and prohibited fishing gears and techniques, sub-optimal limnological characteristics, destruction of spawning grounds, loss and degradation of habitats, land use in the catchment area (shifting cultivation, logging, aquaculture, etc.) of dead leaf masses of vegetation from the catchment area (Gbaguidi, et al., 2016; Micha, 2019).

Fishery products are among the most traded food staples in the world for subsistence or trade (FAO, 2026). Fish are relatively cheaper and their flesh is an alternative to overcome malnutrition. They contain high biological value protein (over 70%) (Pliya, 1980), minerals: iodine, phosphorus and selenium. Vitamins such as B12, B6, B1, B2, D and A (Kraidy et al., 2014). Indeed, fish flesh contains little cholesterol but many essential mono- or polyunsaturated fatty amino acids whose preventive and protective role against cardiovascular diseases has been demonstrated by several studies (Regost et al., 2001; Cahu et al., 2004). These fatty acids are also involved in the development of brain structures and cognitive functions (Bourre, 2004 & 2005). Fatty acids are effective in the treatment of inflammation, certain rheumatological or dermatological diseases, cancers and certain psychiatric conditions (Mori & Berlin, 2004).

It has 3350 species (Fishbase, 2022). According to Paugy et al. (2011), this fish fauna is distinguished by the high proportion of endemic families.

Fish production in African continental waters was 2 804 629 tonnes in 2015 and increased to 3.7 tonnes in 2026 (World Bank, 2026).

The Democratic Republic of Congo (DRC) is endowed with a huge and dense hydrographic network comprising lotic, lentic systems with a total surface area estimated at 86,080 km2 (Micha et al., 2020).

According to Aseke et al, (2026), promoting sustainable fisheries can encourage better management of the ecosystem as a whole and ensure the well-being of the Congolese population.

The species richness of the Congo Geographic Ichthyo Region is the highest of all African Geographic Ichthyo Regions and is estimated at 1250 species of which 75% are endemic (Snoeks et al., 2011). Globally, it is second only to the Amazon basin (Decru, 2017). The DRC's fish fauna comprises some 40 families with 1089 species (Luhusu & Micha, 2013; Decru, 2017; Fishbase, 2022).

The DRC's fisheries sector includes both inland and marine fisheries, but the bulk of its fisheries resources come from inland freshwater (lakes, swamps, rivers and their floodplains) (FAO, 2026). These fisheries potentialities were estimated at 241200 tonnes in 2018 against 707,000 tonnes/year during the Belgian colony (Tusanga Mukanga, 2015, Micha et al., 2020; World Bank, 2022), of which 6,000 tonnes could come from the small maritime zone (40 km of coastline).

The fish potential of Lake Mai-Ndombe is estimated at 10,000 tonnes (Compére & Symoens, 1987). In 1970, the production of Lake Mai-Ndombe and its tributaries, which constitute a single ecosystem, was 4.8 kg/ha/year and that of Lake Tumba 5.8 kg/ha/year (Laë, 1997).

This current total effective fish production in DR Congo, estimated at 241,200 tonnes/year (World Bank, 2022), results in an average fish availability of 5.7 kg/inhabitant/year, which is well below the international standard of 21 kg/inhabitant/year recommended by the FAO (Tusanga Mukanga, 2015, Micha et al., 2020).

In this aquatic ecosystem, fishing is carried out by the local population and is considered an important activity (Balagizi et. al., 2017, Zanga et al., 2019). The demographic growth estimated at 3.8%, the lack of employment, the increase in the number of fishermen on the one hand, and the subsidy to socio-economic needs on the other hand push the majority population to invest massively in fishing (Zanga et al., 2019, Micha et al., 2020).

Unfortunately, some previous studies are less documented and data on the exploitation of fish fauna in Lake Mai-Ndombe are less significant. We have hypothesized that exploitation of fish in lake Mai-Ndombe is not sustainable. Therefore, the scientific objective of the study is to identify some features of the exploitation of the ichthyofauna (species of fish caught, estimation of the quantity of annual catches, catches per unit of effort, revenue due to the fishing activity). Specifically to identifie the taxonomic composition and it specific richness, the Catch Per Unity Effort and occurrence. In order to provide a basis for the preservation of these species.

2. Material and Methods

2.1. . Study environment

Lake Mai-Ndombe (figure 1) is located at 1° 32' - 2°43' South latitude and 18° 03' - 18° 36' East longitude. It is 146 km long, 18 km wide and covers an area of 2300 km² with an estimated catchment area of 67,680 square km (Compére & Symoens, 1987).

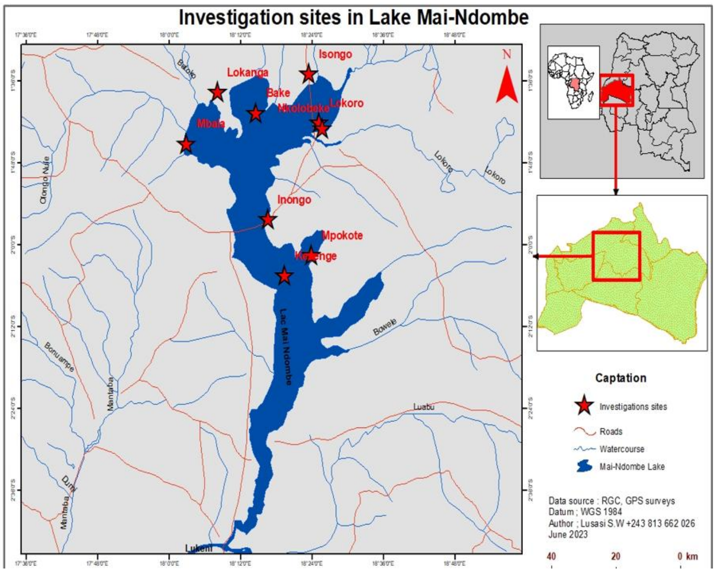

Figure 1. Map of sampling sites at Lake Mai-Ndombe (red dots)

2.2. Climatic data

Results in figure (2) showed the Gaussian umbrothermal curve illustrating the wet and dry months for an 18-year period (2004 to 2021) of observations made at the Mabali and Inongo weather station (stations located near Lake Mai-Ndombe).

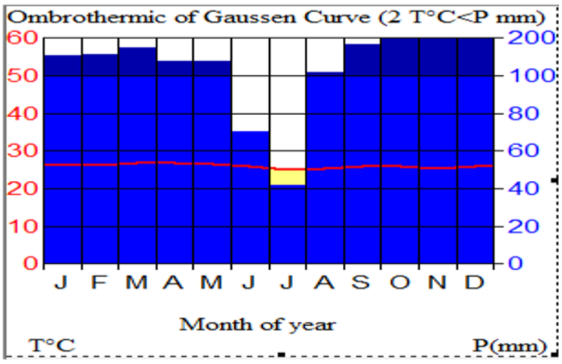

Figure 2. Umbrothermal diagram of the Lake Mai-Ndombe region (2004-2021)

The data analysed by the relationship (2T °C < P mm) shows that drought occurs when double the temperature is less than 60 mm of rain. This shows that the Lake Mai-Ndombe region is in an AW1 type climate according to Köppen's classification, which means that we are in the humid tropical climate where it rains all year round and we experience only one month of drought. In this case we notice that all the months are rainy in blue, the decrease in rainfall starts from June and ends with a single month of drought in yellow where the rainfall is less than 60 mm, which is the month of July. The rainfall range is 186.91 mm. The wettest month is November with 228.56 mm and the least rainy month is July 41.65 mm. The average is 151.84 ± 57.54. While the temperature did not fluctuate much its thermal amplitude is 1.29°C, the highest temperature in the area was observed in March 27.26°C, while the lowest temperature was observed in July 25.96°C for an average of 26.49 ± 0.49°C (Bultot & Griffits, 1971).

The waters of Lake Mai-Ndombe have a pH between 3.94 and 4.05 and are not very transparent (0.5 and 0.8 m) with potassium ion contents between 0.006 and 0.010 meq/l. The concentration of phosphate ions is less than 4 µg/l and silica 1.2 mg/l. The concentration of nitrogen is 21 µg/l (Micha et al., 2020).

From a floristic point of view the study area is in the floristic sector of Kasai Robyns (1948). But in the sense of White (1979) in Belesi (2009), it is in the Guinean-Congolese floristic region. Acording Belesi (2016), the Lac Mai-Ndombe is featured by some kinds of macrophytes as followed Vossia cuspidata (Roxb.) Griffith,1851, *Eichhornia crassipens* (Martius) Solms-Laubach,1883, *Loudetia phragmitoides Hochst* 1854, *Andropogon schirensis L.*, 1753, and *Fimbristylis dichotoma* (L.) *Vahl*, *Solenostemon monostachyus* (P. Beauv.) A. J. Paton concentrated. However, in swamp forest some species such *Zeyherella longipedicellata* (De Wild.) Aubrév. and Pellegr are prevalent vegetal cover.

The population density around the lake is low (four inhabitants per square km on the northern and southern shores of the lake, but less than two inhabitants persquare km on the rest of the lake periphery). The important localities are Isongo, on the northern shore of the lake, and Kutu, at the confluence of the weir with the Lukenie; Inongo is the only town that is the chief town of the Mai-Ndombe Province located to the east of Lake Mai-Ndombe (Compere & Symoens, 1987).

2.3. Materials

The biological material for this study consisted of different fish species caught in Lake Mai-Ndombe from November 2014 to December 2015.

2.4. Methods

2.4.1. Data collection

Data collection was carried out from November 2014 to December 2015 during two hydrological seasons, for 213 days for 639 fishermen in Lake Mai-Ndombe. 11 villages located in the north and center was chosen because of the high number of fishermen living in these villages, namely: Bake, Inongo, Isongo, Kesenge, Lokanga, Lokoro, Mbale, Mpokote, Nkengela, Nkile and Nkolobeke. A daily follow-up in the morning and evening at the fishermen's landing every day measures in grams using a 20 kg commercial scale, each species noted by the identification on the spot of the local name, selling prices proposed by the fishermen in Congolese Francs are noted according to each species, type of gear and fishing techniques of the fish caught; the specimens are counted.

The fish samples were taken, fixed with 10% formalin. In the laboratory identification was done using the determination keys proposed by many authors (Teugels, 1986a; Boden et a.l, 1997; Geerinckx et al., 2004 and Moelant et al., 2014) and checked on the fishbase.org website. A list of fish caught in Lake Mai-Ndombe from 2007 to 2022 was used for to make comparison with my investigation to know what difference is.

4.2. Expression of results

The various data obtained were assessed on the basis of the following relationships and indices:

- Catch Per Unit Effort “CPUE” (Kg) = ∑ P(kg) (FAO, 1994).

- Commercial value of the species “V(FC)” = Px (FC) * CPUE (Kg) (FAO, 1994).

Where: CPUE (kg) = Catch per Unit Effort

P(kg) = Sum of average weight

Px (FC) = Price

V (FC) = Commercial value

- Fishing effort: E = Lt net (m)/100

Where: E = Effort and Lt = Total length of the net

Several indices were used to characterise the fish fauna. These are: relative abundance; species richness; Shannon's diversity index, and Pielou's equitability index (Ricotta, 2002):

H' = -ΣSi = 1pi log 2pi (in bits)

pi = ni/N

Where: N = the total number of individuals of all species; ni = the number of individuals per species; pi = the relative abundance of species i in the sample and S = the number of species caught by the fishing gear.

- The occurrence (F) = (Fi X 100)/(Ft)

Where Fi = number of surveys containing species i and Ft = total number of surveys conducted (Ahouansou Montcho, 2011). According to the value of F, 4 groups of species were distinguished according to the scale proposed by Charbonnel et al. (1995): I (75 - 100%): permanent species, II (50 - 74.9%): frequent species, III (25 - 49.9%): occasional species, IV (< 25%): rare species.

2.5. Statistical analysis

STATISTICA (version 7.1), PAST (version 4.04) and Origin 6.1 were used to calculate. The Catch per Unity Effort, Number Per Unity Effort and incomes earned were submitted in one-way ANOVAs and, to generate histograms. Tests for the Normality of Parameters. The following hypotheses are posited: • H0: b1 = 0 (weight has no effect on price) • H1: b1 ≠ 0 (weight influences price) Test results were considered significant for $p < 0.05$. Confidence intervals were used to assess the test’s power and verify the reliability of the results when sample sizes were small. Results with a p-value < 0.05 were deemed significant, while those with a p-value < 0.01 were considered highly significant (*Legendre & Legendre, 1998*).

The calculation of the occurrence of each fish species was done by Excel (version 2010). The ARCQGS digital mapping software was used to develop the geo-referenced map.

3. RESULTS

3.1 *Taxonomic composition of species*

Data in **(figure 3)** presented the taxonomic composition according to the orders of fish species caught in Lake Mai-Ndombe.

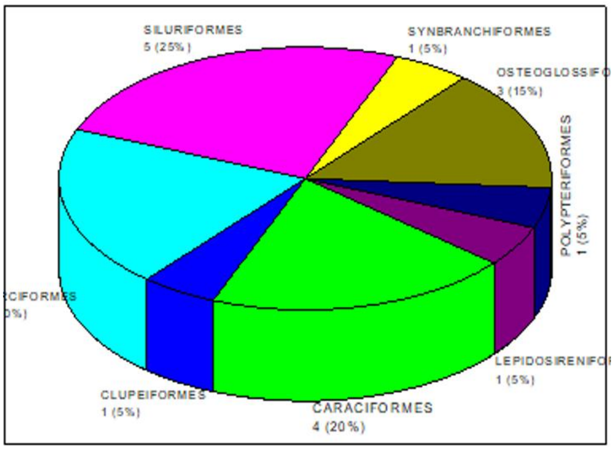

Figure 3. Illustration of taxonomic composition according to orders of collected fish species

During our research we collected 44 fish species belonging to 33 genera, 20 families, 8 orders. The most diversified orders: Siluriformes 27%, Characiformes and Perciformes each 21%, Osteoglossiformes 16% and Remnants each 5%.

3.2. Composition of fish species according to caught families

The results illustrated the taxonomic composition according to the families of fish species caught in figure 4 In this study we found that the most diverse families are the Distichodontidae and Clariidae (14%), followed by the Alestidae, and Cichlidae (9%). To these families should be added the Mormyridae (7%), Citharinidae, Notopteridae and Schilbeidae (5%). The remaining families represent 2% of fish.

In following plot is demonstrated the taxonomic composition according to families of caught fish species in Lake Mai-Ndombe.

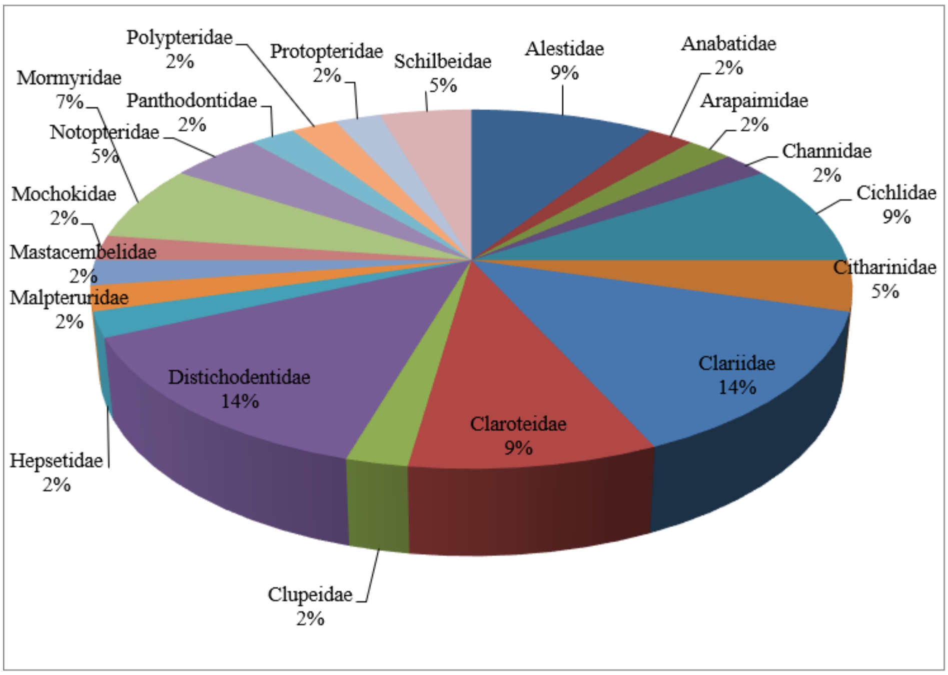

Figure 4 .Taxonomic composition according to families of caught fish species in Lake Mai-Ndombe

3.3. List of caught fish

The main species caught in Lake Mai-Ndombe are presented in table I from 2007 to 2013 by Inogwabini et al. (2007), Decru et al., (2012) and Mutambwe & Wamuini (2012-2013) and from 2013 to 2022 by the present study. The captured fishes belong to 43 species in 32 genera, 19 families and 9 orders. When comparison betwen sampling years is made from statistical test of Kruskal-Walis, showed that there is no significant difference (0.11 > 0.05) betwen years of samples on the species fishes caught in the Lake Mai-Ndombe.

In the table I is illustrated the list of fish caught in Lake Mai-Ndombe from 2007 to 2022 included the year of my performed work

Table I. List of fish caught in Lake Mai-Ndombe from 2007 to 2022

Order		Family	Especies	2022	2007	2012	2013
CHARACIFORMES		Alestidae	*Alestes bimaculatus Boulenger, 1899*		X		
			Brycinus grandisquamis Boulenger, 1899		X		
			Alestes liebrechtsii Boulenger, 1898 LC	X	X		
			Alestes sp	X			
			Alestes sp1		X	X	
			Bryconaethiops sp1		X	X	
			Bryconaethiops sp2			X	
			Hydrocynus vittatus Castelnau, 1861	X			X
			Hydrocynus goliath Boulenger, 1898 L	X	X		X
		Citharinidae	*Citharinus gibbosus Boulenger, 1899 L*	X	X		
			Citharinus macrolepis Boulenger, 1899 L	X	X	X	X
		Cyprinidae	*Distichodus affinis Günther, 1873*		X		
			Distichodus antroventralis Boulenger, 1898 LC	X			X
			Distichodus fasciolatus Boulenger, 1898				
			Distichodus lussoso Schilthuis, 1891 L	X		X	X
			Distichodus maculatus, 1898	X			
			Distichodus noboli Boulenger, 1899 LC	X			X
			Ichthyborus besse Boulenger, 1900	X			
			Ichthyborus ornatus Boulenger., 1899	X		X	X
			Phago intermedius Boulenger, 1899			X	X
			Xenocharax spilurus Günther, 1867				X
			Labeo lineatus Boulenger, 1898		X		
		Hepsetidae	*Hepsetus odoe Bloch, 1794*	X	X		X
LEPIDOSIRENIFORMES		Protopteridae	*Protopterus congicus Poll, 1961*	X			X
		Clupeidae	*Clupeocharax schoutedeni Pellegrini, 1926*			X	
			Nannothrissa stewarti Poll & Robert 1976			X	
OSTEOGLOSSIFORMES		Mormyridae	*Campylomormyrus sp.*				X
			Genyomyrus donnyi Boulenger, 1899			X	X
			Gnathonemus petersii Günther, 1862	X	X	X	
			Hippopotamyrus sp.		X	X	X
			Marcusenius spp.			X	X
			Mormyrops anguilloides Linnaeus, 1758 L	X	X	X	X
			Mormyrus caballus Boulenger, 1898 L	X	X		X
			Mormyrus macrops Boulenger, 1904				X
			Mormyrops nigricans Boulenger, 1899		X		X
			Myomyrus macrops Boulenger, 1904				X
			Petrocephalus spp.		X	X	X
			Pollimyrus sp.			X	X
			Stomatorhinus sp.				X
		Notopteridae	*Papyrocranus afer Günther, 1868 LC*	X			X
			Xenomystus nigri Günther, 1868 LC	X	X	X	X
		Pantodontidae	*Pantodon buchholzi Peters, 1876*	X			
PERCIFORMES		Anabantidae	*Ctenopoma nigropannosum Reichenow, 1875*	X			
			Ctenopoma sp1			X	
			Ctenopoma sp2			X	
		Arapaimidae	*Heterotis niloticus (Cuvier, 1829)**	X			
		Channidae	*Parachanna obscura Günther, 1861 LC*	X	X	X	X
		Cichlidae	*Hemichromis cf fasciatus Peters, 1857*	X	X	X	X
			Hemichromis elongates Guichenot, 1861		X	X	
			Pterochromis congicus Boulenger, 1897 LC	X	X		X
			Coptodon congica Poll&Thys vd aud, 1960 LC	X	X	X	X
			Pelmatichromis nigrofasciatus Pellegrin, 1900	X	X	X	X
			Tylochromis lateralis (Boulenger, 1898)	X	X	X	X
POLYPTERIFORMES		Polypteridae	*Polypterus congicus Boulenger, 1898 LC*	X	X		X
SILURIFORMES		Clariidae	*Clarias angolensis Steindachner, 1866*	X			X
			Clarias gabonensis Günther 1867			X	X
			Clariallabes sp.	X			X
			Clarias pachynema Boulenger, 1903	X	X		
			Channallabes apus Günther, 1902	X		X	X
			Clarias platycephalus Boulenger, 1873	X	X		
			Clarias buthupogon Sauvage, 1878	X		X	
		Bagridae	*Heterobranchus longifilis Valenciennes, 1840*		X		
			Bagrus sp.				X
		Claroteidae	*Auchenoglanis occidentalis Valenciennes, 1840L*	X	X	X	X
			Chrysichthys ornatus Boulenger, 1902 L	X	X		X
			Chrysichthys punctatus Boulenger, 1899	X		X	X
			Chrysichthys sp	X	X	X	
			Gephyroglanis congicus (Boulenger, 1899)			X	X
		Malpteruridae	*Malapterurus melanochir Norris, 2002*	X	X		
		Mochokidae	*Synodontis greshofi Schilthuis, 1891*	X			X
			Synodontis nigriventris, David, 1936		X		
			Synodontis ornatipinnis Boulenger, 1899				X
		Schilbeidae	*Schilbe marmoratus Boulenger, 1911 LC*	X		X	X
			Eutropius laticeps Boulenger, 1899 L	X	X		X
			Parailia sp.			X	X
SYNBRANCHIFORMES		Mastacembelidae	*Mastacembelus greshofi Boulenger, 1901*	X		X	X

* Exotic species, the remains are native species

3.4. Species richness and Shannon-Wiener diversity index values

The species richness and Shannon-Wiener diversity were calculated from the species caught according to the fishing techniques, the results of which are given in table II.

Passive gillnets showed catches of estimated species richness of 25 while longlines and pots each had only 24. Longline 23, hawk net 19 and beach purse seine 11.

As for the Shannon diversity index (**H'**) the pot technique had a higher value of 3.61; hawk net 2.93; set gillnet 2.68; hooks 2.65; longline 2.49 and beach purse seine 1.36. Equitability (**E**) obtained higher values for the creel technique at 0.079; hawk net 0.69; longline and static gillnet (hooks) each shared 0.58 and the beach purse seine is at 0.39 (table II).

Table II. Shannon-Wiener diversity index values for fish caught by fishermen in Lake Mai-Ndombe

Fishing gear	**Fe**	**FMD**	**Ha**	**STP**	**Pa**	**Na**
Specific wealth (S)	19	25	24	11	23	24
Diversity index of Shannon (H')	2,93	2,68	3,61	1,36	2,49	2,65
Equitability (E)	0,69	0,58	0,79	0,39	0,55	0,58

3.5. Commercially valuable fish species in Lake Mai-Ndombe

The fishing done in Lake Mai-Ndombe is according to the gear and techniques corresponding to the species, hydrological season, habitat, and the commercial value of the species (table III).

Ten species of fish caught with high commercial value represent Heterotis niloticus Parachanna obscura, Citharinus macrolepudotus, Clarias sp, Chrysichthys punctatus, Distichodontis sp, Mormyrops anguilloides. Coptodon congicus and Hepsetus odoe, Protopterus dolloi. This catch is made according to the gear and techniques corresponding to the species, hydrological season, habitat, and the commercial value of the species (table III).

Table III. High commercial value fish species caught in Lake Mai-Ndombe from 214 to 2015

Fish species	Fishing gear	Technics		Season Hydrological	Months	Habitat	Depth(m)	Commercial value
		Active	Passive					
Heterotis niloticus	Net, Hook	STP	FMD	Ranny	September-Jan-May	Pélagic	> 3	High
Parachanna obscura	Net, Hook	STP, Pa	FMD	Dry,Ranny	Jun-Aug-Feb-April	Littoral, Swamp	< 3	High
Coptodon congicus	Net, Hook	STP	FMD	Dry	Jun-Aug-Feb-April	Sandy, mouddy, littoral	< 3	High
Citharinus macrolepudotus	Net	STP, Fe	FMD	Dry	Jun-Aug-Febr-April	Pélagic	> 3	High
Clarias sp.	Net,Hook, Nasse	FMD, STP, Barrage	FMD	Dry, Ranny	Jun-Aug-Febr-April	Littoral, Swamp	< 3	High
Chrysichthys unctatusp	Net, Hook	FMD, STP, Pa	FMD	Dry, Ranny	Jun-Aug-Febr-April	Pélagic	> 3	High
Distichodus sp	Net	FMD, STP,	FMD,	Dry, Ranny	Jun-Augt-Febr-Apr	Pélagic	> 3	High
Hepsetius odoe	Net	FMD,	FMD,	Dry	Jun-Aug-Febr-Apr	Swamp	< 3	High
Mormyrops sp	Net, Hook	FMD, STP, Pa, Fe	FMD,	Dry, Ranny	Jun-Aug-Febr-Apr	Pélagic, Littoral	> 3	High
Protopterus dolloi	Hook	STP		Ranny	September-Jan-May	Swamp	< 3	High

Legend: STP = beach purse seine, FMD = set gillnet, Pa = longline, Fe = hawk net

3.6. Catch Per Unit Effort (CPUE) for all associated fishing gears according to season

The results in figure 5a illustrated the CPUE of fish as a function of gear for both seasons. Average CPUE of fish in the dry season figure 5a is 23.57 kg/day/fishing unit and in the rainy season is 16.74 kg/day/fishing unit ($p = 0.2 > 0.05$). The daily average is 17.34 kg/day/fishing unit which gives 6331.35 kg/year.

The results in figure 5b showed the profitability of fishing gear acording seasons. The average Fc gain during the dry season figure 5b was 4312.5 CF/day/net (2.9 USD, where 1 USD = 1500) and the wet season was 3432.53 FC/day/net (2.28 USD) ($p = 0.2 > 0.05$). Daily average is 3509.89 ± 2061FC/day/feet (2.33 USD) which gives 1281109.89 Fc/year/feet (854.1USD).

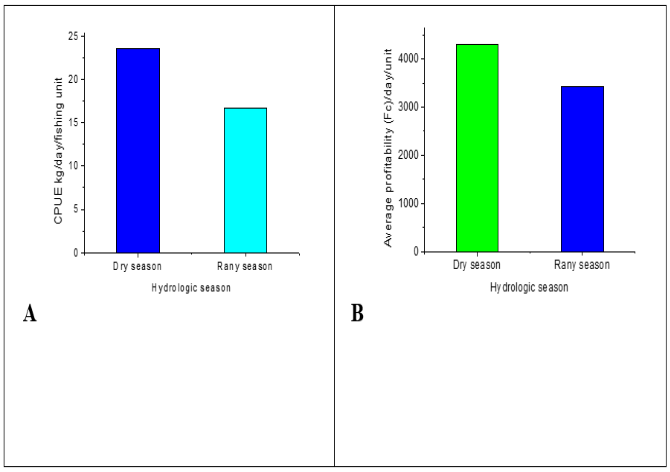

Figure 5. (A) Average CPUE (kg)/d/fishing unit dry and rainy season; (B) Average profitability (FC)/d/unit of dry and rainy season fishing. FC = Franc Congolais

3.7. Catch Per Unit Effort (CPUE) according to fishing gear

The results in figure 5 ploted the catch per unit effort (CPUE) according to fishing gears. It is seen in figure 6 that CPUE was dominant in the beach purse seine with 13.57 kg/day, followed by hawk net 8.64 kg/day, pot 7.15 kg/day, longline 6.33 kg/day, hook 5 kg/day, and still gillnet 3.16 kg/day. The application of ANOVA test reveals that there is a strong significant difference between the gears ($p = 0.004 < 0.05$).

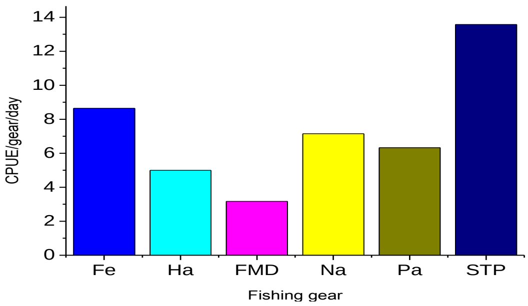

Figure 6. CPUE/gear/day according to fishing gears

STP = beach purse seine, FMD = set gillnet, Pa = longline, Fe = hawk net

3.8. Number of fish per Unit Effort (NPUE/gear/day)

The number of fish caught according to the fishing gear was illustrated in figure 7. It gives the results on the performance of the fishing gears. The one that caught the most specimens was the purse seine with 69 specimens. The beach purse seine followed with 56 specimens, the hawk net 49 specimens, the longline 21 specimens, the gillnet 19 specimens, and the hamecon 17 specimens per day. The ANOVA test revealed that there was no significant difference between the fishing gears ($p = 0.5 > 0.05$).

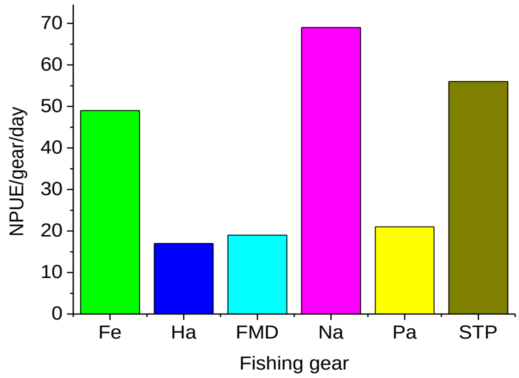

Figure 7. Number of fish per Unit Effort (NPUE/gear/day) according to fishing gears.

STP = beach purse seine, FMD = set gillnet, Pa = longline, Fe = hawk net.

3.9. The profitability of fish according to the fishing techniques

The profitability or revenue in Congolese Francs (CF) of the fish made according to the fishing gear was presented in figure 8. According to the analyses, it showed that the longline gear (hooks) was the most profitable for a gain of 17298.09 FC or (11.53 USD; 1 USD = 1500 FC); followed by beach purse seine 16850.39 FC (11.23 USD); longline 16682.02 FC (11.12 USD), standing gillnet 15148.46 FC (10.1 USD); sparrow net 14499.6 FC (9.67 USD); and creel 12437.79 FC (8.29 USD) per day. The ANOVA analysis showed no significant difference in monetary cost is reported between the gears ($p = 0.11 > 0.05$).

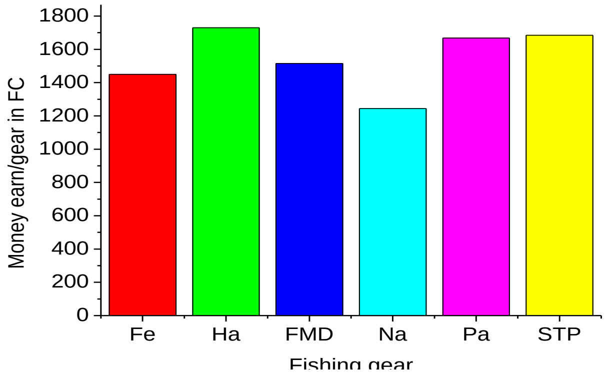

Figure 8. Receipts according to fishing gear in Congolese Francs

Fe = sparrow net; FMD = standing gillnet; Ha = hooks; Na = creel; Pa = longline; STP = beach purse seine

3.10. Species occurrence by fishing station

Data in table IV showed the occurrence of fish by survey station for the family and species. From these results, the species with the highest occurrence was C. punctatus (8); followed by P. obscura (7.65); M. anguilloides (6.74) and C. congica (6). The remaining species had the occurrence less than 5. As for the families those with high occurrence are Claroteidae (17.48%); Cichlidae(17.12%); Mormyridae (12.72%); Clariidae (11.48%); Channidae (7.65%); Notopteridae (6.74%) and Alestidae (5.1%). The remaining families had less than 5%. In the 11 stations surveyed, Mpokote was the more diversity with 29 species, Kengela 28, Nkile 26, Inongo 25, Isongo 24, Kesenge 23, Lokoro 21, Nkolobeke 18, Mbale 14, Lokanga 13 and Bake 12 (table IV).

Table IV. *Occurrence of fish species and families according to fishing stations in Lake Mai-Ndombe*

Order		Family	Especies	2022	2007	2012	2013
CHARACIFORMES		Alestidae	*Alestes bimaculatus Boulenger, 1899*		X		
			Brycinus grandisquamis Boulenger, 1899		X		
			Alestes liebrechtsii Boulenger, 1898 LC	X	X		
			Alestes sp	X			
			Alestes sp1		X	X	
			Bryconaethiops sp1		X	X	
			Bryconaethiops sp2			X	
			Hydrocynus vittatus Castelnau, 1861	X			X
			Hydrocynus goliath Boulenger, 1898 L	X	X		X
		Citharinidae	*Citharinus gibbosus Boulenger, 1899 L*	X	X		
			Citharinus macrolepis Boulenger, 1899 L	X	X	X	X
		Cyprinidae	*Distichodus affinis Günther, 1873*		X		
			Distichodus antroventralis Boulenger, 1898 LC	X			X
			Distichodus fasciolatus Boulenger, 1898				
			Distichodus lussoso Schilthuis, 1891 L	X		X	X
			Distichodus maculatus, 1898	X			
			Distichodus noboli Boulenger, 1899 LC	X			X
			Ichthyborus besse Boulenger, 1900	X			
			Ichthyborus ornatus Boulenger., 1899	X		X	X
			Phago intermedius Boulenger, 1899			X	X
			Xenocharax spilurus Günther, 1867				X
			Labeo lineatus Boulenger, 1898		X		
		Hepsetidae	*Hepsetus odoe Bloch, 1794*	X	X		X
LEPIDOSIRENIFORMES		Protopteridae	*Protopterus congicus Poll, 1961*	X			X
		Clupeidae	*Clupeocharax schoutedeni Pellegrini, 1926*			X	
			Nannothrissa stewarti Poll & Robert 1976			X	
OSTEOGLOSSIFORMES		Mormyridae	*Campylomormyrus sp.*				X
			Genyomyrus donnyi Boulenger, 1899			X	X
			Gnathonemus petersii Günther, 1862	X	X	X	
			Hippopotamyrus sp.		X	X	X
			Marcusenius spp.			X	X
			Mormyrops anguilloides Linnaeus, 1758 L	X	X	X	X
			Mormyrus caballus Boulenger, 1898 L	X	X		X
			Mormyrus macrops Boulenger, 1904				X
			Mormyrops nigricans Boulenger, 1899		X		X
			Myomyrus macrops Boulenger, 1904				X
			Petrocephalus spp.		X	X	X
			Pollimyrus sp.			X	X

			Stomatorhinus sp.				X
		Notopteridae	*Papyrocranus afer Günther, 1868 LC*	X			X
			Xenomystus nigri Günther, 1868 LC	X	X	X	X
		Pantodontidae	*Pantodon buchholzi Peters, 1876*	X			
PERCIFORMES		Anabantidae	*Ctenopoma nigropannosum Reichenow, 1875*	X			
			Ctenopoma sp1			X	
			Ctenopoma sp2			X	
		Arapaimidae	*Heterotis niloticus (Cuvier, 1829)**	X			
		Channidae	*Parachanna obscura Günther, 1861 LC*	X	X	X	X
		Cichlidae	*Hemichromis cf fasciatus Peters, 1857*	X	X	X	X
			Hemichromis elongates Guichenot, 1861		X	X	
			Pterochromis congicus Boulenger, 1897 LC	X	X		X
			Coptodon congica Poll&Thys vd aud, 1960 LC	X	X	X	X
			Pelmatichromis nigrofasciatus Pellegrin, 1900	X	X	X	X
			Tylochromis lateralis (Boulenger, 1898)	X	X	X	X
POLYPTERIFORMES		Polypteridae	*Polypterus congicus Boulenger, 1898 LC*	X	X		X
SILURIFORMES		Clariidae	*Clarias angolensis Steindachner, 1866*	X			X
			Clarias gabonensis Günther 1867			X	X
			Clariallabes sp.	X			X
			Clarias pachynema Boulenger, 1903	X	X		
			Channallabes apus Günther, 1902	X		X	X
			Clarias platycephalus Boulenger, 1873	X	X		
			Clarias buthupogon Sauvage, 1878	X		X	
		Bagridae	*Heterobranchus longifilis Valenciennes, 1840*		X		
			Bagrus sp.				X
		Claroteidae	*Auchenoglanis occidentalis Valenciennes, 1840L*	X	X	X	X
			Chrysichthys ornatus Boulenger, 1902 L	X	X		X
			Chrysichthys punctatus Boulenger, 1899	X		X	X
			Chrysichthys sp	X	X	X	
			Gephyroglanis congicus (Boulenger, 1899)			X	X
		Malpteruridae	*Malapterurus melanochir Norris, 2002*	X	X		
		Mochokidae	*Synodontis greshofii Schilthuis, 1891*	X			X
			Synodontis nigriventris, David, 1936		X		
			Synodontis omatipinnis Boulenger, 1899				X
		Schilbeidae	*Schilbe marmoratus Boulenger, 1911 LC*	X		X	X
			Eutropius laticeps Boulenger, 1899 L	X	X		X
			Parailia sp.			X	X
SYNBRANCHIFORMES		Mastacembelidae	*Mastacembelus greshofii Boulenger, 1901*	X		X	X

= Missing; + = presence; ++ = High presence

4. DISCUSSION

4.1. Fishing techniques and gear

A total of 23 fishing techniques are listed and practiced in Lake Mai-Ndombe, subdivided into traditional and modern techniques. Some fishing gears and techniques are not very selective. They catch all kinds of fish species, regardless of their size except for hooks. These results are similar to that got by Zanga et al. (2019), Boika et al. (2026) in lake Tumba second large and shallow lake neighbored of lake Mai-Ndombe first large and shalow lake both in the Congo basin who have the similar culture peoples and manner of outlive. Furthermore, the impressive number of techniques and gears reflects the lack of monitoring of the regulatory texts, which should support the sustainable management of fisheries resources. These results confirm those obtained by many studies (Luhusu & Micha, 2013; Bongeba & Micha, 2013; Balagizi et al., 2017; Zanga, et al., 2019). Ntumba et al. (2022a) Ntumba et al. (2022b) found that the exploitation of Mormyridae with prohibited fishing gear at Malebo Pool by fishermen from surrounding localities poses a permanent threat to species of the genus Marcusenius. In reversed, the lakes of the east of Congo Democratic Republic are so large, deep, different species than these of lakes of central cuvette and have other kind of gears used.

The best performing gear in CPUE was the beach purse seine with a catch per unit effort of 13.57 kg/day, followed by hawk net 8.64 kg/day, pot 7.15 kg/day, longline 6.33 kg/day, hook 5 kg/day, and standing gillnet 3.16 kg/day. These results confirmed those obtained by Corsi (1984) and Zanga et al. (2019) at Lake Tumba. This explained why all kinds of nets are the most used gear by the communities living around Lake Mai-Ndombe. Because of its availability, affordability, easy handling, no need for bait. It is used in the multiple habitats that fish exploit. On the other hand, the hook requires bait for its use and the creel is seasonal and is only used during the flood period. It is noted that this daily production per gear is low compared to other lakes. The case of the lakes in eastern Kivu, which has almost the same surface area as Mai-Ndombe, produces at least 25 k/gear/day. It is far superior to Lake Mai-Ndombe. Several reasons are put forward, including strong fishing pressure, an increase in the number of fishermen, the use of non-selective and habitat-destroying fishing techniques and tools, lack of control of fishing regulations and high consumer demand for fish have been identified, but also poor environmental variables (Micha et al., 2020). In addition, the increase in fishing effort on the lake, the lack of monitoring and control of net meshes and fishing sites, and the destruction of fauna and flora are the main causes of the decrease in catches in Lake Mai-Ndombe.

4.2. Species caught

Forty three species caught belonging to 32 genera, 19 families, and 7 orders. This diversification is due to the multiple habitats that Lake Mai-Ndombe has. In addition, the large swamp forest allows exchanges between the lake and the forest during flooding. The orders, families are those adapted to poor limnological conditions. These results were similar to those obtained by Zanga et al. (2019) and Boika et al. (2021) in studies of fish from Lake Tumba and swamp forests with similar environmental conditions. But our performing work effort was limited in the lake bed but not extending to the swamp, because there are more kind of species which haven't sampled.

The most dominant species in the captures were Chrysichthys punctatus, Parachanna obscura, Clarias pachynema and Clarias platycephalus; these species have biological characteristics well adapted to the hyper humic environments. These results were similar to those obtained by Bongeba & Micha (2013) in Lake Maï ndombe and Zanga et al. (2019) in Lake Tumba.

Other orders and families are not present in our captures such as Cyprinidae but they are observed in other studies. They are considered as species with low catchability, low accessibility and/or low vulnerability to fishing gear (Lalèyè et al., 2004). According to Snoeks et al. (2012) and Balagizi et al. (2017), rheophilic Cyprinidae prefer lotic system conditions due to their high dissolved oxygen requirement, and in this lentic system, excess humus causes dissolved oxygen consumption in the water (Boika et al., 2022). Other species are easily caught due to the use of earthworm bait and small fish of the family Mormyridae, Clupeidae, etc.; favours the selectivity of species with high commercial value.

Laë (1997) and Micha et al. (2020) confirmed that there was a decrease in catches every year, because the exploitation of natural fish populations has increased dramatically for direct reasons: strong demographic growth leading to an increased demand for proteins, exploitation of new environments and new species, and indirectly the use of new materials such as nylon, which reduces the time needed to make and repair gear, the introduction of more efficient fishing gear, mosquito nets. Also, fish is often cheaper than meat (Weigel, 1998; Lévêque & Paugy, 2006; Zanga et al., 2019; Ntumba et al., 2022c). In other hand, fishermen stated we increased the number of daily fishing sessions, but the yield remained mediocre; we couldn't even achieve the quantity of a single session from previous years. Considering the high level of fishing in lake Mai-Ndombe and its surroundings, as mentioned above, and the intense fishing activity coinciding with the spawning season of most commercially important fish, it can be stated that there is clearly overexploitation of the fish population in the water bodies of the study area.

In terms of occurrences, the predominance of permanent and frequent species such as Chrysichthys punctatus, Parachanna obscura, Mormyrops anguilloides, Coptodon congica, leads us to believe in the ichthyological stability of this aquatic ecosystem (Guillard et al., 2012). This stability is due to its composition, which is largely made up of indigenous species.

The current fish stock seemed to be low in relation to the surface area because of the degradation of the ichthyological diversity of the lake due to the low productivity of the primary and secondary producers in the area (Lévêque, 1997; Micha et al., 2020). However, with the increase in knowledge and the dynamic development of the fisheries sector, the inhabitants are beginning to understand that the fisheries resources, although renewable, are not infinite and must be managed wisely if they are to continue to contribute to the nutritional, economic and social well-being of the growing population of the area, and of the DRC in general (Kasigwa et al., 2020). The resolution of these problems, which are at the origin of the decline in catches, must involve the eradication of bad fishing gear and techniques, and the effective involvement of the provincial ministry of fisheries, local committees and fishermen in the management of fisheries resources. Dormant gillnets showed the high specific richness evaluated at 25 while hooks and traps only reach 24 each.

Monthly and annual prices and earnings in terms of money for the fishermen

As for the income in Congolese Francs, the hook gear was the most profitable for a daily gain of 17,298 FC (11.5 USD; 1 USD = 1500 FC); followed by the beach purse seine 16,850 FC (11.2 USD); longline 16,682 FC (11.1 USD), standing gillnet 15,148 FC (10.1 USD); hawk net 14,499 FC (9.7 USD); and pot 12,437 FC (8.3 USD)/day. These results confirm those obtained by Corsi, (1984); Bongeba & Micha (2013); Micha et al, (2020). The difference in these incomes depends on the performance of each gear having the capacity to catch large fish with high weight and commercial value which gives high profitability.

5. Conclusion

The objective of this study was to determine some aspects of fish exploitation in Lake Mai-Ndombe from 11 randomly selected fishermen's landing stations between 2014 and 2015. To do this, we examined the fishing gear used, the number of people per fishing unit, the species of fish as well as the quantity of fish caught, the catch per fishing unit and the selling price of the fish. The study revealed that, among the gear and techniques used, hooks and gillnets.

The two seasons are no significantly different in terms of CPUE, NPUE and monetary value of fish at Lake Mai-Ndombe from the statistical test. The two seasons are no significantly different in terms of CPUE, NPUE and monetary value of fish in Lake Mai-Ndombe. High fishing pressure, increase in the number of fishermen, use of non-selective and habitat-destroying fishing techniques and tools, lack of control of fishing regulations and high consumer demand for fish were identified; but also poor environmental variables (Micha, 2020). In addition, the increase in fishing effort on the lake, the lack of monitoring and control of net mesh and fishing sites, and the destruction of fauna and flora were identified as the main causes of the decrease in catches in Lake Mai-Ndombe. Indeed, we suggest that environmental governance be strengthened in terms of regulation and scientific research. Given these practices regarding the exploitation of Lake Mai-Ndombe's resources, we call for monitoring of mesh sizes; the establishment of biological closure periods; revitalizing fisheries and aquaculture policy (implementation of the Sustainable Development Goals); revitalize fisheries and aquaculture governance through the sustainable management of aquatic and aquaculture resources, while taking ecological and environmental aspects into account; update regulations; initiate the management of aquatic ecosystems; assess fish stocks in terms of quality and quantity; and determine their habitats. As for social aspects, it is necessary to implement community-based education and adopt co-management of fishery resources. We must focus on creating jobs in the fisheries and aquaculture sector through industrialization, economic development, fisheries development, aquaculture, and traceability, quality, and safety of fishery products; improve fishing technology; revitalize aquaculture; master artificial insemination techniques to increase the availability of fry; improve the genetics and selection of aquaculture species; establish policies and environmental responsibility in aquaculture; promote research, education, and training; and support academic institutions offering these programs.

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Conflict of Interest

There are no conflict of interest betwen coauthors

Author Contributions

N.L.Z.: conducted the sampling, analyzed the data, and wrote the manuscript.

V.K.P.: contributed to the review and correction of the manuscript.

B.M.: contributed to the review and correction of the manuscript.

D.E.A.M.: contributed to the review and correction of the manuscript.

S.M.: contributed to the review and correction of the manuscript.

J.-C. M.: contributed to the review and correction of the manuscript.

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