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Research Article

Length-Weight Relationships of Sixteen Fish Species From the Upper Tietê Basin, Southeaster Brazil

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This study investigated the length-weight relationship (LWR) of 16 fish species from the Upper Tietê Basin under the influence of the Atlantic Forest biome, aiming to provide updated morphometric data and contribute to the knowledge of Neotropical ichthyofauna. 2811 specimens were collected and distributed across five orders and 10 families. Standard length ranged from 0.8 to 24.5 cm, and weight from 0.01 to 34.19 g. The parameters a and b of equation $W = a{\cdot}L^b$ were estimated, revealing that most species exhibited allometric growth, with one isometric species (*Astyanax lacustris*), seven with negative allometry, and eight with positive allometry. The b values ranged from 2.579 (*Imparfinis piperatus*) to 3.651 (*Phalloceros reisi*), the latter being the only one outside the typical range of $2.5 < b < 3.5$. The Bayesian analysis proposed by Froese indicated morphological deviations for *Hyphessobrycon multifasciatus* (α outside the expected range) and a lack of specific classification for *Cambeva iheringi*, *Geophagus iporangensis*, and *Osteogaster aenea*. An apparent scarcity of geographically delimited studies in the basin was evident, hindering broader comparisons. Only *Phalloceros reisi* presented compatible data, with mean, standard-length values similar to those reported in the literature. Also noteworthy is *Pseudotocinclus tietensis*, a threatened species that exhibited positive allometry ($b = 3.2595$), suggesting favorable environmental conditions for its growth in the studied basin. The results highlight the importance of regional morphometric studies as tools for monitoring and conserving ichthyofauna, especially for species whose morphometric characteristics had not yet been documented for the Upper Tietê Basin.

Keywords: body condition; ichthyofauna; morphometries

1. Introduction

The streams of the Atlantic Forest harbor a rich diversity of fish, with approximately 269 species distributed across 89 genera and 21 families [1], although this number is likely even higher. This biome holds great significance for the freshwater ichthyofauna of South America, standing out for its high degree of endemism attributed to geographic isolation and its unique ecological characteristics. Moreover, several recent studies have identified species that have not been formally described [2–4].

The Upper Tietê Basin, Southeast Brazil, located within the Atlantic Forest biome, covers approximately 5868 km^2 and includes, entirely or partially, 40 municipalities of the

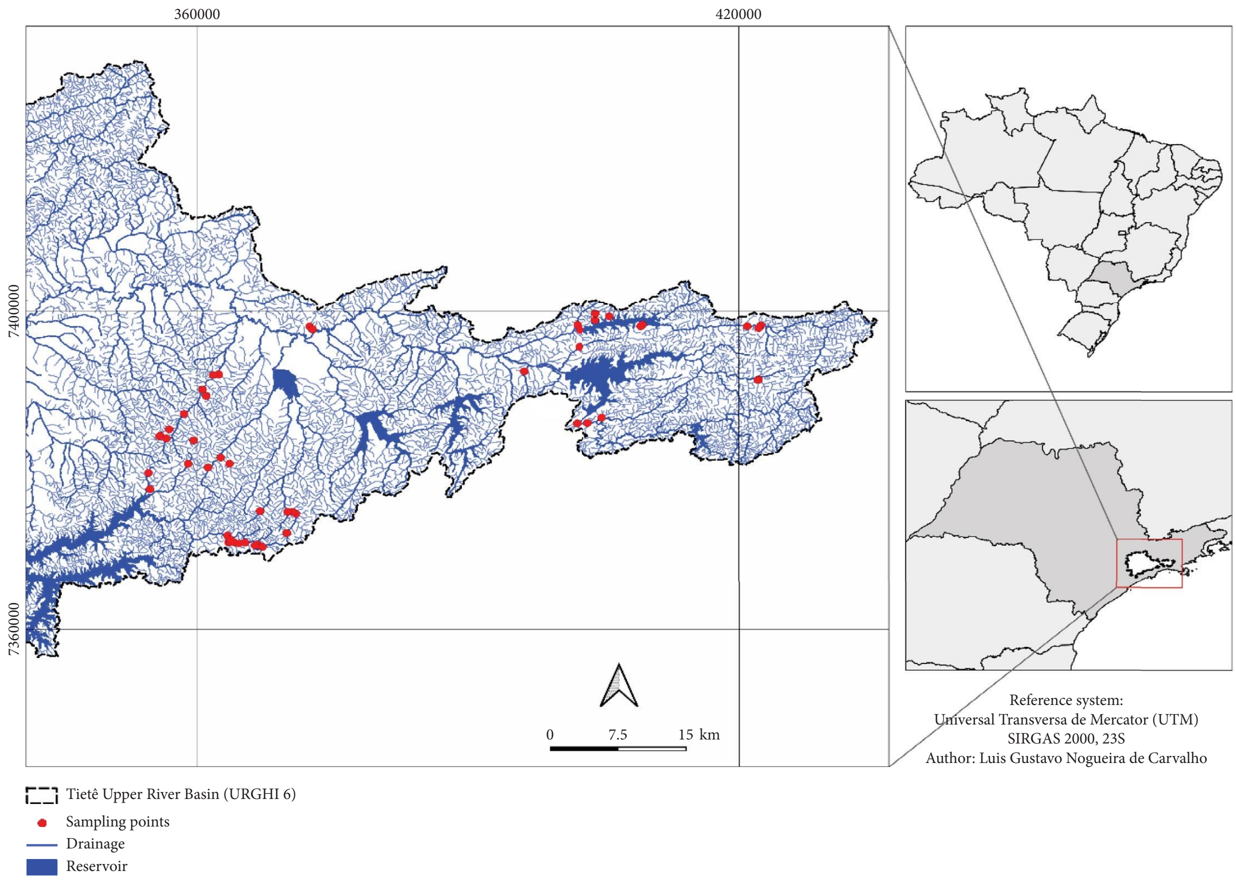

Figure 1: Sampling points for ichthyofauna distributed throughout the Upper Tietê Basin, São Paulo State, Brazil, with the drainage network highlighted.

São Paulo Metropolitan Region, home to around 20 million people [5]. It stretches from the headwaters of the Tietê River in Salesópolis to the Rasgão Dam in Pirapora do Bom Jesus. The basin features a continuous urban sprawl, predominantly expanding eastward, encroaching upon areas near reservoirs and reaching Watershed Protection Areas (WPAs) [6].

Currently, the rivers of this basin face continuous anthropogenic pressure, including deforestation, natural resource exploitation, pollution, habitat fragmentation, and invasive fish species [7]. The situation is mitigated, to some extent, by the existence of 37 conservation units responsible for protecting 31% of the area [8]. The conservation status of the region is considered critical [9]. Despite the intense urbanization process, the basin still harbors a rich and diverse ichthyofauna, particularly in headwater areas such as Salesópolis and Biritiba Mirim, where riparian vegetation remains preserved. Studies indicate the occurrence of approximately 56–70 species [10–12].

The study of the length-weight relationship (LWR) is an essential tool for understanding the population biology of fish communities. The standard-length relationship is a mathematical model that allows for the conversion of length to weight and vice versa and the estimation of biomass from length frequency distributions [13]. This relationship is crucial for comparing populations across rivers and basins and assessing fish health, as it provides the allometric coefficient for calculating the condition factor. Additionally, it enables the conversion of length-growth equations into weight-growth equations, which are helpful in fisheries stock modeling [14, 15]. Therefore, this approach is critical in ecological and fisheries biology studies, supporting estimating biomass, weight, and body condition through the condition factor [16]. The objective of the present study was to collect length and weight data for 16 fish species from the Upper Tietê Basin to calculate their LWRs, contribute to updating the data available in FishBase, and support the conservation and management of the studied fish species.

2. Materials and Methods

2.1. Study Area. The Upper Tietê Basin is located in a highly urbanized region of the state of São Paulo (Figure 1), with about 21.9 million inhabitants [17], distributed within the Atlantic Forest biome. It is characterized by a predominantly tropical climate, with an average annual temperature of 17.8°C [18]. The basin is considered a hotspot for fish biodiversity and conservation [19]. It has a drainage area of approximately 5775.12 km^2 and is located within the Water Resources Management Unit UGRHI, 06 [6].

Table 1: Location of fish sampling points in the Upper Tietê Basin, with their respective UTM coordinates (Zone 23S, Datum SIRGAS 2000).

Points	Latitude	Longitude
P1	360,551	7,390,177
P2	361,728	7,391,995
P3	362,341	7,392,032
P4	372,476	7,398,125
P5	372,804	7,397,746
P6	405,695	7,399,363
P7	404,118	7,398,906
P8	404,150	7,399,743
P9	402,068	7,398,304
P10	422,184	7,391,463
P11	422,122	7,391,385
P12	402,376	7,397,675
P13	402,315	7,395,556
P14	409,356	7,398,328
P15	409,167	7,398,136
P16	422,455	7,398,241
P17	422,204	7,397,910
P18	420,940	7,398,127
P19	396,161	7,392,470
P20	397,539	7,388,332
P21	399,263	7,387,275
P22	402,024	7,385,933
P23	403,280	7,385,972
P24	404,844	7,386,643
P25	354,753	7,377,658
P26	354,584	7,379,703
P27	355,877	7,384,376
P28	355,804	7,384,293
P29	356,556	7,384,042
P30	356,873	7,385,176
P31	363,541	7,380,862
P32	362,555	7,381,624
P33	361,163	7,380,389
P34	358,974	7,380,855
P35	359,570	7,383,781
P36	358,525	7,387,102
P37	362,318	7,392,112
P38	361,727	7,391,992
P39	360,950	7,389,367
P40	363,428	7,370,949
P41	363,613	7,371,041
P43	364,544	7,370,806
P44	365,262	7,370,943
P45	369,856	7,372,137
P46	367,153	7,370,390
P47	366,613	7,370,708
P48	366,391	7,370,570
P49	366,900	7,374,894
P50	366,359	7,370,577
P51	367,172	7,370,424
P52	370,879	7,374,562
P53	370,511	7,374,792
P54	369,961	7,374,799
P55	363,312	7,371,825
P56	363,606	7,371,361

2.2. Ichthyofauna Sampling. Sampling was conducted in August 2024 at 56 riverine sites within the Upper Tietê Basin (Table 1). The primary active capture methods used included hand sieves (50×50 cm, 1 cm mesh), a 3-m-long seine net (5 mm mesh), and electrofishing [20], with a SUSAN 735MP model equipment, with an output voltage of 800 V. After capture, the fish were euthanized in the field using 1–1.5 mL of clove oil solution per liter of water (5 mL of clove oil + 95 mL of 96°–99° GL alcohol), weighed on a digital balance (precision 0.00001 g), and measured with a digital caliper (precision 0.1 mm). Specimens were subsequently fixed in 10% formalin and later transferred to 70% ethanol for preservation in the laboratory.

All specimens were deposited in the ichthyological collection of the Laboratory of Functional and Structural Ecology of Ecosystems at Paulista University (UNIP), Sorocaba campus, São Paulo, Brazil. Collections were conducted under authorization from the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) (SISBIO 93116-2) and the Animal Use Ethics Committee of UNIP (CEUA 9065271124).

2.3. Analytics. For each species, the weight-length relationship was adjusted using equation $W = a \times L^b$, where W is the weight in grams, L is the total length in centimeters, and a and b are parameters obtained from the logarithmic regression. The condition factor (K) was used only to derive the parameters a and b from the weight-length relationship and is not presented as an independent variable. The data used to calculate the condition factor included standard length (cm), weight (g), and the slope coefficient of the weight-length regression (b). The analysis was conducted using Microsoft Excel, where the data were subjected to regression and fitted to a potential model. The parameters a and b were estimated and adjusted using the least squares method. Parameter a represents the intercept of the weight-length relationship, and b is the slope coefficient. When $b = 3$, growth is isometric (weight and length increase proportionally); when $b < 3$, growth is negatively allometric (length increases more than weight); and when $b > 3$, growth is positively allometric (weight increases more than length) [13].

3. Results

In this study, 2811 specimens were collected and distributed across five orders, 10 families, and 16 species. Table 2 summarizes the estimated parameters for the LWRs, along with descriptive statistics. The standard length of the fish ranged from 0.8 to 24.50 cm. The total weight varied from 0.01 to 34.19 g. Figure 2 shows the scatter plots between standard length and weight for the 16 fish species studied. For each species, the data were fitted using power models, represented by the dashed curves in the graphs, which express the relationship between the analyzed morphometric variables.

Table 2: Descriptive statistics and estimated parameters of the length-weight relationships (LWRs) for 16 fish species in the Upper Tietê Basin.

Family	Species	*N*	CP (cm)	Weight (g)	*α*	95% CL of *α*	*b*	95% CL of *b*	R^2
Acestrorhamphidae	*Astyanax lacustris* (Lü tken 1875)	71	7.5–2.3	12.26–0.29	0.02680	0.02546–0.02814	2.996	2.84620–3.14580	0.9737
	Hollandichthys multifasciatus (Eigenmann and Norris 1900)	205	8.6–2.0	14.82–0.2	0.03020	0.02869–0.03171	2.8332	2.69154–2.97486	0.9864
	Hyphessobrycon flammeus Myers 1924	56	2.9–1.2	0.7–0.02	0.01560	0.01482–0.01638	3.5596	3.38162–3.73758	0.8573
	Psalidodon paranae (Eigenmann 1914)	107	9–2.2	17.19–0.24	0.02380	0.02261–0.02499	2.9283	2.78188–3.07471	0.9564
	Hyphessobrycon bifasciatus Ellis 1911	24	4–1.9	1.8–0.15	0.02610	0.02479–0.02740	2.8269	2.68555–2.96824	0.8305
Callichthyidae	*Osteogaster aenea* (Gill 1858)	126	5.7–2.0	7.27–0.29	0.05560	0.05282–0.05838	2.8211	2.68004–2.96215	0.9651
Characidae	*Serrapinnus notomelas* (Eigenmann 1915)	20	2.2–0.9	0.23–0.01	0.00710	0.00674–0.00745	3.075	2.92100–3.22875	0.9567
Cichlidae	*Geophagus iporangensis* Haseman 1911	26	9.5–1.8	34.19–0.2	0.03670	0.03486–0.03853	2.9118	2.76621–3.05739	0.9564
Gymnotidae	*Gymnotus pantherinus* (Steindachner 1908)	29	24.5–3.77	32.14–0.17	0.00360	0.00342–0.00378	2.8568	2.71396–2.99964	0.9422
Heptapteridae	*Imparfinis piperatus* Eigenmann and Norris 1900	24	7.9–2.7	4.1–0.21	0.01220	0.01159–0.12810	2.8622	2.71909–3.00531	0.9845
Loricariidae	*Pseudotocinclus tietensis* (Ihering 1907)	15	7.5–2.8	3.91–0.2	0.00830	0.00788–0.00871	3.2595	3.09652–3.42247	0.8377
Poeciliidae	*Phalloceros reisi* Lucinda 2008	1996	4.3–0.9	1.43–0.01	0.01120	0.01064–0.01176	3.6511	3.46854–3.83365	0.9272
	Phalloceros harpagos Lucinda 2008	38	3.4–0.8	0.51–0.01	0.01430	0.01358–0.01501	3.3084	3.14298–3.47382	0.8577
Stevardiidae	*Pseudocorynopoma heterandria* Eigenmann 1914	44	6.54–2.3	5.07–0.15	0.01000	0.00950–0.01050	3.3303	3.16378–3.49681	0.9321
	Piabina anhembi da Silva and Kaefer 2003	14	7.8–2.4	8.5–0.2	0.01230	0.01168–0.01291	3.1603	3.00228–3.31831	0.977
Trichomycteridae	*Cambeva iheringi* (Eigenmann 1917)	16	4.8–2.5	1.2–0.16	0.00910	0.00864–0.00955	3.0839	2.92970–3.23809	0.8814

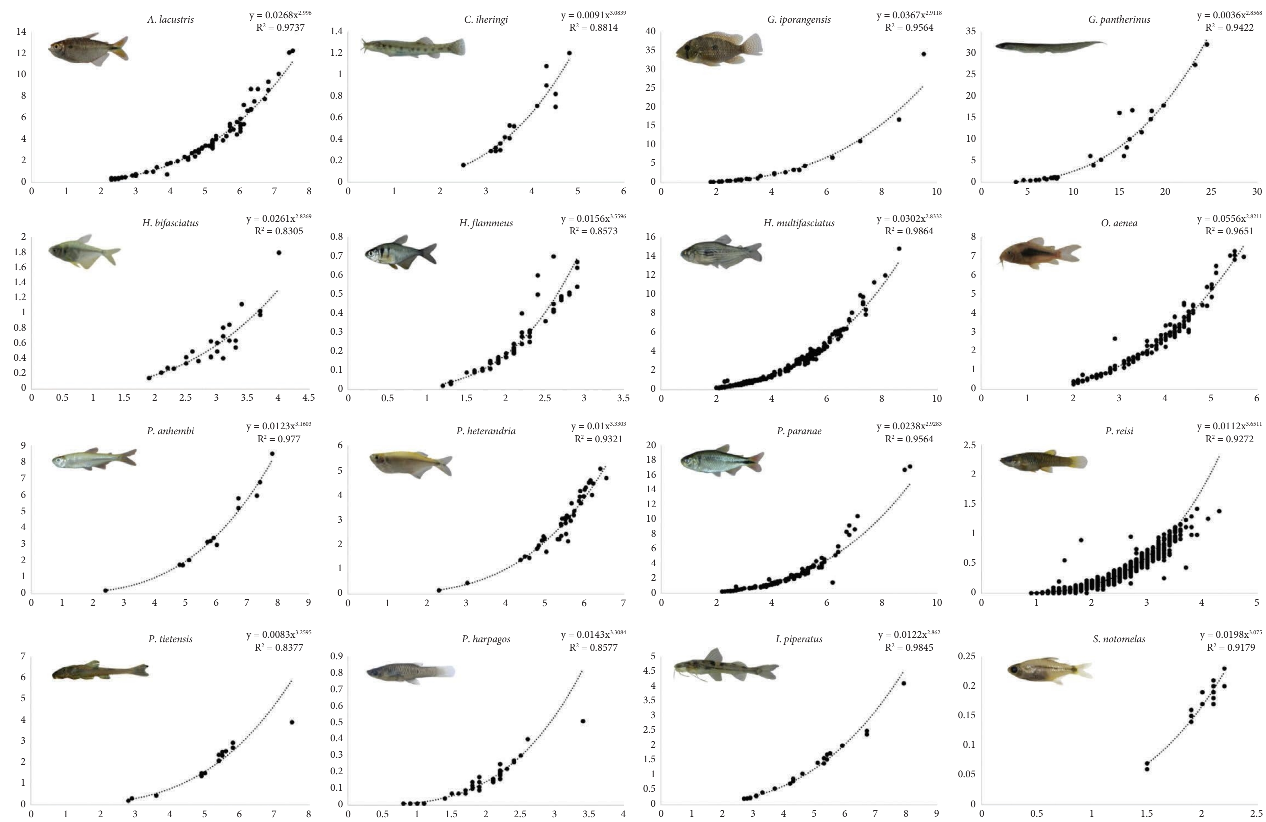

FIGURE 2: Scatterplots of the length–weight relationships of fish species from the Upper Tietê Basin, São Paulo State, Brazil, with weight measured in grams (g) and length in centimeters (cm).

The distribution of points demonstrates the individual variability within each species. At the same time, the high coefficients of determination (R^2) indicate, in most cases, a good fit of the model, reflecting consistent patterns in the weight-length relationship. Furthermore, differences in the slope and curvature of the functions between species can be observed, revealing distinct growth strategies and body shapes. All values and results are described in Table 2. The *b* values of the 16 fish species ranged from 2.579 for I. piperatus to 3.651 for *Phalloceros reisi*. According to the weight-length relationship analysis, the species *A. lacustris* was the only one to exhibit isometry. Negative allometry was found in seven species: *H. multifasciatus, P. paranae, H. bifasciatus, O. aenea, G. iporangensis*, *G. pantherinus, and I. piperatus*. Positive allometry was observed in eight species: *H. flammeus, S. notomelas, P. tietensis, P. reisi, Phalloceros harpagos, P. heterandria, P. anhembi, and C. iheringi*.

4. Discussion

Our study represents the first effort to establish LWRs for 16 species from the Upper Tietê Basin. This research is particularly significant, as data for most species (except *Phalloceros reisi*) were previously unavailable for this region. The data presented here contribute to a better understanding of the species from the Upper Tietê and can be applied in studies assessing the condition and developmental status of the local fish community.

Most species showed high coefficients of determination ($R^2 > 0.90$), indicating a strong fit between length and weight. These results reinforce the reliability of the obtained equations and significantly expand the biometric knowledge of the regional fish fauna, which was previously limited. Despite all checks and adjustments made to the dataset, some species exhibited R^2 values below 0.90, though still close, indicating that the fit remained relatively good for these species.

The values of the exponent *b* were within the expected theoretical range of 2.5–3.5 (Froese, 2006); suggesting growth patterns close to isometric. Species such as *A. lacustris* ($b = 2.996$) and *G. iporangensis* ($b = 2.91$) illustrate this pattern well. However, some cases of positive allometry were evident, such as in *P. reisi* ($b = 3.65$) and *H. flammeus* ($b = 3.55$), indicating that these species tend to increase their weight proportionally more than their length. This pattern may reflect reproductive factors, such as high energy allocation to gonads [21], or adaptations to habitats with low food availability, where energy allocation strategies are altered [22].

On the other hand, species such as *H. bifasciatus* and *O. aenea*, with *a b* coefficient close to 2.82, showed slightly negative allometric growth. This pattern has also been observed in other basins, such as the Paciência River estuary, where this type of growth was attributed to year-to-year variations in the organisms' nutritional condition and population size structure [23]. Similarly, in the Upper

Araguari River, it was found that species with elongated or deep bodies exhibited negative allometric growth, associated with factors such as body shape, nutritional condition, gonadal maturity, seasonality, and habitat [24].

According to Froese's Bayesian analysis [25], the species *H. multifasciatus* showed a value of the parameter α outside the expected range, indicating that the observed body shape deviates from the usual morphological pattern described for the species. The species *C. iheringi* and *G. iporangensis* did not fit into any specific category and were, therefore, included in the general category encompassing all classes. Meanwhile, the species *O. aenea* did not present an α value corresponding to the described classes. The remaining species, however, showed α values within the expected range for each species.

Another essential consideration is *P. tietensis*, which is considered threatened in the study area. Despite this status, the species exhibited positive allometry ($b = 3.2595$), reflecting optimal conditions for growth in the region [26].

5. Conclusion

Based on the obtained results, it is observed that although most species present values of the parameter b within the acceptable range, some deviations were identified in parameter a, indicating variations in growth patterns and body shape. These differences may reflect specific adaptations to the environment or possible inconsistencies in the available data, especially given the scarcity of detailed information for the Upper Tietê region. The positive allometry of *P. tietensis*, a threatened species, suggests that local environmental conditions still favor its development, reinforcing the importance of conservation measures to maintain these habitats.

Data Availability Statement

The data used in this study are available upon reasonable request from the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

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