Current status of Cyprinids abundance and diversity and their potential for aquaculture production in Rwanda

R Mwimba[1,2], S Rukera Tabaro [2], N.M.M Syaghalirwa[3]*

[*]***Corresponding author*:** elrash2002@gmail.com

Abstract

The present study was conducted to get a recent overview of native and exotic cyprinid species in Rwandan waters, focusing on the abundance and the diversity and to identify those that may be used in Rwandan aquaculture industry. Seven hydrological areas were sampled during ten months in 2019-2020. Species identification was done by morphometrical analysis and using key guides. Eight cyprinid species were recorded. Lower Akagera was the most diversified area in cyprinid species (with H'=1.38±0.1 and D=0.29±0.0) and was significantly different ($p<0.05$) compared to other hydrological areas. This area also showed higher fishes' abundance. Beta diversity displayed higher similarity between Kigali water bodies and upper Akagera (SI=0.8), upper Akagera and Akanyaru (SI=0.667), upper Akagera and lower Akagera (SI=0.571). Dissimilarity was total; BCI=0.0 between northern lakes and Lake Kivu. *Cyprinus carpio* (RD=60.1±4.8, F=0.57±0.0) and *Enteromius cercops* (RD=18.1±2.0, F=0.43±0.0) were significantly dominant and frequent ($p<0.05$) compared to other cyprinid species. Captures of common carps were significant and most of the specimens were of big size. Considering their total length and large body weight (TL=33.8±3.13cm, BW=3.0±2.12kg), the exotic species *Cyprinus carpio* revealed to be adapted to Rwandan ecological conditions and it can be used in the aquaculture industry throughout the country. In parallel, the native cyprinids *Labeobarbus altianalis* (TL=32.2±8.32cm, BW=2.5±1.86kg) and *Labeo victorianus* (TL=26.5±4.37cm, BW=0.5±0.12kg) were recorded with big size, they can also offer potentiality in aquaculture sector and further studies on induced spawning and adaptability in aquaculture of these cyprinid species are necessary.

Key words: *Cyprinid fish species, species diversity, species abundance, Rwandan river basins*

[1] University of Rwanda, College of Science and Technology, Department of Biology; KK 737 Street, Gikondo, Kigali PO BOX 4285 Kigali-*Rwanda. Email:* elrash2002@gmail.com. *Mob: +250 783 182 724*

[2] University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine, Department of Animal Production. KK 737 Street, Gikondo, Kigali PO BOX 4285 Kigali-*Rwanda. Email:* simon.rt@gmail.com, *Mob: +250 788 450 031*

[3] Research Unit in Environmental and Evolutionary Biology (URBE), Institute of Life, Earth and Environment (ILEE), University of Namur, Rue de Bruxelles 61, 5000 Namur, Belgium. Email: robert.mandiki@unamur.be. Mob : +32 498 27 66 10

Introduction

Cyprinid species are some of the most cultivated groups of fish in the world, only the common carp (*Cyprinus carpio)* is cultured largely in Africa in spite of an array of indigenous cyprinids in lakes and rivers across the continent (FAO, 2008). Cyprinids are characterized by a pharynx with 1-3 rows of teeth, each row with a maximum of 8 teeth. Usually cyprinids have thin lips, the plicae or papillae are absent; their mouth sometimes is suckerlike (*Garra* and *Labeo*). Cyprinids can possess or not barbels. Their premaxilla usually borders the upper jaw making the maxilla entirely or almost entirely excluded from the gape. Usually cyprinids have a protrusible upper jaw. Their dorsal fin bears spinelike rays in some species. Primitive number of chromosomes 2n = 50, some with 48 but also polyploidy exists. Maximum length at least 2.5 m to probably 3 m in *Catlocarpio siamensis* and many species are less than 5 cm. Concerning the reproductive behavior, mainly non-guarders, but in some species males build nests and/or protect the eggs (Nelson, 1994).

Rwanda water bodies are host to diversity of Cyprinids, some native and others introduced since eighties. De Vos et al. (2001) identified 24 cyprinid species in Rwandan waters, but 22 species are mentioned in Fishbase (All fishes reported from Rwanda). In fact, the Rwandan ichthyological fauna is not much diversified owing to the youth of lakes and the existence of natural obstacles (falls) which prevented the colonization of the upper part of the hydrographic network by various species characteristic of the Nile basin (Snoeks et al. 1997). Most cyprinid species recorded in Rwandan waters are native and small sized without economic aquaculture interest (De Vos et al. 2001). Nevertheless, in 1979 during a North Korean assistance programme, the Asian silver carp (*Hypophthalmichthys molitrix*) and the grass carp (*Ctenopharyngodon idellus*) were introduced from Korea for aquaculture and/or weed control and were brought to some fish ponds near Kigali (Welcomme, 1988). Apparently silver carp was also brought around that time from the Soviet Union against recommendation from the Fish Culture Office in Kigali. Some of these silver carp remained at Kigembe Station, others were transferred in farmers' ponds nearby (Welcomme, 1988). It is unknown what happened later with these fish. The introduced grass carp was spawned and fingerling production was realized at the Kigali Fish Station in the early eighties (Welcomme, 1988). Fingerlings were transferred to Kigembe Station in 1983 or 1984 and to Rwasave Station around 1985-86. However, by 1988 all grass carp at Rwasave had died (Welcomme, 1988). A second transfer to Kigembe station was made in the late eighties (Welcomme, 1988). They were brought into control of Azolla, which became a failure. Apparently Lake Karago was also stocked with grass carp in the late eighties but it is unknown if the species established in this lake (Welcomme, 1988). According to Plisnier (1989) the common carp, the grass carp and the Chinese or silver carp might have been introduced in Lake Muhazi in 1979. Although it appears that a few specimens were caught later, apparently these species did not establish in the lake (Welcomme, 1988). In short, there are no recent reports on the possible adaptation or dispersal of

these various exotic cyprinid species in Rwandan watersheds. Moreover, the competition between these exotic species and native ones has yet to be properly assessed.

Nowadays, cyprinid species show some interest for its introduction in the aquaculture sector in Africa. In particular, it has already been shown that common carp can be used to diversify and improve aquaculture production in some African countries, such as those in North or South Africa, and other high-altitude countries. But it remains necessary to evaluate the profitability of such a use of an exotic species versus an indigenous population to improve fish production. It is in this view that Rutaisire et al. (2015) realized a study on the gonadal recrudescence and induced spawning in *Labeobarbus altianalis* and Chemoiwa (2018) conducted studies on the reproductive biology of *Labeobarbus altianalis* from river Nyando, Lake Victoria basin in Kenya in order to introduce this cyprinid fish in aquaculture production.

Rwandan waterbodies have undergone disturbances and pollutions since eighties (RWFA, 2019). This condition may result in changes in abundance and diversity on the ichthyofauna. The main agro-environmental problems are closely associated with the country's rapid and intensive agriculture and livestock farming. They include soil erosion and land degradation, water pollution and an increase in greenhouses gases emissions leading to climate change (REMA, 2021). These environmental disturbances associated to the climate could affect aquatic biodiversity and specific impacts on fishes.

The present study has been conducted in the perspective to get a recent overview of native and exotic cyprinid species in Rwandan waters, focusing on the abundance and the diversity in selected geographical areas. In addition, the study also aimed to identify cyprinid species that display potentiality for rearing purposes and which may be introduced in the Rwandan aquaculture industry.

Materials and Methods

Study area

The Cyprinid species have been searched in major hydrological areas of Rwanda; the rivers Nyabarongo, Akanyaru, Akagera and different lakes. The sampling was carried out on Southern lakes: Lake Rweru, Lake Cyohoha, Lake Birara, Lake Sake and Lake Mugesera, Eastern lakes: Lake Muhazi, Lake Nasho, Lake Mpanga and Lake Cyambwe, Northern lakes: Lake Ruhondo and Lake Burera, Western lake: Lake Kivu. Seven hydrological zones have been selected for this research: (1) Kigali water bodies comprises a section of Nyabarongo and Upper Akagera, (2) Rweru-Mugesera included a section of Upper Akagera and southern lakes, (3) Eastern Kirehe consisted of the lower Akagera and all sampled eastern lakes, (4) Southern Kirehe covered the middle section of river Akagera, (5) Akanyaru consisted of a section of Akanyaru river, (6) Rugezi-Burera-Ruhondo Complex covered all northern lakes and wetlands, and (7) Lake Kivu (Fig.1).

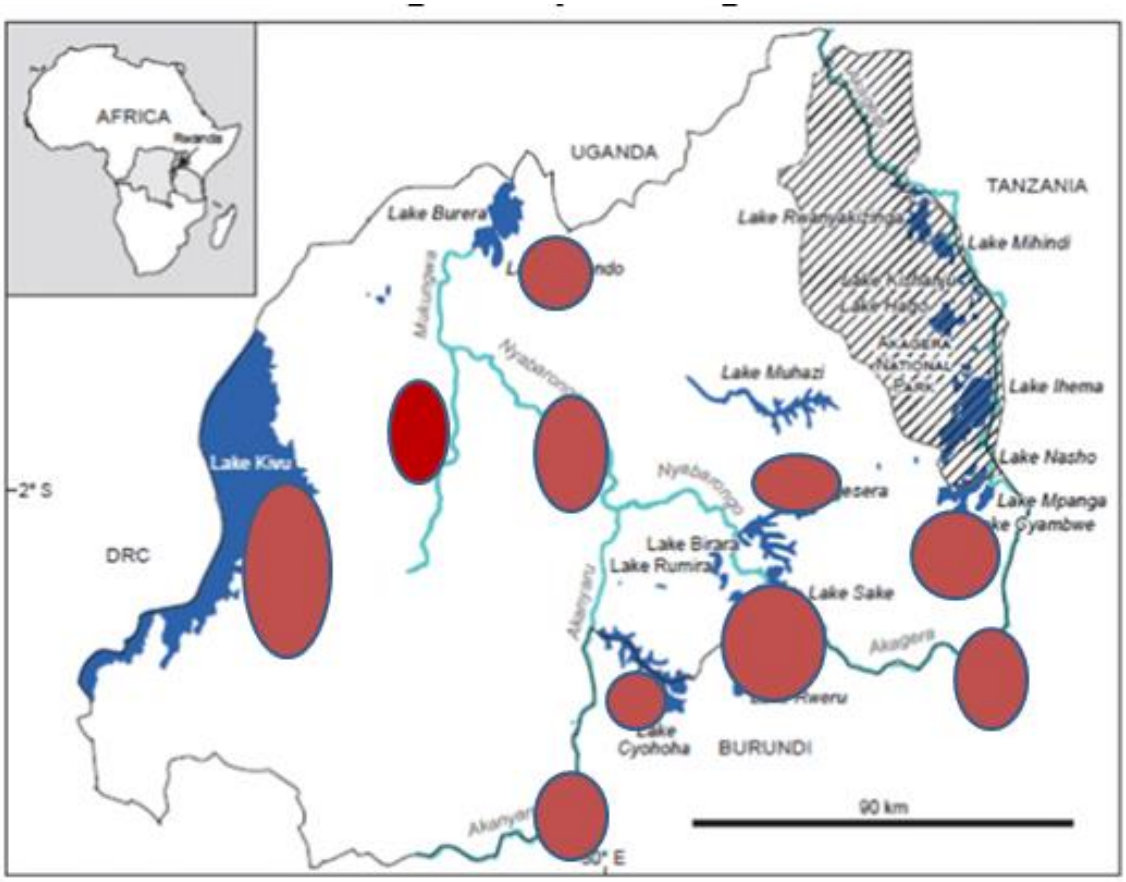

Figure 1. Map of Rwanda showing the major Rwandan rivers and lakes and sampled hydrological areas

Methods

Fish collection

A stratified approach was used to ensure a representative sample size. Fishing sites were visited and local fishermen were involved by interviewing them on the fish species regularly collected (in vernacular language: Kinyarwanda), the daily fish captures, the fishing devices used, the fruitful fishing season etc. Moreover, the features of the hydrological area (soil, hydrology, ecosystem service, socio-economic, pressure or threats…) and the moment the site was visited were noted. The period of sampling was carried out during the dry season (from June to October 2019) and the rainy season (from January to May 2020). Sites were visited once per season and the contact with fishermen (fish observation, fish identification, fish counting, fish weighting and interview) was all the day especially in the morning (6:00 am to 11:00) and the evening (4:00 pm to 6:00 pm).

Fish identification

Fishes captured by fishermen by various fish catching techniques (hand-gathering, spearfishing, netting, angling, and trapping) were used for identification. Fish species identification was done by morphometrical analysis and using field guides. This involved the measurement and counting of characteristic external organs of cyprinids and examining the color pattern, morphology, lateral lines, fins and mouth, and character of the teeth

and scales. In addition, all unidentified fish on the field were photographed and some samples were collected, conserved in a solution of formaldehyde (5%) for subsequent identification in the laboratory. For identification, the classification of collected fish followed the taxonomic keys and guides by De Vos et al. (2001), Check list of fishes of Rwanda (De Vos et al. 2001), Check-list of the freshwater fishes of Africa CLOFFA (Lévêque et al. 1984) and FISHBASE: short description, occurrences, pictures… (De Weirdt et al. 2007; Lévêque, 2003).

Site mapping and species diversity indices

To produce the map displaying the areas where the cyprinid fish species were recorded, these steps were followed: use of the GPS data collection on the field, data entry in excel and analysis, converting excel to CSV format, importing excel to ArcGIS using XY data and projecting them to Rwanda district boundary, and then production of the final map as output. Alpha-diversity and Beta-diversity values were computed using the statistical package EstimateS version 9.1.0. Alpha-diversity was quantified as species richness (local number of species) and as Shannon Wiener Index (H'; local number and abundance of species). The Beta-diversity was calculated to examine the change in species diversity between the different sampled hydrological areas. Data were computed by Sörensen similarity index and Bray Curtis dissimilarity index to compare diversity between the different sampled hydrological areas (Whittaker, 2001).

Statistical analyses

Data were analyzed using the stratigraphic package software IBM SPSS Statistics 29.0.1.0. The one-way analysis of variance (ANOVA 1) and the Scheffe test was applied to compare the means on the fish abundance and the species diversity (alpha diversity) among the hydrological areas. A significant P-value of the ANOVA test indicated for at least one pair, between which the mean difference was statistically significant.

Results

Cyprinid species recorded on hydrological areas in Rwanda

A total of 8 cyprinid species were recorded. Three cyprinid species were more abundant (A: Abundance), dominant (RD: Relative Dominance) and frequent (F: Frequency). The common carp (*Cyprinus carpio*) was significantly abundant, dominant and frequent ($p<0.05$) with respectively: A =569.0±125.9, RD=60.1±4.8, F=0.57±0.0 compared to other recorded cyprinid species followed by *Enteromius cercops* A=176.0±70.7, RD=18.1±2.0, F=0.43±0.0 and *Labeo victorianus* A=116.0±43.8, RD=12.0±1.0, F=0.29±0.0. Five other recorded cyprinid species showed low abundance, dominance and all had a frequency F=0.14±0.0. Regarding the hydrological areas, with respectively H'=1.38±0.1 and H'= 0.98±0.2, the Eastern Kirehe (Lower Akagera) and Kigali water bodies were more diversified in cyprinid fish species with the Shannon Index which was significantly different ($p<0.05$) compared to other hydrological areas. Rweru-Mugesera (Upper Akagera) also

had a better Shannon Index and very higher fish abundance. No cyprinid fish was collected in the Northern lakes: Lake Ruhondo and Lake Burera. The Eastern-Kirehe (Lower Akagera) and Rweru-Mugesera (Upper Akagera) were hydrological areas where cyprinid fishes were abundantly collected with respectively 255±89 and 519±123 specimens during both dry and rainy season sampling periods (Table 1). Globally, higher cyprinid fish species concentration was observed in the South-East of the Rwandan territory (Figure 2).

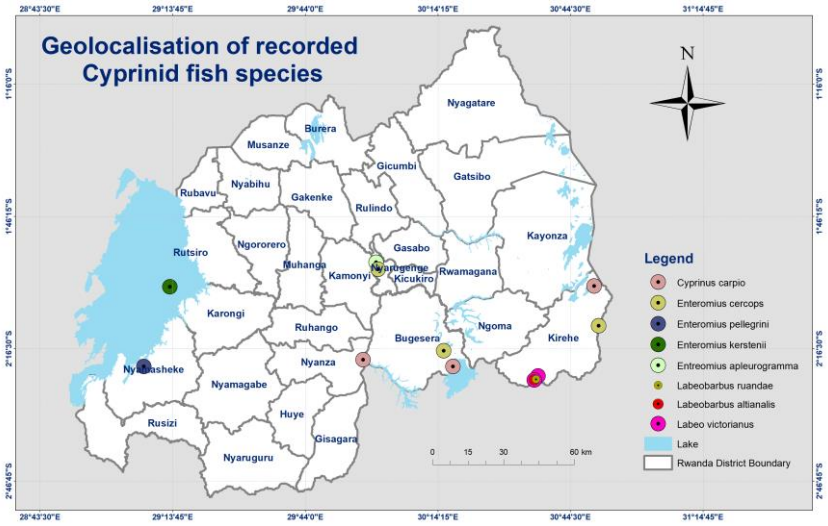

Figure 2. Map of Rwanda showing the cyprinid species observation areas

Alpha diversity in the hydrological areas

Of seven sampled hydrological areas of Rwanda, the Eastern-Kirehe (lower Akagera) was the most diversified area and showed high species richness and species diversity with respectively

Table 1. ***Cyprinid species recorded in Rwandan sampled hydrological areas***

Species name	IUCN Red List	Sampled hydrological areas							Abundance	Relative Dominance	Frequency
		Kigali water bodies	Rweru-Mugesera (upper Akagera)	South-Kirehe (middle Akagera)	East-Kirehe (lower Akagera)	Akanyaru	Rugezi & Burera Ruhondo	Lake Kivu			
*Cyprinus carpio**	VU	13.0±5.7	422.0±82.0	_	106.0±39.6	28.0±1.4	_	_	569.0±125.9^{a}	60.1±4.8^{a}	0.57±0.0^{a}
Enteromius cercops	LC	37.0±19.8	97.0±41.0	_	42.0±9.9	_	_	_	176.0±70.7^{b}	18.1±2.0^{b}	0.43±0.0^{a}
Enteromius kerstenii	LC	_	_	_	_	_	_	31.0±17.0	31.0±17.0^{c}	3.1±0.8^{c}	0.14±0.0^{b}
Enteromius pellegrini	LC	_	_	_	_	_	_	15.0±4.2	15.0±4.2^{c}	1.6±0.0^{c}	0.14±0.0^{b}
Enteromius apleurogramm	LC	16.0±7.1	_	_	_	_	_	_	16.0±7.1^{c}	1.6±0.3^{c}	0.14±0.0^{b}
Labeo victorianus	CR	_	_	44.0±21.2	72.0±22.6	_	_	_	116.0±43.8^{b}	12.0±1.0^{b}	0.29±0.0^{b}
Labeobarbus ruandae	NT	_	_	_	21.0±12.7	_	_	_	21.0±12.7^{c}	2.1±0.7^{c}	0.14±0.0^{b}
Labeobarbus altianalis	LC	_	_	_	14.0±4.2	_	_	_	14.0±4.2^{c}	1.5±0.0^{c}	0.14±0.0^{b}
Total number per site		66.0±32.5	519.0±123.0	44.0±21.2	255.0±89.1	28.0±1.4	0.0±0.0	46.0±21.2	958.0±286.0		
Species richness		3.0±0.0^{ab}	2.0±0.0^{b}	1.0±0.0^{b}	5.0±0.0^{a}	1.0±0.0^{b}	0.0±0.0^{c}	2.0±0.0^{b}			
Evenness		0.89±0.2^{a}	0.69±0.1^{b}	0.0±0.0^{b}	0.86±0.2^{a}	0.0±0.0^{c}	0.0±0.0^{c}	0.91±0.2^{a}			
Shanon Wiener Index (H')		0.98±0.2^{ab}	0.48±0.1^{c}	0.0±0.0^{d}	1.38±0.1^{a}	0.0±0.0^{d}	0.0±0.0^{d}	0.63±0.1^{b}			
Simpson Index (D)		0.40±0.1^{ab}	0.69±0.2^{a}	1.0±0.0^{c}	0.29±0.0^{b}	1.0±0.0^{c}	1.0±0.0^{c}	0.55±0.1^{a}			

*Key: *: Introduced in Rwandan water bodies.* ***-****: Not Recorded on the site,* ***LC****: Least Concern,* ***NT****: Near Threatened,* ***CR****: Critically Endangered,* ***VU****: Vulnerable. - The values express the means and the standard deviation between replication in sampling (Dry and Rainy Seasons). - In the column values with different superscripts are significantly different ($p<0.05$) for Abundance, Relative Dominance and Frequency. - In the row values with different superscripts are significantly different ($p<0.05$) for diversity indices*

H'=1.38±0.1 (Shannon Weiner Index) and D=0.29±0.0 (Simpson Index). Kigali water bodies and Lake Kivu showed also higher Shannon Weiner and Simpson indices respectively H'=0.98±0.2, D=0.40±0.1 and H'=0.63±0.1, D=0.55±0.1 compared to the remaining sampled hydrological areas. Cyprinid species were not observed at Rugezi-Burera-Ruhondo and consequently have H'= 0; Shannon Weiner Index and D=1; Simpson Index (Table 1).

Beta-diversity: similarity and dissimilarity between hydrological areas

The Beta diversity of cyprinid species among the sampled hydrological areas displayed higher similarity between Kigali water bodies and Rweru-Mugesera SI=0.8, Rweru-Mugesera and Akanyaru SI=0.667, Rweru-Mugesera and Eastern-Kirehe SI=0.571. The similarity Index were middle between

Kigali water bodies and East-Kirehe-Akagera, Kigali water bodies and Akanyaru with SI=0.5. The dissimilarity was total; BCI= 0.0 between Rugezi-Burera-Ruhondo and the Lake Kivu (Table 2).

Table 2. ***Sörensen similarity index and Bray-Curtis dissimilarity index of sampled hydrological areas in Rwanda***

Sites	Kigali water bodies	Rweru-Mugesera (Upper Akagera)	South Kirehe (Middle Akagera)	East Kirehe (Lower Akagera)	Akanyaru	Rugezi-Burera-Ruhondo	Lake Kivu
Kigali water bodies		0.8	0	0.5	0.5	0	0
Rweru-Mugesera (Upper Akagera)	0.171		0	0.571	0.667	0	0
South Kirehe (Middle Akagera)	0	0		0.333	0	0	0
East Kirehe (Lower Akagera)	0.312	0.382	0.294		0.333	0	0
Akanyaru	0.277	0.102	0	0.198		0	0
Rugezi-Burera-Ruhondo	0	0	0	0	0		0
Lake Kivu	0	0	0	0	0	0	

Bray-Curtis dissimilarity index

Sorensen similarity index

Similarity between cyprinid fish community in sampled hydrological areas There was close similarity in

cyprinid species between the East Kirehe (Lower Akagera) and Rweru-Mugesera (Upper Akagera). These two hydrological areas had also similarity with the south Kirehe (Middle Akagera), the Akanyaru River and Kigali water bodies. However, the Lake Kivu had not close similarity to other hydrological areas of Rwanda (Figure 3).

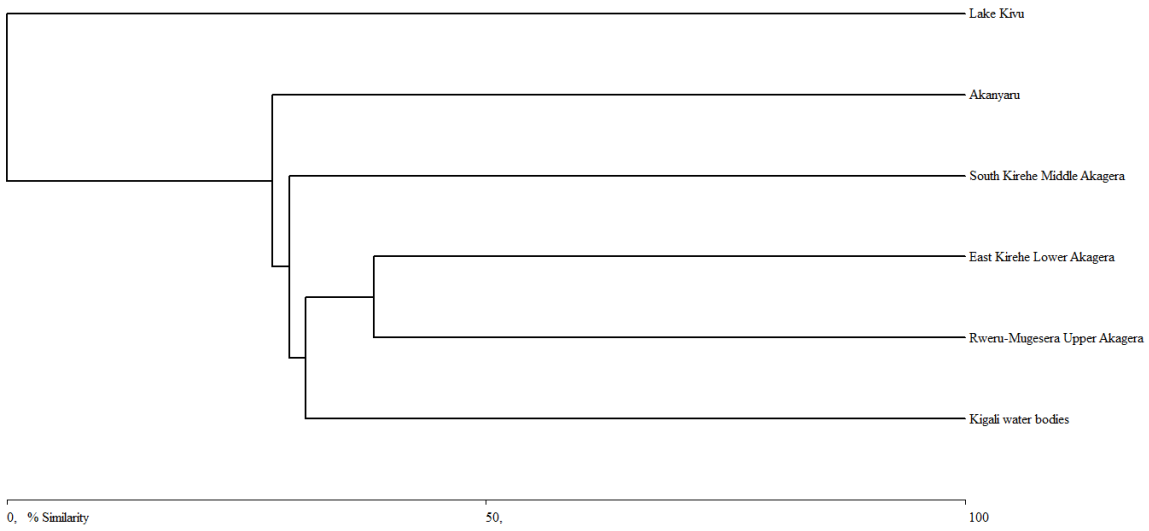

Figure 3. Cluster analysis for the seven sampled hydrological areas in Rwanda

Cyprinid fishes capture and morphometrical measurement

The fish capture varied largely from one area to another. It was significantly higher in water bodies with wide open waters such as at a lake (Lake Rweru, Lake Mpanga…), a river and natural pond. The average value of capture varies from 30-90kg/day on open water to 10-20kg/day on wetlands areas. The fruitful season of the capture was the rainy season. The main captured species were the common carp; *Cyprinus carpio*, *Enteromius cercops* and *Labeo victorianus* with abundance respectively 569±126, 176±71, and 116±44 individuals captured. The common carp; *Cyprinus carpio* captured specimens were of big size (TL= 33.8±2.1cm, BW= 3.0±2.1kg) significantly different ($p<0.05$) compared to all recorded cyprinid fishes except the ripon barbel; *Labeobarbus altianalis*. In addition, the common carp showed higher catch biomass 55.5±10.5 kg/day significantly different ($p<0.05$) compared to others cyprinid fish species. Quite often, specimens of big size of the ripon barbel; *Labeobarbus altianalis* (TL=32.2±8.32cm, BW=2.5±1.86kg), the Victorian barbel; *Labeo victorianus* (TL=26.5±4.37cm, BW=0.5±0.12kg) and the Rwandan barbel; *Labeobarbus ruandae* (TL=21.3±4.42cm, BW=0.3±0.43kg) were recorded in

hydrological areas where these cyprinid fish were collected. However, all species in the Enteromius genus were small sized (Table 3).

Table 3. ***Cyprinid fishes capture and morphometrical measurement***

Fish species	Abundance	Average body weight (kg)	Total Length (cm)	Average capture (kg/day/site
Cyprinus carpio	569.0±125.9^{a}	3.0±2.12^{a}	33.8±3.13^{a}	55.5±10.5^{a}
Enteromius cercops	176.0±70.7^{b}	0.025±0.02^{c}	6.7±1.04^{c}	1.1±0.2^{c}
Enteromius kerstenii	31.0±17.0^{c}	0.042±0.04^{c}	8.4±1.26^{c}	1.6±0.6^{c}
Enteromius pellegrini	15.0±4.2^{c}	0.068±0.03^{c}	10.3±0.11^{c}	1.8±0.4^{c}
Enteromius apleurogramma	16.0±7.1^{c}	0.022±0.01^{c}	4.9±0.95^{c}	1.0±0.1^{c}
Labeo victorianus	116.0±43.8^{b}	0.5±0.12^{b}	26.5±4.37^{ab}	4.2±2.1^{c}
Labeobarbus ruandae	21.0±12.7^{c}	0.3±0.23^{b}	21.3±4.42^{b}	2.2±1.4^{c}
Labeobarbus altianalis	14.0±4.2^{c}	2.5±1.86^{a}	32.2±8.32^{a}	12.8±2.2^{b}

- The values express the means and the standard deviation between replication in sampling (Dry and Rainy Seasons). - In the column values with different superscripts are significantly different ($p<0.05$).

Species accumulation curve

The study had been conducted during the dry and rainy seasons, a total of 756 and 1,160 specimens of cyprinid fish were respectively collected with an average of 958±286 individuals distributed in 8 species for both seasons. Although the effort of sampling, not more than 5 cyprinid species at the Rweru-Mugesera (Upper Akagera), 3 cyprinid species at Kigali water bodies and 2 cyprinid species at the Eastern-Kirehe (Lower Akagera) could be recorded in these Rwandan hydrological areas as the curves bent from those values (Figure 4).

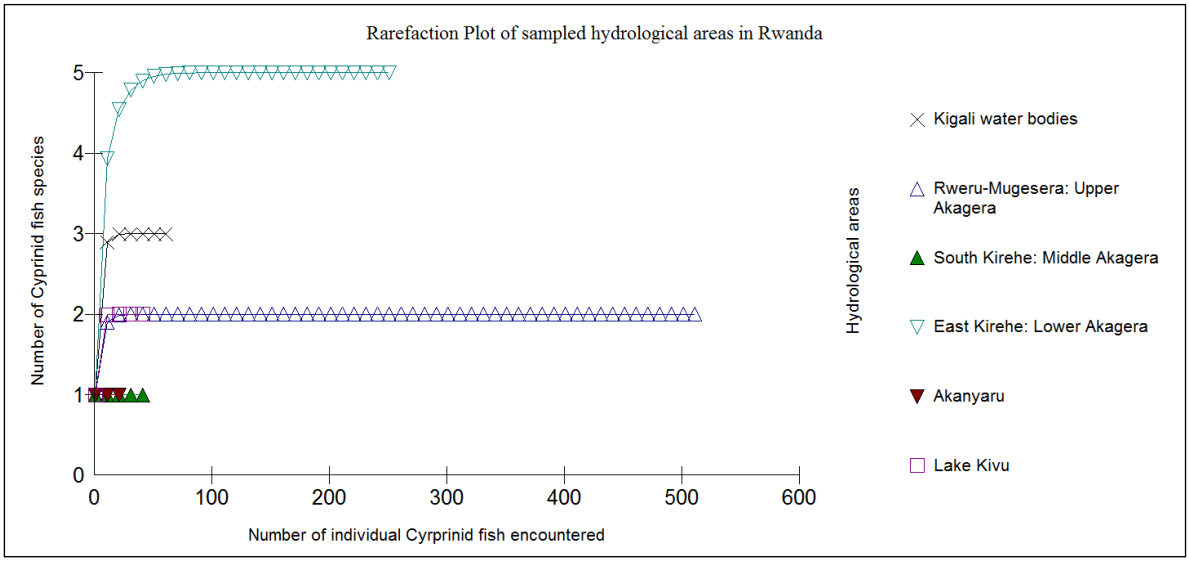

Figure 4. Species accumulation curve

Discussion

Cyprinid species occurrence in Rwanda

Eight cyprinid species were recorded in sampled hydrological areas during ten months of sampling period chronologically in dry and rainy seasons. Apart the exotic common carp, the remaining seven cyprinid species were native and observed in their natural geographical distribution. De Vos et al. (2001) identified 24 cyprinid species in Rwandan waters; rivers and lakes. The low number of species observed relative to De Vos et al. (2001) study may have resulted from the short time of sampling and inaccessibility of sampling in protected lakes in the national parks and remote water bodies. Sites were visited once per season and the contact with fishermen was done a day in the morning (6:00 am to 11:00) and the evening (4:00 pm to 6:00 pm). Of eight recorded species, three cyprinid species may possess potentiality in the aquaculture sector considering their interesting morphometrical values (body weight and total length), these are the introduced exotic *Cyprinus carpio*, the native species namely *Labeobarbus altianalis* and *Labeo victorianus*.

The common carp: *Cyprinus carpio* (VU)

Wild stocks are only present naturally in rivers draining to the Black, Caspian and Aral Sea (Kottelat, Freyhof, 2007). A rheophilic wild population in the Danube is assumed to be the origin of the European species; this population is now under threat (Kottelat, 1997). The common carp was introduced throughout the world. The common carp also was introduced and translocated to Rwandan waters (De Vos et al. 2001). According to Welcomme (1988) common carp was introduced for aquaculture in 1960 from Israel. The species is now found in the Upper Akagera system (Lake Rweru) and is common in Lake Karago (a small highland lake north-east of Gisenyi). Despite its classification on the IUCN Red list as a vulnerable species (IUCN, 2021), the common carp proliferates under tropical conditions where the species has been introduced and is therefore considered as a potential pest since they can efficiently compete for food with native fish species (Chirwa et al. 2016, 2019). The common carp was particularly dominant in Rweru-Mugesera (Upper Akagera) and Eastern Kirehe (Lower Akagera). In view of adaptability and big body size and weight recorded in this study TL= 33.8±3.13cm, BW=3.0±2.12kg of adult individuals of this species in Rwandan waters and TL=31cm, BW=40.1kg reported by Chugunova (1959), Machacek (2007), the common carp may be efficiently used in aquaculture sector throughout the country.

The ripon barbel: *Labeobarbus altianalis* (LC)

Known from the Middle Akagera (De Vos, Thys van den Audenaerde, 1990), Rusizi River, Lake Kivu, Lake Edward, Lake George, Lake Victoria and Lake Kyoga drainages, and northern part of Lake Tanganyika (Snoeks et al. 2012). This is a cyprinid fish with native geographical distribution and endowed with high potential values in the aquaculture sector. The ripon barbel; *Labeobarbus altianalis* was only recorded in Eastern Kirehe (Lower Akagera) with very low relative

dominance. Nevertheless, the species has been abundantly observed and recorded in Lake Kivu (De Vos et al. 2001). In view of its body size and weight recorded in this study TL=32.2±8.32cm, BW=2.5±1.86kg and TL=90cm, BW=120kg reported by De Vos and Thys van den Audenaerde (1990), the ripon barbel has aquaculture potentiality and it would be desirable to realize first trials of inducing spawning on ripon barbel breeders in Rwanda for intensive fry production. In fact, only a few East African cyprinids have been induced to spawn (Kembenya et al. 2017). It is widely acknowledged that the inability to obtain adequate seed supply is a major constraint to the initiation or expansion of aquaculture (Bromage, 1995).

The Rwandan barbel: *Labeobarbus ruandae* (NT)

Known from the Upper Akagera system in Rwanda (De Vos et al. 1990; De Vos et al. 2001) and Burundi (Banyankimbona et al. 2012). This cyprinid fish inhabited the Rwandan northern lakes. The introduction of tilapia and some *Haplochromis* may have been the reason for the decimation or extinction of the species in Lake Luhondo (De Vos et al. 1990). *Labeobarbus ruandae* was only recorded in Eastern Kirehe (Lower Akagera) with very low relative dominance. This cyprinid it is classified on the IUCN Red List Status as Near Threatened; NT (IUCN, 2021). Specimens of this cyprinid were recorded with TL=21.3±4.42 cm and BW= 0.3±0.23kg while De Vos et al. (2001) reported the body size and weight being a maximum TL=26.2cm and BW=0.5kg, this cyprinid fish may have aquaculture potential and a study on the induced spawning and the genetic diversity may be envisaged for the diversification of fish species in Rwandan industry and the restocking in some Rwandan water bodies which are natural habitat of this barbel in view of its IUCN status.

The Victorian barbel: *Labeo victorianus* (CR)

Endemic to the Lake Victoria drainage (Seegers et al. 2003). Present in Lake Victoria and its affluent rivers, Victoria Nile, Lake Kyoga (Van Oijen, 1995) and in the Akagera system in Rwanda (De Vos et al. 2001) and Burundi (De Vos, 1991). *Labeo victorianus* was recorded in Eastern Kirehe (Lower Akagera) and southern Kirehe (Middle Akagera) with better relative dominance. However, the species is classified on the IUCN Red List status as Critically Endangered; CR (IUCN, 2021). Victorian barbel was recorded with TL=26.5±4.37cm and BW=0.5±0.12kg but Van Oijen (1995) has reported a maximum body size TL=41cm and commonly TL=30cm. Thus, this cyprinid presents a potentiality in the aquaculture sector. Research on its induced spawning may be undertaken. Indeed, Rutaisire and Booth (2004 & 2005) carried out studies on reproductive biology and induced ovulation in Uganda, and the aquaculture domestication has been prospected by Kembenya et al. (2017). From these researches on that fish and in a country that is closer to Rwanda and with close environmental conditions, it can predict the high likelihood of obtaining good results if similar research is done in Rwanda. In view of the interesting morphometrical values and the IUCN status of this barbel, also a study on the induced

spawning and the genetic diversity may be envisaged for the diversification of fish species in Rwandan industry and the restocking in some Rwandan water bodies which are natural habitat of this barbel.

Enteromius cercops

Known to the affluent rivers of Lake Victoria in Kenya (De Vos, Thys van den Audenaerde,1990; Seegers et al. 2003), the Malawa River in Uganda (Greenwood, 1966; De Vos, Thys van den Audenaerde, 1990) and the Middle Akagera system in Rwanda (De Vos, Thys van den Audenaerde, 1990; De Vos et al. 2001). *Enteromius cercops* was recorded in Kigali water bodies, Rweru-Mugesera (Upper Akagera) and Eastern-Kirehe (Lower Akagera) with better relative dominance which was significantly different compared to other co-genera. This cyprinid fish was small size, recorded with TL=6.7±1.04cm and BW=0.025±0.02kg but De Vos and Thys van den Audenaerde (1990) have reported a maximum of SL=7.0cm. Considering the morphometrical values of *Enteromius cercops*, this cyprinid fish may not display interest in the aquaculture sector.

Enteromius kerstenii

The cyprinid fish is known in Africa: Cunene, Okavango, upper Zambezi, and tributaries of the lower Zambezi, Save-Runde (Skelton, 1993), Pungwe, Buzi (Marshall, 2011) and Kafue systems (Bell-Cross, 1976). Also recorded in Lake Victoria, Tanganyika, Edward and Kivu basins (Greenwood, 1962), Lake Malawi system (Tweddle et al. 1979), the upper Congo system (Poll, 1976; Balon, Stewart, 1983; Van Steenberge et al. 2014) and coastal river basins in Kenya (Seegers et al. 2003) and Tanzania (Bailey, 1969). *Enteromius kerstenii* was only recorded in Lake Kivu with very low relative dominance. This cyprinid fish was small size, recorded with TL=8.4±1.26cm and BW=0.042±0.04kg but De Vos and Thys van den Audenaerde (1990) have reported a maximum of SL=9.0cm. In view of the morphometrical values of *Enteromius kerstenii*, this cyprinid fish may not present interest in the aquaculture sector.

Enteromius pellegrini

The cyprinid fish is known in Africa: drainage basins of Lakes Kivu, Edward and Tanganyika, both in tributaries and in lakes (Lévêque, Daget, 1984), also observed in Lake Rukwa (Snoeks et al. 2012). In Democratic Republic of the Congo this cyprinid was also collected at Pinga (Lualaba, upper Congo River basin). *Enteromius pellegrini* was only recorded in Lake Kivu with very low relative dominance. This cyprinid fish was small size, recorded with TL=10.3±0.11cm and BW=0.068±0.03kg but Seegers (1996) has reported a maximum of SL=11.7cm. Considering the morphometrical values of *Enteromius pellegrini*, this cyprinid fish may not show interest in the aquaculture sector.

Enteromius apleurogramma

Known in Africa: widely distributed, in the Aswa River, Lake Victoria basin including affluent rivers and Akagera system, Lake Edward-George system, Lake Kivu basin, Lake Tanganyika (De Vos, Thys van den Audenaerde, 1990), Rusizi River, Malagarazi River

(Banyankimbona et al. 2012) and Lake Rukwa drainage (Seegers, 1996). Also in coastal river basins in Kenya (Seegers et al. 2003) and Tanzania (Eccles, 1992), in the Lower Lukuga River (Upper Congo River basin (Kullander, Roberts, 2012) and in the Ennedi Plateau of Chad (Lévêque, 1990). *Enteromius apleurogramma* was only recorded in Kigali water bodies with very low relative dominance. This cyprinid fish was small size, recorded with TL=4.9±0.95cm and BW=0.022±0.01kg but De Vos and Thys van den Audenaerde (1990) have reported a maximum of SL=5.4cm. Considering the morphometrical values of *Enteromius apleurogramma*, this cyprinid fish may not present interest in the aquaculture sector.

Species diversity and abundance

The Eastern-Kirehe (Lower Akagera) was the most diversified area in cyprinid species and was significantly different compared to other hydrological areas of Rwanda. This area showed higher species richness and diversity with respectively H'=1.38±0.1 (Shannon Weiner Index) and D=0.29±0.0 (Simpson Index). Besides, this area also recorded higher fish abundance than other hydrological areas. This situation may have resulted by the fact there is less anthropogenic pressure on aquatic resources than hydrological areas surrounded by dense agglomeration in this case Kigali water bodies. De Vos et al. (2001) recorded 24 cyprinid species and most fish species were encountered in the Akagera system. *Cyprinus carpio* and *Enteromius cercops* were significantly dominant and frequent compared to other cyprinid species with a large number of individuals collected, while there were few individuals of other species in most of hydrological areas. According to Welcomme (1988), the common carp was introduced for aquaculture in 1960 from Israel. The species is now found in the Upper Akagera system (Lake Rweru) and is common in Lake Karago (a small highland lake north-east of Gisenyi). The capture of the common carp was significant and most of the specimens were of big size. Despite being an exotic species, *Cyprinus carpio* seemed to adapt in Rwandan ecological conditions, and therefore the species can be used in the aquaculture industry throughout the country.

There was close similarity in cyprinid species for most of Rwandan hydrological areas but less with the Lake Kivu ichthyofauna. This situation can result in connectivity between water bodies where similarity was observed and non-connectivity in water bodies for the case of dissimilarity. In fact, Rwandan territory has two drainage basins which include the Nile basin to the East that covers a total of 67% and the Congo basin to the west covering 33%. The Lake Kivu distance in cyprinid fish species may result in the fact that it belongs to the Congo basin whereas the other hydrological areas are part of the Nile basin. An important North-South mountain ridge near the western border of the country constitutes the Congo-Nile watershed, the eastern part belonging to the Akagera River system which drains to Lake Victoria and further to the Nile, the western part draining to Lake Kivu and its outlet the Rusizi River, hydrographically both belonging to the Congo system (De Vos et al. 2001). During both dry and rainy seasons, 8 cyprinid species were

identified in sampled hydrological areas. It can be assumed that other cyprinid species not recorded in this study may be encountered in Lake Kivu where 5 cyprinid species were identified (Snoeks et al. 1997) and other non-sampled water bodies. For instance, the lakes located in the protected area; the Akagera National Park might contain other cyprinid species that were not recorded during this study. The Rweru-Mugesera (Upper Akagera) and the Eastern Kirehe (Lower Akagera) provided more cyprinid species abundance and species richness than other Rwandan hydrological areas. However, not more than 5 cyprinid species at the Rweru-Mugesera (Upper Akagera), 3 cyprinid species at Kigali water bodies and 2 cyprinid species at the Eastern Kirehe (Lower Akagera) could be recorded in these Rwandan hydrological areas even though a long sampling time was allocated to the research (fig.4). De Vos et al. (2001) identified only 24 cyprinid species in Rwandan waters and 22 species are mentioned in Fishbase (All fishes reported from Rwanda). In fact, the Rwandan ichthyological fauna is not much diversified owing to the youth of lakes and the existence of natural obstacles (falls) which prevented the colonization of the upper part of the hydrographic network by various species characteristic of the Nile basin (Snoeks et al. 1997).

Conclusion

Height cyprinid species were identified in the sampled hydrological areas and most were recorded in the Akagera River system: Rweru-Mugesera (Upper Akagera) and Eastern Kirehe (Lower Akagera) areas of medium altitudes respectively recorded at 1312m and 1255m. Exotic species, *Cyprinus carpio* was abundant, dominant and frequent, recorded on various hydrological areas, mainly captured and can be cultured in the Rwandan aquaculture industry since the fish seemed to adapt in ecological conditions of the country. *Labeobarbus altianalis* and *Labeo victorianus* were big size native cyprinid fishes and despite their low abundance and frequency in Rwandan water bodies, they can offer potentiality in the aquaculture sector. Further studies on induced spawning and adaptability in aquaculture of these cyprinid species have to be undertaken in the Rwandan territory for the diversification of the aquaculture industry. In addition, studies on the induced spawning and the genetic diversity of the identified cyprinid species may be envisaged for the restocking in some Rwandan water bodies which are natural habitat of the IUCN red listed recorded cyprinids; the Victorian barbel; *Labeo victorianus* and the Rwandan barbel; *Labeobarbus ruandae*.

Acknowledgments

I thank ARCOS (Albertine Rift Conservation Society) for its effort to facilitate the transportation at different sampling sites and its assistance during field work. I also acknowledge varied support and advice from my PhD supervisors and colleagues of the department of Biology of the School of Science of the University of Rwanda.

References

Bailey, R.G. 1969. The non-cichlid fishes of the eastward flowing rivers of Tanzania, East Africa. Rev. Zool. Bot. Afr. 80(1-2):170-199.

Balon, E.K. Stewart, D.J. 1983. Fish assemblages in a river with unusual gradient (Luongo, Africa - Zaire system), reflections on river zonation, and description of another new species. Environ. Biol. Fishes 9(3-4):225-252.

Banyankimbona, G. Vreven, E. Ntakimazi, G. Snoeks, J. 2012. The riverine fishes of Burundi (East Central Africa): an annotated checklist. Ichthyol. Explor. Freshwat. 23(3):273-288.

Bell-Cross, G. 1976. The fishes of Rhodesia. National Museums and Monuments of Rhodesia, Salisbury, Rhodesia. 268 p.

Bromage, N. 1995. Brood stock management and seed quality-general considerations. In: Broodstocks Management and Egg and Larval Quality (ed. by N.R. Bromage & R.J. Roberts), pp. 1–24. Blackwell Science Publications, Oxford, UK.

Chemoiwa, E.J. 2018. Reproductive biology of *Barbus altianalis* from river Nyando, Lake Victoria, basin Kenya. International Journal of Current Research in Life Sciences Vol. 07, No. 02, pp.903-910, February, 2018.

Chirwa E. R., Jere W.L., Mtethiwa A., Sikawa D. 2016. Ecological impacts of common carp and the African sharptooth catfish: A review. RUFORUM Working Document Series (ISSN 1607-9345) No. 14 (2): 869 - 883.

Chirwa E.R., Mtethiwa A., Jere W.L., Kassam L. 2019. Effects of common carp and African catfish on plankton, periphyton, benthic macroinvertebrates in pond ecosystem. Aquatic Biology. Vol. 28: 91–100, 2019.

Chugunova, N.I. 1959. Age and growth studies in fish. A systematic guide for ichthyologists. Israel Program for Scientific Translations. Izdatel'stvo Akademii Nauk SSSR, Moskva. 132 p.
De Vos, L. (1991). Les poissons du parc national de la Ruvubu (Burundi). An. Sci. Zool. 265:1-25.

De Vos, L. Thys van den Audenaerde, D.F.E. 1990. Description de Barbus claudinae sp. n. (Cyprinidae) avec synopsis des grandes espèces de Barbus du Rwanda. Cybium 14(1):3-25.

De Vos, L. Thys van den Audenaerde D.F.E. 1990. Petits Barbus (Pisces, Cyprinidae) du Rwanda. Rev. Hydrobiol. Trop. 23(2):141-159.

De Vos, L. Snoeks, J. Thys van den Audenaerde, D.F.E. 1990. The effects of Tilapia introductions in Lake Luhondo, Rwanda. Environ. Biol. Fishes 27:303-308.

De Vos, L. Snoeks, J. Thys van den Audenaerde, D.F.E. 2001. An Annotated Checklist of the Fishes of Rwanda (East Central Africa), With Historical Data on Introductions of Commercially Important Species. Source: Journal of East African Natural History, 90(1):41-68.
Published By: Nature Kenya/East African Natural History Society.

De Weirdt, D., A. Getahun, S. Tshibwabwa and G.G. Teugels 2007. Cyprinidae. p. 466-572. In M.L.J. Stiassny, G.G. Teugels and C.D. Hopkins (eds.) The fresh and brackish

water fishes of Lower Guinea, West-Central Africa. Volume I. Collection Faune et Flore tropicales 42. Institut de Recherche pour le Développement, Paris, France, Muséum National d'Histoire Naturelle, Paris, France, and Musée Royal de l'Afrique Centrale, Tervuren, Belgium. 800 pp.

Eccles, D.H. 1992. FAO species identification sheets for fishery purposes. Field guide to the freshwater fishes of Tanzania. Prepared and published with the support of the United Nations Development Programme (project URT/87/016). FAO, Rome. 145 p.

FAO (Food and Agriculture Organization). 2008. The State of World Fisheries and Aquaculture ISBN, 978-92- 5-106029-2.

Greenwood, P.H. 1962. A revision of certain Barbus species (Pisces, Cyprinidae) from east, central and south Africa. Bull. Br. Mus. Nat. Hist. (Zool.) 8(4):151-208.

Greenwood, P.H. 1966. The Fishes of Uganda. The Uganda Society, Kampala. 131p

IUCN (2021). The IUCN Red List of Threatened Species. Version 2021-3. Downloaded 14 Jan 2022.

IUCN (International Union for Conservation of Nature). 2021. The IUCN Red List of Threatened Species. Version 2021-3.

Kembenya M.E., Marcial H. S., Outa N.O., Sakakura Y., Hagiwara A. 2017. Captive Breeding of Threatened African Carp, Labeo victorianus of Lake Victoria. Journal of the World Aquaculture Society. Vol. 48, No. 6. doi: 10.1111/jwas.12328

Kottelat, M. 1997. European freshwater fishes. An heuristic checklist of the freshwater fishes of Europe (exclusive of former USSR), with an introduction for non-systematists and comments on nomenclature and conservation. Biologia, Bratislava, 52/Suppl. 5:1-271.

Kottelat, M., Freyhof, J. 2007. Handbook of European freshwater fishes. Publications Kottelat, Cornol and Freyhof, Berlin. 646 pp.

Kullander, S.O. Roberts, T.R. 2012. Out of Lake Tanganyika: endemic lake fishes inhabit rapids of the Lukuga River. Ichthyol. Explor. Freshwat. 22(4):355-376.

Lévêque, C. 1990. Relict tropical fish fauna in central Sahara. Ichthyol. Explor. Freshwat. 1(1):39-48.

Lévêque, C. 2003. Cyprinidae. p. 322-436. In D. Paugy, C. Lévêque and G.G Teugels (eds.) The fresh and brackish water fishes of West Africa Volume 1. Coll. faune et flore tropicales 40. Institut de recherche de développement, Paris, France, Muséum national d'histoire naturelle, Paris, France and Musée royal de l'Afrique Central, Tervuren, Belgium, 457

Lévêque, C. Daget, J. 1984. Cyprinidae. p. 217-342. In J. Daget, J.-P. Gosse and D.F.E. Thys van den Audenaerde (eds.) Check-list of the freshwater fishes of Africa (CLOFFA). ORSTOM, Paris and MRAC, Tervuren. Vol. 1.

Machacek, H. (ed.), 2007. World Records Freshwater Fishing. www.fishing-worldrecords.com, November 2007.

Marshall, B. 2011. The fishes of Zimbabwe and their biology. Smithiana Monogr. 3:290 p.

Nelson, J.S. (1994). Fishes of the world. Third edition. John Wiley & Sons, Inc., New York. 600 p.

Nelson, J.S. 1994. Fishes of the world. Third edition. John Wiley & Sons, Inc., New York. 600 p.

Plisnier, P.D. 1989. Etude hydrobiologique et développement de la pêche au lac Muhazi (Bassin de l'Akagera, Rwanda). Rapport Final (1986-1988). ACDST (ULG)-UNECED (FUNDP)-MINAGRI-AGCD.

Poll, M. 1976. Exploration du Parc National de l'Upemba - Mission G.F. De Witte en collaboration avec W. Adam, A. Janssens, L. Van Meel et R. Verheyen (1946-1949). Fascicule 73. Poissons. Fondation pour favoriser les Recherches Scientifiques en Afrique, Bruxelles. 127 pp.

Reid, G.M. 1985. A revision of African species of Labeo (Pisces: Cyprinidae) and a re-definition of the genus. Verlag von J. Cramer, Braunschweig. 322 p.

REMA (Rwanda Environment Management Authority). 2021. Rwanda State of Environment and Outlook Report 2021. 19p

Rutaisire J., Booth, A.J. 2004. Induced ovulation, spawning, egg incubation and hatching of the Cyprinid fish Labeo victorianus in captivity. Journal of World Aquaculture Society 35, 383–391.

Rutaisire, J., Booth, A.J. 2005. Reproductive biology of Ningu Labeo victorianus (Pisces: Cyprinidae), in the Kagera and Sio Rivers, Uganda. Environmental Biology of Fishes 73, 153–162.

Rutaisire, J. Levavi-Sivan, B. Aruho1, C. Ondhoro, C.C. 2015. Gonadal recrudescence and induced spawning in Barbus altianalis. Aquaculture Research, 2015, 46, 669–678.

Rwanda Water and Forestry Authority (RWFA). 2019. Water Quality Monitoring phase I & II final report (25th April 2019).

RWFA (Rwanda Water and Forestry Authority). 2019. Water Quality Monitoring phase I & II final report (25th April 2019).

Seegers, L. 1996. The fishes of the Lake Rukwa drainage. Ann. Mus. R. Afr. Centr., Sci. Zool., 278:1-407.

Seegers, L. De Vos, L. Okeyo, D.O. 2003. Annotated checklist of the freshwater fishes of Kenya (excluding the lacustrine haplochromines from Lake Victoria). J. E. Afr. Nat. Hist. 92:11-47.

Skelton, P.H. 1993. A complete guide to the freshwater fishes of southern Africa. Southern Book Publishers. 388 p.

Snoeks, J. De Vos, L. Thys van den Audenaerde, D.F.E. 1997: The ichthyogeography of Lake Kivu. South African Journal of Science, Vol 93. Pp 579-584.

Snoeks, J. Kaningini, B. Masilya, P. Nyinza-wamwiza, L. Guillard, J. 2012. Chapter 8. Fishes in Lake Kivu: Diversity and Fisheries. pp. 127-152. In J.-P. Descy, F. Darchambeau and M. Schmid (eds.). Lake Kivu: Limnology and biogeochemistry of a tropical great lake. Aquatic Ecology Series 5, Springer, 190p

Tweddle, D. Lewis, D.S.C. Willoughby, N.G. 1979. The nature of the barrier separating the Lake Malawi and Zambezi fish faunas. Ichthyol. Bull. Rhodes Univ. 39:1-9.

Van Oijen, M.J.P. 1995. Appendix I. Key to Lake Victoria fishes other than haplochromine cichlids. p. 209-300. In F. Witte and W.L.T. van Densen (eds.) Fish stocks and fisheries of Lake Victoria. A handbook for field observations. Samara Publishing Limited, Dyfed, Great Britain.

Van Steenberge, M. Vreven, E. Snoeks, J. 2014. The fishes of the Upper Luapula area (Congo basin): a fauna of mixed origin. Ichthyol. Explor. Freshwat. 24(4):329-345.

Welcomme, R. L. 1988. International introductions of inland aquatic species. FAO Fisheries Technical Papers 294: 1-318.

Whittaker, R. J. 2001. Scale and species richness: towards a general, hierarchical theory of species diversity. Journal of Biogeography, 28, 453-470.

Conflict of interest

No conflict interest that could have influenced the work reported in this paper. All authors have accepted the authorship order.