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Length-weight relationship of 32 fish species from oligotrophic headwater streams of northwestern Colombian Amazon

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ABSTRACT

This study examines the length-weight relationships (LWR) for 32 freshwater fish species sampled in five oligotrophic headwater streams in northwestern Amazonia, Department of Guaviare, Colombia. Fish were sampled between August 2021 and February 2022 using gillnets, hand nets, and seine net. Total weight and standard length were measured to calculate LWR. Allometric coefficient *b* ranged from 2.67 to 3.43. The study includes two new reports and is the first time LWRs are presented for this region.

KEYWORDS: allometry, growth patterns, fish, fisheries, reproduction

Relación longitud-peso de 32 especies de peces de arroyos de cabecera oligotróficos del noroeste de la Amazonia Colombiana

RESUMEN

Este estudio examina las relaciones longitud-peso (LWR) para 32 especies de peces de agua dulce muestreadas en cinco arroyos de cabecera oligotróficos del noroeste de la Amazonia, en el Departamento de Guaviare, Colombia. Los peces fueron muestreados entre agosto de 2021 y febrero de 2022 utilizando redes de enmalle, redes de mano y redes de arrastre. Se midieron el peso total y la longitud estándar para calcular las LWR. El coeficiente alométrico *b* varió entre 2.67 y 3.43. El estudio incluye dos nuevos reportes y es la primera vez que se presentan las LWR para esta región.

PALABRAS-CLAVE: alometría, patrón de crecimiento, peces, pesquerías, reproducción

Studying the length-weight relationship (LWR) is crucial for understanding the dynamics of aquatic ecosystems. This relationship is a useful tool for fisheries, ecological research and monitoring programs, as it provides valuable insights into growth patterns, health condition, reproductive success, habitat quality and fish stocks (Le Cren 1951, Froese 2006, Giarrizzo *et al.* 2015). Despite this utility, the highly diverse fish assemblages and the current threats over the Amazon region, LWR studies have received little attention. Therefore, our objective was to establish LWRs parameters of 32 species from oligotrophic headwater streams in northwestern Amazonia to enhance scientific understanding and contribute to the preservation of these species.

This study was conducted in the Guaviare River basin near the Municipality of San José del Guaviare (2°34'N, 72°38'W), in the Department of Guaviare, northwestern part of Colombian Amazon (Figure 1). The research was done under the scientific research permit no. Resolution 0255 date March 14, 2014 of Autoridad Nacional de Licencias Ambientales (ANLA), and was approved by the Ethical Committee of the Sciences Faculty of Universidad Nacional de Colombia, Bogotá. Fish samples were taken in August 2021 and February 2022 at 15 sampling stations encompassing five oligotrophic headwater streams (Table 1). Station selection was based on: 1) Land owner permission: 2) physical security and 3) good accessibility. Each station was identified using the name of the stream and the distance to the Guaviare River (i.e. upper, middle, lower reaches). At each station, a reach of 350-400 m was established. These oligotrophic streams are small, nutrient poor with acidic dark water in which diverse and rich fish fauna thrive (Correa and Winemiller 2018). Fish were collected using active seining (30 m x 2 0 with 2.5 cm mesh) from downstream to upstream, passive gill netting (15 m x 3 m with 2.5 cm mesh), and active hand netting (2

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cm mesh). Fish were identified using taxonomic keys (Gery 1977, Galvis *et al.* 2006, Kullander 2006, Urbano-Bonilla *et al.* 2017, Bogotá-Gregory *et al.* 2022) and expert assistance when necessary. Standard length (SL, cm) and total weight (W, g) were measured using a digital caliper (0.01 mm) and a scale (0.1 g), respectively, and specimens were deposited in the Ichthyological collection of the Instituto de Ciencias Naturales (ICN) of Universidad Nacional de Colombia – Bogotá, Colombia (Table 2).

Before analyses, SL and W data were log transformed. Outliers were graphically identified by plotting log SL vs log W, and obvious outliers values (i.e., ± 2SD) were removed (Froese 2006). LWR were calculated using the equation $W = a L^b$, where W is weight, L is length, a is the linear coefficient (intercept) and b is the allometric coefficient (slope). Parameters a and b were estimated using the linear regression of the log-transformed equation (i.e. $\log(W)=\log(a)+ b\log(L)$) (Froese 2006). If $b = 3$, fish body shape does not change as it grows (isometric growth); if $b < 3$, the fish becomes slender as its length increases (negative allometric growth) and if $b > 3$, the fish becomes deeper-bodied as its length increases (positive allometric growth) (Riedel *et al.* 2007).

We captured and measured a total of 1608 individuals from 32 species belonging to four orders, and 16 families (Table 2). The best represented family was Characidae (11 species), followed by Cichlidae (four species), while the rest had two or one species. Around half (47%) of the species presented negative allometric growth ($b < 3$), whereas 53 % presented positive allometric growth ($b > 3$). The b values ranged from 2.67 for *Anablepsoides* sp1. to 3.43 for *Steindachnerina argentea,* and the mean value was 3.03 (SD=0.21). The coefficient of determination (R^2) ranged from 0.89 to 0.99 and regressions were highly significant ($p < 0.001$) for all species (Table 2).

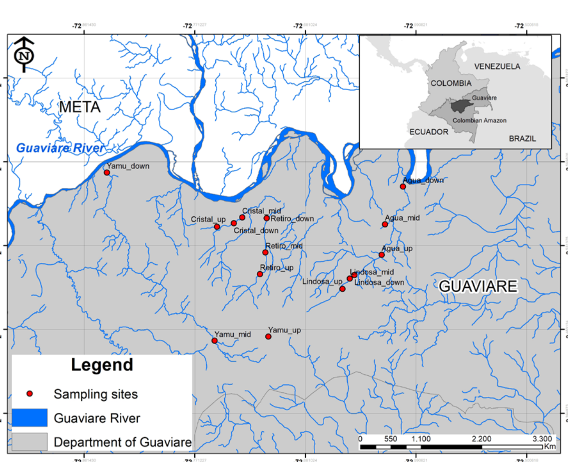

Figure 1. Location of the study area in the northwestern Colombian Amazon. Red dots represent sampling sites.

The values of coefficient b observed among our 32 species were within the expected range of 2.5 – 3.5 (Froese 2006). Our study included two new b reports, for *Knodus alpha* (2.85) and *Anablepsoides* sp. (2.67). These species, together with *Characidium zebra*, *Aphiocharax alburnus*, *Hoplerythrinus unitaeniatus*, *Hoplias malabaricus*, *Copella arnoldi*, *Pyrrhulina lugubris*, *Prochilodus mariae*, *Aequidens tetramerus*, *Bujurquina mariae*, *Duriglanis romani*, and *Rineloricaria eigenmanni*, *Pimelodella metae* and *Ituglanis metae* had $b < 3$ values, indicating that fishes became more elongated as they grew up (Riedel *et al.* 2007). The opposite pattern ($b > 3$ values) was obtained for *Acestrorhynchus falcatus, Brycon whitei, Astyanax interger, Astyanax bimaculatus, Charax metae, Creagrutus calai, Hemmigramus barrigonae, Hyphessobrycon acacia, Moenkhausia comma, Moenkhausia Mikia, Moenkhausia oligolepis, Satanoperca mapiritensis, Corydoras melini, Ancistrus triradiatus* and *Steindachnerina argentea*, *Bryconops giacopinii*, and *Crenicichla alta*, indicating that fishes became heavier as they grew up (Riedel *et al.* 2007). No species presented equal increase of dimensions at the same rate, i.e. $b = 3$. As reported by Fontoura et al (2010) the b coefficient can change depending on season, resource availability, sex, and environmental condition; oligotrophic systems are highly dependable on allochthonous inputs and this might explain why fish captured in sampling sites close to Guaviare River

Table 1. Geographical coordinates of the sample sites in the oligotrophic headwater streams in the Department of Guaviare, northwestern Colombian Amazon. Upper-reach sites are characterized by gravel bottoms, middle-reach sites present a mix of gravel and sand, and the lower-reach sites mostly present sandy - clay substrates. All sites present allochthonous material such as litter and logs.

Sampling Station	Reach	Geographical coordinates	
		N	W
Yamu	Upper	2°27′13.70″	72°45′17.80″
	Middle	2°27′25.90″	72°42′40.30″
	Lower	2°35′26.70″	72°50′34.20″
Retiro	Upper	2°31′32.70″	72°42′48.80″
	Middle	2°30′29.00″	72°43′5.00″
	Lower	2°33′13.10″	72°42′44.90″
Lindosa	Upper	2°29′21.71″	72°39′37.92″
	Middle	2°29′45.60″	72°39′2.20″
	Lower	2°30′26.40″	72°38′27.10″
Aguabonita	Upper	2°31′25.80″	72°37′7.50″
	Middle	2°32′55.00″	72°36′57.30″
	Lower	2°34′45.50″	72°36′4.90″
Cristalina	Upper	2°33′15.50″	72°43′56.60″
	Middle	2°32′58.10″	72°44′21.70″
	Lower	2°32′47.80″	72°45′10.70″

Table 2. Length-weight relationships (LWRs) parameters of 32 species of headwater streams in northwestern Amazonia, Department of Guaviare, Colombia.

Order/Family/Species	N	SL range (cm)	W range (g)	a	95% CI of a	b	95% CI of b	r2
Characiformes								
Acestrorhynchidae								
Acestrorhynchus falcatus (Bloch, 1794)	12	6.4 - 25.2	2.7 - 150.6	0.011	0.004 - 0.027	3.03	2.71 - 3.35	0.97
Bryconidae								
Brycon whitei (Myers & Weitzman, 1960)	25	10.4 - 25.5	13.7 - 198.5	0.002	0.0008 - 0.005	3.33	3.40 - 4.06	0.95
Characidae								
Aphyocharax alburnus (Günther, 1869)	30	2.2 - 7.9	0.1 - 5.4	0.021	0.014 - 0.027	2.81	2.57 - 3.02	0.96
Astyanax interger (Myers, 1930)	108	2.4 - 13.4	0.3 - 83.3	0.018	0.013 - 0.025	3.16	3.01 - 3.33	0.96
Astyanax bimaculatus (Linnaeus, 1758)	110	2.6 - 5.1	0.3 - 2.6	0.014	0.009 - 0.0220	3.21	2.87 - 3.53	0.98
Charax metae (Eigenmann, 1922)	32	2.6 - 6.5	0.3 - 5.8	0.011	0.008 - 0.017	3.25	3.02 - 3.49	0.98
Creagrutus calai (Vari & harold, 2001)	80	2.3 - 6.1	0.2 - 3.8	0.017	0.012 - 0.025	3.04	2.80 - 3.27	0.96
Hemmigramus barrigonae (Eigenmann & Henn, 1914)	111	2.1 - 4.7	0.1 - 3.1	0.013	0.008 - 0.023	3.36	2.91 - 3.81	0.96
Hyphessobrycon acaciae (García-Alzate, Román-Valencia & Prada-Pedreros, 2010)	101	2.2 - 3.5	0.2 - 1.3	0.009	0.002 - 0.033	3.26	2.57 - 4.95	0.98
Knodus alpha (Eigenmann, 1914)	16	2.6 - 4.5	0.3 - 1.6	0.022	0.014 - 0.036	2.85	2.47 - 3.24	0.97
Moenkhausia comma (Eigenmann, 1908)	95	4.1 - 8.2	1.7 - 18.5	0.016	0.004 - 0.053	3.37	2.69 - 4.0	0.98
Moenkhausia mikia (Marinho & Langeani, 2010)	52	2.6 - 6.6	0.3 - 5.9	0.018	0.014 - 0.023	3.07	2.91 - 3.24	0.98
Moenkhausia oligolepis (Günther, 1864)	92	2.1 - 7.2	0.2 - 12.1	0.024	0.020 - 0.029	3.13	3.01 - 3.25	0.99
Crenuchidae								
Characidium zebra (Eigenmann, 1909)	82	2 - 5.2	0.2 - 1.9	0.025	0.013 - 0.047	2.82	2.06 - 3.17	0.95
Curimatidae								
Steindachnerina argentea (Gill, 1858)	15	8.9 - 14.9	23.7 - 137.7	0.012	0.004 - 0.034	3.43	2.99 - 3.87	0.98
Erythrinidae								
Hoplerythrinus unitaeniatus (Spix & Agassiz, 1829)	10	9.9 - 20.5	19.5 - 146.3	0.042	0.021 - 0.085	2.89	2.43 - 2.94	0.99
Hoplias malabaricus (Bloch, 1794)	26	3.1 - 24.5	0.5 - 235.2	0.021	0.016 - 0.028	2.91	2.78 - 3.02	0.99
Iguanodectidae								
Bryconops giacopinii (Fernández-Yépez, 1950)	163	2.3 - 9.8	0.1 - 19.1	0.011	0.010 - 0.013	3.23	3.13 - 3.32	0.96
Lebiasinidae								
Copella arnoldi (Regan, 1912)	92	2.2 - 4.8	0.1 - 1.9	0.017	0.013 - 0.022	2.86	2.63 - 3.09	0.97
Pyrrhulina lugubris (Eigenmann, 1922)	37	2.1 - 4.7	0.2 - 2.2	0.019	0.014 - 0.025	2.98	2.75 - 3.21	0.95
Prochilodontidae								
Prochilodus mariae (Eigenmann, 1922)	11	3.4 - 14.3	1.2 - 19.5	0.079	0.018 - 0.329	2.79	1.72 - 3.06	0.89
Cichliformes								
Cichlidae								
Aequidens tetramerus (Heckel, 1840)	28	4.1 - 15.2	2.9 - 102.1	0.088	0.045 - 0.169	2.74	2.44 - 3.04	0.95
Bujurquina mariae (Eigenmann, 1922)	26	2 - 11.1	0.6 - 73.1	0.065	0.043 - 0.097	2.8	2.57 - 3.03	0.97
Crenicichla alta (Eigenmann, 1912)	25	3.2 - 13.7	0.4 - 55.6	0.007	0.005 - 0.010	3.42	3.27 - 3.58	0.99
Satanoperca mapiritensis (Fernández-Yépez, 950)	27	2.4 - 13.8	0.5 -99.6	0.033	0.029 - 0.038	3.01	2.95 - 3.07	0.97
Cyprinodontiformes								
Rivulidae								
Anoblepsoides sp1.	60	2.5 - 6.7	0.4 - 3.2	0.047	0.036 - 0.061	2.67	1.98 - 2.33	0.95
Siluriformes								

Table 2. Continued

Order/Family/Species	N	SL range (cm)	W range (g)	a	95% CI of a	b	95% CI of b	r2
Auchenipteridae								
Duringlanis romani (Mees, 1988)	18	2.1 - 3.3	0.2 - 1.3	0.046	0.027 - 0.078	2.76	2.66 - 3.18	0.95
Callichthyidae								
Corydoras melini (Lönnberg & Rendhal, 1930)	28	1.9 - 5.2	0.2 - 5.8	0.041	0.017 - 0.093	3.07	2.46 - 3.69	0.95
Loricariidae								
Ancistrus triradiatus (Eigenmann, 1918)	27	2.8 - 7.5	0.4 - 12.9	0.021	0.014 - 0.031	3.04	2.81 - 3.27	0.97
Rineloricaria eigenmanni (Pellegrin, 1908)	27	3.8 - 11.1	0.3 - 8.5	0.005	0.001 - 0.020	2.93	2.30 - 3.56	0.96
Heptateridae								
Pimelodella metae (Eigenmann, 1917)	15	3.4 - 8.4	0.6 - 7.6	0.014	0.004 - 0.043	2.9	2.21 - 3.58	0.98
Trichomyceridae								
Ituglanis metae (Eigenmann, 1917)	27	3.1 - 6.9	0.4 - 2.9	0.032	0.015 - 0.068	2.85	1.83 - .87	0.96

N= sample size, SL = standard length, W = total weight, a = linear coefficient, b = allometric coefficient, r^2 = coefficient of determination.

were heavier and larger than their counterparts in mid and upper parts of the streams. Downstream sites present larger forest cover on the banks which might provide additional resources than less forested areas upstream, where local settlements and agricultural activities are present and can affect resources quality and quantity (pers. obs). More studies are needed to understand how these conditions can affect the *b* parameter. Despite some species having either a small sample size or low r^2 values, we decided to include them since it was the first time these coefficients were reported for these locations. However, these LWRs should be treated with care (Giarrizzo *et al.*, 2015).

LWRs can be used to convert length into biomass, calculate fat storage and gonadal development and understand life cycles, therefore it can be used to asses fish stocks and fisheries, principally in regions where this activity represent pivotal economic income and fish is the main food source for local communities (Freitas *et al.* 2014) as it happens in the study region with species such as *C. melini*, *C. alta, P. mariae, B. giacopinii,* (Mojica *et al.* 2005, Sanabria Ochoa 2005, Gálvis *et al.* 2007). Thus, our results contribute a baseline for research programs that monitor how the values of coefficients *a* and *b* and other ecological traits change as fish populations are used, thus allowing sound decisions for sustainable fisheries.

Currently, northwestern Amazonia face threats associated with forest degradation, agricultural expansion, and illicit crops (Etter *et al.* 2006, Dávalos *et al.* 2011, Armenteras *et al.* 2019) that constitute deleterious effects on freshwater communities by altering streams integrity (Pelicice et al. 2017), fish life strategies and biological parameters as those presented herein. Accordingly, this study provides complementary information of the understudied fish fauna of these locations and that could contribute to local management and conservation policies (da Silva Freitas et al. 2017) by providing information that can be used for better understanding of the species growth patterns, fish stocks and health condition.

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