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Morphometry of a Freshwater Shrimp *Macrobrachium sollaudii* (De Man, 1912), Collected in the Kinombe and Maseko Rivers of the Babagulu Forest Reserve (Tshopo, Democratic Republic of the Congo)

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Abstract

This study describes the morphometric characteristics of *Macrobrachium sollaudii* (De Man, 1912) collected from two rainforest rivers (Maseko and Kinombe) in the Babagulu Forest Reserve over a three-month period. A total of 146 specimens were measured for standard body lengths and total weight. Data were analysed using ANOVA, multivariate dispersion, and multiple linear regression. Results showed that males from Maseko River were significantly larger than those from the Konombe River, while sex had no significant effect on any morphometric parameter; most variables were strongly intercorrelated. The study provides the first detailed biometric baseline for this poorly studied species; however, additional methodological and statistical details are needed for full reproducibility and robustness of interpretation.

Subject Areas

Environmental Sciences

Keywords

Freshwater Crustacea, Biometric, Kisangani, Tropical Forest

1. Introduction

Shrimps are organisms belonging to the arthropod phylum, with their bodies covered by a chitin-protein exoskeleton called the exocuticle, often impregnated with calcium carbonate [1] [2]. Globally, shrimp are classified into more than 20 different families, with over 2000 described species, the majority of which are predominantly found in marine environments [3]. The aquatic ecosystems of the Democratic Republic of Congo (DRC), particularly those surrounding Kisangani are recognised for their remarkable biodiversity. Previous surveys have recorded more than 1,200 freshwater fish species and over 60 species of decapod crustaceans, including representatives from Palaemonidae and Atyidae families. These river systems demonstrate species richness exceeding 100 species per sub-basin, indicating their ecological productivity and structural complexity. These two freshwater families are frequently cultivated in controlled breeding ponds for aquaculture purposes [2]. This limited exploitation rate could be attributed to the scarcity of scientific research conducted on the majority of *Macrobrachium* species [4]. Fishing activities targeting various commercially important decapod crustaceans [2], are commonly practised in numerous tropical lakes and rivers, including the Amazon [5], Oueme [6], Niger [7], and Lake Tumba [8]. These species are harvested for human consumption and occupy a prominent position in scientific research due to their considerable economic significance [9] [10]. The *Macrobrachium sollaudii* faces considerable pressure from human activities [11] [12]. Many studies have identified five key threats to freshwater biodiversity: overexploitation, pollution, alteration of flow regimes, habitat destruction and degradation, and the introduction of non-native species [13]. These factors, both individually and in combination, contribute to declining water quality and the loss of certain aquatic species [13] [14]. A recent study by [15] highlighted the difficulties in identifying freshwater shrimp species, such as *M. sollaudii*, due to the existence of cryptic species. The research revealed that traditional morphological identification methods could lead to misidentifications, as several species share similar physical characteristics. For example, *M. sollaudii* was found to be genetically similar to *M. dux*, suggesting that it may belong to the same species. This indicates that the classification of cryptic species arises from the presence of forms that are difficult to distinguish morphologically. Given these similarities, existing information on morphometric comparisons remains unclear or insufficient for reliable species identification [16] [17]. Morphometry is widely recognised as a useful method for resolving species identification challenges in shrimp. For instance, [18] showed that both traditional and truss-based morphometric analyses can accurately distinguish between male and female *Penaeus monodon*, achieving classification success close to 95%. In this study, we examine morphometric characteristics of *M. sollaudii* that are essential for precise species identification and for understanding its growth patterns and life story.

2. Materials and Methods

2.1. Study Area

The Babagulu Forest Reserve is located approximately 50 km northeast of Kisangani, within Tshopo province in the Democratic Republic of Congo. It covers an area of 1,693.42 hectares [19]. The reserve is geographically positioned between 25˚35' and 25˚37' East longitude, and between 0˚26' and 0˚47' North latitude. It is bisected by National Road No. 4, which divides the reserve into two distinct sections (Figure 1).

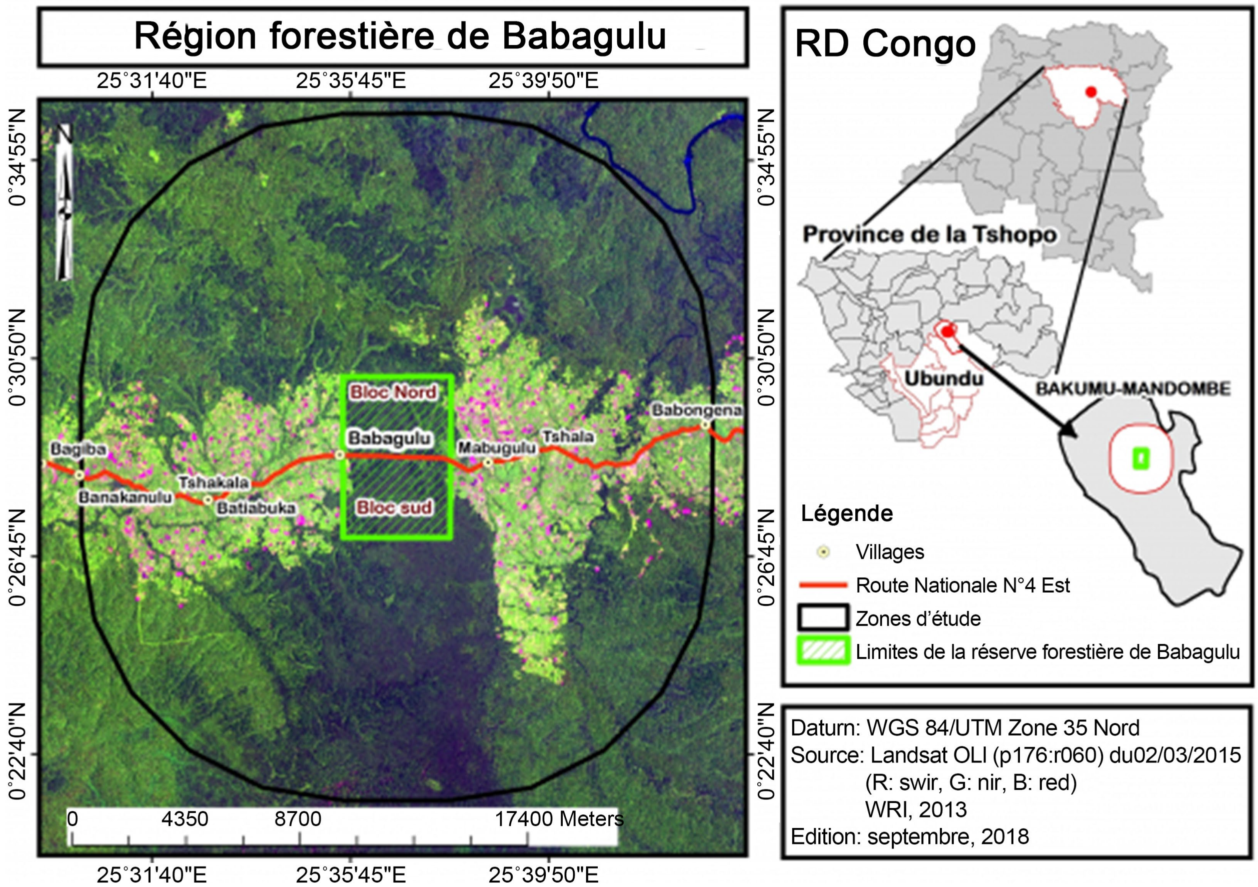


Figure 1. Location of the Babagulu Forest Reserve. Legend = Babagulu Forest Region (Région forestière de Bagulu), DR Congo (RD Congo), Tshopo Province (Province de la Tshopo), National Road No. 4 East (Route Nationale N˚4 Est), Study Area (zone d'étude), Boundary of the Babagulu Forest Reserve (Limite de la reserve forestière de Bangulu), Northern Block and Southern Block (Bloc du Nord et Sud). (Source: QGIS software (version 3.12))

The climate of this reserve is classified as equatorial Af according to Köppen's classification [20] [21]. This is characterised by hot and humid conditions with dry seasons that are scarcely discernible. The region is subject to substantial rainfall and temperature variability, receiving between 1500 and 2000 mm of annual precipitation, with an average of approximately 1750 mm. The temperatures fluctuate between 20˚C and 30˚C, maintaining a mean annual temperature of around 25˚C [20] [21]. The vegetation of this reserve is predominantly composed of monodominant primary forest, chiefly characterised by the presence of *Gilbertiodendron dewevrei* (De Wild.), (Fabaceae) [22]. In addition to this dominant forest type, the reserve encompasses a mosaic ecological zone, including fallow land, young and mature secondary forests, as well as mixed primary forest formations [23]. The hydrographic network of the Babagulu Forest Reserve comprises approximately ten watercourses. In the northern sector, the principal streams include Minamba, Makombo, Mangoingoi, and Bombe. The southern sector is traversed by Madje, Maseko, and Kinombe streams (**Figure 2**). Other notable watercourses within the reserve include Makala, Mafwaga, Mboa (also referred to as Pembe), Ngayani, and Kokondodja.

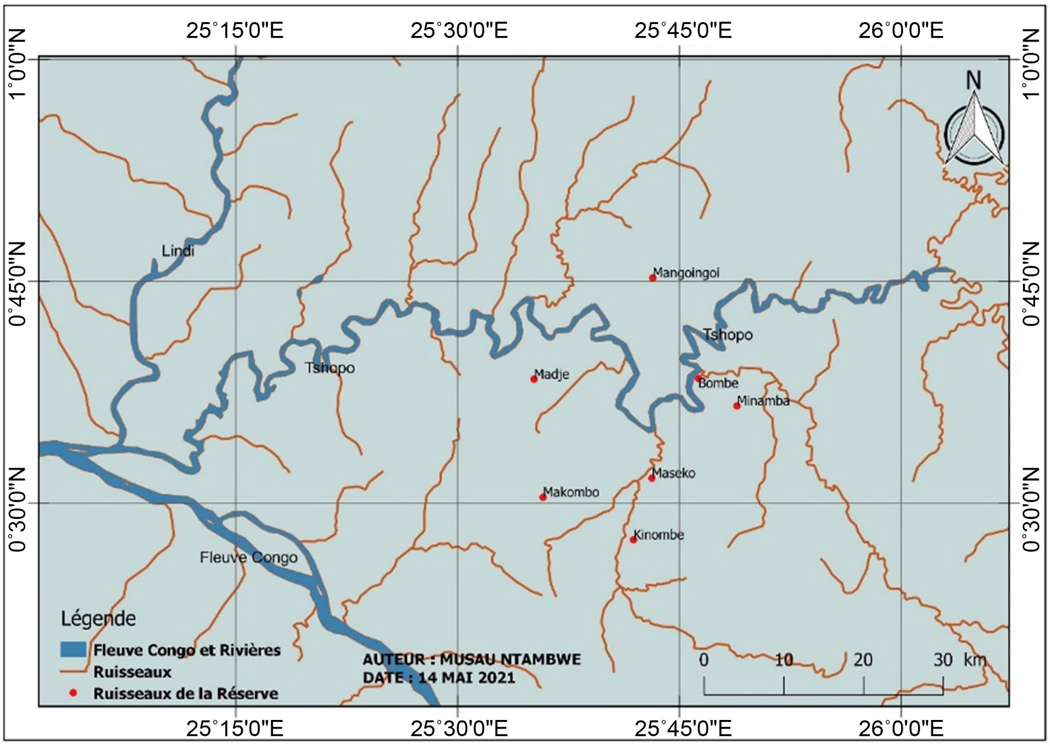


Figure 2. Location of the main watercourses in the Babagulu Forest Reserve. Legend = Congo River and tributaries (Fleuve Congo et rivières), Streams (Ruisseaux), Streams within the reserve (Ruisseaux de la Réserve). (Source: QGIS software (version 3.12))

Shrimp specimens were collected from the Kinombe and Maseko rivers. These sites are described below.

2.1.1. Kinombe

Kinombe is located in the southern sector of the Bagulu Forest Reserve, positioned at 00˚27.032' North latitude and 025˚35.414' East longitude, at an elevation of 465

m. Due to its relative isolation, the site experiences minimal anthropogenic disturbance. To facilitate, four sampling stations were established two upstream and two downstream of the main access routes to the watercourse, each spaced 50 m. Vegetation cover in the area is estimated at 80%, while the riverbed is characterised by accumulations of branches and deadwood, assorted plant debris. Substrate composition varies across sample points and includes pebbles, silt, sand, gravel, and stones. The riverbanks are predominantly clay-based and support riparian vegetation. Average depth: 0.6 m, Average riverbed width: 7.4 m; Average dissolved oxygen: 5.68 mg/l; Average pH: 7.81; Average electrical conductivity: 49.31 μS/cm; Average water temperature: 23.30˚C; Average velocity: 0.29 m/s and the water is clear.

2.1.2. Maseko

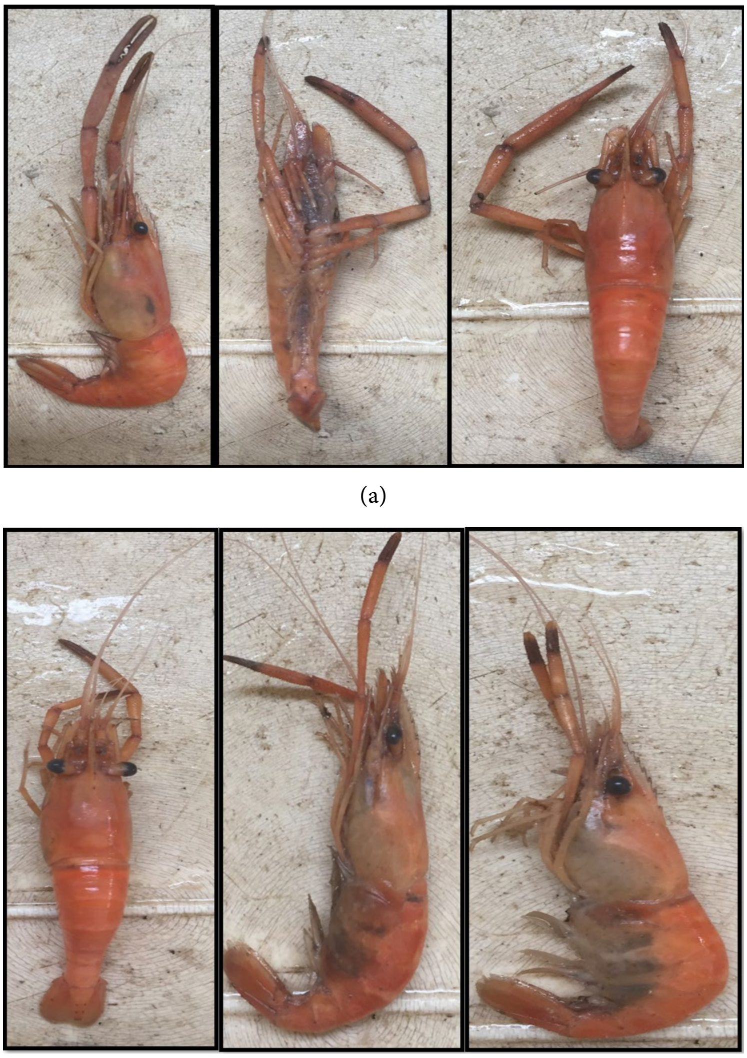
This watercourse is situated within the southern sector of the Babagulu Forest Reserve, positioned at 00˚27.282' North latitude and 025˚35.489' East longitude, at an elevation of 453 m. It lies in a densely forested area that remains undisturbed by agricultural practices or logging. Four sampling stations were established two upstream and two downstream of the primary access routes to the watercourse, with each station spaced 50 m. The vegetation cover is notably dense, estimated at approximately 85%, and the riverbed contains a substantial accumulation of deadwood, branches, and plant debris. The substrate predominantly consists of silt and mud, although patches of sand and gravel are also present. The banks are generally composed of clay and are lined with riparian vegetation. Hydrological and physicochemical parameters recorded at the site include Average depth: 0.4 m; Average riverbed width: 5.2 m; Average dissolved oxygen: 5.31 mg/l; Average pH: 7.43; Average electrical conductivity: 32.33 μS/cm; Average water temperature: 23.36˚C; Average velocity: 0.26 m/s. The water is generally clear, though it exhibits a slight turbidity due to suspended fine sediments.

2.2. Methods

Specimens of *M. sollaudii* were collected from the Kinombe and Maseko rivers over a three-month period, spanning August to October 2021. Sampling was carried out once each month, and at each sampling station, three distinct fishing techniques were employed: Funnel trap fishing, hand net fishing (targeting turbid trickles) and manual scooping was performed using a 5-litre basin to capture shrimp specimens.

Prior to fishing activities or the employment of nets, a range of environmental parameters was recorded at each sampling station. Geographical coordinates (latitude, longitude, and altitude) were obtained using a GARMIN GPS device (GPSmap 62stc. Physicochemical measurements including water temperature, pH, electrical conductivity, and dissolved oxygen concentration were taken using a HACH multiparameter instrument. Additional site-specific recorded following: Riverbed width measured using a 50-metre measuring tape; Water depth determined using a measuring stick and tape; Substrate composition: comprised of sand, gravel, silt, deadwood, and herbaceous vegetation; Bank characteristics: predominantly Clay-based with riparian vegetation and Canopy cover (shading): assessed through direct visual observation.

Figure 3 below illustrates the sexes of *M. sollaudii*.



(a)

(b)

Figure 3. Males (a) and females (b) shrimp.

At each sampling station, specimens were placed into jars and grouped according to their size and morphological characteristics for subsequent identification. Taxonomic identification was conducted using established keys and reference materials, including those by [24]-[26].

Morphometric measurements were performed on 146 *Macrobrachium sollaudii* specimens using a precision calliper. The parameters recorded: Carapace Length (CL); Abdominal Length (AL); Rostrum Length (RL); Segment Length (SL); Total Length (TL) and Uropod Length (UL). In addition, the total weight (TW) of each specimen was measured using a calibrated balance Sartorius Universalis mark. All samples were preserved in jars containing 70% alcohol and appropriately labelled with the corresponding collection station and date of capture.

2.3. Data Analysis

Measurement data were processed using Microsoft Excel (Windows version 2016), where values were summarised as means and standard deviations. To further analyse the data, the vegan package in R. (Core Team R) was employed to calculate multivariate dispersion (variance) and distance to the centroid. Prior to performing ANOVA and regression analyses, dataset was evaluated to ensure compliance with the requisite statistical assumptions. Residual normality was assessed using the Shapiro-Wilk test, and Levene's test was employed to examine the homogeneity of variance (homoscedasticity) across groups. This analysis enabled the assessment of whether the measured variables within a given group differed significantly from those in other groups, and relative distance of each group from the centroid, representing the point of convergence. Subsequently, a multiple linear regression analysis was conducted in R to determine the extent to which each morphometric parameter influenced the others.

3. Resultats

3.1. Number of Specimens per River

A total of 146 *M. sollaudii* specimens were collected during the study, comprising 93 females and 53 males. As shown in Table 1, species abundance was markedly higher in Kinombe River, where 62.3% of the specimens were female and 27.3% male. In contrast, the Maseko River accounted for only 1.3% females and 8.9% males indicating a significantly lower population density in that locality.

Table 1. Number of specimens per river.

Sites	Sex	N	%
Maseko	M	13	8.9
	F	2	1.3
Kinombe	M	40	27.3
	F	91	62.3
Total		146	99.8

3.2. Measurements

Table 2 clearly indicates that male specimens collected from the Maseko River exhibited the highest average total length (54.45 ± 13.82 mm), whereas those from the Kinombe River recorded the lowest average total length (35.6 ± 9.51 mm). This pattern was consistent across all measured morphometric parameters, with males from the Maseko River consistently displaying higher values, in contrast to their counterparts from the Kinombe River, which showed comparatively lower measurements.

Table 2. Measurements of *M. sollaudii* specimens, considering sex.

Sites	Sex	N	AL (mm)	CL (mm)	RL (mm)	SL (mm)	TL (mm)	UL (mm)	TW (g)
Maseko	M	13	23.81 ± 5.18	15.25 ± 5.05	10.25 ± 2.36	38.36 ± 9.66	54.45 ± 13.82	47.25 ± 12.9	3.17 ± 2.6
	F	2	24.08 ± 0.5	13.84 ± 0.28	9.63 ± 0.09	37.19 ± 1.3	53.07 ± 1.4	48.43 ± 0.6	2 ± 0.36
Kinombe	M	40	15.8 ± 3.9	9.57 ± 3.5	6.33 ± 1.7	25.5 ± 7.23	35.6 ± 9.51	30.4 ± 8.85	0.78 ± 1.59
	F	91	22.8 ± 3.8	13.5 ± 2.9	9 ± 1.6	36.3 ± 6.2	51.14 ± 8.54	45.14 ± 7.8	2.24 ± 1.3

*AL: Abdominal Length, CL: Carapace Length, RL: Rostrum Length, SL: Segment Length, TL: Total Length, UL: Uropod Length, TW: Total Weight.

3.2. Comparative Morphometry

Figure 4 illustrates the degree of similarity and divergence in the morphometric parameters of *M. sollaudii* specimens collected from the Maseko and Kinombe rivers. While individuals from sires exhibit comparable morphometric traits, they differ markedly in terms of overall variance and group centroid positioning. Specimens from Masako River display greater uniformity, while those from Kinombe River show a broader range of variation. These findings suggest that environmental or ecological conditions may influence the morphometric expression of populations, even within the same species.

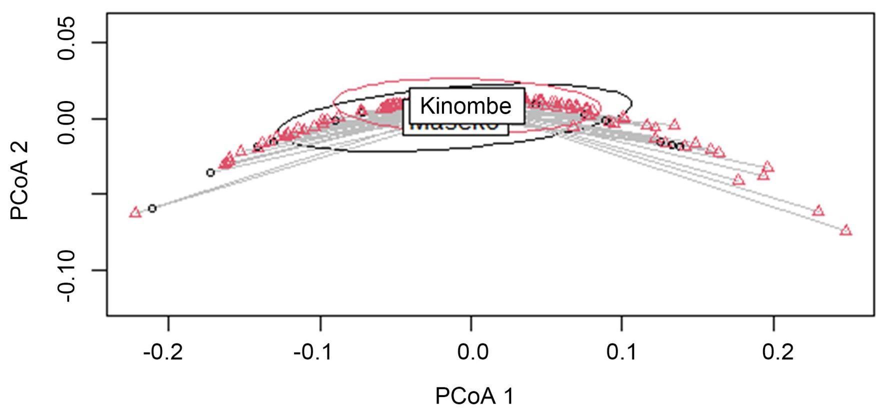


Figure 4. Multivariate Dispersion (Variance): Resemblance among group members. * Maseko in black and Kinombe in red.

It is noted that all morphological parameters showed a minor variation in the pairwise comparisons. The p-value presented below the diagonal, alongside the permuted p-value above the diagonal, indicates differences that were not statistically significant (Table 3).

Table 3. Pairwise comparisons.

	Maseko	Kinombe
Maseko		0.04
Kinombe	0.048	

Analysis of variance ANOVA was applied to assess whether the dispersions (variances) between the two groups (Maseko and Kinombe) differ significantly. The results showed a clear difference in group dispersion (Figure 5 and Table 4). Figure 5 further illustrates that the distance to the centroid between the two groups is substantial, which accounts for the observed variation in morphometric measurements among individuals from the Maseko and Kinombe rivers. This distinction is statistically supported by the p-value presented in Table 4.

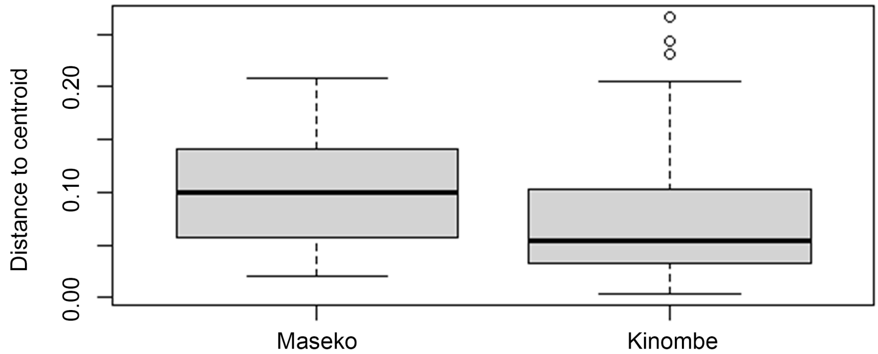


Figure 5. Variance between groups (distance to centroid).

The distance between the centroids, representing the average position of each group within morphometric space, indicates a marked distinction between the two populations. This interpretation is supported by the results of the ANOVA (Table 4), which shows a statistically significant difference between groups (**p = 0.02**).

Table 4. Analysis of variance applied to the two groups.

	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Groups	1	0.014	0.014	4.8	0.02*
Residuals	144	0.43	0.003		

Signif. codes: '' 0.05.

The multiple linear regression analysis revealed that sex had no significant influence on any of the morphometric parameters. However, each parameter exhibited a strong correlation with other length and weight-related variables (Table 5).

Table 5. Multiple linear regression analysis.

Parameter1	Parameter 2	P
AL	CL	<0.001***
AL	SL	<0.001***
AL	TL	<0.001***
AL	UL	<0.001***
AL	TW	<0.001***

Continued

AL	**Sex**	**>0.999**
CL	SL	<0.001***
CL	TL	<0.001***
CL	UL	<0.001***
CL	TW	<0.001***
CL	Sex	0.974
SL	TL	<0.001***
SL	UL	<0.001***
SL	TW	<0.001***
SL	Sex	>0.999
TL	UL	<0.001***
TL	TW	<0.001***
TL	Sex	>0.999
UL	TW	<0.001***
UL	Sex	>0.999

*Signif. codes: '***' 0.001.

Supplementary Table 6 provides the complete results of the multiple linear regression analyses, detailing the regression coefficients, standard errors, coefficients of determination (R^2), and adjusted R^2 values for each model. The findings confirm that sex does not exert a statistically significant effect on any of the morphometric parameters of *M. sollaudii*. In contrast, robust linear associations were observed between the length and weight variables.

Table 6. Full multiple regression outputs.

Parameter1	Parameter 2	Coefficient (β)	Std. Error	t-value	P-value	R^2	Adjusted R^2
AL	CL	0.85	0.07	12.02	<0.001	0.82	0.81
AL	SL	0.78	0.06	13.02	<0.001	0.84	0.83
AL	TL	0.92	0.05	17.44	<0.001	0.89	0.88
AL	UL	0.88	0.05	16.21	<0.001	0.87	0.86
AL	TW	0.79	0.08	9.78	<0.001	0.77	0.76
AL	Sex	0.02	0.04	0.45	>0.999	0.01	−0.01
CL	Sex	0.01	0.05	0.28	>0.974	0.00	−0.01
SL	Sex	−0.03	0.06	−0.50	>0.999	0.00	−0.01
TL	Sex	0.02	0.06	0.33	>0.999	0.00	−0.01
UL	Sex	−0.01	0.05	−0.22	>0.999	0.00	−0.01

4. Discussions

Overall, the number of male specimens was significantly lower than that of females, with 53 males recorded compared to 93 females. This phenomenon is likely attributable to the timing of sampling and the selection of collection sites. Specimens were obtained from river confluences during the rainy season, a period when female *M. sollaudii* typically migrate towards estuaries to release their larvae, which require warmer waters for optimal developmental [27].

Morphometric data from the Maseko River (**Table 1**) indicate that males exhibited Carapace length, Total length and Total weight of 15.25 ± 5.05 mm, 54.45 ± 13.82 mm and 3.17 ± 2.6 g, respectively. In contrast, females from the same site measured 13.84 ± 0.28 mm in Carapace length, 53.07 ± 1.4 mm in Total length, and 2 ± 0.36 g in Total weight. In Kinome River, male specimens presented a Carapace length of 9.57 ± 3.5 mm, a total length of 35.6 ± 9.51 mm, and a weight of 0.78 ± 1.59 g. Female specimens from the location were notably larger, with Carapace lengths of 13.5 ± 2.9 mm, Total length of 51.14 ± 8.54 mm, and weight of 2.24 ± 1.3 g. Variations observed may be attributed to genetic factors as well as environmental conditions, including food availability, temperature, and ecological parameters. Their findings align closely with the study of [17], which examined the morphometric characteristics of *Atya gabonensis* and *Atya scabra*, in the Paraíba do Sul River, Brazil. The study emphasised that body weight and length are critical indicators of a species' survival status, serving as a foundation for estimating growth and productivity, and for characterising the structural attributes of individuals in populations. In this context, our results suggest that, despite the potential human activities pressures, the *M. sollaudii* populations inhabiting the Kinombe and Maseko rivers in Babagulu Forest Reserve exhibit comparable potential to other populations across Africa, showing the importance of preserving the integrity and natural state of reserve, as meaning of safeguarding biodiversity, particularly among freshwater shrimp species.

The multiple linear regression analysis (**Table 5**) revealed no significant influence of sex on the morphometric parameters of *M. sollaudii*, including Abdominal Length (AL), Carapace Length (CL), second Segment Length (SL), Total Length (TL), and Uropod Length (UL). However, certain morphometric traits exhibited intercorrelations. These findings are consistent with the observations of [4], who reported that the absence of laterality and the presence of an isochely pattern may be associated with the size of specific parameters, such as Carapace Length (CL), in the individual specimens.

The results of this study indicate a high degree of similarity between male and female *M. sollaudii*, with sexual dimorphism appearing to be relatively weak across the majority of morphometric traits analysed. Comparable findings were observed by [28] in their study of *M. macrobrachium* from the Niger Delta. This observation is consistent with broader trends within the genus Macrobrachium, where sexual dimorphism is generally subtle in morphometric assessments. Nonetheless, certain species within this genus such as *M. brasiliense* [29] and *M. felicinum* [28] have demonstrated a tendency for males to exhibit higher average biometric values than females. In the present study, only slight variations in morphometric parameters were observed through pairwise comparisons. The p-value presented below the diagonal, alongside the permuted p-values above the diagonal, indicates no statistically significant differences (see **Table 3**). Considering the sampling locations and prevailing environmental conditions, these results are in agreement with those of [30], who investigated the biomorphology of *M. vollenhovenii* in Ivorian rivers. Their study similarly found no significant difference between specimens collected from two rivers within a protected reserve.

In this study, the distance between the centroids of the two groups indicates a statistically measurable difference in the morphometric data of individuals from the Maseko and Kinombe rivers (p-value = 0.02, see **Table 4**). Population differentiation between shrimp from the two rivers was evaluated using distance to centroid dispersion, derived from multivariable morphometric data. This method quantifies the variability of individuals relative to their group centroid within multivariate space and serves as a robust indicator of morphological divergence among populations [31]. In contrast to MANOVA, which relies on assumptions of multivariate normality and homogeneity of covariance matrices, the distance to centroid approach also referred to as PERMDISP, is non-parametric and operates through permutations of dissimilarity matrices. Consequently, it offers a more dependable measure of morphological dispersion, particularly when these statistical assumptions are not fully satisfied, as is frequently the case with natural biological datasets [31] [32]. [33] proposed a similar pattern in their research, attributing the observed variation to differing rainfall regimes across the rivers studied. However, this explanation is not applicable to the present case, as both Maseko and Kinombe rivers are subject to the same climatic conditions.

5. Conclusions

The aim of this study was to assess the morphometric characteristics of *Macrobrachium sollaudii*, collected from the Kinombe and Maseko rivers in the Babagulu Forest Reserve, Democratic Republic of Congo. A total of 146 specimens were obtained, comprising 53 males and 93 females, indicating a markedly lower number of males relative to females.

Analysis of the morphometric parameters revealed that males from the Maseko River exhibited the highest mean total length (54.45 ± 13.82 mm), while those from the Kinombe River displayed the lowest (35.6 ± 9.51 mm). This pattern was observed across all other measured traits, with Maseko males consistently showing higher values and Kinombe males lower ones. Similarly, the highest mean weight was recorded in Maseko males (3.17 ± 2.6 g), compared to the lowest in Kinombe males (0.78 ± 1.59 g). Pairwise comparisons of morphometric parameters showed only slight variation. Furthermore, multiple linear regression analysis demonstrated that sex did not significantly influence any morphometric traits. However, strong correlations were observed among the various length and weight parameters. While this study does not claim to have fully resolved the complexities surrounding the morphometry of freshwater shrimp, it nonetheless represents a meaningful contribution to the field. It is hoped that these findings will encourage further research aimed at deepening our understanding of *M. sollaudii*, and related species.

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Authors' Contributions

Vianney Mulema Ngabo wrote the article, Noëlla Kibonge Fiama collected most of the field data, Alexender-Armand Amatcho Kalonda, Hector Basongwa Ataenafa and Faustin Bonyoma Bassoy participated in the field activities. Oscar Wembo and Alidor Kankonda Busanga supervised the team and reviewed the manuscript draft.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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