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RESEARCH ARTICLE

Identification, location and characterisation of spawning grounds and nurseries in the littoral zone of Lake Kivu (eastern DR Congo)

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Abstract

Worldwide biodiversity is on the brink of extinction following the complete disappearance of many forest and freshwater vertebrates. This disappearance is closely linked to the reduction and disturbance of habitats, which should instead benefit from special conservation. In the case of lake ecosystems, fish spawning grounds remain the most vulnerable. This study aims to identify, characterise and locate fish spawning and nursery sites in Lake Kivu for better conservation. Sixteen sampling sites were selected along the shoreline of the Bukavu sub-basin. Physico-chemical parameters were measured in situ, and fish were captured using multi-mesh nets, identified and dissected, gonads observed and sexual maturity stages determined. Twenty-five fish species were identified, but 17 of these use the selected sampling sites as spawning and/or nursery. Eleven spawning and nine nursery sites were identified and located. Physico-chemical analyses showed that temperature ($F=2.124$, $p=0.011$), dissolved oxygen ($F=2.792$, $p<0.001$), depth ($F=5.915$, $p<0.001$) and transparency ($F=3.421$, $p=0.004$) were significantly different, which characterise each site and may be key factors in species distribution between spawning sites. Fish size–weight relationships indicate allometric growths. The results of this research contribute to empirical knowledge of fish spawning grounds.

KEYWORDS
conservation, Lake Kivu, nursery, spawning

Résumé

La biodiversité mondiale est au bord de l'extinction suite à la disparition complète de nombreux vertébrés forestiers et d'eau douce. Cette disparition est étroitement liée à la réduction et à la perturbation des habitats qui devraient au contraire bénéficier d'une conservation particulière. Dans le cas des écosystèmes lacustres, les frayères à poissons restent les plus vulnérables. Cette étude vise à identifier, caractériser et localiser les sites de frayères et de nurseries de poissons dans le lac Kivu pour une meilleure conservation. Seize sites d'échantillonnage ont été sélectionnés le long du littoral du sous-bas sin de Bukavu. Les paramètres physico-chimiques ont été mesurés

in situ et les poissons ont été capturés à l'aide de filets à mailles multiples, identifiés et disséqués, les gonades observées et les stades de maturité sexuelle déterminés. Vingt-cinq espèces de poissons ont été identifiées, mais 17 d'entre elles utilisent les sites d'échantillonnage sélectionnés comme frayères et/ou nurseries. Onze sites de frai et neuf sites d'alevinage ont été identifiés et localisés. Les analyses physico-chimiques ont montré que la température ($F = 2.124$, $p = 0.011$), l'oxygène dissous ($F = 2.792$, $p < 0.001$), la profondeur ($F = 5.915$, $p < 0.001$), et la transparence ($F = 3.421$, $p = 0.004$) étaient significativement différents, caractérisent chaque site et peuvent être des facteurs clés dans la distribution des espèces entre les sites de frai. Les relations taille-poids des poissons indiquent des croissances allométriques. Les résultats de cette recherche contribuent à la connaissance empirique des frayères du lac Kivu.

1 | INTRODUCTION

Biodiversity worldwide is in a critical state, with a large number of plant and animal species are on the brink of extinction. According to Jenkins et al. (2002), in the space of three decades, 15%, 35% and 51% of forest, marine and freshwater vertebrates, respectively, have completely disappeared from the planet's surface. The decline and disappearance of species is intimately linked to the kinetics of habitat reduction and perturbation. The lake ecosystems being more affected by these disturbances due to several factors.

Urban, industrial and agricultural activities exert major pressures on aquatic ecosystems, which result in the degradation of water quality and the habitats on which aquatic life depends (Allan & Flecker, 1993). These pressures have been increasing in recent decades, resulting in, but not restricted to, the alteration of aquatic ecosystems (Sanderson et al., 2002).

The littoral environment in most of the lakes presents a greater diversity of habitats, leading to a diversity of people according to the different roles of these habitats in the aquatic life (Coenen et al., 1993). These habitats are often used by the species living there as spawning and breeding areas (Ntakimazi, 1995; Ntakimazi et al., 2005).

Located in Africa, in the East African Rift valley, Lake Kivu faces external inputs, consisting of sedimentary discharges due to runoff at the watershed level, household waste and wastewater from slaughterhouses, factories and hospitals discharge nutrient salts (Lina, 2016; Muvundja et al., 2009), which would promote the proliferation of algae. These algae can lower oxygen levels and interfere with aerobic life, even after they die, as their decomposition makes life impossible (USEPA, 2023). These nutrients that flow into Lake Kivu from different sources, in the case of ammonium and nitrate, reach the lake from exogenous sources and thus contribute to the external input of the lake. Muvundja et al. (2009) show that the supply of bioavailable P is the primary productivity limiting factor in Lake Kivu.

With 29 fish species, Lake Kivu, the poorest of the large lakes of the East African Rift valley in terms of fish species (Snoeks et al., 2012), has experienced historical disturbances (Haberyan & Hecky, 1987; Kaningini, 1995). Thus, the need for conservation measures is very important, especially as anthropogenic disturbances are increasing in its watershed (Muvundja et al., 2009). To be effective, these measures require a good knowledge of the species and the environments they live (Lalèyè et al., 2004). All fish species in Lake Kivu are littoral, at least at one stage of their development (Isumbisho et al., 2004). Moreover, 27 of the 29 fish species in Lake Kivu are entirely littoral (Snoeks et al., 2012). The two other pelagic species use this area, a receptacle for watershed inputs (Muvundja et al., 2009), as a place for spawning and/or larval growth (Balagizi et al., 2016). The dumping of topsoil, either naturally or by the population, threatens the spawning substrates in the littoral zone and thus hinders fish reproduction. This area therefore deserves special attention for enhanced fish conservation.

However, it is well-known that the future of any animal population is totally compromised if reproduction and/or larval growth are threatened (Comizzoli & Holt, 2019), regardless of the nature of the threat; this calls for the protection of breeding sites and the protection of larval and young stages of development. Their protection presupposes first of all that they can be identified. This identification is done by the analysis of the permanent presence of larvae and adults during the breeding season (Bouchoucha, 2016; Heyman & Kjerfve, 2008; Mulimbwa et al., 2022; N'Dri et al., 2020). In Lake Kivu, despite the concentration of almost all ichthyological diversity in the littoral zone, no long-term scientific study has been devoted to determining the spawning sites there.

Thus, the aim of this article is to identify, characterise and locate fish spawning sites in Lake Kivu for their best conservation measures. The main questions are: (1) Are physico-chemical characteristics different between sites? (2) Which of the selected sites are spawning sites or nurseries in this study area? (3) According to fishes' body size–weight relationship at the spawning sites, are fish growth types isometric or allometric?

We assume that the physico-chemical parameters differ between sites and then influence the fish discrepancy. In addition, among sites, those located in the bays and the mouths of rivers could be spawning or nurseries sites for several fishes because of calmer conditions (low waves) for the former and a greater input of resources from the watershed and carried by tributary rivers for the latter. Then, fish growth types at spawning sites are expected to be allometric.

2 | MATERIALS AND METHODS

2.1 | Study site

Lake Kivu is located at an altitude of 1464 m between 1°34′S and 28°50′E (Capart, 1960) on the east border of the Democratic Republic of the Congo, with the Republic of Rwanda. It is divided into four major basins including the northern basin, the eastern basin, the western basin and the southern basin (Kaningini, 1995). This study was conducted in one of the two sub-basins of the southern basin, specifically the Bukavu sub-basin in the extreme southern part of this basin. This sub-basin was chosen because of accessibility and especially because it is the sub-basin in which fishing activities are more intense than in all other Congolese parts of Lake Kivu (Figure 1). In order to identify fish spawning sites in the littoral zone of Lake Kivu, 16 study stations were selected according to the physical composition (substrate, depth, presence of macrophytes and their morphology). Some of the sites are located in bays and river mouths, others are strewn around the coastal area. The features of the sampling sites are given in Table 1.

2.2 | Sampling

2.2.1 | Site selection and sampling design

The choice of sampling sites was based on site morphology and location. Some sites are located in bays and river mouths. The presence or absence of macrophytes, vegetation type and substrate composition were also factors in the selection of sampling sites.

The geographical coordinates of each site were obtained using a Garmin GPS. These geographic coordinates were used to generate the map locating the various sampling sites, using QGIS software.

Sampling occurred monthly and diurnally (7 h of net immersion; always from 7 AM to 2 PM). It spanned an annual cycle, from March 2020 to February 2021. Each site (see Table 1 for codes) was sampled once a month.

2.2.2 | Physico-chemical parameters measurement

The environmental variables were measured in situ.

Physico-chemical parameters such as water temperature, pH, conductivity and dissolved oxygen were measured with a Nikon multi-parametric probe. The water transparency and depth were respectively taken using a Secchi disc and a Plastimo ECHOTEST II echo sounder. Three depth measurements were taken at each site and the average values were reported as the site depth.

Substrate percentage composition was estimated by samples of substrate collected using a sediment collection bucket. After collection, the sediments were dried and sieved to assess the particle size composition (Bruton & Gophen, 1992; N'Dri et al., 2020): fine sediment/mud <0.1 mm, sand/silt <2 mm, coarse aggregate/gravel 0.2–2.5 cm, rock/pebbles 2.5–25 cm, boulders >25 cm, uniform surfaces such as rocks, slabs (naturally cemented). The percentage of each substrate component was calculated according to Launois (2011).

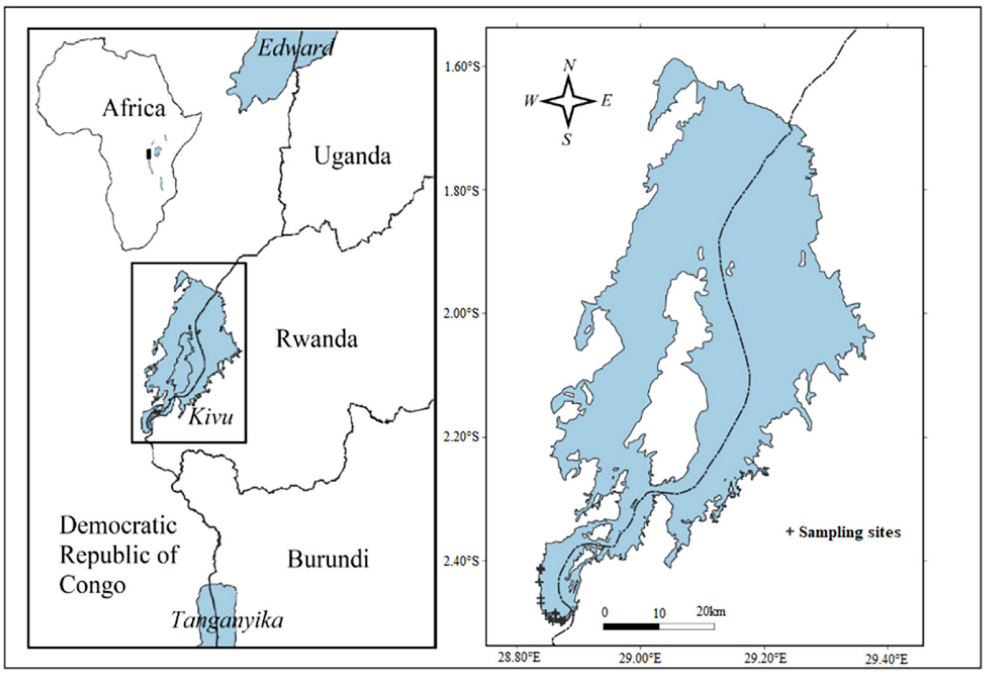

FIGURE 1 Investigated area in Lake Kivu (from geographic data collected with a Garmin GPS and processed using QGIS software).

TABLE 1 (a) Sampling sites, their location and characteristics in the southern Bukavu sub-basin of Lake Kivu, (b) sampled sites, codes of sampled sites and their characteristics in the southern Bukavu sub-basin of Lake Kivu.

Sites	Geographic location	Site features
S1	2°24.680 S–28°50.239 E	Total absence of shoreline vegetation and intensive anthropic activity (hotel, fishermen's landing, …). Mixed substrate
S2	2°29.089 S–28°50.777 E	Intense anthropic activities, dumping of soil dug from house construction sites, nearness to a harbour and two gas stations, absence of coastal macrophytes. Sandy substrate
S3	2°29.658 S–28°51.111 E	Kahuwa river mouth, holding plants present, area of intense anthropic activities, i.e. (the fishermen's landing stages and boots from Idjwi Island, the so-called Bondeko market leads to the dumping of all kinds of waste (plastic waste, liquid, other types of solid waste). On the other side (because it is a bay) a small occasional market due to the presence of fishermen, ports for several boats, a soccer field, mill houses, …). Silty substrate (80%) and 20% sand
S4	2°29.031 S–28°51.715 E	Located near the Connexion Beach Hotel, with a concrete shoreline and ornamental plants with branches spilled onto the lakefront. Sandy substrate (70%) and 30% gravel
S5	2°29.163 S–28°51.754 E	Located near 'Nganda hotel Exaucé' and is characterised by a concreted and completely bare bank. The ground is made of gravel (70%), 20% sand and 10% of boulder
S6	2°29.881 S–28°51.470 E	Holding plants (*Eucalyptus globulus*, *Cyperus papyrus*). Bay coveted by the fish farming in cage. Artisanal fishermen practice angling in search of *Tilapia* spp. on some points is observed as a large amount of household waste. Mixed substrate (70% silty, 30% sand)
S7	2°29.739 S–28°52.226 E	Located behind the provincial governor's residence, this site is less frequented by the population or even fishermen because it is forbidden to fish here at night (oral source from the police officers on duty). The bank is made of high support plants with a macrophyte littoral (100%) of plants of the genus *Phragmites*, *Scirpus* and *Nymphea*. Sandy substrate (80%) and 20% silt
S8	2°29.940 S–28°52.278 E	Bank is a field of long bamboos which block the sun's penetration into the lake shore throughout a long time of day. Currently, fish farming in cages is very common because not enough water movement. Silty substrate (80%) and 20% sand
S9	2°29.833 S–28°52.419 E	Boulders substrate (90%), whose size of pebbles exceeds 25 cm. The bank is made of macrophytes constituted more by crawling plants, while 30% of macrophytes made of plants of the *Phragmites* genus only are observed in the littoral
S10	2°29.730 S–28°52.583 E	Littoral with macrophytes of genus *Phragmites*, *Potamogeton*, *Naja* and *Scirpus*. Small mammals called Otters can be observed during the day time (own opinion during the sampling). Several fish caught at these sites were found to be missing some body parts as they were fed by otters). Mixed substrate (silty–sandy)
(b)		
S11	2°28.109 S–28°50.306 E	Locate at Mugaba River mouth, the sediment is predominantly silty (70%) and 30% of sand and gravel, the shoreline is macrophytes genus of *Scirpus*, *Naja* and *Nymphea*. Recreation activity on the slope. The artisanal fishermen practice clandestinely the fry fishing
S12	2°27.598 S–28°50.290 E	Intense anthropic activity due to an artisanal fishermen's landing. Silty substrates, modified as a result of the ongoing construction. Gravel dumped in the shoreline and some stone blocks support the building plot wall. Silty substrate (70%)
S13	2°26.066 S–28°50.165 E	One section has a boulder substrate (60%) and 40% of silt and sand, while another part is made up of silt swept away by the water. It is also observed that an abundance of macrophytes of the *Phragmites* genus in the littoral and at the shoreline level
S14	2°24.877 S–28°50.329 E	Ground cemented, presence of volcanic rock (slab) (100%). The bank is naked and always made of the same rock. Some boulders can also be seen on the substratum in boulders stuck together on which a sufficient quantity of algae grows
S15	2°24.816 S–28°50.292 E	Site Kagaba river mouth in a small bay. Vegetation abundant on a shoreline, but the substratum with boulders on a large part and near the mouth, it is mixed sandy–rocky (70%) and 20% of boulder. Artisanal fishermen have erected a landing stage for fish unmeshing
S16	2°24.634 S–28°50.381 E	Cemented, copy of Amsar Roche1 (S14), which presents the same characteristics because also constituted by a substratum made of a volcanic rock (slab) (100%) with blocks of rocks stuck on each other

2.2.3 | Fish sampling and eggs collection

Fish were collected using 30 m length and 1.5 m drop height multi-mesh nets (2.5, 5, 10, 15, 20, 30, 35, 40 and 50 mm mesh size). The nets were set each time between 6:00 AM and 9:00 AM and lifted between 3:00 PM and 6:00 PM, i.e. 7 h immersion.

As soon as the nets were set, the larvae and fry, individuals were harvested using mosquitoes netting with a mesh size of 0.6–1.2 mm. In all

sites, this fishing was standardised: it involved a distance of 10 m in length and 2 m in width on both sides of the net and swept for 15 min. The area swept when fishing for larvae and fry individuals was calculated as:

$S=\pi\times r^2$ or $r=d/2$, π being equal to 3.14 and $d=50$ cm (0.5 m) so $3.14\times(0.25)^2=3.14\times0.0625$ then $S=0.19625\,m^2$, with r (radius), $r=d/2$ and $S=$surface area in m^2; $d=$diameter.

The volume of water filtered calculated as: $V=S\times h$, where $S=$net surface area and $h=$depth at which sample sites.

These computations allowed us to estimate the larvae density.

A systematic egg search was undertaken on floating objects, wood pieces, submerged vegetation and rocks. In addition, cinder blocks, egg traps based on the model of Poulin and Routhier (2014), were also placed at each site. They were built on four pieces of wood tied together in a rectangular shape having four small blocks of rock underneath to facilitate immersion. This wooden rectangle was mounted with a piece of blanket attached to a tracking buoy made from an empty 5-L drum. The traps set at the sites were visited every 2 weeks. The first visit occurred 1 month later to allow the fabric and attachment cables to adjust to the colour of the site debris.

2.2.4 | Sample treatment and analysis

For spawning area identification, captured fish were identified according to Snoeks (1994) and Snoeks et al. (2012) and then dissected. Next, the gonads of each specimen were removed and weighed, the sex was determined and the stage of sexual maturity was assessed according to the five-stage maturity scale inspired by Plisnier et al. (1988) as well as Kaningini (1995) as follows:

1. For male individuals the stages were defined as

(I) Gonads transparent to observation, (II) testicles pink-reddish or pink-white, (III) testicles whitish or whitish pink, well developed, with milt spots, (IV) white testicles, milt expelled by finger pressure on the abdomen, spermiduct bursting with milt and (V) pinkish-pale testicles, flaccid and empty of sperm.

2. For females

(I) Gonads transparent to observation, ovocytes discernable with binocular (×10 or ×40), (II) ovaries pinkish, light pink or reddish with a grainy appearance; ovocytes clearly visible but difficult to dissociate, (III) ovaries yellowish, pinkish-yellowish or whitish yellow, oocytes well visible and dissociable, (IV) yellow, orange-yellow or lemon-yellow ovaries, presence of ovules committed in the oviduct and expelled by simple pressure of the fingers, (V) ovaries are dull pink, brick-red or brick-pink, they are empty, flaccid, sometimes with small whitish granulations.

As for the immature individuals (*i*), their sex was not recognisable with the binocular (×40) and their small gonads were still attached to the spine.

Individuals with gonads at sexually mature stages I and II were considered immature, while those with gonads at sexually mature stages III and IV and those at post-spawning stage V were taken to be mature individuals in the reproductive phase (Balagizi et al., 2016; Heyman & Kjerfve, 2008; Shi et al., 2022; Thompson & Riley, 1981).

A sampling site was considered to be a spawning site for a given species when the number of individuals caught for that species at that site was greater or equal to 10 and the abundance of spawners at sexual maturity stages III, IV and V was above 70% (Heyman & Kjerfve, 2008; N'Dri et al., 2020).

When immatures' proportion was above that of matures', and the size (TL) of the larvae was below 19 mm [*Lamprichthys tanganicanus* (*La. tanganicanus*), *Limnothrissa miodon* (*Li. miodon*)] or 15 mm (*Haplochromis* sp., *Enteromius* sp.) and the occurrence value (percentage of number of days that larvae were observed over the number of sampling days) of larvae was high (>70%), the site was considered as a nursery (Bouchoucha, 2016; Desaunay et al., 1981; Mulimbwa et al., 2014, 2022; N'Dri et al., 2020).

The species *La. tanganicanus* and *Haplochromis astatodon* were selected in the analyses of reproductive indices in relation to their monthly presence at some biotopes.

To differentiate larvae and fry, the first reference was the yolk sac, then the size of the individual. More concretely, both the larvae and the fry were very small (smaller for the former than the latter), but the former still had their yolk sac while the latter had already resorbed it. Their classification, counting and identification were done using an OLYMPUS binocular loupe. For some of the groups, the identification was done up to genus level, while for other well-known groups, the identification was done up to species level.

The condition factor (K) was calculated for some species at some of the sites by the formula of Tesch (1971):

$$K=\frac{W}{L^b}\times 100.$$

We selected these species because of their permanent presence at these sites during the study period, with the b value that comes from the weight–length relationship whose linear equation of the form $\ln W=\ln a+b\ln L$ was generated from Excel 2016. Only S3, S6 and S8 sites were included in these analyses because of the larval diversity observed.

The gonadosomatic index (GSI) used to determine the number of the fish spawning as well as monthly or seasonal, and determination of fish reproduction time (Saleh & Ali, 2017; Zin et al., 2011) was calculated for fish that had reached at least stage II sexual maturity according to the relationship:

$$\mathrm{GSI}=\frac{\mathrm{GoW}}{\mathrm{FeW}}\times 100,$$

with GSI=gonadosomatic index, GoW=gonad weight (g) and FeW=fish's eviscerated weight (g).

2.2.5 | Statistical analysis

The physico-chemical parameter values, adult fish and larvae abundances were compared according to the sampling sites by one-factor ANOVA test and Kruskal–Wallis test. The software Past version 3.1 was used and $p<0.05$ was deemed significant. Linear regression curves for the weights and heights graphs were generated using Excel 2016 after the data log transformation in Past 3.1. This linear logarithmic transformation such as $\ln(p)=\ln(a)+b\ln(L)$ reduced the variability and homogenised both the weight and height variables. The b constant varying between 2 and 4, but often close to 3 (Pauly & Moreau, 1997) was deduced from this linear regression line. This value was used to decide if the fish growth was isometric ($b=3$) or allometric (b different from 3). To ensure this difference, the 'one sample' Student's t test in Past version 3.1 was used.

A principal component analysis (PCA) was performed on the physico-chemical parameters that showed significant differences between sites. This was done in an attempt to detect correlations between the various physico-chemical parameters and the different sampling sites. This analysis related only to sites identified as spawning or nursery sites.

3 | RESULTS

3.1 | Sites physico-chemical parameters

Temperature ranges from 23.4±1.2 to 24.5±0.7°C (Table 2) with significant differences between sites (one-factor ANOVA, $F=2.124$, $p=0.011$). This heterogeneity between sites was not noticeable for the mean pH values (one-factor ANOVA, $F=1.212$, $p=0.266$) (min–max: 8.6±1.2 to 9.5±0.6), which show the waters of different sites being alkaline. For dissolved oxygen, the mean values are also different from each other (Table 2; one-factor ANOVA, $F=2.792$, $p<0.001$; min–max: 3.1±1.8 to 8.6±5.4 mg/L). Electrical conductivity showed mean values between 1175.6±176.5 and 1259.2±169.8 µs/cm, which did not vary between sites (one-factor ANOVA, $F=0.2779$, $p=0.996$). Finally, depth (max–min: 4.0±1.1 to 1.9±0.5 m; one-factor ANOVA, $F=5.915$, $p<0.001$) and water transparency (min–max: 1.1±0.5 to 2.4±0.6 m; one-factor ANOVA, $F=3.421$, $p=0.004$) had average values that were different between sites.

According to the PCA (Figure 2), the axes 1 and 2 explain 85.61% of the correlation between sites according to physico-chemical parameters. Thus, sites S4, S9, S11, S14 and S15 showed the largest values of temperature and dissolved oxygen are positively correlated with axis 1. While sites S3, S7, S5, S10, S8, S6, S12 and S13 presented the lowest values of transparency and depth and are negatively correlated with axis 1 (Figure 2).

3.2 | Identification and location of spawning sites and nurseries

3.2.1 | Trapping and egg capture

There were no eggs trapped on the floating objects. However, they were trapped in sites S11 and S12 using the cinder blocks. The abundance of eggs collected on the cinder blocks was low, as very often only one egg was found on the cinder block.

TABLE 2 Mean values±standard deviations of physico-chemical parameters measured in 16 sites of the Bukavu sub-basin.

Sites	T (°C)	pH	Cond (µs/cm)	Dep (m)	Transp (m)	O_2 (mg/L)
S1	24.3±0.5	9.1±0.5	1238±165	2.5±0.7	1.5±0.5	7.8±5.2
S2	24.1±0.4	9.5±0.6	1216±192	4.0±1.1	1.1±0.5	8±4.3
S3	24.1±0.6	9.2±0.5	1227±164	2.8±1.2	1.7±0.2	5±1.9
S4	24.3±0.5	9.3±0.4	1233±181	1.9±0.5	1.6±0.3	6.4±2.1
S5	23.9±1.1	9.5±0.5	1181±174	3.3±1.3	2.3±0.4	8.7±5.4
S6	24.3±0.6	9.3±0.5	1259±169	3.5±1.3	2±0.8	5.1±2.3
S7	24.2±0.6	9.5±0.3	1253±193	2.8±1	2.1±0.5	5.3±1.0
S8	24.2±0.8	9.4±0.3	1201±146	3.4±1.2	2.2±0.5	5.2±1.4
S9	24.5±0.7	9.3±0.5	1185±114	2.8±0.7	2.0±0.6	5.8±2.1
S10	24.3±0.5	9.2±0.4	1205±156	3.3±1	2.4±0.6	5.7±1.9
S11	23.9±0.4	8.8±1.1	1177±184	2.0±0.4	1.3±0.5	4.7±2.4
S12	23.4±1.2	8.6±1.2	1195±186	2.4±1	1.6±0.5	3.1±1.8
S13	23.9±0.4	9.3±0.7	1175±176	2.0±0.6	1.6±0.6	3.6±2.1
S14	23.8±1.2	9.2±0.7	1179±177	2.0±1	1.5±0.3	4.3±7
S15	24.1±1.3	9.2±0.5	1184±179	2.0±0.4	1.6±0.5	3.4±1.5
S16	24.2±1.3	8.9±0.6	1199±203	2.6±0.6	2.1±0.5	3.9±1.8

Abbreviations: Cond, electrical conductivity; Dep, depth; O_2, dissolved oxygen; T, temperature; Transp, transparency.

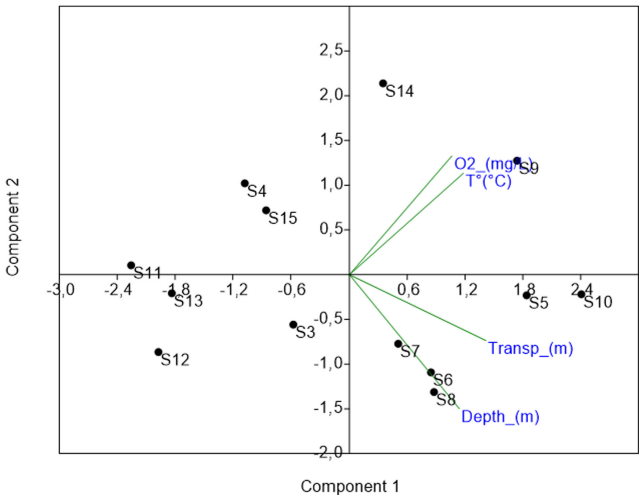

FIGURE 2 Principal component analysis of physico-chemical parameters of different sites (O_2, dissolved oxygen; *T*, temperature; Transp, transparency).

3.2.2 | Species richness and spawning sites identification

The results of the different fish species captured and identified at different sampling sites (Table 3) showed that sites S3, S6, S7, S8, S11, S12, S13 and S15 were the most diversified with fish species richness ranging from 10 to 17.

For spawning sites analysis, *Haplochromis vittatus*, *Haplochromis olivaceus*, *Haplochromis scheffersi*, *Oreochromis niloticus*, *Li. miodon* and *Enteromius kerstenii* had high proportions of mature and immature individuals (Table 4), but only at sites S2, S3, S5, S6, S8, S10, S12, S13 and S15. Within this group, the proportions of *H. olivaceus*, *Li. miodon*, *H. vittatus* and *H. scheffersi* were very high at the sites S5 and S6, while the remaining had high proportions in S2 or S3 sites. For these species, the ratios of immatures were high at sites S4 and S9 for *H. olivaceus*, S6, S7, S10 and S12 for *H. vittatus*, S7 and S9 for *H. scheffersi*, S13 for *O. niloticus*, S9 and S15 for *Li. miodon* and S15 for *E. kerstenii*.

Other species such as *Haplochromis crebridens*, *Haplochromis adolphifrederici*, *Haplochromis graueri*, *Haplochromis rubescens*, *Haplochromis kamiranzovu*, *H. astatodon*, *Enteromius apleurogramma* and *La. tanganicanus* showed high ratios of mature individuals at sites S3, S4, S7, S8, S9, S11, S12 and S14 (Table 4). *Lamprichthys tanganicanus* presented higher proportions of mature individuals in eight sites. The species *Haplochromis insidiae* and *Haplochromis microchrysomelas* showed high proportions of immature individuals only. They were found at sites S4, S7 and S9 for *H. microchrysomelas* and only S7 for *H. insidiae* (Table 4).

Sites S3, S6 and S8 were more frequented by several fish species than others, with higher proportions of mature individuals for more than one species. The size–weight relationships of fish at these spawning sites are given in Table 7.

The analysis of the larval fishing data by the percentage composition of larval taxa (Figure 3) showed that *La. tanganicanus* larvae were more abundant at sites S4, S5, S7, S9, S12, S14 and S16 where they reached 80%–98%. *Haplochromis* spp. larvae were more represented in sites S3, S11, S13 and S15. *Enteromius* spp. larvae were observed in sites S3, S6, S8, S11, S13 and S15, but dominant in sites S6 and S8 where they reached 70%–80% (Figure 3). *Oreochromis* spp. larvae were found in low abundance in sites S3, S11, S13 and S15 which are mouth of rivers. There were no larvae observed at all in S1, S2 and S10. The larval abundances showed significant differences between sites (Kruskal–Wallis, $H = 11.5$, $p = 0.021$).

Some breeding aspects of La. tanganicanus and H. astatodon in the littoral zone of Lake Kivu

Temporal variations of GSI and number of mature adults of *La. tanganicanus* showed a trend of continuous reproduction throughout the year whatever the biotope (sandy or silty) (Figure 4a,b). The highest average GSI values were found in February, May, July, August and December. Mean GSI values did not differ between seasons in silty substrates for males and females respectively (one-factor ANOVA, $F_{males} = 0.202$, $p_{males} = 0.665$ and $F_{females} = 0.145$, $p_{females} = 0.714$) and sandy substrates (one-factor ANOVA, $F_{males} = 1.454$, $p_{males} = 0.256$ and $F_{females} = 0.071$, $p_{females} = 0.795$).

Male and female proportions of mature individuals of *La. tanganicanus* did not differ between seasons in the silty (one-factor ANOVA, $F_{males} = 0.514$, $p_{males} = 0.494$ and $F_{females} = 0.229$, $p_{females} = 0.547$) and sandy biotopes (one-factor ANOVA, $F_{males} = 3.267$, $p_{males} = 0.104$ and $F_{females} = 0.018$, $p_{females} = 0.895$).

For *H. astatodon* (Figure 4c), the GSI means of males and females were the same between seasons in the silty substrate respectively (one-factor ANOVA, $F_{males} = 1.288$, $p_{males} = 0.289$ and $F_{females} = 2.509$, $p_{females} = 0.152$). Mature proportion of *H. astatodon* in the same biotope were different between seasons for females (one-factor ANOVA, $F = 3.65$, $p = 0.009$) and not different for males (one-factor ANOVA, $F = 0.05669$, $p = 0.818$).

Larvae occurrence is highest in the 70% and 80% silty biotope, it is low in 70% gravel. But the larvae density was high in the 70% sandy and 100% rocky sites. Larvae species richness is high at 70%–80% silt sites (Table 5). Total larvae abundance differed among sites (Kruskal–Wallis, $H = 25.95$, $p = 0.021$).

Catch periods for fish species at spawning sites

Several species of fish were caught at the spawning and nursery sites during specific periods, depending on the time of capture. This was the case for species that were present in the rainy season (November–May) and in the dry season (June–October) (Table 6). However, *La. tanganicanus* was captured at these sites each month in both seasons (Table 6).

For certain species their breeding sites have been identified as nursery sites for other species. This is the case for *H. graueri* for which spawning site S8 is a nursery for *Li. miodon* and *H. crebridens* for which spawning site S12 is a nursery for *H. vittatus*. The site S4 is a spawning site for *La. tanganicanus*, but a nursery for several species including *H. paucidens*, *H. olivaceus* and *H. microchrysomelas*. Other

TABLE 3 Fish species richness, composition and species distribution by site in the Bukavu sub-basin (+: presence).

Family	Species/sites	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
Cichlidae	*Haplochromis crebridens*	+			+	+	+			+		+	+			+	+
	Haplochromis adolphifrederici			+					+			+				+	+
	Haplochromis graueri	+	+	+				+	+	+		+	+	+		+	
	Haplochromis vittatus			+		+		+	+		+	+	+			+	
	Haplochromis paucidens	+		+	+	+	+	+	+	+						+	
	Haplochromis olivaceus	+	+	+	+	+	+	+	+	+		+	+		+	+	+
	Haplochromis rubescens			+				+					+				+
	Haplochromis microcrysomelas	+		+	+			+		+	+	+	+			+	+
	Haplochromis kamiranzovu					+	+			+		+	+			+	+
	Haplochromis astatodon						+		+	+		+			+		
	Haplochromis nigroides				+												
	Haplochromis gracilior	+											+				+
	Haplochromis scheffersi	+				+	+	+		+	+		+				
	Haplochromis insidiae							+									
	Haplochromis occultidens													+			
	Oreochromis niloticus			+			+	+	+					+		+	
	Oreochromis macrochir			+			+		+								
	Coptodon rendalli			+			+							+			
Clariidae	*Clarias gariepinus*			+										+			
	Clarias liocephalus			+										+			
Clupeidae	*Limnothrissa miodon*			+			+		+							+	
Cyprinidae	*Enteromius apleurogramma*			+			+		+			+		+		+	
	Enteromius kerstenii			+			+		+			+		+		+	
	Enteromius pellegrini	+		+			+		+			+		+		+	
Procatopodidae	*Lamprichthys tanganicanus*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Specific richness	9	3	17	6	7	14	10	13	9	4	12	10	10	3	14	8

TABLE 4 Immature (stages I and II) and mature (stages III, IV and V) individual proportions sampled in the 16 sampling sites in the Lake Kivu Bukavu sub-basin from March 2020 to February 2021.

	S1		S2		S3		S4		S5		S6		S7		S8		S9		S10		S11	
Species $N \geq 10$	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im
Haplochromis crebridens[a]			59.4	40.6							67.6	32.4										
Haplochromis adolphifrederici[a]					92	8																
Haplochromis graueri[a]															100	0						
Haplochromis vittatus[b]					76.9	23.1					13.6	86.4	0	100	73.4	26.6			0	100		
Haplochromis paucidens[c]							30	70			53.6	46.4										
Haplochromis olivaceus[b]			33.4	66.6	72.7	27.3	18.2	81.8	73.4	26.6	73.3	26.7			61.5	38.5	23.8	76.2				
Haplochromis rubescens[a]											92.4	7.6										
Haplochromis microchrysomelas[c]							20	80	66.6	33.4			12.5	87.5			15.4	84.6				
Haplochromis kamiranzovu[a]											80	20										
Haplochromis astatodon[a]					80	20					75.7	24.3										
Haplochromis nigroides																						
Haplochromis gracilior																						
Haplochromis scheffersi[b]			70	30									9.1	90.9	94.2	5.8	0	100	71.5	28.5		
Haplochromis insidiae[c]													6.6	93.4								
Haplochromis occultidens																						
Oreochromis niloticus[b]											72.7	27.3										
Oreochromis macrochir																						
Coptodon rendalli																						
Clarias gariepinus																						
Clarias liocephalus																						
Limnothrissa miodon[b]					76.4	23.6					73.4	26.6			4.8	95.2	0	100				
Enteromius apleurogramma[a]															81.8	18.2						
Enteromius kerstenii[b]					83.4	16.6															66.6	33.4

(Continues)

TABLE 4 (Continued)

Species $N \geq 10$	S1		S2		S3		S4		S5		S6		S7		S8		S9		S10		S11	
	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im	M	Im
Enteromius pellegrini					69.2	30.7																
Lamprichthys tanganicanus[a]					77	23	85.6	14.4	61.3	38.7	62.5	37.5	80.1	19.9	80.6	19.4	95.4	4.6	58.6	41.4	97	3

Species $N \geq 10$	S12		S13		S14		S15		S16	
	M	Im	M	Im	M	Im	M	Im	M	Im
Haplochromis crebridens	90.9	9.1								
Haplochromis adolphifrederici										
Haplochromis graueri	46.6	53.4								
Haplochromis vittatus	16.6	83.4								
Haplochromis paucidens										
Haplochromis olivaceus							90.9	9.1		
Haplochromis rubescens										
Haplochromis occultidens										
Oreochromis niloticus			0	100						
Oreochromis macrochir										
Clarias liocephalus										
Limnothrissa miodon							16.6	83.4		
Enteromius apleurogramma										
Enteromius kerstenii							8.4	91.6		
Enteromius pellegrini										
Lamprichthys tanganicanus	98.5	1.5			87.8	12.2	62.5	37.5	50.5	49.5

Note: Colours show high mature and immature proportions acceptable to define spawning or nursery.

Abbreviations: Im, immature; M, mature.

[a]Species with high proportions of mature only.

[b]Species with high proportions of both mature and immature.

[c]Species with high proportions of immature only.

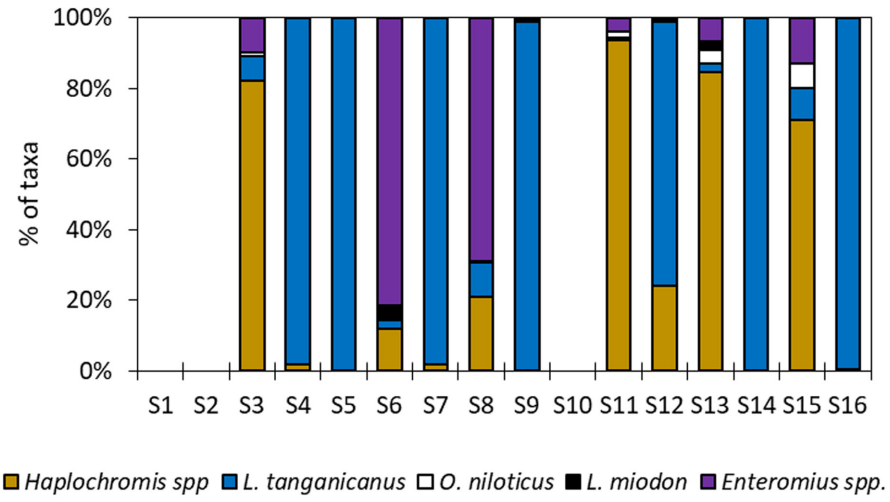

FIGURE 3 Percentage of larval taxa composition in the 16 sampling sites in the Lake Kivu Bukavu sub-basin from March 2020 to February 2021.

such as S3, S11 and S14 all other spawning sites for *La. tanganicanus* are also nursery sites for other species. The site S3 is a spawning site for several different species such as *H. adolphifrederici*, *H. vittatus*, *H. olivaceus*, *H. astatodon*, *Li. miodon*, *E. kerstenii* and *La. tanganicanus*. Sites S7 and S9 are nurseries for several species such as *H. vittatus*, *H. microchrysomelas*, *H. scheffersi* and *H. insidiae* for site S7 and *H. olivaceus*, *H. microchrysomelas*, *H. scheffersi* and *Li. miodon* for site S9 (Table 6).

3.2.3 | Location of spawning and nursery sites

As mentioned in the result of Table 6, the geographical location of the different spawning and nursery sites of the different species (Figure 5) shows that some spawning areas for some species are nurseries for other species, while other areas are either only spawning or nursery areas for a single species.

3.2.4 | Size–weight relationship of fish at some of the spawning sites

The length–weight relationship for each of the species examined are strongly significant (p value always <0.05) with the coefficients (r^2) ranging from 0.82 to 0.98 (Table 7). Referring to b values, growth patterns vary from one species to another and from one site to another for the same species. Thus, the species *H. vittatus* has isometric growth in sites S3 and S6, whereas in site S8 it has negative allometric growth. For *H. astatodon* and *H. olivaceus*, the growth was isometric in site S3, in sites S6 and S8 the growth was allometric. For *Enteromius kerstenii*, *H. adolphifrederici*, *H. kamiranzovu* and *E. apleurogramma*, growth was allometrically positive at sites S3, S6 and S8 respectively. The species *La. tanganicanus*, *Li. miodon*, *O. niloticus* and *H. graueri* had negative allometric growth at three considerable sites. The condition factor (K) values ranged from 0.012 to 0.99. These values of K are always lower than 1, indicating a poor condition.

4 | DISCUSSION

4.1 | Physico-chemical characteristics of the study area

The results on water physico-chemical parameters in the Bukavu sub-basin during this study highlighted a large variability of temperature mean values in the different sampling sites, though these values remain in the range of values obtained by others (Akonkwa, 2017; Guillard et al., 2012; Isumbisho et al., 2006). As for the pH, values did not differ between sites. In contrast, the depth, water transparency and dissolved oxygen differed between sites. Thus, site S2, the deepest, is located near the Alleluia harbour where the dredging was done. As for the differences in water transparency, they could be explained by the unequal reception of external inputs from the watershed by different parts of the littoral zone of Lake Kivu (Lina, 2016; Muvundja et al., 2009). Bisimwa (2009) and Lina (2016) report an increase in sedimentation and water turbidity, which has affected the water quality and ecology of the lake. Finally, dissolved oxygen values obtained indicates good conditions for aquatic life. According to IGBE (2005) and Bokossa et al. (2014), the range from 4 to 6 mg/L located in the range of values obtained in this study characterises optimal conditions for aquatic life. The average conductivity values do not differ between sites. All physico-chemical values observed in this study are optimal for aquatic life (ANZECC, 2002; CCME, 2009; USEPA, 1995) and could affect and influence fish distribution. It is further stated that human activities around water areas have a significant influence on the concentration of dissolved oxygen in lakes, disrupting the aquatic life of some species (Dupont, 2004; Hade, 2002). The high oxygen values (9.5–10 mg/L) obtained were in areas without macrophytes, it is inconsistent, but those sites are located in the area of intense anthropogenic activity which would influence this concentration (Hyangya et al., 2021), by the algal bloom resulting from the nutrient overload. The PCA showed that dissolved oxygen and temperature are factors that influence positively the presence or absence of fish in the sites S4, S9, S11, S14 and S15. For the second case, the depth and the transparency are the factors that

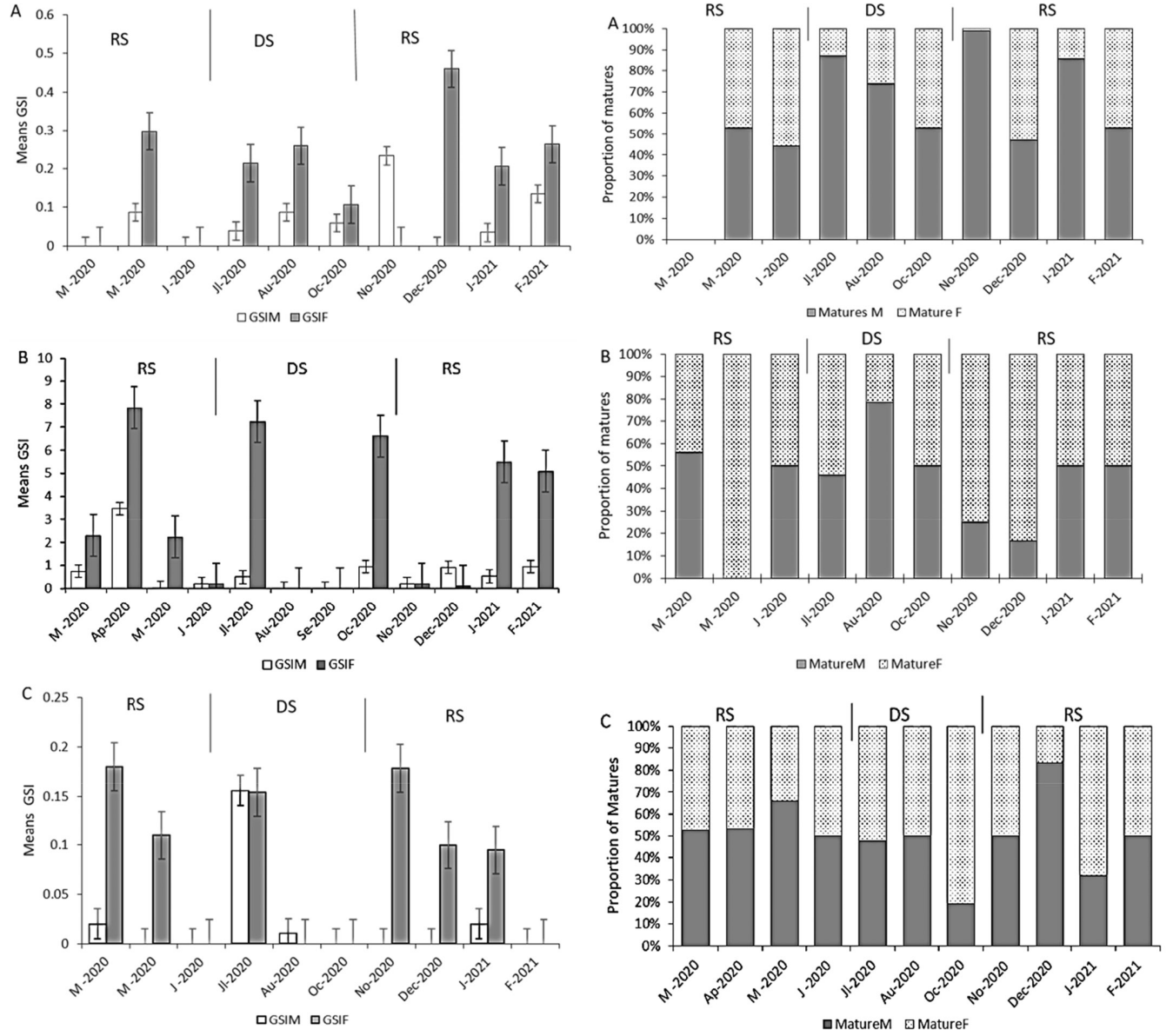

FIGURE 4 Monthly evolution of gonadosomatic indices (GSI) of *Lamprichthys tanganicanus* and *Haplochromis astatodon* in the spawning sites of Lake Kivu, Bukavu sub-basin (a: mean ± standard error of GSI of *La. tanganicanus* and proportions of mature individuals in 80% silty; b: mean ± standard error of GSI of *La. tanganicanus* and their proportions of mature individuals in 70% sandy biotope; c: mean ± standard error of GSI of *H. astatodon* in the 80% silty biotopes. DS, dry season; RS, rainy season).

explain negatively the presence of fish in sites S3, S7, S5, S10, S8, S6, S12 and S13. This influence of temperature and DO in the fish distribution have been reported in different studies in Ivory Coast (Aboua et al., 2010; Da Costa et al., 2000; Tanoh et al., 2013).

4.2 | Spawning and nursery sites identification and location

Several spawning sites were identified during this research for several fish species in Lake Kivu. They are more located in bays and river mouths. That is the case for sites S3, S6, S7, S8, S11, S12, S13 and S15. Indeed, in lentic ecosystems, it has long been reported that river mouths are commonly richer and more diversified than other sites (Ntakimazi et al., 2005). The discrepancy in diversity between sites (higher diversity of some sample sites than others) could be explained by a high specific richness of larvae. Duponchelle et al. (2008) explained this fact with the majority of fishes of the genus *Haplochromis* (most species in Lake Kivu) used buccal incubation, i.e. the eggs and then the larvae develop inside the buccal cavity of one of the parents, most often the female. They cannot be released until an advanced stage. This warrants the parents' presence next to the youth to keep them safe. Another explanation is the concentration of physico-chemical parameters. That is the case of concentration of oxygen with negative correlation with temperature (it decreases with increasing temperature). Some species, because

TABLE 5 Larvae occurrence, abundance and density at different sites where larvae were observed at least once in the Bukavu sub-basin. Sites S1, S2 and S10 are not included in this table (no larvae observed) (occurrence is the percentage of times larvae were observed over the number of sampling days).

Sites	Number of sampling days	Number of times larvae observed (%)	Larvae species richness	Dep/h (m)	*S* (m^2)	*V* (m^3)	Larvae abundance	Density (larvae/m^3)
S3	8	6 (75)	4	2.8	0.19625	0.5495	453	824.39
S4	12	7 (58.3)	3	1.9	0.19625	0.372875	5445	14,602.75
S5	12	1 (8.3)	1	3.3	0.19625	0.647625	409	631.54
S6	12	10 (83.3)	5	3.5	0.19625	0.686875	2470	3596.00
S7	12	2 (16.6)	2	2.8	0.19625	0.5495	60	109.19
S8	12	8 (66.6)	4	3.4	0.19625	0.66725	1345	2015.74
S9	12	6 (50)	3	2.8	0.19625	0.5495	1750	3184.71
S11	12	7 (58.3)	4	2	0.19625	0.3925	574	1462.42
S12	12	9 (75)	4	2.4	0.19625	0.471	1012	2148.62
S13	12	9 (75)	5	2	0.19625	0.3925	386	983.44
S14	12	8 (66.6)	2	2	0.19625	0.3925	2984	7602.55
S15	10	8 (80)	4	2	0.19625	0.3925	771	1964.33
S16	12	9 (75)	3	2.6	0.19625	0.51025	1891	3706.03

of their oxygen concentration requirements, will prefer colder water to warmer water, while others will prefer the opposite. This is the case of *Oreochromis mossambicus* of Natal Lake for which the high mortality were observed because of cold water decreases until 13°C (Bruton, 1979). But *Oreochromis niloticus* can support lower concentration of O_2 until 0.1 ppm (Magid & Babiker, 1975; Whitworth, 1964) in spite of its high tolerance limit, 1.4 mh/L, according to Mahdi (1973).

Some species, such as *H. olivaceus* and *La. tanganicanus*, with higher number of spawning sites than other species, affectionate several types of biotopes in the littoral zone of Lake Kivu (Mazambi et al., in press.). In contrast, *La. tanganicanus* (introduced species in Lake Kivu) in Lake Tanganyika, where it originates, prefers rocky substrates (Eccles, 1992; Ntakimazi et al., 2005). Several nurseries are identified, but the sites S7 and S9 are used by different species and then they constitute important nurseries observed during this study. Both sites are located in the Nyofu Bay with very little anthropogenic activities. Other nursery sites are located in places where household waste is dumped; which is true for the site S6, in Jardini bay, cited also by Kaliza et al. (2018).

Sites S3, S4, S7, S8, S9, S11, S12 and S14 have been identified as spawning sites for several species such as *H. crebridens*, *H. adolphifrederici*, *H. graueri*, *H. rubescens*, *H. kamiranzovu*, *H. astatodon*, *E. apleurogramma* and *La. tanganicanus*. In these sites, the larval diversity observed indicates the presence of many species for the breeding activity, thus confirming their spawning status (Duponchelle et al., 2008). It should be mentioned, however, that some of these spawning sites for these species, namely S4 and S9, also proved to be nursery sites (Bouchoucha, 2016; Desaunay et al., 1981) for other species, mainly *H. insidiae* and *H. microchrysomelas*.

Larval occurrence index values and species richness were highest at sites S14 and S16, located in the 70% and 80% silty biotopes and 100% rocky, suggesting the use of these sites as spawning and nursery areas (Bouchoucha, 2016; Desaunay et al., 1981; N'Dri et al., 2020). This preference is about some life conditions such as chemical conditions, and larval prey disponibility. *Lamprichthys tanganicanus* larvae taxon reached 80%–98% abundance at sites S4, S5, S7, S9, S12, S14 and S16. Of these, S14 and S16 are the rocky sites and were the most abundant occupied at 98% only by *La. tanganicanus*. This suggests a nursery site for *La. tanganicanus*, as site S16 was not identified as a spawning site for this species. It was observed that the sites used by *La. tanganicanus* as spawning are nurseries for others, but not as nurseries for *La. tanganicanus* who uses other sites. This observation must be more verified, but we assumed that *La. tanganicanus* avoids larval competition.

Haplochromis sp. and *Enteromius* sp. larvae were observed in some sites but with an overwhelming abundance of *Enteromius* sp. in sites S6 and S8. This may be related to the environmental parameters such as transparency and depth that correlated positively with these sites. These conditions are associated to others namely low water movement, presence of special macrophytes in bays and mouths, availability of prey (Desaunay et al., 1981; Lelièvre, 2010; Mulimbwa et al., 2022). In Lake Tanganyika, Mulimbwa et al. (2022) refer to low predation rates to explain the larval abundance of some species, but in Lake Kivu there are no predators. This leads to other factors first cited and which require more stability for fish life for conservation.

Reproductive indices such as the GSI, mature and immature proportion and larval abundance are most important in identifying fish spawning and breeding sites, though these alone are not sufficient (Mulimbwa et al., 2014, 2022). The presence of eggs is an important parameter but the results were not sufficient because of ecological constraints in the study area.

TABLE 6 Catch periods, spawning and nursery sites of fish species with proportions of mature (stages III, IV and V) and immature (I and II) individuals higher than or equal to 70% ($N \geq 10$) in the Bukavu sub-basin.

Species	Number of spawning sites	Number of nursery sites	Catch periods	Spawning sites	Nursery sites
Haplochromis crebridens	1		March, April, December and February	S12	
Haplochromis adolphifrederici	1		August and February	S3	
Haplochromis graueri	1		March, May, July and August	S8	
Haplochromis vittatus	2	4	February, April, July, August, November and December	S3, S8	S6, S7, S10, S12
Haplochromis paucidens		1	April, July, August and December		S4
Haplochromis olivaceus	4	2	January, April, May, July, August, October, November	S3, S5, S6, S15	S4, S9
Haplochromis rubescens	1		July	S6	
Haplochromis microchrysomelas		3	May, December		S4, S7, S9
Haplochromis kamiranzovu	1		February, August	S6	
Haplochromis astatodon	2		January, May, August, October, November, December	S3, S6	
Haplochromis scheffersi	3	2	May, July, December	S2, S8, S10	S7, S9
Haplochromis insidiae		1	March		S7
Oreochromis niloticus	1	1	January, February, April, July, August, September	S6	S13
Limnothrissa miodon	2	3	January, February, May, July, November, December	S3, S6	S8, S9, S15
Enteromius apleurogramma	1		January, February, November, December	S8	
Enteromius kerstenii	1	1	January, February, November, December	S3	S15
Lamprichthys tanganicanus	8		Every month (From January to December)	S3, S4, S6, S8, S9, S11, S12, S14	

Spatial variations in GSI values of different species showed that *La. tanganicanus* and *H. astatodon* species have continuous reproduction and then reproduce several times a year as already demonstrated also by Balagizi et al. (2016) indicated the reproduction peaks appearing more in February–April, June–July and November–December showed a reproduction spread over the whole year. These breeding peaks were therefore observed in both seasons, as confirmed by our results. Reproduction spread over several periods of the year has already been reported by some authors on inland water fish species in Africa. This is the case for *Li. miodon* in Lake Kivu (Kaningini, 1995) and Lake Tanganyika (Mannini, 1991); *Lamprologus ornatipinnis* cichlids in Lake Tanganyika (Gordon & Bills, 1999), *O. niloticus* in Lake Victoria (Njiru et al., 2006) and Lake Abu-Zabal (Egypt) (Kariman & Hanan, 2008). These reproduction patterns would be related to the biology of each species regardless of the anthropogenic pressure (Lévêque & Quensière, 1988), around Lake Kivu and including fishing pressure, dredging and concreting of the banks observed in the Bukavu basin.

4.3 | Individual types of growth of fish in the spawning sites

For most species, the growth was allometric (positive or negative) in the same sites. This observation would appear to be normal in a spawning area where fish in the spawning period would weigh differently from the cube of their size due to the presence of eggs (Balagizi et al., 2016; Mazambi et al., 2020). This was observed in *La. tanganicanus* females in Lake Kivu for which their GSI was high compared to males and was explained by the high weight of the eggs despite the small size of the females (Balagizi et al., 2016).

The location of fish spawning sites is often considered an adaptive option to increase larval feeding opportunities (Agostini & Bakun, 2002; Bakun, 2006), reduce larvae, eggs and adult predations (Bakun, 2013) or facilitate transport to suitable nursery sites (Bailey et al., 2005; Karnauskas et al., 2011; Symonds & Rogers, 1995). The condition factor (K) values lower than 1 indicated a poor condition of fish (Fulton, 1902) at the spawning sites in all cases. Such conditions probably result from some ecological

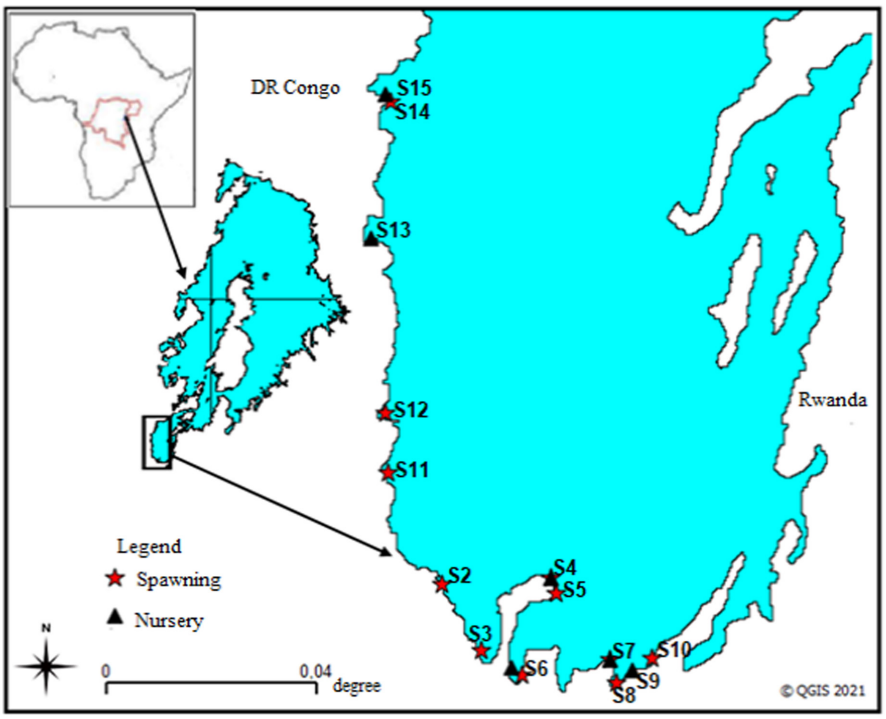

FIGURE 5 Location of some spawning and nursery areas identified in the littoral zone of Lake Kivu, Bukavu sub-basin.

TABLE 7 Fish body size and weight relationship of some fish species in Lake Kivu Bukavu sub-basin in three sites identified as spawning areas [the SNCC bay site (S3), Jardini Bay (S6) and Fizi Bamboo Bay (S8)] for samples of more than 10 specimens.

Site	Species	*n*	$\ln W = \ln a + b \ln L$	*a*	*b*	r^2	Mean (*K*)	GT
SNCC (S3)	*Haplochromis olivaceus*	15	$-4.9649 + 3.0562x$	4.96	3.05	0.97	0.19	I
	Haplochromis vittatus	14	$-5.1104 + 3.1584x$	5.11	3.11	0.98	0.09	I
	Haplochromis astatodon	13	$-4.48086 + 3.00x$	4.48	3.0	0.98	0.17	I
	Haplochromis adolphifrederici	14	$-5.6308 + 3.4x$	5.63	3.4	0.98	0.28	A^+
	Enteromius kerstenii	16	$-9.1001 + 5.483x$	9.10	5.4	0.95	0.03	A^+
	Lamprichthys tanganicanus	18	$-2.4507 + 1.6584x$	2.45	1.65	0.96	0.37	A^-
Jardini bay (S6)	*Haplochromis olivaceus*	48	$-3.1578 + 2.1109x$	3.12	2.11	0.85	0.37	A^-
	Haplochromis astatodon	31	$-5.4069 + 3.3131x$	5.40	3.31	0.97	0.012	A^+
	Haplochromis vittatus	22	$-5.1196 + 3.0871x$	5.11	3.08	0.98	0.15	A^+
	Limnothrissa miodon	12	$-3.9562 + 2.5195x$	3.95	2.51	0.97	0.012	A^-
	Oreochromis niloticus	12	$-4.3916 + 2.8957x$	4.39	2.89	0.91	0.046	A^-
	Haplochromis kamiranzovu	12	$-5.5941 + 3.4137x$	5.59	3.41	0.98	0.025	A^+
Fizi Bamboo (S8)	*Lamprichthys tanganicanus*	85	$-4.1997 + 2.5654x$	4.19	2.56	0.82	0.57	A^-
	Haplochromis graueri	12	$-4.0912 + 2.603x$	4.09	2.60	0.96	0.098	A^-
	Enteromius apleurogramma	15	$-5.1887 + 3.2685x$	5.18	3.26	0.95	0.99	A^+
	Haplochromis vittatus	12	$-4.2666 + 2.7087x$	4.26	2.70	0.93	0.067	A^-

constraints such as food poverty for parents, the prey availability for larvae being important. Under these conditions, the parents seek only optimal and favourable conditions for the larvae development. Other factors like physico-chemical parameters are considered in the literature to be favourable to aquatic life and choice of spawning sites (Bokossa et al., 2014; IGBE, 2005; Rutherford et al., 1989; Saucier et al., 1992) and to the fish distribution in the water (Aboua et al., 2010; Da Costa et al., 2000; Tanoh et al., 2013). Disrupting these parameters through anthropogenic activities would threaten the fish species biology in Lake Kivu and therefore the larvae development, then affect conservation. Our results therefore indicate that, for the sustainable management and conservation of these species in Lake Kivu, it is essential to mark out these spawning and nursery areas so that local residents can recognise them and refrain from carrying out any human activity there or in their immediate vicinity. Finally, the catchment areas of tributary rivers whose mouths have been identified as main spawning sites must be managed in such a way as to prevent the rivers from carrying pollutants and waste of various kinds likely to threaten the survival of larvae and young individuals in these sites.

5 | CONCLUSION

The aim of this article was to identify, characterise and locate fish spawning sites in Lake Kivu. After sampling and analysis, results from this study indicate that 11 spawning and 9 nursery sites were identified and located. Most were located in bays and at mouths of rivers. *Lamprichthys tanganicanus* reproduces on eight sites whatever its use by other species. Physico-chemical parameters were characterised for all sampled sites. Analyses indicated that temperature, dissolved oxygen, depth and transparency were different between sites. Those parameters characterise each of sites and then this would affect and influence fish distribution in Lake Kivu. Fish growth types were allometric at the spawning sites.

We recommend that the rational management of these sites attracts the full focus of everyone's attention for a better conservation of the fisheries resources of Lake Kivu. For scientists, a large-scale diet study of adult and larval fish at spawning sites to fully complement the true causes of site selection is necessary.

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CONFLICT OF INTEREST STATEMENT

All authors declare that there are no conflicts of interest and responsibility for this study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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