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Length-weight relationship of 12 fish species from streams of a protected area in the Southwestern Amazon, Brazil

Relação peso-comprimento de 12 espécies de peixes de igarapés de uma área protegida no sudoeste da Amazônia, Brasil

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Abstract: We analyzed the length-weight relationships of 12 lesser-known fish species sampled in four streams in the Southwestern Amazon, in Acre State, Brazil. Diurnal and nocturnal sampling took place in four streams in 150-meter sessions in March and November 2017. Linear regression was applied using the least squares adjustment method. In total, 867 specimens were collected, representing four orders, ten families, and 12 species. The *b* coefficient of the length-weight regression ranged from 2.58 to 3.22, and r^2 from 0.77 to 0.99. Five species had negative allometric growth ($b < 3$), six had isometric ($b = 3$), and one had positive allometric growth ($b > 3$). The length-weight relationship was documented for the first time in 10 of the 12 species – *Chrysobrycon hesperus*, *Knodus smithi*, *Phenacogaster pectinata*, *Carnegiella myersi*, *Pyrrhulina obermulleri*, *Gymnotus curupira*, *Brachyhypopomus sullivani*, *Corydoras cervinus*, *Denticetopsis seducta*, and *Bujurquina syspilus*. Our results contribute to the knowledge on life cycle parameters of fish species from the Southwestern Amazon.

Keywords: Amazonian streams; allometry; conservation; growth pattern; isometry.

Resumo: Analisamos as relações peso-comprimento de 12 espécies de peixes pouco conhecidas amostradas em quatro igarapés de terra-firme no sudoeste da Amazônia, no estado do Acre, Brasil. As amostragens diurnas e noturnas ocorreram em março e novembro de 2017. No total, foram coletados 867 exemplares, representando quatro ordens, dez famílias e 12 espécies. O coeficiente *b* da regressão peso-comprimento variou de 2,58 a 3,22, e o r^2 de 0,77 a 0,99. Cinco espécies tiveram crescimento

alométrico negativo (b < 3), seis tiveram crescimento isométrico (b = 3) e uma teve crescimento alométrico positivo (b > 3). A relação peso-comprimento foi documentada pela primeira vez em 10 das 12 espécies – *Chrysobrycon hesperus*, *Knodus smithi*, *Phenacogaster pectinata*, *Carnegiella myersi*, *Pyrrhulina obermulleri*, *Gymnotus curupira*, *Brachyhypopomus sullivani*, *Corydoras cervinus*, *Denticetopsis seducta* e *Bujurquina syspilus*. Nossos resultados contribuem para o conhecimento dos parâmetros do ciclo de vida de espécies de peixes do sudoeste da Amazônia.

Palavras-chave: riachos amazônicos; alometria; conservação; padrão de crescimento; isometria.

Length-Weight Relationships (LWRs) provide a tool for assessing growth patterns and nutritional status in fish populations (Le Cren, 1951; Froese, 2006; Oliveira et al., 2022). These indices can be used to estimate biomass based on body length, growth rates, the relative age of individuals, and other parameters (Froese, 2006; Barros et al., 2023), thereby contributing fundamentally to the assessment of fishery stocks and environmental management (Souza et al., 2017).

The Amazon basin has the world's most diverse freshwater fish fauna, with 2,716 species, including 1,696 endemic taxa (Dagosta & De Pinna, 2019). Despite this diversity (Lubich et al., 2021), knowledge gaps persist in many areas, and few studies have focused on the LWRs of the fish from the Southwestern Amazon basin (Corrêa et al., 2018; Silva et al., 2019; Oliveira et al., 2022). Given this, the present study analyzed the LWRs of 12 species found in a protected area in the Southwestern Amazon basin. The 47,000-hectare Antimary State Forest (ASF; 9°20'1.89"S; 68°17'22.94"W) straddles the municipalities of Bujari and Sena Madureira in Acre State, Brazil (Acre, 2012; Figure 1). Annual precipitation is approximately 2100 mm and the mean temperature is 25ºC. The dry (May-September) and rainy (October-April) seasons are well-defined. The ASF includes three principal phytophysiognomies: dense and open tropical forest, and bamboo forest, known locally as taboca, at altitudes of 90-300 m above sea level.

The study focused on four non-floodplain (*terra-firme*) streams in March and November 2017 (rainy season), collecting specimens during both diurnal and nocturnal periods, to maximize the number of species. The fish were caught using 5-mm mesh sieves (80 cm × 50 cm) and hand nets (50 cm × 30 cm), which were deployed for 30 minutes along the entire length of the stream in 150-meter session (Corrêa et al., 2018). The fish were anesthetized in an aqueous lidocaine solution, fixed in 10% formalin for 24 hours, and then transferred to 70% alcohol for storage. Each specimen was weighed (W) in grams (g), measured (standard length, L) in centimeters (cm), and identified to the lowest possible taxonomic level, based on Claro-García et al. (2013), Queiroz et al. (2013a, b, c), and Crampton et al. (2016). Specimen collection was authorized by the Biodiversity Authorization and Information System (SISBio) of the Chico Mendes Institute for the Conservation of Biodiversity (license 11185-1). The specimens were deposited in the collection of the UFAC Laboratory of Ichthyology and Aquatic Ecology in Rio Branco.

The LWR was calculated by Equation 1:

$$W = a^* L^b \quad (1)$$

where W = total weight of the fish (g); a = a coefficient of body shape; L = standard length (cm); b = an exponent of the variation in body shape (Froese, 2006).

The a and b values were estimated by the linear regression using the least squares adjustment method in addition to the log-transformed Equation 2:

$$\log W = \log a + b \log L \quad (2)$$

The outliers were identified and excluded manually (Froese & Binohlan, 2000) prior to regression analysis at discretion absolute value of standardized residuals ≥ 4. The type of growth was identified from the b value associated with the confidence interval (Froese, 2006). These analyses were run in the R software, considering a 5% significance level (R Core Team, 2023).

A total of 867 specimens were collected, representing 12 species in four orders and ten families (Table 1). The mean standard lengths of the species ranged from 0.9 cm to 11 cm, and mean total weights, 0.02-55.88 g. The exponents (b) of each species ranged from 2.58 to 3.22, and the r^2 values, 0.77-0.99. Five species presented negative allometric growth (b < 3), one had positive growth (b > 3) and six species had isometric growth (b = 3). All the species analyzed here are small in size, with standard lengths of no more than 11 cm (Castro & Polaz, 2020). The b values (Table 1) were all within the expected range of 2.5-3.5 (Froese, 2006). This study provides the first estimates of the LWR of 10 fish species from Southwestern Amazonia (see Froese

& Pauly, 2023). Of these species, only *Bujurquina syspilus* (Cope, 1872) and *Corydoras cervinus* Rössel, 1962 presented *b* values similar to those of closely-related taxa (FishBase), whereas the other eight returned considerably different estimates (Froese & Pauly, 2023). Cella-Ribeiro et al. (2015) estimated the LWR of *Hypostomus pyrineusi* (Miranda Ribeiro, 1920) from the Madeira River, and recorded *b* = 2.92 (CI = 2.823-2.032; n = 28), close than the value recorded here, i.e., *b* = 3.16 (CI = 2.78-3.54; n = 31), indicating isometric growth. Adjustments for the 12 species in Figure 2.

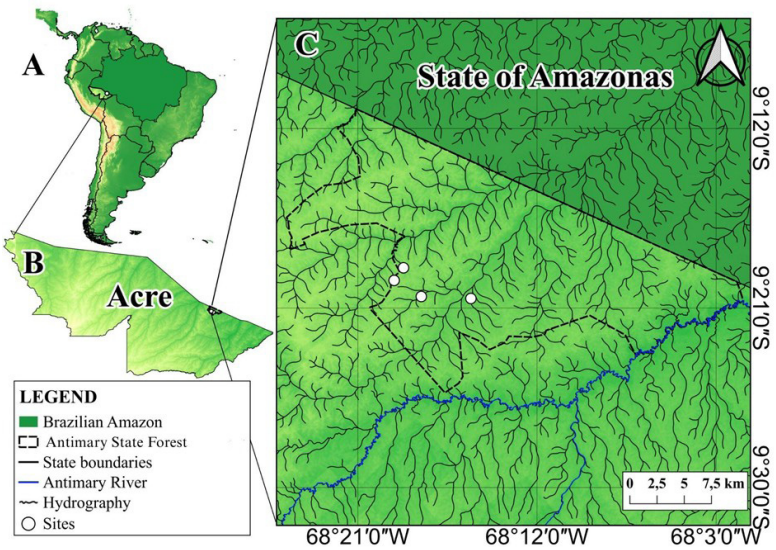

Figure 1. (A) Location of the State of Acre in the Brazilian Amazon; (B) location of Antimary State Forest (ASF) in Acre State; (C) location of the sampling sites (white circles) in four streams within ASF.

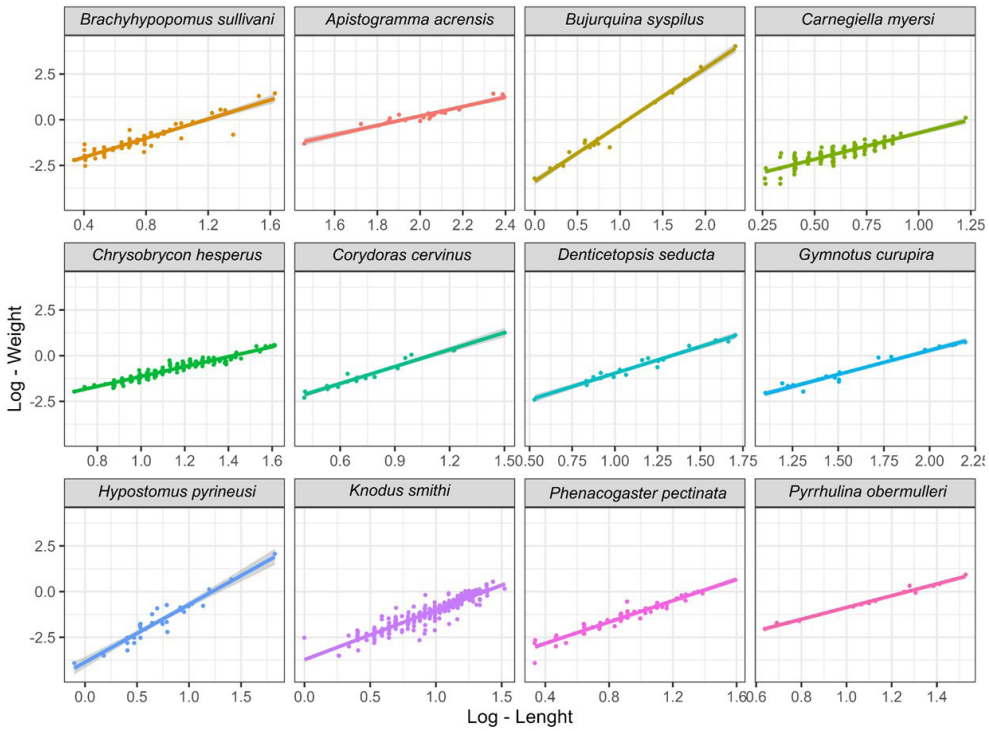

Figure 2. Graphs showing linear regression adjustments and confidence intervals (gray outline) for 12 fish species in four *terra-firme* streams in the Southwestern Brazilian Amazon basin.

Table 1. Body size and LWR estimates of 12 fish species collected in four *terra-firme* streams in the Southwestern Brazilian Amazon basin.

ORDER/Family/*Species*	Voucher	N	L (cm)		W (g)		Estimated parameters				r^2
			Min	Max	Min	Max	*a*	*a* 95% CI	*b*	*b* 95% CI	
CHARACIFORMES											
Characidae											
Phenacogaster pectinata (Cope, 1870)*	MUFAC-IC 1234	66	1.4	4.9	0.02	1.89	0.0174	0.0183-0.017	2.92	2.71-3.13	0.92
Gasteropelecidae											
Carnegiella myersi Fernández-Yépez, 1950*	MUFAC-IC 1241	120	1.3	3.4	0.03	1.11	0.0157	0.0165-0.015	2.89	2.60-3.17	0.77
Lebiasinidae											
Pyrrhulina obermulleri Myers, 1926*	MUFAC-IC 1245	16	1.9	4.6	0.13	2.53	0.0178	0.0188-0.017	3.22	3.01-3.44	0.99
Stevardiidae											
Chrysobrycon hesperus (Böhlke, 1958)*	MUFAC-IC 1227	155	2	5	0.14	1.8	0.0167	0.0174-0.016	2.71	2.58-2.84	0.92
Knodus smithi (Fowler, 1913)*	MUFAC-IC 1231	303	1	4.6	0.03	1.72	0.0162	0.0167-0.016	2.72	2.60-2.84	0.87
GYMNOTIFORMES											
Gymnotidae											
Gymnotus curupira Crampton, Thorsen & Albert, 2005*	MUFAC-IC 1251	21	3	9	0.13	2.09	0.0022	0.0024-0.02	2.64	2.39-2.89	0.96
Hypopomidae											
Brachyhypopomus sullivani Crampton, de Santana, Waddell & Lovejoy, 2017*	MUFAC-IC 1254	24	4.3	11	0.27	4.14	0.0022	0.0025-0.018	2.58	2.23-2.93	0.91
SILURIFORMES											
Callichthyidae											
Corydoras cervinus Rössel, 1962*	MUFAC-IC 1264	18	1.5	4.5	0.1	3.5	-0.0147	0.0016-0.014	3.10	2.77-3.43	0.96
Cetopsidae											
Denticetopsis seducta Vari, Ferraris & de Pinna, 2005*	MUFAC-IC 1266	20	1.7	5.5	0.09	3.09	0.0168	0.0018-0.015	2.91	2.60-3.21	0.96
Loricariidae											
Hypostomus pyrineusi (Miranda Ribeiro, 1920)	MUFAC-IC 1274	31	0.9	6.2	0.02	7.89	0.0168	0.0181-0.016	3.16	2.78-3.54	0.91
CICHLIFORMES											
Cichlidae											
Apistogramma acrensis Staeck, 2003	MUFAC-IC 1248	69	1.4	5.1	0.08	4.24	0.0135	0.0014-0.013	2.62	2.36-2.88	0.86
Bujurquina syspilus (Cope, 1872)*	MUFAC-IC 1249	24	1	10.5	0.04	55.88	0.0147	0.0002-0.014	3.10	2.92-3.27	0.98

N = sample size; L = standard length; W = total weight; *a* = intercept; *b* = slope; CI = confidence interval; *indicates that LWR was estimated for the first time for this species.

The only study that evaluated LWR in *Apistogramma acrensis* (Staeck, 2003) was that of Corrêa et al. (2018), however, they evaluated almost 20 times more specimens than in the present study, which makes the studies incomparable. Sample sizes varied negligibly in *H. pyrineusi*, however. Other factors, including the sex of the specimens and the timing of their collection (day/night, month) may have influenced the low r^2 values ($r^2 = 0.95$) recorded in seven of the species analyzed here, as is the case with *Carnegiella myersi* ($r^2 = 0.77$), *Apistogramma acrensis* ($r^2 = 0.86$), and *Knodus smithi* ($r^2 = 0.87$), Table 1. A number of factors influence the LWR, including seasonal variation, specimen collection techniques, sex and age, and photoperiod (Noeske & Spieler, 1984; Froese, 2006; Freitas et al., 2014; Silva et al., 2019; Oliveira et al., 2022; Barros et al., 2023). Seasonal factors influence the availability of food, especially invertebrates, which can affect fish growth (Le Cren, 1951). The photoperiod is also potentially important – digestion rates vary considerably over time (Noeske & Spieler, 1984; Amano et al., 2006). Environmental factors, including spawning site availability, may also contribute to varying growth patterns (Ziober et al., 2015). This study provides important insights into the life cycle parameters of 12 fish species from the Southwestern Amazon basin.

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Data availability

Research data analyzed in this study is not publicly available by any mean.

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