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TECHNICAL CONTRIBUTION

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Length–Weight relationships of 23 fish species from floodplain ecosystems of the Andean Amazon piedmont, Peru

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Summary
Length–weight relationships (LWRs) for 23 freshwater fish species from the Andean Amazon piedmont in Peru are presented in this study. Fishes were captured between 2009 and 2010 on lagoons from three basins; Amazonas (Ampiyacu and Apayacu) and Ucayali (Pachitea) using gillnets. In this study, new LWRs are reported for 20 species of 23 species analyzed. The study provides new information on less-studied species and can serve as a basis for management of fisheries and conservation of this area.

1 | INTRODUCTION

With the increase of the continental and marine fishing pressure, it has been necessary to implement a management system to regulate catches of the fish target species (Froese, Thorson, & Reyes, 2014). Fish body length and fish body weight are two useful empirical measures in stock assessment and more generally, in population ecology, community and ecosystem ecology studies (Jellyman, Booker, Crow, Bonnett, & Jellyman, 2013). Fish weight may be required and this may be estimated from length whether the weight-length relationships (WLRs) are known for the fish population under study (Froese, Tsikliras, & Stergiou, 2011). In recent years, scientific researchers have generated models to indirectly derive species-specific WLRs parameters. An example is the Bayesian hierarchical approach used by FishBase (Froese, 2006; Froese & Pauly, 2017; Froese et al., 2014). Weight-length relationships are often modeled with simple linear regressions by applying logarithm to predictor and response variables. This information is critical, allowing fishery scientists to estimate: weight of fish when it was impossible due to technical and field restrictions, fish age structure, fish growth rate, fish condition factor and moreover to modeling food webs or simulate fish population dynamics (Hilborn & Walters, 2001; Jellyman et al., 2013; Ogle, 2016). In Peru, few studies of freshwater ecosystems provide WLRs of fish species. Instituto del Mar del Peru (IMARPE) is the main Peruvian institution that performs this type of studies. The institute focuses its studies on the main species of commercial importance landed in the main ports of the country. However, there is a lack of scientific knowledge for the species, which play an important role in ecosystems and diet of the rural human populations. As regards the Amazonian basin, we have constancy of some studies for the ichthyofauna weight-length relationships (Giarrizzo, Bastos, & Andrade, 2011; Giarrizzo et al., 2015; Ruffino & Isaac, 1995; Schmid et al., 2015). Tobes, Miranda, Pino-del-Carpio, Araujo-Flores, and Ortega (2016) published the WLRs for 22 freshwater fish species collected in the Alto Madre de Dios River, Peru, study that presents weight-length relationships for freshwater fish species mostly endemic to the Peruvian Andean-Amazon piedmont. Our study estimates the weight-length relationships of 23 fish species captured in the Amazonian floodplain ecosystems of the North, and Central Peruvian's regions. These fish species are distributed throughout the Amazon Basin and play a very important role in the diet of the native communities of the northern, central and southern Peru.

TABLE 1 Descriptive statistics and LWRs parameters for 23 selected fish species from the floodplain ecosystems of Andean Amazon Basin (*N*: sample size; LS: Standard length (cm); *W*: weight (g); min: minimum; max: maximum; *SE*: Standard error; CI: Confidence interval; *a*: intercept; *b*: slope). *Species that have no empirical length–weight relationships estimates in FishBase database (Froese & Pauly, 2017). New records of maximum lengths in bold, max SL. Species with sample size is small in bold, estimate is indicated as "tentative"

Order/Family/Species	*N*	LS (cm) min–max	*W* (g) min–max	*a*	(95% CI of *a*)	*b*	(95% CI of *b*)	Residual standard error	Determination coefficient (r^2)
CHARACIFORMES									
Erythrinidae									
Hoplerythrinus unitaeniatus (Spix & Agassiz 1829) *	46	13.2–**28.5**	45.0–520.0	0.016	0.0087–0.0303	3.099	2.8898–3.3078	0.049	.95
Curimatidae									
Curimatella alburna (Müller & Troschel 1844)*	195	7.8–14.7	17.0–120.0	0.065	0.0505–0.0842	2.731	2.6181–2.8442	0.046	.92
Psectrogaster essequibensis (Günther 1864)*	23	11.3–15.8	20.0–115.0	0.014	0.0054–0.0343	3.304	2.9232–3.6850	0.048	.94
Chalceidae									
Chalceus erythrurus (Cope 1870)*	14	9.7–18.6	15.0–175.0	0.006	0.0030–0.0113	3.511	3.2645–3.7573	0.034	.99
Triportheidae									
Triportheus auritus (Valenciennes 1850)	**8**	13.4–**26.5**	25.0–160.0	0.021	0.0014–0.3204	2.785	1.8818–3.6880	0.089	.89
Acestrorhynchidae									
Acestrorhynchus abbreviatus (Cope 1878)*	**7**	13.7–**27.0**	30.0–200.0	0.02	0.0015–0.2704	2.861	1.9828–3.7383	0.08	.92
Acestrorhynchus lacustris (Lütken 1875)	**11**	14.2–**31.8**	30.0–290.0	0.022	0.0042–0.1116	2.779	2.2252–3.3319	0.071	.94
Characidae									
Charax tectifer (Cope 1870)*	**10**	9.9–**14.4**	20.0–60.0	0.035	0.0102–0.1194	2.783	2.2926–3.2741	0.038	.96
Cynopotamus amazonum (Günther 1868)*	**5**	9.1–**18.4**	15.0–130.0	0.017	0.0022–0.1314	3.028	2.2324–3.8234	0.068	.97
Gymnocorymbus thayeri Eigenmann 1908*	21	5.4–**7.4**	7.0–17.0	0.056	0.0271–0.1170	2.806	2.4048–3.2080	0.031	.92
SILURIFORMES									
Doradidae									
Amblydoras affinis (Kner 1855)*	15	7.5–**13.2**	12.0–55.0	0.032	0.0185–0.0556	2.901	2.6569–3.1458	0.033	.98
Amblydoras nauticus (Cope 1874)*	20	6.1–**11.1**	6.0–35.0	0.054	0.0178–0.1647	2.715	2.1828–3.2479	0.063	.86
Anadoras grypus (Cope 1872)*	53	7.5–**13.8**	10.0–70.0	0.058	0.0921–0.0921	2.71	2.5138–2.9068	0.047	.94
Trachydoras nattereri (Steindachner 1881)*	61	8.7–**12.4**	15.0–50.0	0.011	0.0058–0.0201	3.388	3.1193–3.6560	0.038	.92

(Continues)

TABLE 1 (Continued)

Order/Family/Species	N	LS (cm) min–max	W (g) min–max	a	(95% CI of a)	b	(95% CI of b)	Residual standard error	Determination coefficient (r^2)
Heptapteridae									
Goeldiella eques (Müller & Troschel 1849)*	48	7.4–25.5	5.0–210.0	0.016	0.0087–0.0275	3	2.8004–3.1990	0.077	.95
Callichthyidae									
Corydoras splendens (Castelnau 1855)*	36	6.5–**9.9**	12.0–40.0	0.063	0.0359–0.1099	2.867	2.6004–3.1341	0.039	.93
Megalechis picta (Müller & Troschel 1849)*	**13**	9.9–**17.0**	30.0–150.0	0.056	0.0196–0.1586	2.747	2.3204–3.1736	0.047	.94
Megalechis thoracata (Valenciennes 1840)*	**10**	9.8–15.5	30.0–140.0	0.015	0.0050–0.0447	3.313	2.8719–3.7543	0.03	.97
Loricariidae									
Pseudorinelepis genibarbis (Valenciennes 1840)*	41	10.5–20.5	35.0–250.0	0.016	0.0080–0.0305	3.252	3.0002–3.5040	0.052	.95
Pterygoplichthys pardalis (Castelnau 1855)*	192	8.1–31.5	15.0–465.0	0.039	0.0281–0.0529	2.784	2.6677–2.9000	0.086	.92
CICHLIFORMES									
Cichlidae									
Aequidens tetramerus (Heckel 1840)	23	6.5–14.6	15.0–175.0	0.053	0.0281–0.0991	2.991	2.7105–3.2715	0.526	.96
Mesonauta mirificus (Kullander & Silfvergrip 1991)*	16	5.7–8.9	10.0–40.0	0.044	0.0246–0.0779	3.071	2.7991–3.3431	0.028	.98
Pterophyllum scalare (Schultze 1823)*	24	5.1–**7.8**	7.0–25.0	0.054	0.0270–0.1065	3.018	2.6637–3.3727	0.041	.93

2 | MATERIALS AND METHODS

The study was conducted on four rivers of the Peruvian Andean-Amazon piedmont, belonging to two hydrogeological basins. Ampiyacu River, in four lagoon (Centro: 3°21′04.1″S 71°55′36.4″W; Ichichimi: 3°22′27.3″S 72°04′33.2″W; Larga: 3°21′58.2″S 72°04′39.6″W and Shangay: 3°20′38.5″S 71°55′59.9″W). Apayacu rivers in three lagoon (Largo: 3°25′11.7″S 72°14′16.7″W; Paco: 3°25′38.0″S 72°14′34.9″W, and Tipishca: 3°27′04.7″S 72°14′56.1″W), and, Pachitea River in four lagoon (Charuya: 8°45′12.7″S 74°36′44.6″W; Intiruya: 8°44′04.3″S 74°35′32.5″W; Pablo: 8°45′37.0″S 74°31′16.9″W, and Yanayacu: 8°46′18.2″S 74°34′55.9″W).

Sampling was carried out during 2009 and 2010. Fish were caught by two gillnets with six sections of 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, and 6.0 inches mesh size each. The two gillnets were 40 m long and 2.0 m high. The collected fishes were anesthetized, measured to the nearest 0.1 cm standard length (SL); the same fishes were weighed on a digital scale to an accuracy of 0.01 g and subsequently fixed in formalin (10%). Voucher specimens were kept for identification and preserved in alcohol (75%). Scientific names were validated according to the Catalog of Fishes of the California Academy of Sciences (Eschmeyer, Fricke, & van Laan, 2017).

2.1 | Weight-length relationships

The arithmetical form of the relationship between length (SL; in cm) and weight (*W*; in g) can be described by the power function (Eq. 1), and the parameters α and β can be estimated from linear regression applied to the log-transformed variables and fitted by the least squares statistic method using *W* as the dependent variable (Eq. 2). *Wi* is total weight of species *i*, SL*i* refers to standard of species *i*, α is the regression intercept and β is the regression slope. Several factors may affect fish length and weight, this can introduce bias (error) to the estimates, and therefore, we extended the model (Eq. 2) to include an error term (ε_i). This error assumed to be independent and normally distributed (Ogle, 2016; Ricker, 1973; Ricker, 1975).

$$W_i = a\mathrm{SL}_i^b 10^{\varepsilon_i} \quad (1)$$

$$\log_{10}(W_i) = \log_{10}(a) + b\log_{10}(\mathrm{SL}_i) + \varepsilon_i \quad (2)$$

In addition, the coefficient of determination (r^2), the confidence limits (95%) of the parameters *a* and *b*, and the level of significance of r^2 were calculated. In order to perform the linear regression method, these assumptions were corroborated: a line adequately represents the data, the measurement errors (i.e., ε_i) are independent, are normally distributed, and have a constant variance regardless of the value of the explanatory variable (i.e., homoscedastic).

3 | RESULTS

For this study, 892 individuals representing 3 orders, 11 families and 23 species were selected. Results of the regression analysis together with the descriptive statistics are shown in Table 1. All regressions are significant ($p < .01$), with a coefficient of determination (r^2) higher than .86 for all species. For 20 species (98% of the total), the length-weight parameters are previously unknown in the FISHBASE database (Froese & Pauly, 2017) marked by a star in Table 1. Nineteen species (87% of the total) present a new record of maximum length, previously unreported in FISHBASE database (Froese & Pauly, 2017) mark in bold in Table 1.

4 | DISCUSSION

In the present study the values of parameter b in the WLR varied from 2.71 to 3.51, the values is inside the range suggested by Carlander (1969), which show that the values of *b* should normally be between 2.5 and 3.5. Where; for $b = 3$, small specimens have the same shape and condition as large specimens; $b > 3$, large specimens have increased more in height or width than in length and in $b < 3$, large specimens have changed their body shape to become more elongated or small specimens were in better nutritional conditions at the time of sampling (Froese, 2006). This study shows more species with negative allometric than with positive allometric growth, where length increases more than weight $b < 3$ (negative allometric) and the weight of an organism increases more than length $b > 3$(positive allometric) (Wootton, 1992). Carlander (1977) demonstrated that values of $b < 2.5$ or >3.5 are often derived from samples with narrow size ranges and we found these size ranges for some species of Characiformes and Siluriformes.

The estimate of LWR of *Acestrorhynchus abbreviatus*, *Acestrorhynchus lacustris*, *Charax tectifer*, *Cynopotamus amazonum*, *Megalechis thoracata*, and *Triportheus auritus* is considered as tentative for the sample size that is very small. The results will be useful to fisheries studies because the data were sampled in a relatively preserved area and can be considered a reference for the natural conditions of the floodplain ecosystems of the Peruvian Amazon. Finally, this study provides basic information on LWRs for 23 fish species, constituting an important tool for the management of local fisheries, and an input to monitor potential environmental impacts on piedmont ecosystems in the Peruvian Andean Amazon.

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