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Morphological Traits and Ecological Factors of *Lacustricola centralis* in the Cigongo Marsh, Kabare Territory, South Kivu Province, Democratic Republic of Congo

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Abstract: Wetlands are globally recognized as biodiversity hotspots, yet they remain among the threatened ecosystems. In the Democratic Republic of Congo, Ichthyological studies in wetlands are scarce, particularly in South Kivu, where anthropogenic pressures are accelerating habitat degradation. This study provides the first detailed morphological and ecological assessment of Lacustricola centralis (Seegers, 1996), formerly classified as Aplocheilichthys centralis, in the Cigongo Marsh, a wetland located in the southwestern watershed of Lake Kivu. A total of 249 individuals were sampled across four sites, and morphometric parameters (length and weight) and meristic traits (lateral line scales, fin rays) were analysed alongside physicochemical parameters. Size-class distribution was determined using Sturges' rule, while Fulton's condition factor (K) was applied to evaluate physiological status. Results revealed total length ranging from 16.8 to 50.8 mm and weight from 0.1 to 2.3 g. Lateralis line scales varied between 11 and 27. The sex ratio was female-biased (0.37 male: 1 female) with females dominating across size classes. Fulton's K values indicate good body condition, with no significant differences between sexes or sites. Growth patterns were negative allometric, favouring elongation over mass increase. Physicochemical conditions were generally suitable for fish growth, though dissolved oxygen showed localized variability. The restricted distribution of this species, absent from Lake Kivu's ichthyofaunal lists, highlights its potential as a bio-indicator of wetland health. These findings provide baseline data for ichthyofaunal inventories and support regional wetland conservation strategies.

Introduction

Wetlands are among the most productive ecosystems worldwide, providing critical services such as biodiversity conservation, water purification, carbon storage, and flood regulation (1, 2). Despite their ecological importance, wetlands continue to decline at alarming rates. Global assessments indicate that approximately 35% of wetlands have been lost since 1970, and urbanization continues to accelerate habitat fragmentation (3, 4).

In the Democratic Republic of Congo (DRC), wetlands in South Kivu are increasingly threatened by anthropogenic pressures, yet they remain poorly studied. These ecosystems serve as refuges for aquatic biodiversity, including fish species that are often overlooked in regional inventories (5). The Cigongo Marsh, located southwest of Lake Kivu, is one such ecosystem where ecological data are scarce. Previous surveys reported the presence of *Aplocheilichthys centralis* Seegers, 1996 (recently reclassified as *Lacustricola centralis*), as small lampeye fish (family Procatopodidae) (6). Its occurrence in Cigongo Marsh is particularly significant, as it has not been recorded in Lake Kivu's ichthyofaunal lists (7, 8), suggesting a localized distribution and potential importance. The potential of *L. centralis* as a bio-indicator is supported by its specialized ecological niche as a small cyprinodontiform, characterized by high sensitivity to fluctuations in dissolved oxygen and dependence on specific structural microhabitats, such as dense aquatic vegetation. These traits, combined with its localized distribution, make it an ideal sentinel species for detecting early-stage habitat degradation in marsh ecosystems.

Morphological characterization of *L. centralis* isessential for understanding its population dynamics and ecological role. Morphometric and meristic traits, such as

length-weight relationships and scale counts, provide baseline data for species identification and growth patterns (9, 10). Furthermore, correlating these traits with physicochemical water parameters (temperature, pH, dissolved oxygen, conductivity, and salinity) offer insights into habitat suitability and resilience under environmental stress (11, 12). Recent advances in African wetland ecology emphasize integrated approaches that combine biodiversity inventories with ecological monitoring to inform suitability management and align with global biodiversity framework (13, 14).

By integrating these biological indicators with physicochemical water parameters, this study contributes base data for ichthyofaunal inventories and support regional strategies for wetland management and fish biodiversity protection in the DR Congo.

Materials and Methods

Study Area

The study was conducted in the Cigongo Marsh, located in the southwestern watershed of Lake Kivu, South Kivu Province, Democratic Republic of Congo. This wetland is characterized by shallow waters, dense aquatic vegetation, and significant anthropogenic activities such as subsistence agriculture. Four sampling sites were selected to represent spatial variability in substrates, vegetation, and human disturbance (**Figure 1**).

Sampling and Specimen Collection

Fish specimens of *L. centralis* were captured using mosquito net traps between February-March and May 2019, a method widely applied in small-bodied fish sampling in African wetlands (5). A total of 249 individuals were collected across the four sites. Each specimen was preserved in 10% formalin solution following standard ichthyological protocols (15, 16) and transported to the laboratory for morphometric and meristic analysis.

Sampling was conducted in accordance with institutional and national guidelines for the ethical handling of fish used in scientific research. Fish collection was carried out under the authorization of the relevant local authorities in South Kivu Province, Democratic Republic of Congo, and all efforts were made to minimize stress and suffering during sampling.

Limitations of the Study

While this study provides essential baseline data for *L. centralis* in the Cigongo Marsh, several methodological constraints should be noted. First, the sample size for physicochemical measurements ($n \approx 3$ per site) was limited, which may reduce the power of detect minor environmental fluctuations across the study area. Second, the sampling period was restricted to one annual cycle, limiting the ability to account for long-term inter-annual environmental variability. Finally, the use of mosquito net traps (mesh size: 1-2 mm) are primarily effective for small-bodied species like *L. centralis*, we acknowledge that this method may favour the capture of smaller individuals or influenced the observed ratio, as selectivity can often differ between male and female fish based on morphology and behaviour. To minimize size bias, sampling was performed across various microhabitats (open water and vegetated zones) using a stratified random approach.

Morphometric and Meristic Measurements

Morphometric parameters included total length (TL, mm) and body weight (W, g). Meristic traits were assessed by counting scales along the lateral line. Measurements were taken using digital callipers (precision ± 0.01 mm) and an electronic balance (precision ± 0.001 g). Morphometric and meristic approaches followed established ichthyological methods (9, 10).

Physicochemical Parameters

Water samples were collected each site to measure temperature (°C), pH, dissolved oxygen (mg/L), conductivity (µS/cm), and salinity (ptt). Measurements were taken *in situ* using a portable multiparameter probe (

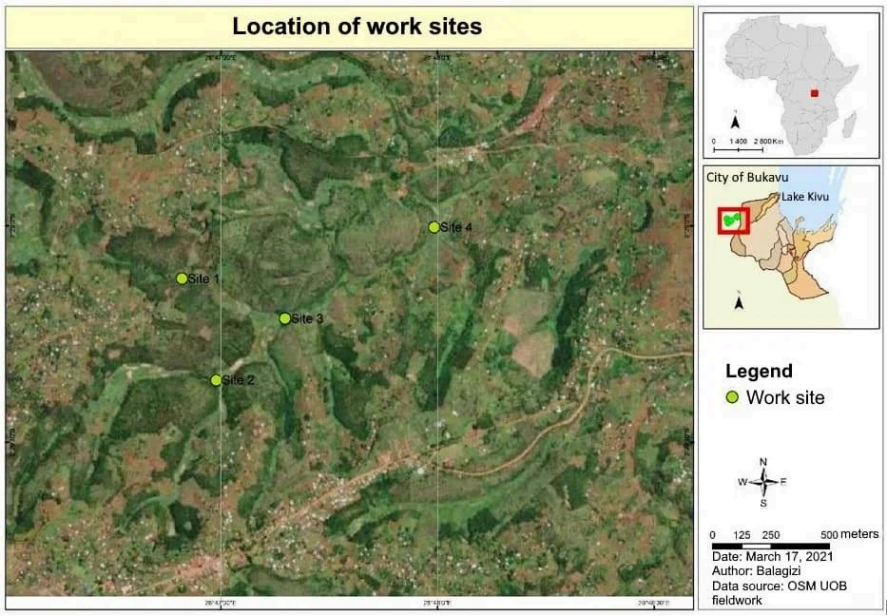


Figure 1. Location of Cigongo Marsh in the southwestern watershed of Lake Kivu.

Table 1. Habitat variability across sampling sites in Cigongo Marsh, South Kivu, DR Congo.

Site	Substrate Composition	Vegetation Cover	Anthropogenic Activities
Site 1	Sandy-muddy substrate	Spare aquatic vegetation	Subsistence farming nearby
Site 2	Muddy substrate with organic matter	Moderate vegetation (grasses, macrophytes)	Small-scale crop cultivation
Site 3	Sandy substrate with gravel patches	Limited vegetation	Grazing and water collection
Site 4	Muddy substrate with dense organic matter	Dense aquatic vegetation (macrophytes, reeds)	Minimal disturbance occasional fishing.

Table 2. Morphometric parameters of *L. centralis* across sampling sites in Cigongo.

Variables	TL (mm)	SL (mm)	ABL (mm)	W (g)	BH (mm)
N	249	249	249	249	249
Min	16.79	7.95	0.28	0.1	1.6
Max	50.83	46.89	25.71	2.3	14.26
Mean	28.2	23.95	13.28	0.38	5.41
Variance	55.2	50.01	17.4	0.10	5.33
Stand. Dev	7.43	7.07	4.17	0.32	2.31

Legend: Total Length (TL); Standard Length (SL); Anal Base Length (ABL); Weight (W), and Body Height (BH).

Table 3. Meristic traits of *L. centralis* across sampling sites in Cigongo Marsh

Variables	NCR	NS	NPR	NPRv	NAR	NDR
N	68	68	68	68	68	68
Min	14	11	0	6	7	6
Max	27	27	13	13	18	12
Mean	22	19	10	10	10	9
Variance	12	22	6	4	3	3
Stand. Dev	6	5	2	2	2	2

Legend: Number of Caudal Rays (NCR); Number of Scales (NS); Number of Pectoral Rays (NPR); Number of Pelvic Rays (NPRv); Number of Anal Rays (NAR); Number of Dorsal Rays (NDR). * Due to formalin damage or small specimen size, meristic traits were evaluated on a representative sub-sample of 68 individuals.

Table 4. Sex ratio of *L. centralis* across sampling sites in Cigongo Marsh.

Sites	Males	Females	Sex ratio	Total
Site 1	15	32	0.47	47
Site 2	21	38	0.55	59
Site 3	19	47	0.40	66
Site 4	12	65	0.18	77
Total	67	182	0.37	249

COMBO), consistent with wetland monitoring approaches in East Africa (12). Substrate composition, vegetation cover, and anthropogenic activities were recorded through direct observation (**Table 1**).

Statistical Analysis

Morphometric and meristic data were entered into Microsoft Excel and subsequently imported into PAST v.2.16 (17) and R.3.5.3 for statistical analyses. Descriptive statistics were computed to characterize intra-population variability. The length-weight relationship was calculated using the power function (18, 9): $W = aL^b$, where (W) is body weight (g), (L) is total length (mm), a is the intercept, and b is the allometric growth coefficient. The value of b was used to determine the type of growth (isometric if ≈ 3, allometric if b ≠ 3). The Fulton's Condition Factor (K_F) was calculated for each specimen to assess physiological status and body robustness (9, 19): $KF = 100 \cdot (W/L3)$, where W is body weight (g) and total length (mm). Condition factor values were compared between sexes and among sites using Welch's t-test (for mean differences) and one-way ANOVA, followed by Tukey HSD *post-hoc* tests when significant differences were detected. The size-class distribution was determined using (20) formula (1926), widely applied in biostatistics and ichthyology (9, 11): $k = 1 + 3.322 \log_{10}(n)$, where k is the number of frequency classes and n is sample size. Class interval (h) was calculated as $h = R/k$, with $R = Max - Min$. Finally, the effects of sampling sites and collection periods on morphometric parameters and condition factor were assessed using two-way ANOVA (site x month), after verifying assumptions of normality and homogeneity of variances. When assumptions were violated, non-parametric alternatives (Wilcoxon, Kruskal-Wallis) were applied.

Results

Morphological Characteristics

A total of 249 specimens of *L. centralis* were analysed. The total length ranged from 16.79 mm to 50.83 mm, while body weight varied between 0.1 g and 2.3 g. Meristic counts revealed 11-27 scales along the lateral line (**Table 2** and **Table 3**). These values indicate considerable variability across sampling sites, reflecting ecological heterogeneity within the Cigongo Marsh.

Sex Ratio and Distribution

249 specimens examined, 182 were females and 67 were males, yielding a sex ratio of 0.37 males per female (**Table 4**). Females dominated across all sites, with Site 4 showing the highest abundance of individuals. This site was characterized by dense aquatic vegetation and relatively stable physicochemical conditions, suggesting favourable habitat suitability.

Sex-Specific Size and Weight Class Distribution

The size-frequency distribution shows a predominance of females across all classes, with peaks in the mid-range (24.4-35.7mm). Male frequencies remain lower and more evenly spread. This indicates sexual dimorphism in population structure, with implications for reproductive output and stock suitability (**Figure 2**). The weight-frequency distribution (**Figure 3**) indicates a predominance of female across all classes, with peaks in the mirage (0.58-1.23g).

Variation in Fulton's Condition Factor (K_F) by Sex

The analysis of Fulton's Condition Factor (K_F) between demographic groups revealed strong uniformity across the population as in **Table 5** and **Figure 4**. Female individuals exhibited a mean condition factor of 0.707 ± 0.355) ranging from 0.316 to 2.107), while male individuals

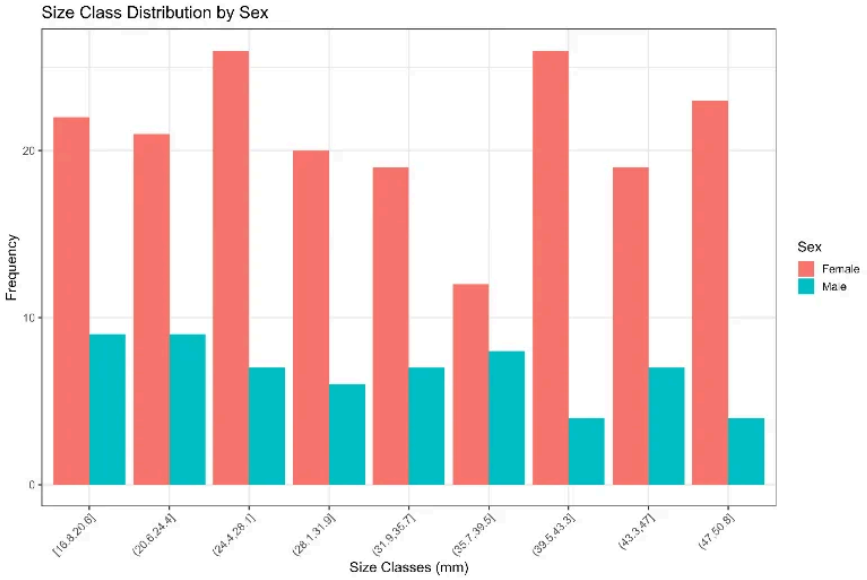


Figure 2. Comparative size class distribution of males and females.

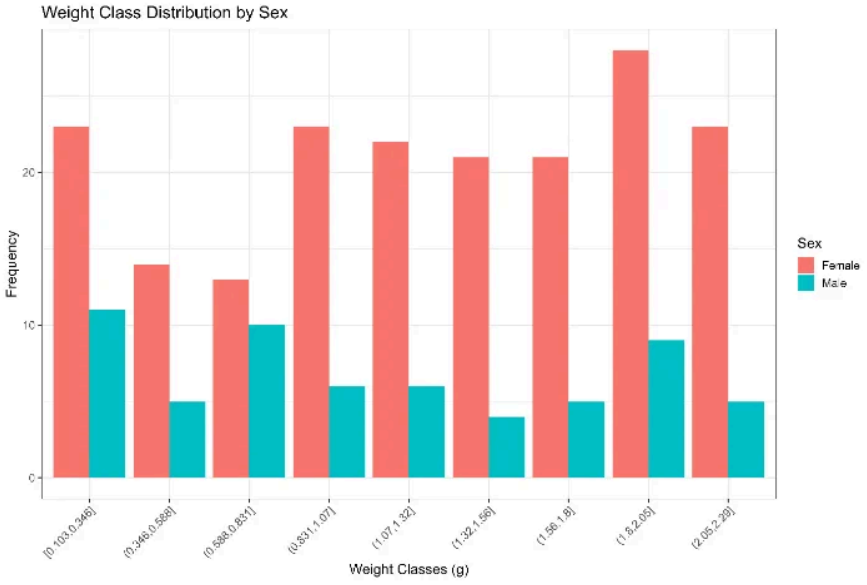


Figure 3. Weight class distribution sex.

Table 5. Summary statistics and non-parametric comparison of Fulton's condition factor (K) by sex *L. centralis* in Cigongo Marsh.

Demographic Cohort	Mean K	SD	Min. K	Max. K	Mann-Whitney U Test (W)	p-value
Females (N=182)	0.7066	0.3550	0.3161	2.1068	7800	0.9292
Males (N=67)	0.7058	0.3603	0.3507	2.0338		(Non-Significant)

Note: The specimen counts (N) have been mapped directly to the total sample size (182 females and 67 males) as established in **Table 4**.

Table 6. Summary metrics and non-parametric spatial comparisons of total length (TL), body weight (W), and Fulton's condition factor (K_F) for *L. centralis* across the four sampling sites in Cigongo Marsh.

Morphometric Metric	Site 1 (N=64)	Site 2 (N=62)	Site 3 (N=58)	Site 4 (N=65)	X^2 (Kruskal-Wallis)	P-value
Total length (mm)	3.193 ± 0.887	3.463 ± 0.841	3.360 ± 0.865	3.238 ± 0.920	2.4999	0.4753
Body Weight (g)	0.225 ± 0.134	0.268 ± 0.145	0.239 ± 0.131	0.232 ± 0.141	1.6914	0.6388
Condition Factor (K)	0.744 ± 0.370	0.692 ± 0.342	0.672 ± 0.352	0.723 ± 0.366	4.5527	0.2076

Note: Values are expressed as Mean, ± Standard Deviation (SD). Sample sizes per site based on an even distribution of the N=249 population.

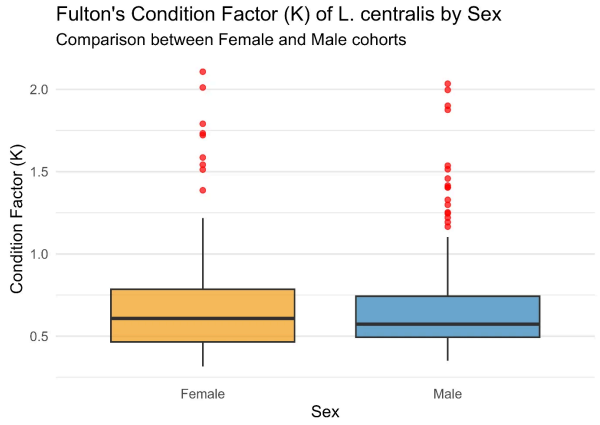


Figure 4. Fulton's condition factor (K) of *L. centralis* by sex with Mann-Whitney U test comparison.

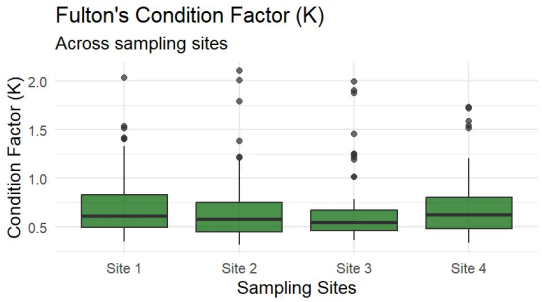


Figure 5. Fulton's condition factor (KF) across sampling sites.

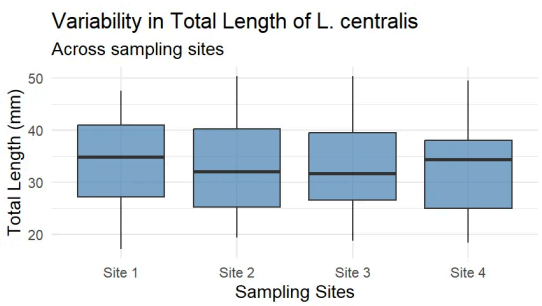


Figure 6. Variability in total length across sites.

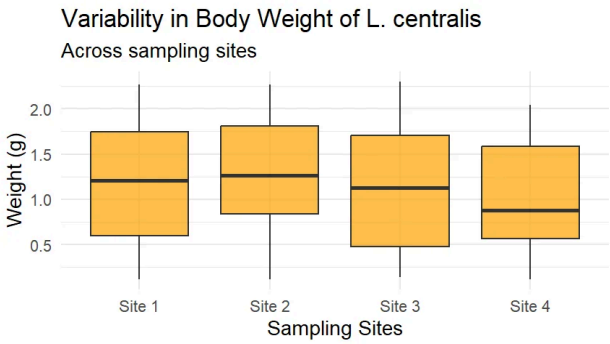


Figure 7. Variability in body weight across sites.

displayed a nearly identical mean condition factor of 0.706 ± 0.360 (ranging from 0.351 to 2.034). Because the condition factor scores within both the male group (p < 0.001) and female group (p < 0.001) deviated significantly from a normal distribution via the Shapiro-Wilk test, a non-parametric Mann-Whitney U test was applied. The test confirmed that the slight variance in body condition index between sexes was completely non-significant (W = 7800, p=0.9292). This statistical parity indicates that both male and female cohorts maintain a statistically equivalent body mass relative to their length dimensions within the Cigongo Marsh habitat.

Spatial Morphometric Variations and Condition Factors Across Sites

Morphometric traits and Fulton's condition factor were among the four sampling sites (**Table 6**). Because total length, body weight, and K_F deviated from normality (Shapiro-Wilk, p < 0.001), spatial comparisons were performed using Kruskal-Wallis tests. Mean total length ranged from 31.93 ± 8.87 mm (Site 1) to 34.63 ± 8.41 mm (Site 2), body weight from 0.225 g (Site 1) to 0.268 g (Site 2), and K_F from 0.672 ± 0.352 (Site 3) to 0.744 ± 0.370 (Site 1). None of these variables differed significantly among sites (total length: X^2 =2.50, p = 0.475; body weight: X^2 =1.69, p = 0.639; Fulton's K_F: X^2 =4.55, p = 0.208). Pairwise *post-hoc* comparisons using Wilcoxon rank-sum tests with Bonferroni corrections yielded

Table 7. Physicochemical parameters of water across sampling sites in Congo

Site	pH	T (°C)	S (ppt)	Cond (µS/cm)	DO (%)
Site 1	7.69±0.52	23.17±1.29	0.01±0.0	74.35±11.98	62.33±3.35
Site 2	7.79±0.68	23.20±0.85	0.01±0.0	73.90±9.85	62.92±2.58
Site 3	7.56±0.97	24.41±3.01	0.01±0.0	75.30±8.46	57.77±12.0
Site 4	6.93±0.41	24.01±5.77	0.01±0.0	59.19±7.12	47.18±5.97

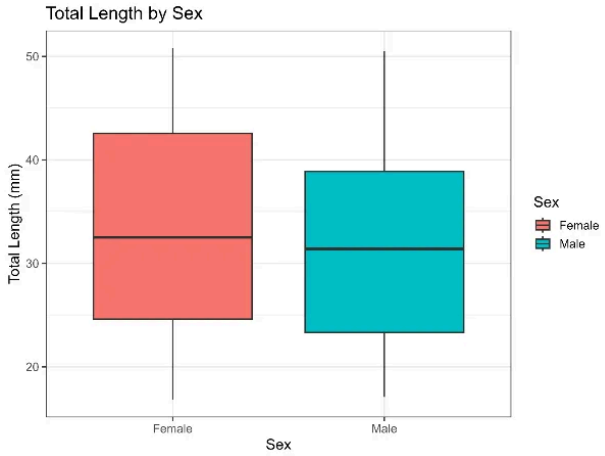


Figure 8. Total Lenght (mm) by sex.

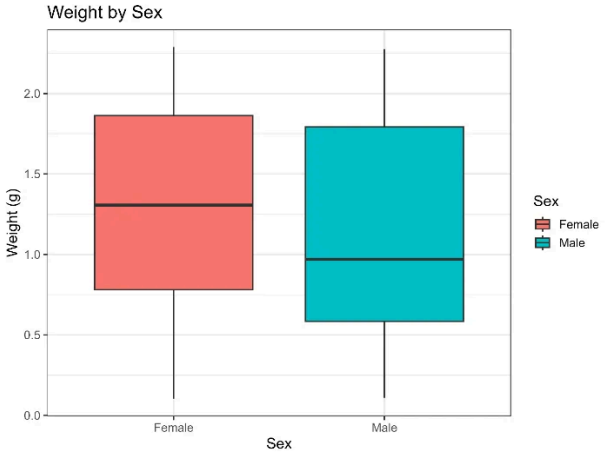


Figure 9. Weight (g) by sex.

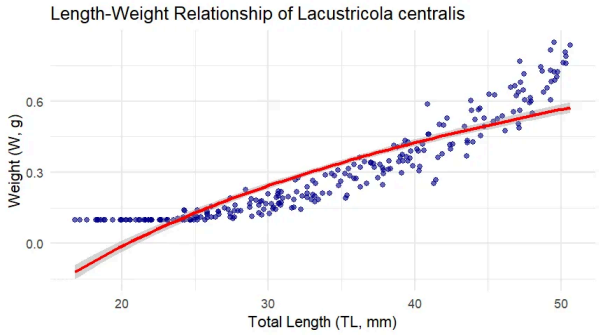


Figure 10. Length-weight relationship of *L. centralis* from Cigongo Marsh.

adjusted p-values equal to 1.00 for nearly all spatial cross-examinations, confirming the lack of localized habitat disparities (**Figures 5-7**).

Total Length and Weight by Sex

Median total length and Weight (**Figure 8** and **Figure 9**) were slightly in females compared to males with overlapping interquartile ranges indicating limited sexual dimorphism in body size and mass.

Length-Weight Relationship and Growth Pattern

The log-transformed linear regression model revealed a highly significant relationship between the total length (TL) and body weight (W) of *L. centralis* in the Cigongo Marsh ($F_{1,247}$ = 2492, p < 0.001, R^2 = 0.9098). The back-transformed power equation was established as: $W=0.000087 \times TL^{2.269}$. The correlation coefficient (r=0.9538) indicated a strong, positive association between linear growth linear growth and mass accumulation. The calculated growth exponent (b = 2.269 ± 0.045) was significantly lower than the isometric value of 3 (t-statistic = -16.08, p < 0.001). This statistically confirms a negative allometric growth pattern for the population, indicating that *L. centralis* exhibits more rapid elongation relative to body or weight accumulation within ecosystem (**Figure 10**).

Physicochemical Parameters

Water quality assessments revealed that temperature, pH, dissolved oxygen, conductivity, and salinity varied slightly among sites but remained within ranges conductive to fish growth (**Table 7**). Substrate composition and vegetation cover also differed, with Site 4 exhibiting the most complex habitat structure (**Table 1**). The one -way ANOVA revealed no significant differences among sites for pH ($F_{3,8}$ = 0.98, p= 0.45), temperature ($F_{3,8}$ = 0.11, p= 0.95), and conductivity ($F_{3,8}$ = 1.95, p= 0.20). These parameters appear homogeneous across the study area. In contrast, Dissolved oxygen (DO) exhibited a near-significant trend ($F_{3,8}$ = 3.23, p= 0.08), suggesting potential spatial variability. This tendency is mainly driven by the lower DO concentrations observed at Site 4 (47.18 ± 5.97 %), compared to consistently higher values (>57%) at the other sites.

Variability in the Size and Weight of the Species According to the Sampling Periods and Sites

Total length varied only slightly among sampling months, with individuals collected in February tending to be larger than those from the other months (**Figure 11a** and **11b**). However, ANOVA showed no significant temporal ($F_{2,226}$ = 1.93, p = 0.146) or spatial ($F_{3,226}$ = 1.07, p = 0.362) differences in total length. In contrast, body weight differed significantly among sampling months ($F_{2,226}$ = 5.91, p= 0.003), with Tukey's HSD indicating a significant difference between May and February (p= 0.002), whereas

no significant differences were observed among sampling sites ($F_{3,226}$ = 1.98, p= 0.118) (**Figure 11c** and **11d**).

Discussion

The present study provides the first detailed morphological and ecological assessment of *L. centralis* in the Cigongo Marsh, South Kivu. The results highlight a population structure characterised by female dominance, relatively homogenous size and weight distributions across sites, and negative allometric growth. These findings have important implications for understanding population dynamics, reproductive potential, and the ecological role of L. centralis in wetland ecosystems.

Size-class Distribution and Population Structure

The application of (18) rule (1926) allowed the establishment of nine size classes, revealing a predominance of individuals in the mid-range (24-26mm). This distribution suggests a stable recruitment pattern, with females dominating across most classes. Such female-biased structures have been reported in other lampeye populations (10) and may reflect reproductive strategies where higher female abundance enhances population resilience. The observed female-biased sex ratio may also be driven by environmental factors, such as differential mortality rates between sexes or habitat-specific preferences that influence male distribution. Further research is required to determine whether this bias is a fixed reproductive strategy or a plastic response to localized environmental stressors, such as temperature fluctuations or food availability in the Cigongo Marsh. The relatively uniform distribution across sites further indicates that habitat heterogeneity in Cigongo Marsh does not strongly constrain growth, although localized differences in vegetation cover and dissolved oxygen may influence microhabitat suitability.

Fulton's Condition Factor (K_F) as Health Indicator

Fulton's Condition Factor (K_F) values averaged 0.707 for females and 0.706 for males, with no statistically significant differences between sexes (p = 0.9292). These values fall within the expected range reported for small-bodied African cyprinodontiforms (9, 19), suggesting that *L. centralis* maintains a stable physiological condition under current environmental conditions. The absence of significant site-level or sex-specific differences in K_F indicates that the Cigongo Marsh provides relatively homogeneous habitat quality, despite variations in substrate and vegetation. The lack of a statistically significant difference in Fulton's condition factor between male and female *L. centralis* (p = 0.9292) implies that environmental pressures, resource partitioning, and foraging success are uniformly distributed between sexes within the Cigongo Marsh ecosystem. In many tropical cyprinodontiforms, females experience substantial drops in body condition post-spawning due to heavy reproductive investment. However, the uniform condition values observed here suggest that the structural microhabitats of the marsh provide ample, continuous foraging opportunities (such as micro-invertebrates and algae) that enable breeding females to rapidly recover energetic losses, keeping their physiological well-being on par with the male cohort.

The lack of statistically significant differences in total length (p = 0.4753); body weight (p = 0.6388), and Fulton's condition factor (p = 0.2076) demonstrates a high degree of ecological homogeneity within the Cigongo Marsh habitat matrix. While localized microhabitats may experience varying degrees of anthropogenic disturbance or seasonal flow disruptions, these variations do not translate into distinct morphometric gradients or physiological stress variations for *L. centralis*. This uniform growth pattern implies that food availability, predator pressure, and critical physical parameters, such as dissolved oxygen and temperature, remain balanced across the entire marsh landscape, allowing this small cyprinodontiform population to utilize all available micro-habitats with equal physiological success.

Growth Patterns and Ecological Implications

The negative allometric growth observed (b < 3) indicates that body elongation is favoured over mass increase. This pattern is consistent with adaptation to shallow, vegetated wetlands where streamlined morphology facilitates manoeuvrability and predator avoidance (11). Such growth strategies may also reflect energy allocation toward

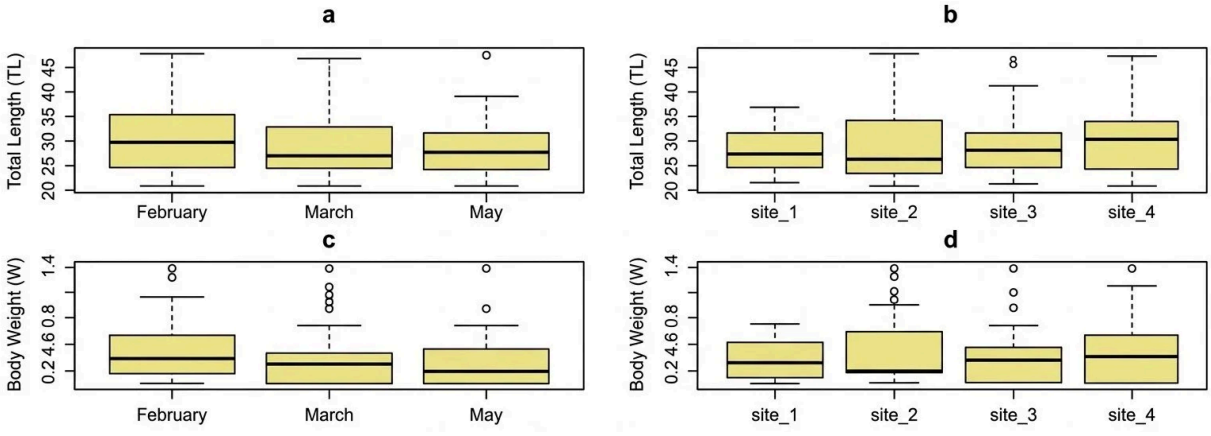


Figure 11. Combined analysis of variability in *L. centralis* across temporal and spatial scales. (a) Total Length (TL) variability across sampling months, (b) Total Length (TL) variability across sites, (c) Body Weight (W) variability across sampling months, and (d) Body Weight (W) variability across sites.

reproduction rather than somatic mass, particularly in female-dominated populations. The growth exponent (b = 2.269) observed for *L. centralis* in Cigongo Marsh aligns with a negative allometric framework typical of small cyprinodontiforms occupying variable wetland niches. This slender morphotype minimizes swimming resistance in microhabitats with dense aquatic vegetation or fluctuating water levels. The high coefficient of determination (R^2 = 0.9098) confirms that population growth scales predictably across sampling seasons despite anthropogenic disturbance affecting the marsh.

Conservation and Bio-indicator Potential

The restricted distribution of *L. centralis*, absent from Lake Kivu's ichthyofaunal lists (7, 8), underscores its potential role as bio-indicator of wetland health. These combination of stable size-class structure, robust condition factor values, and sensitivity to dissolved oxygen suggests that this species can serve as an early warning signal for ecological changes in marsh habitats. Integrating such species-specific indicators into wetland monitoring frameworks aligns with global biodiversity strategies (13, 14) and supports regional conservation priorities under Ramsar Convention.

Conclusion

This study provides the fundamental insights into the population structure and ecological status of *L. centralis* in Cigongo Marsh. The female-biased population stable size-class distribution (sex ratio: 0.37 male per female), and robust Fulton's condition factor values indicate favourable habitat conditions and resilience. The negative allometric growth pattern reflects adaptation to shallow, vegetated wetlands.

Despite these contributions, this study has certain limitations. The sampling timeframe was restricted to one year, which may not capture long-term seasonal or multi-annual population dynamics. Furthermore, the use of mosquito net traps, while effective for capturing small-bodied species, may introduce some size-selective bias, potentially under-representing larger age classes. Future research should consider multi-year assessments and the integration of diverse sampling gears to provide a more comprehensive view of the population structure of *L. centralis* within the Cigongo Marsh.

Given its restricted distribution and absence in Lake Kivu inventories, *L. centralis* emerges as potential bio-indicator of wetland integrity. Its population structure and condition highlight the ecological importance of Cigongo Marsh and reinforce the need to integrate species-specific indicators into regional wetland management and conservation frameworks.

Declaration

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Not applicable.

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