Identification and Characterization of Some Fish Breeding Areas in Lake Kivu, Bukavu Basin

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Abstract

The majority of Lake Kivu's fish species inhabit the littoral zone, which is regrettably a target of overfishing. In the present study, four bays (Lwacigoli, Nyakadaka, Cigezi and Kwamuzungu) were selected in the northern part of the Bukavu basin, between Birava isthmus, the Gombo and Ibinja islands, in order to evaluate their potential as fish breeding areas. The physico-chemical parameters of the water were measured by using the Hanna HI 9829 multiparameter probe and the Secchi disk was used for water Transparency. Experimental fishing sessions were carried from September to November 2022 using a beach seine net of 350 m long, 6 m wide and 5 mm in mesh size, between 6 pm and 5 am. Sample processing and data analysis continued in the laboratory. These sites were characterized on the basis of ecological variables including the nature of the bottom, the vegetation on the littoral zone, the flora, and the anthropogenic activities. Thus, in addition to the physico-chemistry of the water being conducive to fish breeding activity, the bottom of Lwacigoli bay is characterised by a rocky substrate, that of Nyakadaka by a rocky, gravelly and muddy substrate, those of Cigezi and Kwamuzungu are more dominated by mud, clay, some rocks and detritus, with some vegetation cover on the coastal part. More fingerlings were found at Kwamuzungu (611), followed by Nyakadaka and relatively lesser at Cigezi and Lwacigoli (400-465). In the four bays explored, the predominant size classes for Limnothrissa miodon and Lamprichthys tanganicanus are those between 50 - 80 mm and between 40 - 60 mm for Haplochromis spp. Therefore, sexual maturity stages I and II of the fishes represent 63.5% of specimens and those in stages III, IV and V represent 36.5%. According to the increasing fishing pressure in Lake Kivu, linked with the excessive use of fishing-gear and practices that threaten the survival of the fish species, identification and description of spawning areas should be continued in order to better protect its ichthyofauna. Fishing regulations are also essential for the sustainable management of the Lake Kivu.

Keywords: Identification, Characterization, Breeding Areas and Lake Kivu

INTRODUCTION

Pressures on the natural aquatic environment have been increasingly observed in recent decades, resulting in the deterioration of these ecosystems (Sanderson et al. 2002). Fish play a very important nutritional role as a major source of animal protein. However, in most aquatic environments, fishery resources are seriously threatened by human pressure, including overexploitation and habitat modification (Fathi et al. 2018). Located between DR Congo and Rwanda, Lake Kivu offers favourable conditions for the growth, reproduction and survival of several aquatic organisms.

Among the 29 fish species already identified in Lake Kivu, 19 species belong to the Cichlidae family (Snoeks et al. 1997). Generally, fish species in this lake colonise the littoral zone, which supports the fish stocks (Kaningini et al. 1999). It is a place for reproduction and ichthyological diversity, where fish lay their eggs and get most of the preys to survive. Unfortunately, anthropogenic pressures, including illegal fishing mainly in spawning grounds and urbanization involving land-grabbing on the littoral zone, resulting into sedimentation as well, have led to the destruction of stocks and the loss of certain fish species (Akonkwa et al. 2017).

Also, in Lake Kivu fish breeding grounds are still poorly known. Due to this situation, an improved management of fisheries in Lake Kivu is necessary, which must certainly go through the identification and delimitation of fish breeding areas.

Thus, this study aims to identify and characterise some fish spawning areas in Lake Kivu in the northern part of its Bukavu basin, with a view to contributing to the protection of its ichthyofauna against the threats to which it is currently exposed.

MATERIALS AND METHODS

Study area and sampling sites

In addition to the Kabuno-Kashanga bay, Lake Kivu is divided into five major basins from north to south: the Northern basin, the Eastern basin of Idjwi Island, Kalehe basin, Ishungu basin and Bukavu basin (Damas 1937, Capart 1960). Bukavu basin has an estimated area of 96.5 km^2 and a maximum depth of 105m. It is bounded to the northwest by the Birava isthmus and to the northeast by the islands of Gombo and Ibinja, and to the south by the outlet of the Ruzizi River, which connects Lake Kivu to Lake Tanganyika (fig 1). The Bukavu watershed has a morphological mosaic that is currently threatened in terms of relief, vegetation, land use and water use.

Four bays were selected in the north-western part of the Bukavu basin based on their surface expanse, between the isthmus of Birava, the islands of Gombo and Ibinja. Geographical coordinates were collected with a GARMIN GPS to map the spawning areas. Characterisation of the substrate in the different bays was by Snorkeling, while the habitat around the sites was assessed on the basis of ecological variables, namely: the quality of the bottom, the condition of the littoral, the threats to the sites and anthropic activities. The study covered a period of two months, from September to November 2022 at a rate of one sample per week, corresponding to fish reproduction period.

Experimental fishing in selected bays in the Northern Bukavu basin of Lake Kivu

At each site, four experimental fishing sessions were carried out in the coastal areas of the lake using a beach seine net of 350 m long, 6 m wide and 5 mm in mesh size, between 6 pm and 5 am. The choice of the beach seine net is due to its non-selectivity during capture. The fish caught were fixed with 5% formalin and kept in plastic jars.

Physico-chemical parameters measurement

The physic-chemical parameters of the water such as pH, TDS, dissolved oxygen, salinity and conductivity were measured in situ by using the Hanna HI 9829 multiparameter probe. Transparency was measured with the Secchi disk at 4pm and 7am.

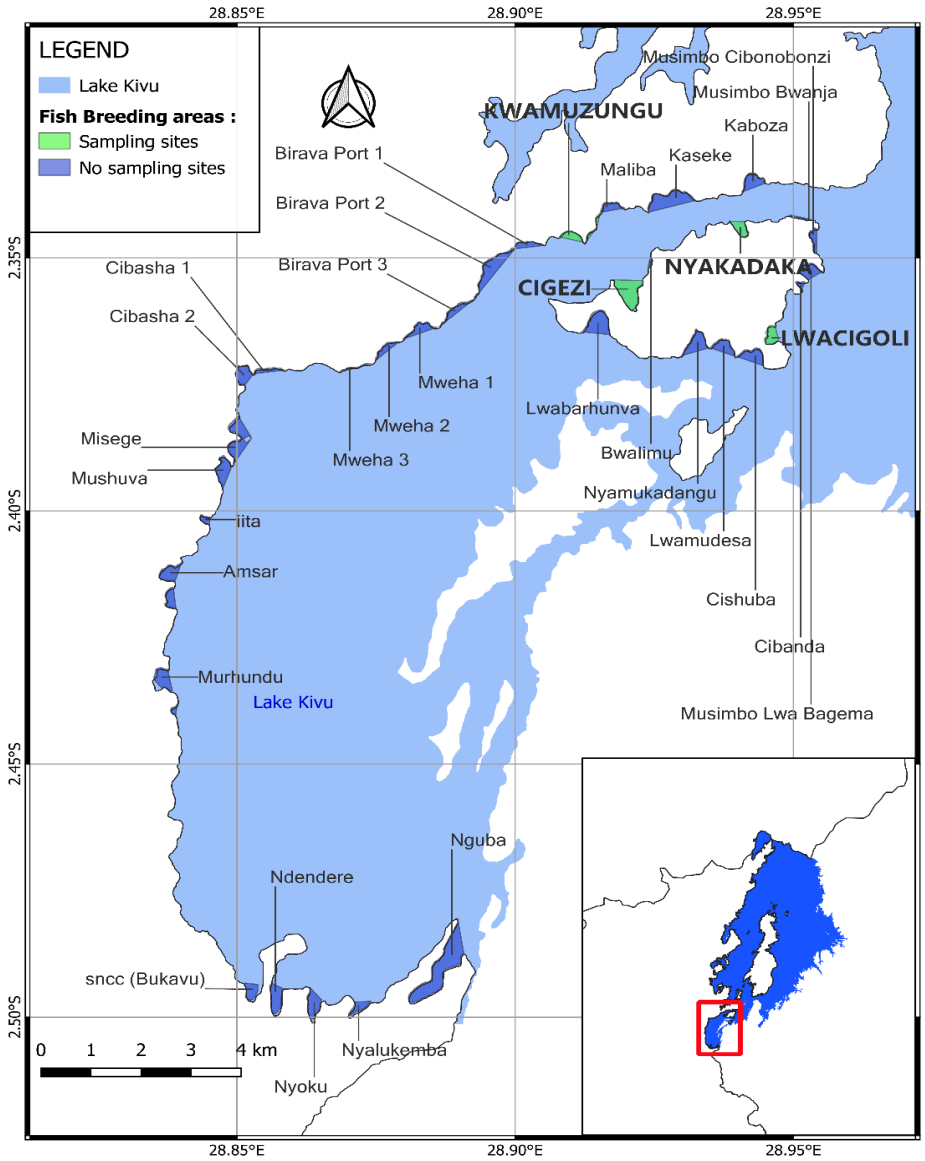

Figure 1: Sampling and non-sampling sites in the Bukavu basin, Lake Kivu

Fish identification

A total of 2001 fish samples were captured and transported to LHAGREN-UOB laboratory for identification by using Snoeks Keys (1994 and 2004) and Snoeks et al. (2012), Hubbs & Lagler (1958). Fish specimens were weighed with an OHAUS precision balance. Morphological parameters namely total length (TL) and standard length (SL) were measured for each individual using a Mitutoyo Stainless caliper S/N.21335971. Dissection of each specimen was done by using a dissection kit and determination of gonadal maturation stages was done using the scales proposed by Plisnier et al. (1988) and Kaningini (1995).

Data analysis

The data were analysed using R software (R Core Team 2019), STATISTICA 10, Past 4.11 and Excel. The Chi² test allowed to detect association between the maturity stages of the species in each bay (Millot 2009). One-way Analysis of Variance (ANOVA) was used to compare treatment means at the 5% level of significance for the total length of specimens

and for physic-chemical parameters between the sampling bays. Statistically significant treatment means were separated using Tukey's multiple comparison (Millot 2009). The Wilcoxon test was used to compare the average of the total length for specimen within species in different bays. The packages ggplot2 (Wickham et al. 2022) and ggpubr (Kasambara 2020) were used to produce boxplots of inter-site variations of total length of specimen for species. The STATISTICA 10 software was used to determine the size class (SC) frequencies of *Limnothrissa miodon*, *Lamprichthys tanganicanus* and *Haplochromis ssp*. specimens in the sampled bays. Finally, Past 4.11 software was used for the multivariate analyses.

RESULTS

Habitat characterisation of the selected bays of the Bukavu basin, Lake Kivu

The bottom of Lwacigoli bay is characterised by a rocky substrate. At Nyakadaka, the substrate is rocky, gravelly and muddy. The bottom of Cigezi bay is more subjugated by a muddy and clayey substrate with detritus. Kwamuzungu bay has a rocky and muddy substrate with detritus. The presence of hills was recorded in Lwacigoli, Nyakadaka and Kwamuzungu bays. The threats in the sites provide more information on the presence of anthropogenic activities. Cigezi bay is more threatened than all the other bays by shoreline sliding, erosion, cage farming and the presence of fields. The same is observed at Lwacigoli and Nyakadaka bays. Anthropogenic activities are widespread and almost present in all sites. Lwacigoli bay comes first with fishing, leaching, housing, swimming and agriculture followed by Cigezi bay with fishing, housing, swimming and agriculture. Nyakadaka bay is characterized by fishing and agriculture while Kwamuzungu bay is more characterized by fishing and swimming. In their coastal parts, the best vegetation cover characterises Kwamuzungu and Nyakadaka bays. Figure 2 presents the habitat characteristics of the sites explored in the North Bukavu basin of Lake Kivu.

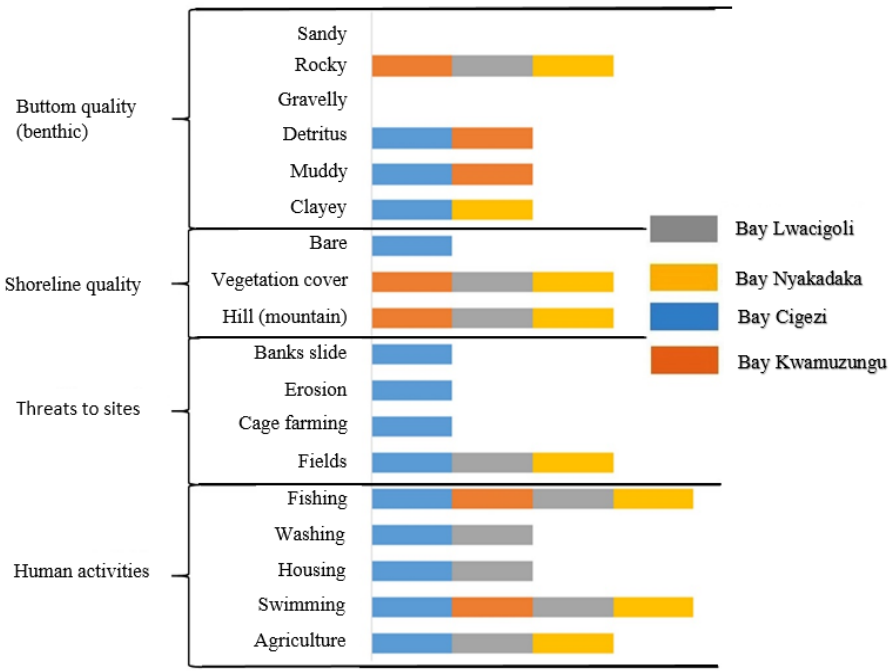

Figure 2: Habitat characteristics in the selected bays of the Bukavu basin, Lake Kivu

Physico-chemical parameters of the bays explored in the Bukavu basin

Usually in all 4 bays, water temperature values vary little and oscillate around 24.5°C. The basic pH was recorded in all the bays with slight variations between 9.1 and 9.15. The

average concentrations of dissolved O_2 (D.O.) vary between 94.17±14.41 and 110.1±6.51 % saturation, with minor variations between bays. The average electrical conductivity (EC) fluctuates between 1125±22.11 and 1156±10.58 µS in the four bays with slightly higher values in Cigezi bay. The average TDS is almost the similar in the four bays (between 806.25±18.15 and 834.3±41.8 ppm) with slightly higher values at Kwamuzungu Bay. The salinity of the water indicates fresh water (between 0.57 and 0.58 ppt) with almost no variance between bays. The mean values of water transparency are between 2.37±0.3 m and 3±0.5 m with a relatively low transparency in Cigezi bay. Therefore, no significant difference was observed for all the above parameters measured (p>0.05) between the bays (Table 1).

Parameters	**NYAKADAKA**	**LWACIGOLI**	**CIGEZI**	**KWAMUZUNGU**	**Stat.**	***p-value***
T (°C)	24.2±0.12	24.36±0.16	24.21±0.06	24.17±0.55	Anova	0.75
pH	9.13±0.03	9.14±0.03	9.10±0.06	9.15±0.02	Anova	0.29
D.O. (%.mg.l)	94.17±14.41	110.1±6.51	105.8±13.71	97.47±16.20	Kruska-Wallis	0.65
EC (µS)	1126±41.7	1125±22.11	1156±10.58	1127±25.12	Anova	0.36
TDS (ppm)	806.25±18.15	813.25±9.6	820±5.23	834.3±41.8	Kruska-Wallis	0.66
Salinity (ppt)	0.57±0.008	0.58±0.01	0.58±00	0.58±0.01	Kruska-Wallis	0.18
Transparency (m)	3±0.5	2.9±0.5	2.37±0.3	2.68±0.28	Anova	0.28

Table 1. Physic-chemical parameters of selected bays in the Bukavu basin, Lake Kivu

Number of fish specimen per species according to gonadal maturity stage

The maturity stages III, IV and V represent 36.5% of specimen while stages i, I and II represent 63.5% (Table 2). Results clearly show that larvae, fry and juveniles were caught much more in bays than the adult fish. The largest catch was observed in the species *L. tanganicanus*, i.e. 63%, the distribution of specimen of the harvested fish species not being equitable (p=0.0001***).

Table 2: Gonad maturity stage of fish by species of selected bays in the Bukavu basin, Lake Kivu

Species	**i**	**I**	**II**	**III**	**IV**	**V**	**Chi²**
Limnothrissa miodon	8	32	68	66	26	2	***
Lamprichtys tanganicanus	244	74	309	331	210	33	***
Haplochromis spp.	184	138	148	7	19	0	***
Total	436	244	525	404	255	35	***
Frequency (%)	23.0	12.8	27.6	21.3	13.4	1.8	

Gonad maturity stage according to species and bays

Kwamuzungu bay has half of fish samples at stage III, IV and V, followed by Nyakadaka bay with 40.4% (Table 3). Lwacigoli and Cigezi bays are almost close with a frequency of 34.25% and 29.1%. It is clear that juveniles are more abundant within bays than adult fish. The chi² test shows that only *L. miodon* is almost evenly distributed in Cigezi Bay at the 5% level. The other species are not evenly distributed (p=0.0001***).

Table 3: Maturity stage of fish caught in the selected bays of the Bukavu basin, Lake Kivu

CIGEZI								**LWACIGOLI**						
Species	i	I	II	III	IV	V	Chi²	i	I	II	III	IV	V	Chi²
L. miodon	0	1	3	2	2	0	*ns*	5	15	16	22	14	0	*
L. tanganicanus	94	10	25	38	59	1	***	0	0	1	10	8	0	***
Haplochromis spp.	114	56	27	27	2	4	***	46	73	107	66	17	0	***
Total	208	67	55	67	63	5	***	51	88	124	98	39	0	***
F (%)	45	14.4	12	14	14	1.1		12.8	22	31	24.5	9.75	0	
KWAMUZUNGU								**NYAKADAKA**						
Species	i	I	II	III	IV	V	Chi²	i	I	II	III	IV	V	Chi²
L. miodon	1	11	36	34	9	1	***	2	5	13	8	1	0	***
L. tanganicanus	94	12	111	200	60	3	***	56	52	172	83	83	29	***
Haplochromis spp.	17	7	10	4	0	1	***	7	2	4	8	0	0	**
Total	112	30	157	238	69	5	***	65	59	189	99	84	29	***
F (%)	18	4.91	26	39	11	0.8		12.4	11.2	36	18.9	16	5.5	

More fingerlings were found at Kwamuzungu (611), followed by Nyakadaka and lesser at Cigezi and Lwabagoli (400-465) (Figure 3).

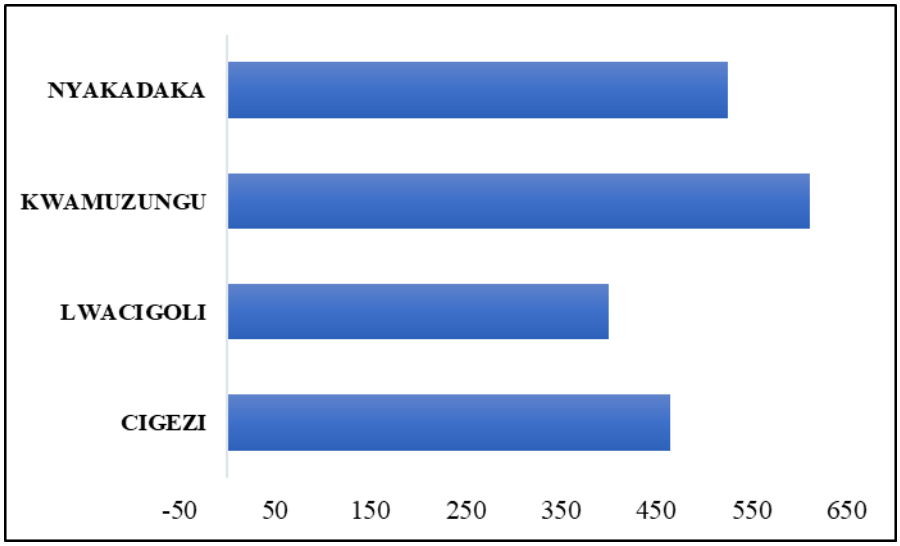

Figure 3: **Fingerlings abundance within selected bays of the Bukavu basin, Lake Kivu**

According to figure 4, axes 1-2 respectively account for 80% and 18% of the variance in the discriminant analysis. Axis 1 is dominated by species and maturity stages. Axis 2 is predominated by fish size. Nyakadaka and Kwamuzungu bays show much similarity in terms of species composition, fish size and maturity stages. The two bays harbor more *Lamprichthys tanganyicanus*. They also harbour high proportions of fingerlings. Thus, they are high quality breeding sites. On the other hand, Lwacigoli and Cigezi are regrouped by more *Limnothrissa miodon* and *Haplochromis*, both mature and immature. Thus, they important breeding sites of *Limnothrissa miodon* and *Haplochromis spp*. Another cluster regroups Kwamuzungu and Lwacigoli with mature *Limnothrissa* and *Haplochromis*. A subgroup is an assemblage of Cigezi and Nyakadaka with females of *Limnothrissa* and many immature individuals.

Comparison of total body length (TL) of fish specimen by species according to bays in the Bukavu basin, Lake Kivu

For *L. tanganicanus*, Lwacigoli bay had the highest mean TL of 73.07 mm compared to the other bays (p=0.0003***). For *L. miodon*, Cigezi bay had specimen of a relatively high mean sizes, reaching 66.9 mm with a significantly different mean for TL between bays (p=0.04*). For *Haplochromi ssp*. the highest mean TL was observed in Lwacigoli Bay, with a highly significant (p=0.0002***) difference in the mean TL of individuals depending on the bay (Figure 5).

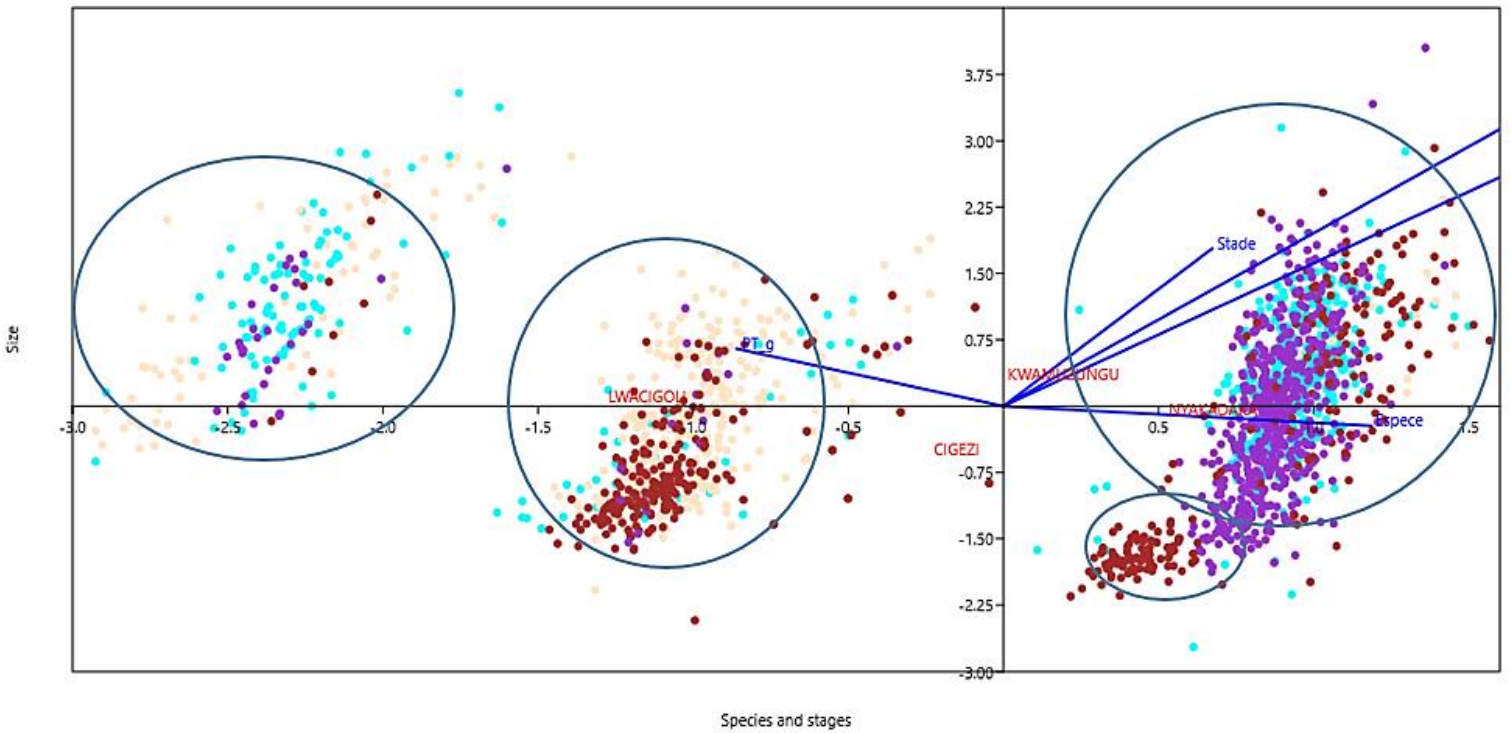

Figure 4: Fish species size and maturity stages within the breeding sites of the Bukavu basin, Lake Kivu

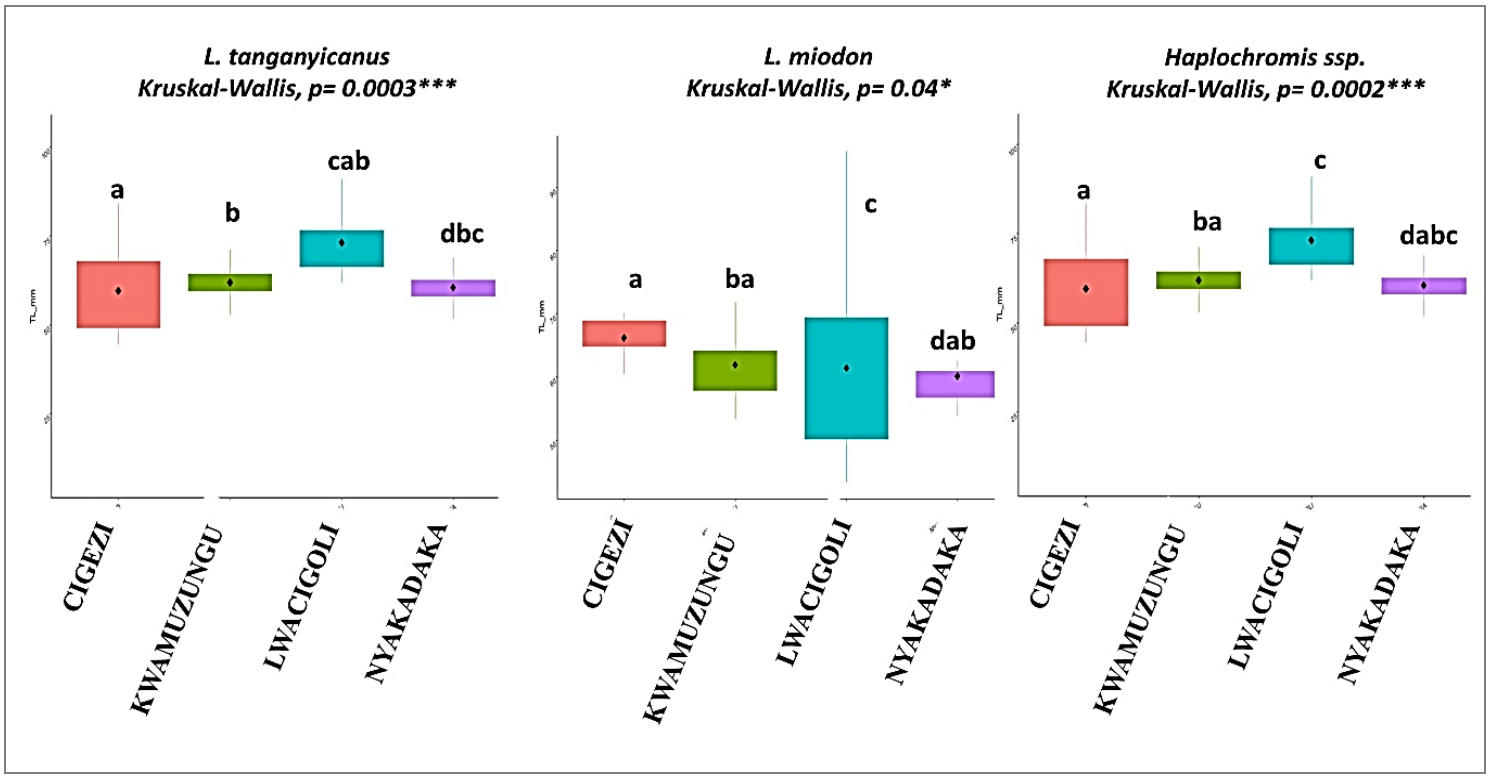

Figure 5: Total body length (TL) of fish specimens by species in the bays of the Bukavu basin, Lake Kivu

Size class frequencies (TL) of *L. miodon, L. tanganicanus* and *Haplochromis spp*. in the selected bays of the Bukavu basin, Lake Kivu

The major size classes of *L. miodon* and *L. tanganicanus* are range between 50 and 80 mm, bearing in mind that for these fish species in Lake Kivu, most of them in these size ranges are either juveniles or spawners (Figures 6 and 7). As for specimens of *Haplochromis spp*. size classes within 40-60 mm predominate in all bays (Figure 8). This predominance also expresses a strong presence of either juveniles or spawners of these species in these bays in Lake Kivu.

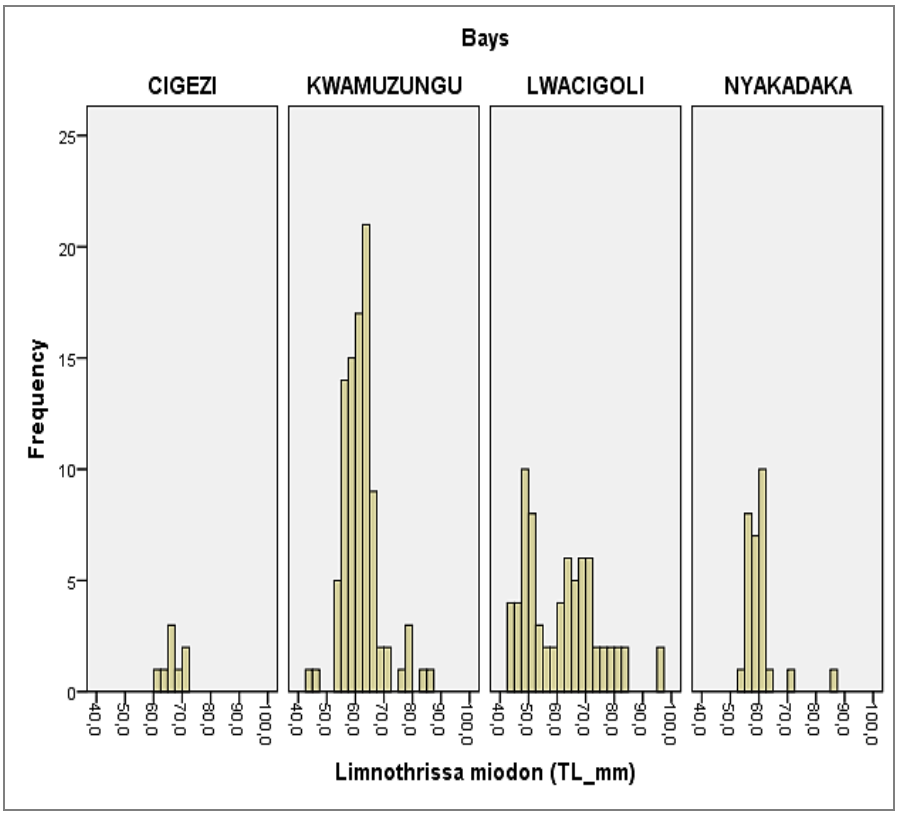

Figure 6: Size class (SC) frequencies of *L. miodon* specimen in the bays explored in the North Bukavu basin, Lake Kivu

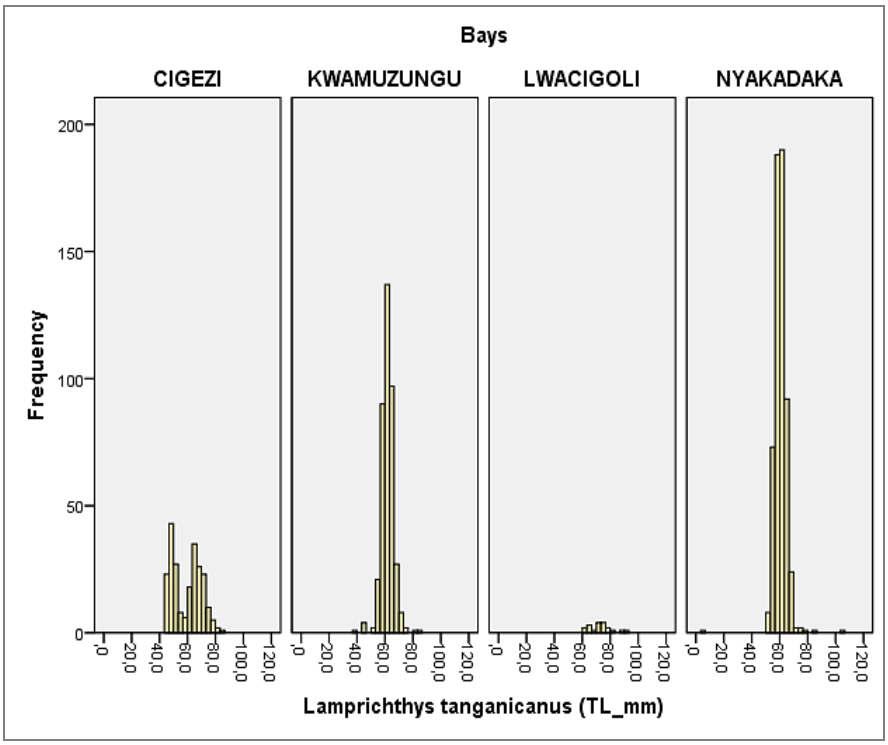

Figure 7: Size class (SC) frequencies of *L. tanganicanus* specimen in the bays explored in the North Bukavu basin, Lake Kivu

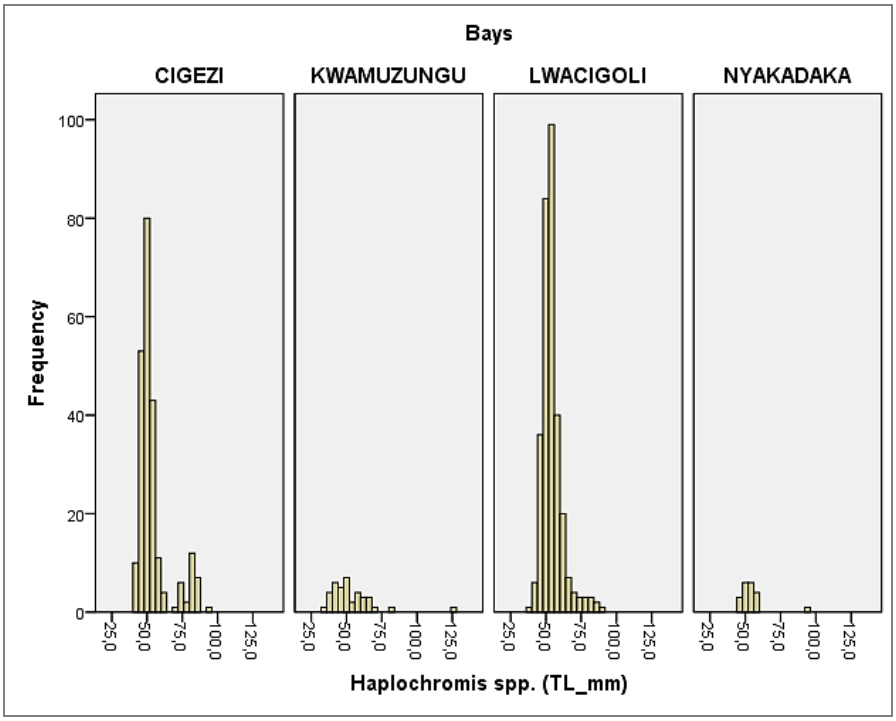

Figure 8: Size class (SC) frequencies of *Haplochromis ssp*. specimen in the bays explored in the North Bukavu basin, Lake Kivu

DISCUSSION

Habitat characterization of sites in the North Bukavu Basin, Lake Kivu

The bottom of Lwacigoli bay is characterised by a rocky substrate, that of Nyakadaka by a rocky, gravelly and muddy substrate, those of Cigezi and Kwamuzungu are more dominated by mud, clay, some rocks and detritus. The choice of substrate type and location of fish nests depends on the fish species (N'Dri et al. 2020). The predominance of mud in these areas is thought to be related to soil erosion, bank slides and the presence of fields around the bays and catchment area, but is also justified by the physical characteristics of Lake Kivu, which is dominated by a predominantly clay substrate (Thys Van Den Audenaerde et al. 1980) with most of the northern shoreline being rocky (Beadle 1974).

Physico-chemical parameters of the bays of the North Bukavu basin in Lake Kivu

The physico-chemical parameters in the bays explored make it possible to assess the quality of the water in these spawning areas. Despite small variations, no significant differences were noted between the different bays explored. The average temperature was around 24.5°C in the four bays. The pH varies between 9.10 and 9.15 in the four bays, values included in the range previously recognised in Lake Kivu. These values are close to those reported by Akonkwa (2017) in this aquatic environment.

Mean dissolved O2 (D.O) concentrations vary between 94.17±14.41 and 110.1±6.51 % saturation with lesser variation between bays, indicating good water quality in these bays for fish spawning activities. Dissolved oxygen is among the factors that determine the survival and growth of aquatic organisms (Mbalassa et al. 2014). These oxygen levels are thought to be related to the strong seasonal wind circulation (Isumbisho et al. 2006). The average electrical conductivity varies between 1125±22.11 and 1156±10.58 µS in the four bays with slightly higher values in Cigezi bay. These conductivity values appear to be lower than those reported by Hecky and Kling (1987) and Marshall (1993) in Lake Kivu, which can be explained by the fact that on the northern side of the Bukavu basin there are no tributaries likely to carry pollutants rich in mineral salts as in the extreme southern part of the basin. Conductivity can vary between 10 and 1000 µS.cm-1 in fresh water, while for water polluted by external inputs these values can be exceeded (Bartram and Ballance 1996).

The TDS is almost matching in all bays with a slight increase in Kwamuzungu Bay. The lower TDS values would justify the quality of the water in these four bays, which are suitable for fish reproduction. Salinity varied between 0.57 and 0.58 ppt, low compared to the values of 1.115g/l previously recorded in Lake Kivu by Hecky and Kling (1987) and Marschall (1993), and 120 mg/l and 480 mg/l by Muvundja et al. (2009). This difference would be justified by the fact that the present research was limited to the bays of the northern basin of Bukavu in Lake Kivu. The lower transparency values (between 2.37±0.3 m and 3±0.5 m) in the four bays are due to the influences of the rainy season. The low transparency of Cigezi bay is thought to be due to the lower vegetation cover on the coastal part. In the coastal part of Lake Kivu, water transparency tends to decrease by half during the rainy season (Isumbisho et al. 2006). Furthermore, Muvundja et al. (2009) points out that the quality of the waters of Lake Kivu remains more dependent on the population density and anthropogenic activities in the catchment area.

Maturity stage of species caught in the bays of the North Bukavu basin, Lake Kivu

The bays of Kwamuzungu and Nyakadaka have more fish sample for maturity stages III, IV, V and more fingerlings, which is justified by their better vegetation cover, creating an attraction to fish spawners for reproduction. Reproduction, survival and growth of larval fish are influenced by favourable environmental conditions, location and timing of spawning (Arsh et al. 2019). Fry and juvenile fish were more abundant in the bays than adult fish. This

predominance of fry is one of the clues to recognising fish beanies in the bays of Lake Kivu (Tchangaboba et al. 2018).

Furthermore, the equitable distribution of *L. miodon* in Cigezi Bay is thought to be a result of its predominance over other fish species in the waters of Lake Kivu. This species colonizes the whole of Lake Kivu and breeds in the littoral zone, especially in the bays (Kaningini 1995).

Total length (TL) of fish species according to bays in the North Bukavu basin, Lake Kivu

Lwacigoli bay showed fish sample with the highest mean TL size of 73.07 mm in *L. tanganicanus* while results from Akonkwa et al. (2016) had reported *L. tanganicanus* sizes ranging from 2.3 cm to 13.2 cm across Lake Kivu. According to Masilya et al. (2011) young *L. tanganyicanus* specimen are between 9-36 mm TL and adults between 72-129 mm in Lake Kivu. Conferring to Wildekamp's observations in Lake Tanganyika (2004), *L. tanganicanus* harbours rocky areas, which would justify their predominance in the bays of Lwacigoli and Nyakadaka where the substrate is dominated by rocks.

In the present study, Cigezi Bay had the highest mean size of *L. miodon* individuals of 66.9 mm TL. Across Lake Kivu, the average size of *L. miodon* is 77 mm (Akonkwa et al. 2016). In Lake Tanganyika, its size was 17 cm (Collart 1960). Referring to studies by Kaningini (1995), the size of *L. miodon* reached 69 mm TL in males and 73 mm TL in females.

The differences in TL noted in *L. tanganicanus* and *L. miodon* between the results of this research in the bays of the northern Bukavu basin in Lake Kivu and earlier results in Lake Kivu and Lake Tanganyika, are thought to be a result of the difference in the extent of the study and the increasing ecological stress of overfishing in this aquatic ecosystem (Akonkwa 2017).

For the present study, specimen of *Haplochromis ssp*. were not identified to species level due to strong morphometric similarities (Snoeks et al. 2012) requiring further analysis. The size (TL) of *Haplocromis ssp*. specimen ranged from 33.98 to 95.35 mm with a mean TL of 75 mm observed in Lwacigoli bay. This size appears to be smaller than the average sizes of the different Haplocrhomis species studied by Akonkwa et al. (2016) in Lake Kivu. This difference could be justified by differences in the fishing gear used, the area covered by the study and the specific composition of the sample.

Size class (SC) frequencies of *L. miodon, L. tanganicanus* and *Haplochromis ssp.* in the bays of the northern Bukavu basin, Lake Kivu

Within four bays explored, the main size classes for *L. miodon* and *L. tanganicanus* are between 50 and 80 mm, of which for these species in Lake Kivu most within this interval are either juveniles or spawners, the same for *Haplochromis sp*. with a predominance of size classes from 40 to 60 mm. In research on the growth, population dynamics and exploitation of fish in Lake Kivu, size classes between 7 and 9 cm were commonly the most frequent in catches of *L. miodon, L. tanganicanus* and *Haplochromis sp.* with a unimodal size frequency distribution (Akonkwa et al. 2017).

Compared to the results reported by Akonkwa et al. (2016), the relatively smaller sizes of fish sampled in the frequent size classes in the present study would be justified by the fact that the present study focused only on four bays of the lake, while the previous covered the entire extent of the lake. The continued increase in fishing pressure may also explain these differences (Akonkwa 2017).

CONCLUSION AND RECOMMEDATION

The results of this study on the identification and characterization of some fish spawning areas in Lake Kivu in the northern basin of Bukavu revealed the existence of a rocky substratum in Lwacigoli bay, a gravelly and muddy substratum in Nyakadaka Bay, a muddy and clayey substratum with detritus in Cigezi bay, rocky substratum with detritus in Cigezi bay, gravelly and muddy substrate in Nyakadaka Bay, a muddy and clayey substrate with detritus in Cigezi bay, and a rocky and muddy substrate with detritus in Kwamuzungu Bay, the latter being additionally characterised by a good vegetation cover.

In the four bays explored, no significant difference was noted between the values of the physic-chemical parameters, with the temperature varying between 24.17°C and 24.36°C and the pH between 9.10 and 9.15. An average dissolved oxygen level varying between 94.17±14.41 and 110.1±6.51 % saturation was recorded in these bays with an electrical conductivity varying from 1125 µS to 1156 µS. The highest TDS value was observed in Kwamuzungu (834.4 ppm), with an average salinity around 0.57 g/l, with transparency remaining between 2.37 m and 3 m.

The predominant size classes of the fish species *Limnothrissa miodon* and *Lamprichthys tanganicanus* are those between 50 and 80 mm and between 40 and 60 mm for *Haplochromis spp*. in the four bays, knowing that for these species in Lake Kivu, most specimen within these size ranges are either juveniles or spawners, with also a good presence of fry. Thus, stages i, I and II of fish gonad maturation represent 63.5% of individuals and stages III, IV and V represent 36.5%.

The abiotic and biotic characteristics presented above demonstrate that the bays of Lwacigoli, Nyakadaka, Cigezi and Kwamuzungu are part of the fish breeding areas in the northern part of the Bukavu basin in Lake Kivu.

In view of the current threats to these bays, which are sites of great ecological importance in Lake Kivu, the prohibition of anthropic activities in these sites, mainly fishing, can contribute to their better conservation. The identification, description and mapping of spawning areas should also be continued in remaining basins of Lake Kivu in order to better protect the itchyofauna of this aquatic ecosystem.

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