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Inventory of the Ichthyofauna of the Mpem and Djim National Park (Center, Cameroon) Provides Baseline Data for a Conservation Project

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Abstract: The intense anthropization of the Sanaga basin requires an acceleration of research on biodiversity and the conservation of its aquatic resources. In this framework, the ichthyofauna of the Mpem and Djim National Park (MpDNP) has been inventoried for the first time. The fish were sampled from 2017 to 2021 using diverse experimental fishing gears. A total of 79 species classified into 39 genera, 14 families, and 8 orders have been identified in the MpDNP. This ichthyofauna represents 46.7% of the 169 freshwater fish species known in the Sanaga basin. It contains 15 (62.5%) of the 24 endemic species reported in this basin, among them two Endangered and three Vulnerable species known on the IUCN Red List. Furthermore, two non-indigenous species have been inventoried. Siluriformes (36%) and Characiformes (22%) are the most represented in the MpDNP. It is suggested that the issues for conservation in this park must be focused as a priority on 15 endemic species, which may be ranged into two national protection classes A (5) and B (10), then on those in class C, which will be identified posteriorly as supplementary priorities for the offset of the residual impacts of the Nachtigal upstream hydropower plant development.

Keywords: freshwater; conservation; fish diversity; native; endemic; non-indigenous

1. Introduction

Cameroon has a great diversity of natural habitats due to the variability of its physical and climatic characteristics, from mangroves and dense humid forests to the Sahelian steppes, from sea level to 4100 m altitude for Mount Cameroon, the highest point in Central Africa [1]. This diversity of natural habitats is accompanied by a rich and abundant biodiversity including many endemic species, both plant and animal, making Cameroon an "Africa in miniature" [2].

In order to safeguard and enhance this biodiversity, Cameroon signed important international agreements, from 1969 to 2003, concerning the creation of protected areas and the protection of its biodiversity [2]. Since the signing of these agreements, particular attention has been paid to the conservation of large and small mammals in natural environments as well as tropical forests and terrestrial ecosystems. However, the situation of continental waters is also in peril yet generally overlooked, with challenges for freshwater fish conservation and ecosystem services related to hydropower development, drought, sand extraction, deforestation, introduction of exotic fish to the ecosystem, and pesticide spraying of cocoa trees and other crops within the catchment area [3,4]. The presence of cryptic species and largely undescribed ecology of fishes in Cameroon also contributes to these conservation challenges. Cameroon currently has more than 101 protected areas (PA) covering approximately 22% of the national territory and divided into wildlife reserves (23%) and national parks (75%) [2]. According to the Ministry of Forests and Wildlife (MINFOF), this number should be revised and increase to 107 PA including 3 (2.8%) zoological garden, 22 (20.6%) national parks, 5 (4.7%) wildlife reserves, 5 (4.7%) wildlife sanctuaries, 45 (42%) cynegetic interest zone (CIZ), and 27 (25.2%) cynegetic interest zone with community management (CIZCM) (Tanyimadjob, com. pers, accessed on 20 February 2022). Conservation in PA is regulated by several laws, such as the most recent one No. 053/MINFOF of 01/04/2020 [5], which classifies animal species into three protection categories, namely: fully protected class A species, their capture and possession is prohibited, except by derogation granted to holders of fishing or scientific research permits, and they include Vulnerable (VU), Endangered (EN), and Critically Endangered (CR) species according to the IUCN status [6]; partially protected class B species, their capture and possession may be authorized after obtaining a fishing permit explicitly authorizing the exploitation of these species following the regulations in force, and they include Near Threatened (NT) and Least Concern (LC) species according to the IUCN status [6]; and common species of class C, which benefit from the general protection measures provided by law, in compliance with the international conventions to which Cameroon is a party. Their capture and detention is authorized following the regulations in force to maintain the dynamics of their populations, and they include all species that are not listed as category A and B species.

Among the national parks, the Mpem and Djim National Park (MpDNP) is a vast natural area of 97,480 ha whose boundaries correspond to the loop formed by the Mpem and Djim rivers. It is the second largest PA in the forest–savannah ecotone zone in Cameroon [1]; since its creation in 2004, some inventories of its terrestrial fauna [7,8], then its aquatic and terrestrial flora [9] have been undertaken there. However, none of these studies were focused on fish, even though fishing activities and other threats to the ichthyofauna of this PA have been recently documented [10]. The threats to fish populations largely documented in Africa, such as overfishing, excessive catches for the aquarium hobby, export trade, introduction of non-indigenous species, pollution, pastoral activities, deforestation, climate change, and physical barriers to migrations [3,11] have also been identified in this park [10]. Despite the documentation of these pressures, a good understanding of ichthyotaxa and the factors that influence their distribution is a prerequisite for any fish fauna conservation program [12–15], which is currently lacking in this PA.

This study is part of a large research program on the inventory of the fauna and flora in the MpDNP to offset posteriorly the impacts of the Nachtigal upstream hydropower plant development in the Sanaga River in Cameroon. Its aim is to identify the ichthyotaxa present in this PA and to discuss their conservation status according to the international classification of the IUCN and national legislation [5,6] to identify conservation priorities and measures that could be applied in the context of the offset program.

2. Materials and Methods

2.1. Study Environment

The Djim River and its tributary the Mpem River are located in the Center region of Cameroon, Mbam, and Kim Division (Figure 1). These two rivers constitute the natural limits of the MpDNP. The Djim River drains its waters into the Mbam River, the major tributary of the Sanaga River [16].

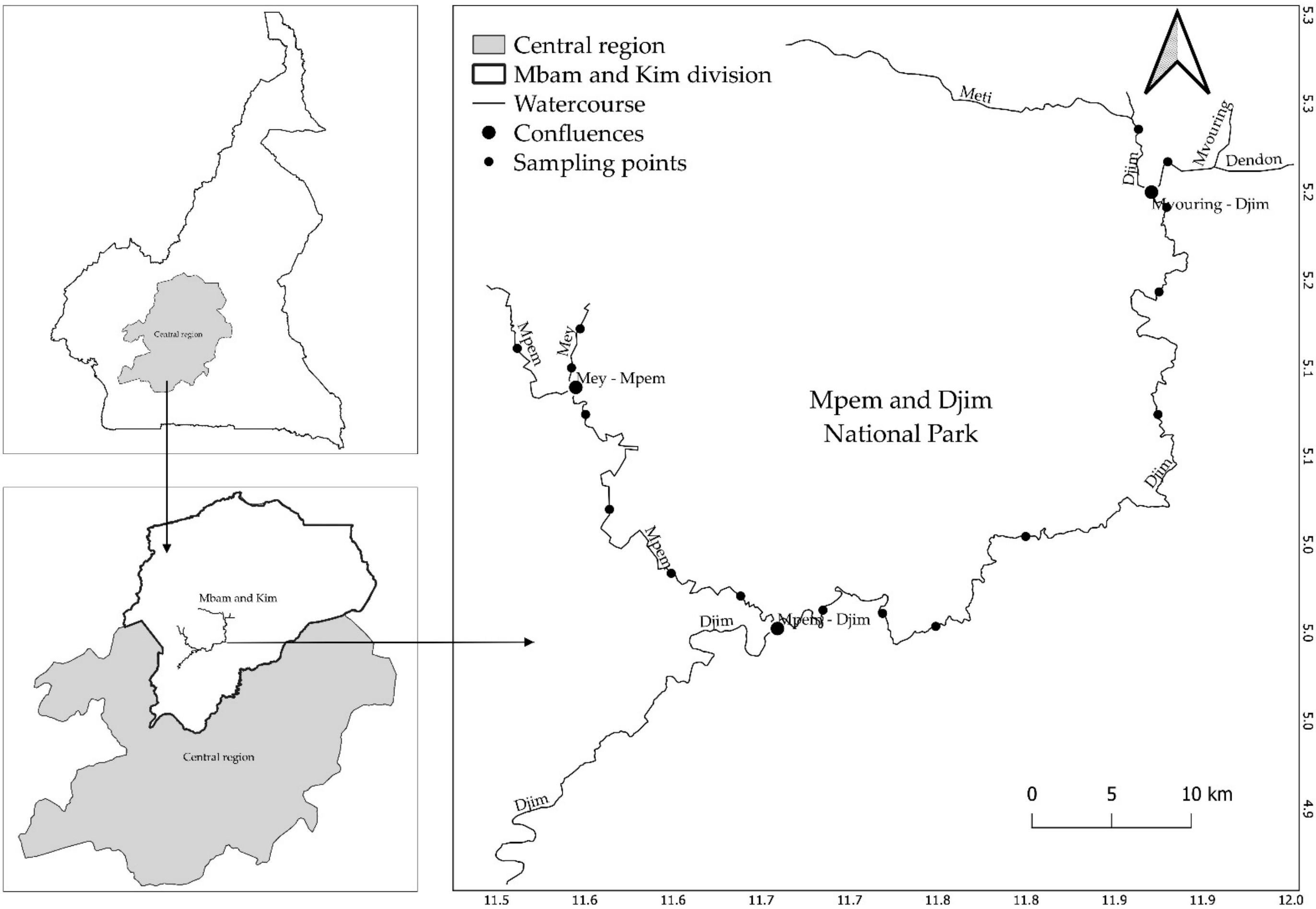

Figure 1. Geographical location of the study sites.

The Mpem and Djim rivers and their main tributaries (Mey River and Mvouring River, respectively) were sampled seasonally and discontinuously from 2017 to 2018 and 2020 to 2021. Sampling was conducted between August and November during the rainy season and between February and April during the dry season. There were 5 sampling points in the Mpem River station, 8 in the Djim River, 2 in the Mey River, and 1 in the Mvouring River (Table 1).

All of the different sampling points of the same watercourse were grouped to form a sampling station; therefore, we obtained four sampling stations corresponding to four rivers (Mpem, Djim, Mey, and Mvouring) (Figure 1). Similarly, all of the sampling events that occurred in a given season were grouped together (rainy or dry season).

The Djim River has a rocky, sandy, and muddy substrate with some areas of rapids. The riparian canopy is very dense, covering entirely or partially the width of the river, depending on the area. On the left bank of this river, there is a Forest Management Unit (UFA) which facilitates access to this watercourse. Here, we noted the presence of agro-pastoral activities (transhumance, agriculture, and livestock watering) on the banks of this river. Fishing is also practiced there in all seasons, especially in the southeastern part of the MpDNP up to the confluence with the Mpem River. The number of fishermen observed along this stretch of river varies between 40 and 75 depending on the season. In the northeastern zone of the park, fishing is less practiced because of the more difficult access to the river.

The Mvouring River has a rocky and sandy bottom; it is subject to little anthropogenic pressure due to its remoteness from the villages and difficult accessibility. It flows in the savannah under riparian vegetation that is open in its upstream reach and relatively closed further downstream before its confluence with the Djim River. Only the downstream zone was sampled. Fishing is rarely practiced there, only five fishermen have been observed along this river.

Table 1. Sampling stations and frequencies or seasons (D = dry season; R = rainy season). Sampled (X) or not sampled (empty).

Sampling Station											
Djim River			**Mpem River**			**Mey River**			**Mvouring River**		
Sampling Point	**Season**		**Sampling Point**	**Season**		**Sampling Point**	**Season**		**Sampling Point**	**Season**	
	D	**R**		**D**	**R**		**D**	**R**		**D**	**R**
2017/2018											
Djim bridge	X	X	Mindou bridge down-stream	X	X	Mindou	X	X	Camping point	X	X
Camping point 1	X	X	Malabo	X	X						
Daniel's camping	X		Camping point 2		X						
Kamkata	X										
Jérusalem		X									
2020/2021											
Mekoassim	X		Mindou bridge upstream	X		Mindja	X				
Mapendjeng	X		Kounoungou	X							
Jérusalem	X										
Djim assi	X										
Total	8	3		4	3		2			1	

The Mpem River has a rocky, sandy, and muddy substrate with some areas of rapids, and a dense riparian canopy, similar to the Djim River. However, it is less accessible than the Djim River and is subject to less anthropogenic pressure due to its remoteness from the neighboring villages. Even though there are agro-pastoral activities along its banks (agriculture and livestock watering), they are less intense than those practiced on the banks of the Djim River. At least 35 fishermen exploit this river.

The Mey River is a small tributary of the Mpem River with rocky and muddy substrate; it flows under a dense riparian canopy. Fishing is practiced there upstream of its confluence with the Mpem by approximately a dozen fishermen. We also noted the presence of agricultural activities along the banks of this tributary, but less intense than along the Djim and Mpem rivers.

2.2. *Measurement of Environmental Parameters*

The physicochemical parameters of the surface water (temperature, pH, conductivity, and suspended solids) at each sampling point were measured in situ using a Hanna HI 98,129 multiparameter before each fish sampling event.

2.3. *Capture and Storage of Fish Samples*

Fish were caught using a set of seven gillnets each measuring 25 m long and 2 m depth with varying mesh sizes of 10, 15, 20, 25, 30, 35, and 40 mm, respectively. To minimize bias due to gillnet selectivity, a second gear combination consisting of three traditional fish traps, two dip nets, and a seine net 30 m long and 5 mm mesh size were used in shallow near-shore habitats, and in forest streams containing a diversity of fish habitats likely to shelter dwarf species, such as Cyprinodontiformes. Gillnets and traps were set in the evening between 5 p.m. and 6 p.m., visited between 7 a.m. and 8 a.m. the next day, then surveyed the evening of the same day at 5 p.m., thus continuously so as to carry out night and day fishing for 48 h per sampling site [11]; while the dip nets and seine net were actively used in the shore zones a couple of hours during our presence in the field.

As soon as caught, live fish were quickly photographed on the left side in an aquarium containing water; then they were weighed using an electronic balance sensitive to the nearest gram. The living specimens were returned to the water after their identification; those unidentified were immediately anaesthetized with phenoxyethanol and stored in the 10% formalin to be further processed. Dead fish were numbered, photographed, weighed, and their standard and total lengths (SL and TL) were measured using an ichthyometer graduated to the nearest millimeter. A longitudinal incision in the abdominal wall was made to allow proper diffusion of the 10% formalin in the carcasses stored in a container, which was then transported to the laboratory [11].

In the laboratory, after elimination of the formalin by abundant washing with tap water changed in the morning and in the evening during seven to ten days, the fixed specimens were preserved in jars containing 70° ethanol. Measurements of metric characteristics and meristic counts were carried out on the specimens, which were then identified according to current taxonomic references for the region [17,18] and subsequent revisions of specific taxonomic groups involving the study area [19–22].

2.4. Data Analysis

The physicochemical parameters measured were reported by station and by season (average values for the different sampling points and dates). The Mann–Whitney U-test of the pairwise comparisons following the Kruskal–Wallis test ($p < 0.05$) was used to evaluate pairwise differences in parameter values between seasons and among rivers. The statistical differences were considered significant for $p < 0.05$.

The fish communities of different rivers have been characterized by different indices of diversity, in particular: the specific richness (S) or the total number of species identified in a river [23], the Shannon–Weaver index (H') or specific diversity was calculated as follows:

$$H' = -\sum p_i \times log_2(p_i)$$

with p_i = ni/N; p_i is the relative abundance of species i in the sample; ni corresponds to the number of individuals of species i and N the total number of individuals sampled for all species [24]. The value of the Shannon index varies from 0 (a single species largely dominates all the community) to $\log_2 S$ (H' max, when all the species have the same abundance) [25].

The Pielou equitability index (J) or fairness index was calculated by the following formula:

$$J = \frac{H'}{log_2(S)}$$

This index assesses the quality of the distribution of species in the community of each watercourse compared to a theoretical distribution [11,26]. It measures the distribution of individuals within species. Its value varies from 0 (dominance of one of the species) to 1 (even distribution of individuals in the species) [25].

The similarity index of Jaccard (q) was calculated by the following formula:

$$q = \left[\frac{c}{(a+b-c)}\right] \times 100 \quad (1)$$

where, a is the number of species of a sampling unit A, b that of sampling unit B, and c that of the species common to the sampling units A and B. The similarity index of Jaccard was used in pairwise comparisons of the stations to evaluate the similarity of the fish communities between two rivers [27]. Two groups are considered similar if the value is higher than 0.5 and dissimilar if this value is lower than 0.5 [27].

2.5. Status of Fish Species according to IUCN

The conservation status of each species was determined referring to the International Union for Conservation of Nature Red List [6]. That list places each species in 1 of 11 categories: Extinct (EX) and Extinct in the Wild (EW) are globally extinct species; Regionally Extirpated (RE) applies to species that have disappeared from the region under consideration, but persist elsewhere. The three categories Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) include species threatened with extinction. These species face a relatively high (VU), high (EN), or very high (CR) risk of extinction. The Near Threatened (NT) category includes species close to meeting the quantitative thresholds specific to threatened species, and which could become threatened if specific conservation measures were not taken. The Least Concerned (LC) category includes species that present a low risk of extinction in the region under consideration. The Data Deficient (DD) category includes species for which the best available data are insufficient to directly or indirectly determine their risk of extinction. The Not Evaluated (NE) category includes species that have not yet been evaluated with the criteria of the Red List by IUCN experts [6].

3. Results

3.1. Characteristics of the Environment

The spatio-temporal values of the water temperature, pH, conductivity, and suspended solids measured during sampling events are reported in Table 2. The highest and lowest water temperature were registered in the Djim and Mey rivers, respectively; whereas there was no significant variation between seasons (Table 2).

Table 2. Values of the physicochemical parameters measured in the rivers of the Mpem and Djim National Park during sampling events: average ± standard error, Cond = conductivity, SS = suspended solids, pH = hydrogen potential, R = rainy season, D = dry season, T = temperature. For the sampling site comparisons, values assigned with different letters (a, b, or c) in a given column are statistically different and those with the same letter are not different from the 5% threshold; no letters were used for seasonal comparisons as there are no statistically significant differences between seasons.

Stations	Seasons	T (°C)	pH	Cond (µS/cm)	SS (ppm)
Djim River	R	23.5 ± 0.42	7.62 ± 0.36	34.5 ± 0.70	17.25 ± 0.35
	D	24.4 ± 0.28	7.1 ± 0.36	38 ± 1.41	19 ± 0.70
	D + R	23.95 ± 0.59 **a**	7.36 ± 0.42 **a**	36.25 ± 2.21 **c**	18.12 ± 1.10 **c**
Mpem River	R	23.52 ± 0.74	7.68 ± 0.29	50.5 ± 0.70	25.25 ± 0.35
	D	22 ± 0.56	6.95 ± 0.09	54 ± 8.48	27 ± 4.24
	D + R	22.76 ± 1.03 **ab**	7.31 ± 0.45 **a**	52.25 ± 5.31 **a**	26.12 ± 2.65 **a**
Mey River	R	22.55 ± 0.21	7.62 ± 0.14	46 ± 5.65	23 ± 2.82
	D	21.05 ± 0.77	7.22 ± 0.28	47 ± 2.82	23.5 ± 1.41
	D + R	21.8 ± 0.98 **b**	7.42 ± 0.29 **a**	46.5 ± 3.69 **ab**	23.25 ± 1.84 **ab**
Mvouring River	R	23.25 ± 0.07	7.42 ± 0.00	38.5 ± 0.7	19.25 ± 0.35
	D	23.4 ± 0.98	6.79 ± 0.45	41.5 ± 2.12	20.75 ± 1.06
	D + R	23.32 ± 0.57 **a**	7.11 ± 0.45 **a**	40 ± 2.16 **bc**	20 ± 1.08 **bc**

Conductivity and suspended solids had similar patterns, being highest and lowest in the Mpem and Djim rivers, respectively. For these two parameters, no statistical difference was observed between seasons. In contrast, pH did not vary significantly among rivers nor between seasons.

3.2. Specific Composition

In total, 79 fish species were identified during the sampling campaigns (Table 3). They are distributed in 39 genera, 14 families, and 8 orders. The most represented orders were the Siluriformes (36%) and the Characiformes (22%) with, respectively, five and three families (Figure 2).

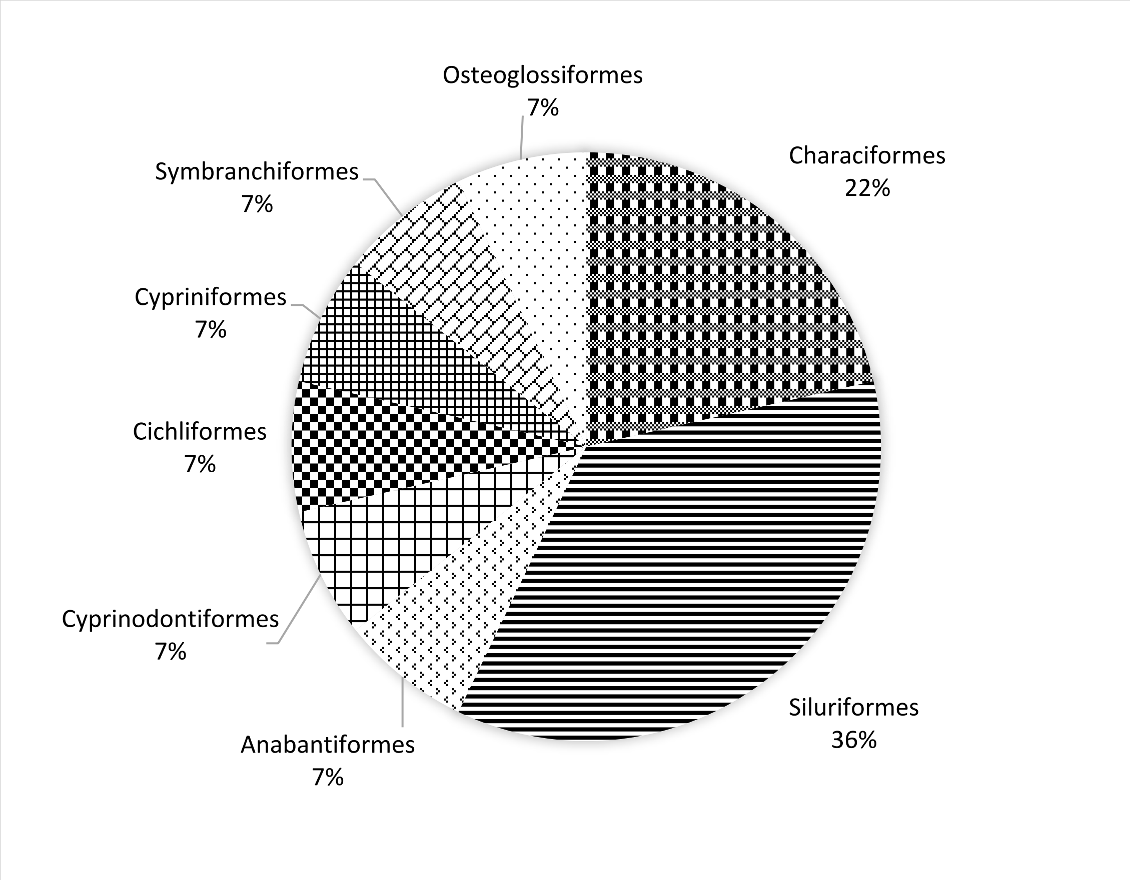

Figure 2. Percentage abundance of the different orders of fish sampled in the overall study area.

The most diversified families were the Cyprinidae (7 genera, 22 species) and the Mormyridae (6 genera, 14 species) (Figure 3). They are followed by Cichlidae (5 genera, 5 species) and Alestidae (4 genera, 6 species), then Mochokidae (3 genera, 7 species) and Claroteidae (3 genera, 5 species).

In the study area, there were 15 endemic species (to the Sanaga River basin), 60 native species and 2 non-indigenous species. The analysis of the IUCN Red List status [6] revealed that there were several species of conservation concern. In particular, in the study area, there are 2 Endangered (EN) species (*E. bourdariei* and *L. mbami*) and 3 Vulnerable species (VU; *A. dargei*, *M. sanagaensis* and *N. rubrolabiatus*), which are all endemic to the Sanaga River basin, 56 species are of Low Concern (LC), including 7 endemic species (*C. sanagaensis*, *C. cameronensis*, *D. kolleri*, *D. sanaga*, *L. sanagaensis*, *M. sanagali* and *P. melanhypopterus*) and 2 non-indigenous species (*O. niloticus* and *C. gariepinus*), 6 species are Data Deficient (DD), of which one is endemic (*S. rebeli*), and 7 species have not yet been evaluated (NE), including 2 endemics (*P. similis* and *S. galilaeus sanagaensis*) (Table 3).

The species rarefaction curve of fish species sampled In the MpDNP rivers is still slightly increasing beyond the 79 inventoried species and has not converged, even if the large majority of species (42/79, 60/79, and 71/79) were found within the first 558, 1116, and 1674 individuals, respectively (Figure 4).

Table 3. List of fish taxa inventoried in the MpDNP: Dj = Djim River, Mp = Mpem River, Me = Mey River, Mv = Mvouring River; IUCN status: LC = Least Concern, VU = Vulnerable, NE = Not Evaluated, EN = Endangered, DD = Data Deficient; presence (X) or absence (empty); **E** = endemic (to the Sanaga River basin), N = native (indigenous to the Sanaga River basin, but present elsewhere as well); I = introduced (and non-native to the Sanaga River basin); Pa = percentage abundance; Bs = Biogeographic status.

Orders and Families	Species	Stations				IUCN [6]	Pa %	Bs [17,21]
		Dj	Mp	Me	Mv			
Anabantiformes							**0.94**	
Anabantidae	*Ctenopoma maculatum* Thominot, 1886	X	X	X	X	LC	0.89	N
	Microctenopoma nanum (Günther, 1896)		X			LC	0.04	N
Characiformes							**19.30**	
Alestidae	*Alestes macrophthalmus* Günther, 1867	X	X			LC	1.20	N
	Brycinus kingsleyae (Günther, 1896)	X	X	X	X	LC	7.38	N
	Brycinus macrolepidotus Valenciennes, 1850	X	X	X		LC	4.29	N
	Hydrocynus forskalii (Cuvier, 1819)	X	X			LC	0.08	N
	Phenacogrammus major (Boulenger, 1903)	X		X	X	LC	0.22	N
	Phenacogrammus urotaenia (Boulenger, 1909)	X				LC	0.04	N
Distichodontidae	*Distichodus kolleri* Holly, 1926	X	X			LC	1.79	N,E
	Nannocharax intermedius Boulenger, 1903	X	X	X		LC	0.71	N
	Nannocharax rubrolabiatus Van den Bergh et al., 1995	X				VU	0.08	N,E
Hepsetidae	*Hepsetus odoe* (Bloch, 1794)	X	X		X	NE	3.44	N
Cichliformes							**7.92**	
Cichlidae	*Coptodon cameronensis* (Holly, 1927)	X	X	X	X	LC	2.82	N,E
	Hemichromis camerounensis Bitja Nyom, Agnèse, Pariselle, Bilong Bilong, Gilles & Snoeks, 2021	X	X	X		LC	3.44	N
	Oreochromis niloticus (Linnaeus, 1758)	X				NE	0.67	I
	Parananochromis caudifasciatus (Boulenger, 1913)			X		LC	0.04	N
	Sarotherodon galilaeus sanagaensis (Thys van den Audenaerde, 1966)	X	X			NE	0.94	N,E
Cypriniformes							**27.45**	
Cyprinidae	*Enteromius aspilus* (Boulenger, 1907)	X	X	X	X	LC	5.06	N
	Enteromius bourdariei (Pellegrin, 1928)	X				EN	0.31	N,E
	Enteromius camptacanthus (Bleeker, 1863)	X				LC	0.08	N
	Enteromius guirali (Thominot, 1886)	X	X	X	X	LC	6.85	N
	Enteromius holotaenia (Boulenger, 1904)	X				NE	0.26	N
	Enteromius jae (Boulenger, 1903)	X	X	X		LC	1.34	N
	Enteromius martorelli (Roman, 1971)	X	X	X	X	LC	6.35	N
	Labeo annectens Boulenger, 1903	X	X			LC	0.13	N
	Labeo batesii Boulenger, 1911	X				LC	0,17	N
	Labeo camerunensis Trewavas, 1974	X	X			LC	1.92	N
	Labeo cf *sanagaensis*		X				0.31	N
	Labeo sanagaensis Tshibwabwa, 1997	X	X	X		LC	0.76	N,E
	Labeobarbus brevispinis (Holly, 1927)		X			LC	0.08	N
	Labeobarbus habereri (Steindachner, 1912)	X	X	X		LC	0.62	N
	Labeobarbus mariae (Holly, 1926)	X	X			LC	0.13	N
	Labeobarbus mbami (Holly, 1927)	X	X			EN	0.17	N,E
	Labeobarbus micronema (Boulenger, 1904)	X				LC	0.04	N

Table 3. *Cont.*

Orders and Families	Species	Stations				IUCN [6]	Pa %	Bs [17,21]
		Dj	Mp	Me	Mv			
	Labeobarbus progenys (Boulenger, 1903)		X			LC	0.04	N
	Leptocypris crossensis Howes & Teugels, 1989	X				LC	0.49	N
	Opsaridium ubangiense (Pellegrin, 1901)	X				LC	0.04	N
	Prolabeops melanhypopterus (Pellegrin, 1928)	X	X			LC	1.25	N,E
	Raiamas senegalensis (Steindachner, 1870)	X	X	X		LC	0.94	N
Cyprinodontiformes							**0.58**	
Nothobranchidae	*Aphyosemion* cf *bamilekorum*	X					0.08	N
	Aphyosemion dargei Amiet, 1987	X				VU	0.13	N,E
	Aphyosemion elberti (Ahl, 1924)		X			LC	0.26	N
	Epiplatys sp.	X					0.08	
Osteoglossiformes							**0.58**	
Mormyridae	*Hippopotamyrus castor* Pappenheim, 1906	X		X		LC	0.13	N
	Marcusenius mento (Boulenger, 1890)	X	X			LC	0.31	N
	Marcusenius moorii (Günther, 1867)	X				LC	0.08	N
	Marcusenius sanagaensis Boden et al., 1997	X	X	X		VU	4.47	N,E
	Mormyrops anguilloides (Linnaeus, 1758)	X	X		X	LC	0.26	N
	Mormyrops breviceps Steindachner, 1894	X	X			LC	0.35	N
	Mormyrus rume Valenciennes 1847		X			NE	0.04	N
	Mormyrus sp.	X					0.08	
	Mormyrus tapirus Pappenheim, 1905	X	X			LC	0.26	N
	Paramormyrops batesii (Boulenger, 1906)	X	X	X		DD	0.31	N
	Paramormyrops kingsleyae (Günther, 1896)			X		DD	0.04	N
	Petrocephalus christyi Boulenger, 1920	X	X	X		LC	2.37	N
	Petrocephalus microphthalmus Pellegrin, 1909	X				LC	0.40	N
	Petrocephalus similis Lavoué, 2011	X	X		X	NE	0.80	N,E
Siluriformes							**33.49**	
Amphiliidae	*Doumea sanaga* Skelton, 2007	X	X			LC	0.98	N,E
Clariidae	*Clarias buthupogon* Sauvage, 1879	X	X	X	X	LC	1.07	N
	Clarias camerunensis Lönnberg, 1895	X	X	X	X	LC	1.47	N
	Clarias gariepinus (Burchell, 1822)	X		X		LC	0.31	I
	Clarias jaensis Boulenger, 1909	X	X	X		LC	0.76	N
	Clarias longior Boulenger, 1907			X		LC	0.04	N
	Clarias pachynema Boulenger, 1903	X	X	X	X	LC	1.65	N
Claroteidae	*Chrysichthys auratus* (Geoffroy Saint-Hilaire, 1809)	X	X	X		LC	9.18	N
	Chrysichthys nigrodigitatus (Lacépède, 1803)	X	X			LC	0.76	N
	Notoglanidium macrostoma (Pellegrin, 1909)	X				LC	0.44	N
	Parauchenoglanis balayi (Sauvage, 1879)	X	X	X		LC	1.11	N
	Parauchenoglanis monkei (Keilhack 1910)				X	NE	0.04	N
Mochokidae	*Chiloglanis batesii* Boulenger, 1904	X	X			LC	0.31	N
	Chiloglanis cameronensis Boulenger, 1904	X	X			LC	0.44	N
	Chiloglanis sanagaensis Roberts, 1989	X				LC	0.58	N,E
	Microsynodontis batesii Boulenger, 1903	X				DD	0.08	N
	Microsynodontis nasutus Ng, 2004		X			DD	0.04	N
	Synodontis marmoratus Lönnberg, 1895		X			DD	0.08	N

Table 3. *Cont.*

Orders and Families	Species	Stations				IUCN [6]	Pa %	Bs [17,21]
		Dj	Mp	Me	Mv			
	Synodontis rebeli Holly, 1926	X	X	X	X	DD	7.97	N,E
Schilbeidae	*Schilbe intermedius* Rüppel, 1832	X	X	X	X	LC	4.47	N
	Schilbe mystus (Linnaeus, 1758)	X	X			LC	1.61	N
Synbranchiformes							**0.31**	
Mastacembelidae	*Mastacembelus sanagali* Thys van den Audenaerde, 1972	X	X	X		LC	0.31	N,E
Species richness	79	67	53	32	16			

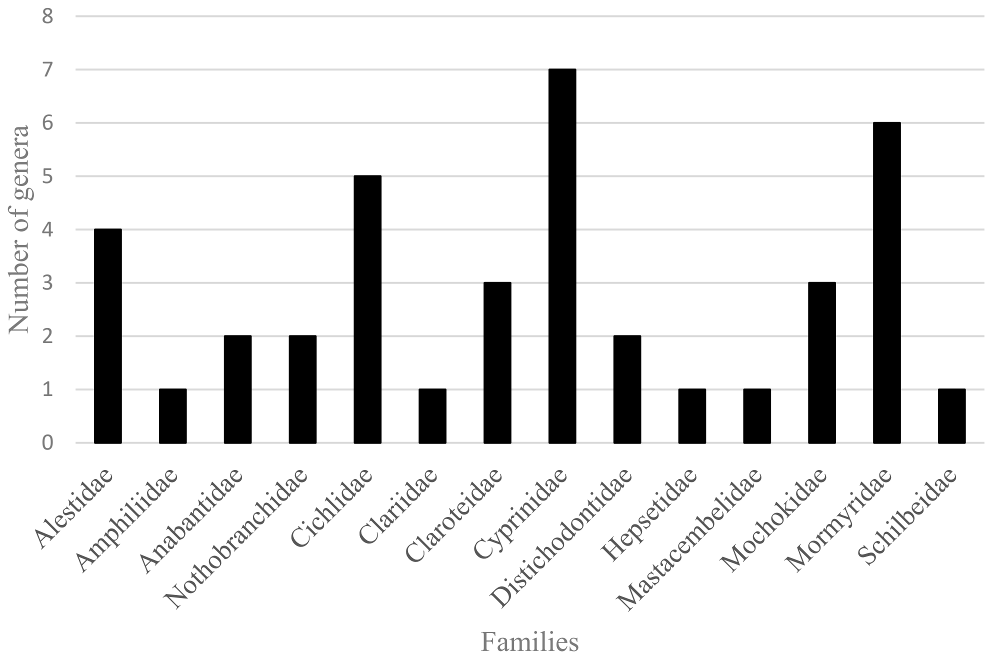

Figure 3. Number of genera per fish family sampled in the all studied area.

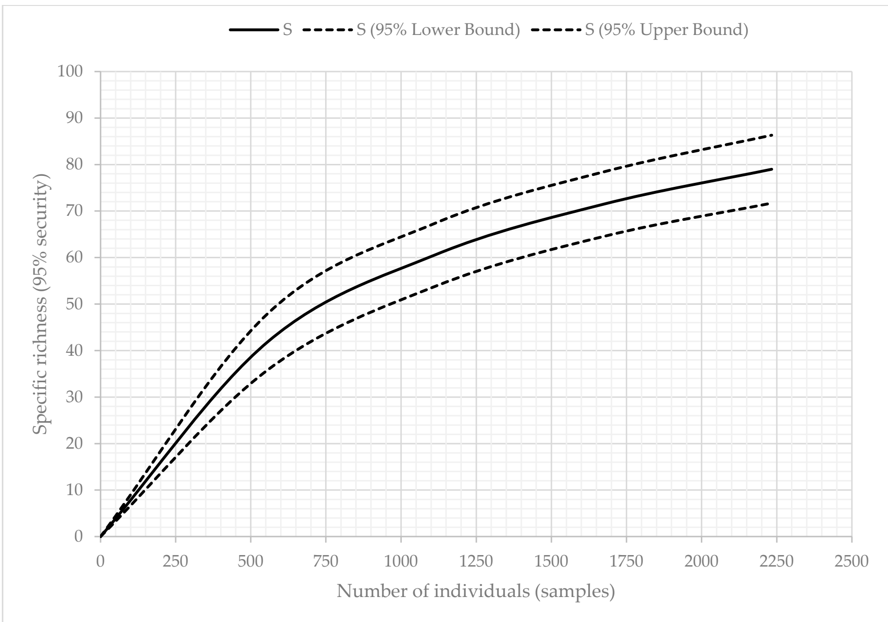

Figure 4. Species rarefaction curve of fishes sampled in the MpDNP rivers.

3.3. Community Diversity

When comparing all sampling data, the species richness was S = 67 in the Djim River, S = 53 in the Mpem River, S = 32 in the Mey River, and S = 16 in the Mvouring River. The Shannon diversity of the ichthyofauna was in general higher in the Djim (H' = 3.4) and in the Mpem (H' = 3.28), as compared to the Mey (H' = 3.09) and the Mvouring (H' = 2.67). These Shannon index values followed the same pattern in the dry season. In the rainy season, the Mpem had higher values than the Djim, which differs from the dry season pattern (Table 4).

Table 4. Variations of the values of the species richness (S), Shannon diversity (H') and Pielou (J) indices in the communities of the different park rivers (Dj = Djim River; Mp = Mpem River; Me = Mey River; Mv = Mvouring River) and seasons (D = dry season; R = rainy season).

Stations	***S***			**H′**			**J**		
	Overall	**Season**		**Overall**	**Season**		**Overall**	**Season**	
		D	**R**		**D**	**R**		**D**	**R**
Dj	67	12 ± 7.01	44 ± 1.41	3.41	3.20 ± 0.22	2.02 ± 0.86	0.81	0.84 ± 0.06	0.82 ± 0.14
Mp	53	19.5 ± 19.09	27.33 ± 7.23	3.33	2.84 ± 0.20	2.25 ± 1.07	0.83	0.86 ± 0.04	0.84 ± 0.01
Me	32	24	13	2.97	2.23	2.59	0.85	0.87	0.81
Mv	16	5	13	2.19	2.04	0.59	0.79	0.79	0.36

The Pielou index was in general higher in the Mey (J = 0.87), followed by the Mvouring and the Mpem (J = 0.83 for both), and the Djim (J = 0.81). This profile was quite similar in the dry season, but differed in the rainy season, being higher in the Mpem (0.85) and Djim (0.84) than in the Mey (0.78) and the Mvouring (0.36) (Table 4).

These results indicate that the ichthyofauna was less diverse and aggregated in the Mvouring River during the rainy season. During that period, this fauna was dominated by four species (*E. martorelli*, *E. aspilus*, *S. rebeli*, and *H. odoe*).

The different values of the Jaccard index obtained by pairwise comparisons between the stations, and expressed in percentages, showed a much higher ichthyofaunal similarity (60%) between the Mpem and the Djim; this similarity gradually diminished lower between the other stations, in particular between the Mvouring and the other stations: Mey (33.33%), Mpem (25.45%), and Djim (22.05%), respectively (Table 5).

Table 5. Variation of the Jaccard (q) similarity index expressed as percentage of similarity.

Mpem	60		
Mey	41.4	38.3	
Mvouring	22.1	25	33.3
	Djim	**Mpem**	**Mey**

4. Discussion

This study identified 79 fish species sampled in four rivers (67 in the Djim River, 53 in the Mpem River, 32 in the Mey River, and 16 in the Mvouring River), and indicates that the ichthyofauna in the rivers of the MpDNP are particularly diverse. Among the 79 species mentioned above, two species (*Epiplatys* sp. and *Mormyrus* sp.) remained undetermined and may correspond to new species to be described later. Two other species, *Aphyosemion* cf *bamilekorum* and *Labeo* cf *sanagaensis*, were identified with reservations as they resemble well-known described species of the Sanaga River basin ichthyofauna. An in-depth taxonomic study is underway to determine the status of these four species, undetermined or identified with reservations. The fish fauna identified in the MpDNP represents 46.7% of the 169 freshwater species known in the entire Sanaga River basin [11,17,21]. Fifteen species

(15) inventoried in the MpDNP are endemic in the Sanaga basin [11,21]; they represent an endemism rate of 8.87% of the whole Sanaga basin species and 18.9% of the 79 species inventoried in the MpDNP); no species is exclusively endemic in this park.

Some species previously reported by Stiassny et al. [17] in the median part of the Sanaga basin, namely, *Labeo nunensis*, *Mastacembelus niger*, *Paramormyrops sphekodes*, *Garra dembeensis*, *Sanagia velifera*, *Bagrus docmak*, *Chrysichthys longidorsalis*, *Schilbe djeremi*, *Heterobranchus longifilis*, and *Enteromius nounensis*, have not been sampled during this study. Their absence in our samples could reflect their current rarity, preference for the main Sanaga River habitats, or could be the result of insufficient sampling efforts (according to the species rarefaction curve, suggesting that additional sampling efforts could result in increasing the documented species richness). The fact that the species rarefaction curve is not plateaued could be explained also by gear selectivity; it is considered that each gear used has a selectivity; although the combination of these different gears aimed to reduce this selectivity [11]. We suggest that investigations continue over several years before concluding on their persistence or not in this protected area and estimating abundances by catch-weighted per unit effort.

The Shannon–Weaver (H') and Pielou (J) indices values showed that there is no widely dominant taxon (except for the Mvouring River during rainy season); consequently, these fish populations appear to be balanced overall. The low values of the Pielou index obtained in the Mvouring station during the rainy season when the ichthyofauna was dominated by four species (*E. martorelli*, *E. aspilus*, *S. rebeli*, and *H. odoe*) could be explained probably by a sampling bias related to the low number of samples (only one site was sampled in both seasons in the Mvouring River). It was also observed that in the sampling area, only this river flows in the savannah under riparian vegetation that is open in its upstream reach and relatively closed further downstream where sampling was done; relationships between fish diversity and riparian vegetation are discussed below. Another hypothesis made concerns the possible transverse migration of fish in the floodplains according to the flood pulse concept [28,29], which explains how the periodic inundation and drought control the lateral exchange of water, nutrients, and organisms between the main river channel and the connected floodplain. According to Hossain et al. [30], the main causes of seasonal differences in fish biodiversity indexes are seasonal variations of nutrients and high-water velocities in the main rivers affecting the coexistence of many fish species and seasonal fish migrations. Although this phenomenon is probably common in many tropical rivers, it is not really highlighted by this result because it would have occurred similarly in other tributaries or sampling stations.

The Mpem and the Djim rivers have in common a high percentage (60%) of the inventoried species, which could be explained by the fact that the Mpem River is the main tributary of the Djim River and the habitats of these two rivers are geomorphologically and physiochemically more similar to each other than with their respective sub-tributaries (Mey and Mvouring).

Despite the existence of diverse anthropogenic pressures, water quality in the MpDNP is generally better than in the Mbam and Djerem National Park (MDNP), which is another National Park located in the upper Sanaga River basin [11]. In the MpDNP, the temperature (21.8 ± 0.98 to 23.95 ± 0.59 °C) is lower than in the MDNP (25.2 ± 0.3 to 26.6 ± 0.1 °C), while pH (7.11 ± 0.45 to 7.42 ± 0.29) and conductivity (36.25 ± 2.21 to 52.25 ± 5.31 µS/cm) were higher than in the MDNP (5.0 ± 0.1 to 6.1 ± 0.1 and 23.0 ± 0.3 to 44.4 ± 1.1 µS/cm, respectively) [11]. Such differences may be due to the location of the MpDNP in a highly forested area with rivers protected by a thick canopy, while the sampled area of the MDNP is located in the savannah zone downstream of the Mbakaou regulation dam with rivers poorly protected by a sparse canopy cover [11]. In the case of MpDNP, the riparian canopy appears to act as a temperature regulator, as was also demonstrated in the middle Congo [31]. As highlighted by Dallaire [32], maintaining riparian forests is essential to the conservation of fish habitat. It helps to maintain the physicochemical quality of the water that is essential for fish growth [33], regulate hydraulic regimes, and also provides shelter (overhanging vegetation and large woody debris) and structures fish habitat in streams and lakes. The role of riparian forests in the functioning of tropical African rivers has been well documented [34,35].

The two non-indigenous species (*O. niloticus* and *C. gariepinus*) inventoried in the MpDNP were probably introduced by human activities, such as fisheries. The literature provides more information on their probable origins. According to Vreven et al. [36], stocks of *O. niloticus* from the Chad Basin (Chad and Central African Republic) have been introduced into the Sanaga basin, in particular into the Noun, Djerem, and Lom marshes. Some of these introductions of non-indigenous species were accidental [36]; others were undertaken with the intention of developing aquaculture and fishing, and to improve the productivity of natural environments [11,37]. *C. gariepinus* appears to have become established in the Sanaga basin following introductions in various fish farming stations (established since the 1970s) from which it escaped [36]. Today, these species are regularly captured in the Sanaga River basin.

The spread of non-indigenous species is recognized as a major threat to freshwater biodiversity [38,39], as introduced fish can compete with indigenous species and eventually eliminate them [4,40–42]. Control and monitoring of the presence of these non-indigenous species in the MpDNP are strongly recommended; if their abundance increases substantially (currently, they have a relatively low abundance, 0.67% and 0.31% for *O. niloticus* and *C. gariepinus*, respectively), their progressive elimination by selective fishing could prove to be an effective method of limiting their proliferation.

Among the 15 endemic species identified in MpDNP, 3 species (*E. bourdariei, N. rubrolabiatus*, and *P. melanhypopterus*) have a very small adult size and are often found in typical habitats of pollution-sensitive streams. This result highlights the necessity of limiting the use of pollutants and the deforestation on the outskirts of the MpDNP. We propose that the regulations that apply to classes A, B, and C terrestrial animals also apply to fish recognized here in the same categories.

According to national legislation concerning the protection of animal species [5], we suggest to the Ministry of Forests and Wildlife (MINFOF) to consider five species and include them in class A (*E. bourdariei*, *L. mbami*, *A. dargei, M. sanagaensis*, and *N. rubrolabiatus*) as they are considered as endemic to the Sanaga River basin [17,18] and are threatened species [6]. We also suggest to include 10 species in class B (*C. sanagaensis, C. cameronensis, D. kolleri, D. sanaga, L. sanagaensis, M. sanagali*, *P. melanhypopterus*, *S. rebeli*, *P. similis*, and *S. galilaeus sanagaensis*) that are Sanaga River basin endemics [17,18]. These classifications would contribute to the protection and conservation of the diverse fish communities of the Sanaga River basin.

5. Conclusions

This study provides preliminary data on the fish fauna of the Mpem and Djim National Park. The issues for conservation in this park must be focused as a priority on all of the species belonging to the protection classes A and B (including those proposed for theses classifications), in particular for the offset of the residual impacts of the Nachtigal upstream hydropower plant development. Specifically, maintaining intact riparian forests and the connectivity between the rivers and the floodplain are likely to be important actions to meet overall conservation goals, in addition to reducing fishing pressures or encouraging least harmful fishing techniques (e.g., avoiding the use of ichthyotoxins). The actions undertaken for identified "priority species" will undoubtably benefit other non-classed fish species.

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