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Research Article

Weight-Length and Length-Length Relationships of the Endangered Zebra Pleco *Hypancistrus zebra* (*Siluriformes*, *Loricariidae*) from the Xingu River, Amazon, Brazil

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Hypancistrus zebra is a *Loricariid* endemic to a very limited stretch of the Xingu River and has a high value in the ornamental fish trade. The natural populations have experienced high fishing pressure since the late 80s and were recently impacted by the construction of the third largest hydroelectric dam complex in the world, the Belo Monte Project. Since 2004, it has been considered critically endangered and had its capture and trade forbidden. Even with its capture and trade prohibited since 2004, the species continues to be one of the most trafficked fish in the world. The biometric knowledge of the species is essential for monitoring its natural populations and management in *ex situ* environments. This work aims to establish the weight-length relationship (WLR) and length-length relationship (LLR) of the species and to evaluate the condition factor (K) of *H. zebra* rescued from trafficking. The study was conducted at the Laboratório de Aquicultura de Peixes Ornamentais do Xingu from February 2022 to June 2022, estimating the parameters of WLR and LLR of 1165 specimens divided into four simple linear regression (SLR) models: all specimens, only juveniles, only females, and only males. The K of 190 specimens rescued from trafficking by the Brazilian Federal Police was evaluated. The WLRs and LLRs were estimated using SLR. The difference between the allometry coefficients (b) and between the residuals of the models (juveniles, females, and males) was evaluated using the ANOVA significance test. The total length of the species ranged from 1.6 to 9.3 cm. The coefficient of allometry (b) of the WLR of the species is 3.22 and of the LLR is 1.04, demonstrating that *H. zebra* presents positive allometric growth. The evaluation of the residuals of the models showed differences between ontogenetic stages and between sexes. The development of juveniles is isometric until the first sexual maturation phase and differs in negative allometric for females and positive allometric for males, showing sexual dimorphism in the species. Among the specimens rescued from trafficking, 54.74% were underweight, and 13.16% were under 60% of the expected K value, demonstrating the poor conditions in which these animals are transported by trafficking.

1. Introduction

Hypancistrus zebra (Isbrücker and Nijssen [5]) is a small-sized species of pleco (Siluriformes, Loricariidae) endemic to the middle Xingu River, a tributary of the Amazon basin [1]. The distribution of natural populations of this species is limited to a short stretch of approximately 150 km of river in a region that presents a biodiversity hotspot [2, 3]. The species inhabits regions of high environmental heterogeneity, characterized by the presence of rocky outcrops and the formation of strong currents [4]. These environments consist of sections of rocky substrates, promoting the formation of crevices that are used as shelters for protection and reproduction [4].

The species exhibits a pattern of oblique black and white stripes that extends throughout the body, including the fins [5]. Additionally, it features "E"-shaped stripes on the snout region, characterized by a black line connecting the two nostrils, extending downwards, along with another black line passing between the nostrils [5]. Its peculiar and attractive color pattern, rarity, and other ornamental fish characteristics have placed the species among the most sought-after in the aquarium market worldwide [3].

The demand for *H. zebra* in the international trade has intensified the fishing pressure on its natural populations since its discovery in the late 80s, contributing to its insertion into the list of critically endangered species [6, 7]. From then on, its trade was prohibited, but the illegal capture and market continued, and today the species is one of the most trafficked in the world [3]. It is estimated that 100,000 specimens are annually trafficked out of Brazil, with an average retail price of US$ 155 (± US$ 23 based on geographical location) per animal and an average wholesale price of US$ 100 (± US$ 94 over time) [3].

In addition to the fishing pressure on their natural populations, the construction of the Belo Monte Hydroelectric Plant brought considerable changes in its natural habitat, placing even more uncertainty about the future of the species [8]. All these factors converge to the urgency of implementing conservation and monitoring technologies for their populations, drawing attention to the importance of knowledge about their biology and ecology [9].

Two biometric records are fundamental for environmental monitoring and *ex situ* management: the weight-length relationship (WLR) and the length-length relationship (LLR) of the species [10]. The allometry coefficient (b) calculated in the WLR establishes the proportion in which the total weight rate increases in relation to length, establishing three growth patterns (positive allometric, negative allometric, and isometric) [11, 12]. The b also makes it possible to calculate the condition factor (K), indicating a rate, for which it is possible to evaluate the proportion at which the biomass of some specimens varies under certain conditions, and the LLR establishes the calculation to convert standard length to total length [13]. Therefore, the objective of this study is to establish the WLR and LLR relationships of *Hypancistrus zebra*, and to evaluate the condition factor (K) of specimens rescued from trafficking.

2. Materials and Methods

The study was conducted at the Laboratório de Aquicultura de Peixes Ornamentais do Xingu (LAQUAX), from Universidade Federal do Pará (UFPA), Altamira city, Pará state, Brazil. Measurements were performed between February 2022 and June 2022. All procedures were authorized by the Committee for the Use and Experimentation of UFPA (CEUA No. 1921240222) and IBAMA (No. 801598/2019).

All the fish used for collecting biometric data were rescued from trafficking through enforcement operations conducted by the Brazilian Federal Police and were housed at LAQUAX under the faithful custodian agreement (No. 801598/2019). The weight-length and length-length relationships were calculated based on biometric data from 1165 animals kept under suitable conditions for 2 years, simulating the limnological patterns of the Xingu River. The condition factor was assessed in 190 animals rescued immediately from trafficking.

A total of 1165 animals were used. The fish were anesthetized with $25\,mg.L^{-1}$ of eugenol. The total and standard lengths were measured with a digital caliper (0.01 mm) make ZAAS Precision, model digital 0–300 mm. The total weight of each specimen was measured with a digital scale with a Precision of 0.001 g, make Laborana, model EL. Sex was determined by macroscopic analysis of external secondary sexual characteristics (Figure 1) [14], and the age of first sexual maturation was established based on the size of the specimens (Figure 2) [15].

After evaluating the assumptions of simple linear regression, the parameters intercept (a) and angular coefficient (b) of WLRs and LLRs were estimated by regression analysis on log-transformed data [13]. The degree of association between the variables was calculated by the correlation coefficient (r) [10]. The verification of outliers was determined from the coefficient of determination less than 0.95 (R^2) [16].

The growth type was determined by the angular coefficient (b), and the difference between the residuals of the regression models was calculated using the one-way ANOVA significance test comparing (juveniles and females), (juveniles and males), and (females and males) [17].

Subsequently, the condition factor (K) was verified for 190 animals seized from trafficking by the Brazilian Federal Police at the airport in the city of Altamira, the starting point for the trafficking route [3]. The ideal K ($K \geq 1$) was calculated by the ratio of the observed weight (W_o) by the estimated weight (W_e) and the (W_e) specific to each model, were calculated from the equations generated by the trend lines of the scatter plots of the regressions [13].

3. Results

We analyzed the biometric data of 1165 specimens of the species *Hypancistrus zebra*, divided into two ontogenetic stages (juveniles and adults) and between sexes (Table 1). The total length of the observed animals ranged from 1.62 to 9.30 cm, and the weight ranged from 0.04 to 7.40 g (Table 1).

All regressions were highly significant ($P < 0.001$), with the correlation coefficient R^2 ranging from 0.9003 to 0.9848 for WLRs (Table 2) and from 0.9016 to 0.9860 for LLRs (Table 3). The allometric coefficient (b) of the WLRs and the residuals of the models of all regressions varied significantly ($P < 0.001$), demonstrating a difference in growth between ontogenetic stages and between sexes (Table 2).

The regressions with their respective equations for the trend lines of the WLRs of the species are represented in (Figure 3), for juveniles only in (Figure 4), for females in (Figure 5), and for males in (Figure 6). All regressions were represented by scatter plots with a significance level of 95%.

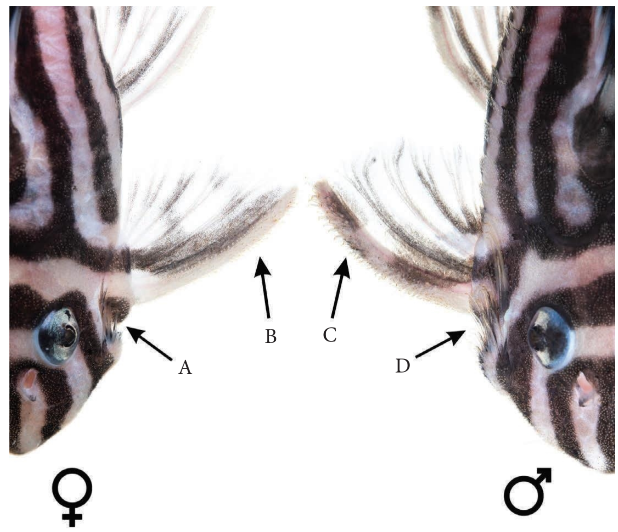

Figure 1: External sexual dimorphism in two adult zebra plecos. The female (SL = 5.67 cm) presents smaller odontodes on the opercular region (A) and on pectoral spine (B) while the male (5.92 cm) has hypertrophied odontodes on the pectoral spine (C) and (D) opercular region.

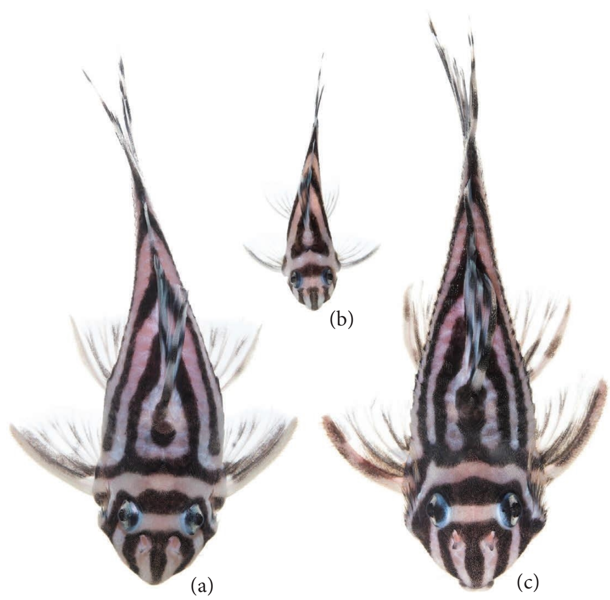

Figure 2: Body shape and size comparison between adult zebra plecos and a juvenile. (a) An adult female (SL = 5.67 cm), (b) a juvenile (SL = 2.93 cm), and (c) an adult male (SL = 5.92 cm).

Table 1: Biometric data for the species (all), juveniles only, females only, and males only. *N* is sample size, (TL) is total length in cm, (*W*) is weight in g, (Min.) equals minimum, and (Max.) is maximum.

		Standard length (cm)		Weight (g)		Average	
	N	Min.	Max.	Min.	Max.	TL	*W*
All	1165	1.62	9.30	0.04	7.40	5.74	2.24
Juveniles	418	1.62	4.98	0.04	1.32	4.10	0.65
Females	269	5.09	8.06	1.50	4.94	6.46	2.78
Males	478	4.99	9.30	1.02	7.40	6.78	3.32

Table 2: Weight-length relationships (WLRs) of the species (all), juveniles only females only, and males only, based on the equation LOG (W) = LOG (*a*) + (*b*) LOG (TL), where (*a*) is the intercept and (*b*) is the angular coefficient. *N* is the sample size, (TL) is total length in cm, and (*W*) is weight in g. CL is the confidence limits, and R^2 is the coefficient of determination.

	N	(*a*)	95% CL *a*	(*b*)	95% CL *b*	R^2
All	1165	0.00648	0.00622–0.00675	3.22	3.20–3.25	0.9848
Juveniles	418	0.00881	0.00813–0.00954	2.98	2.93–3.04	0.9600
Females	269	0.01441	0.01165–0.01783	2.81	2.69–2.92	0.9003
Males	478	0.00550	0.00472–0.00640	3.31	3.23–3.39	0.9354

Table 3: Length-to-length relationships (LLRs) of the species (all), females only, and males only, based on the equation LOG (TL) = LOG (*a*) + (*b*) LOG (SL), where (*a*) is the intercept and (*b*) is the angular coefficient. *N* is the sample size, (TL) is total length in cm, and (SL) is standard length in cm. CL is the confidence limits and R^2 is the coefficient of determination.

	N	(*a*)	95% CL *a*	(*b*)	95% CL *b*	R^2
All	1165	0.67465	0.66624–0.68318	1.04	1.03–1.04	0.9860
Juveniles	418	0.67698	0.65756–0.69696	1.03	1.01–1.05	0.9599
Females	269	0.74192	0.68891–0.79902	0.99	0.95–1.03	0.9016
Males	478	0.65490	0.62815–0.68279	1.05	1.03–1.07	0.9512

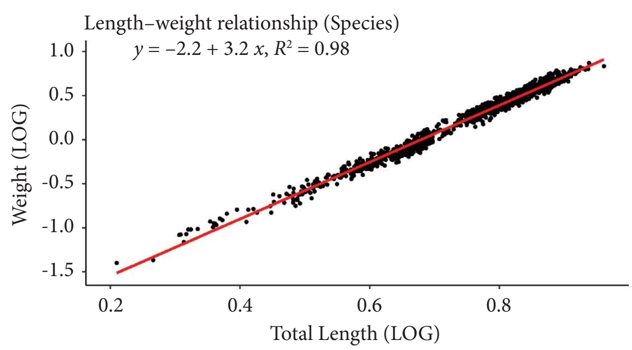

Figure 3: Weight-length relationship (WLR) of *Hypancistrus zebra* based on the equation $y = (\text{LOG (W)}) = \text{LOG } (a) + (b)\ x = (\text{LOG (L)})$, where (*a*) is the intercept, (*b*) is the angular coefficient, and R^2 is coefficient of determination. (*L*) is the LOG of total length in cm, and (*W*) is the LOG of weight in g.

Regressions with their respective equations for the trend lines of the LLRs of the species are represented in (Figure 7), for juveniles only (Figure 8), females (Figure 9), and males (Figure 10). All regressions were represented by scatter plots a with 95% significance level.

We analyzed the condition factor (*K*) of 190 species seized from trafficking, showing that 54.74% of the specimens analyzed were below the expected weight ($K < 1$), with 13.16% of the specimens presenting biomass below 60% of the condition factor.

4. Discussion

Giarrizzo et al. [10] established the length-weight relationship of 135 fish species from the middle Xingu River. Among the sampled species, nine specimens of *Hypancistrus zebra* were evaluated without distinction of sex or ontogenetic phase. To improve this, our study used a more significant sample of 1165 specimens, divided by sex and ontogenetic stage, and applied the coefficient (*b*) to establish the condition factor (*K*) of 190 animals rescued from trafficking in the city of Altamira.

The values of (*b*) of the WLRs observed in the species were within the expected range of 2.5–3.5 [18]. As suggested in [11], several fish species may show differences between the values of the angular coefficient of WLRs, between ontogenic stages, and between sexes. For example, *H. zebra* showed a difference between juveniles compared to adults and between females and males.

The juveniles of the species grow isometrically until they reach the age of first sexual maturation. Upon reaching adulthood, growth varies between the sexes. Females show negative allometric growth, while males develop a pattern of positive allometric growth, exhibiting sexual dimorphism in the body shape of *H. zebra*. This change in body anatomy occurs due to variations in the still developing secondary sexual characteristics in juveniles. Males tend to be more slender, while females require a larger abdominal space to accommodate mature gonads.

Among the 190 specimens of *H. zebra* rescued from trafficking, we observed that 54.74% of the animals were underweight, with 13.16% below 60% of the condition factor. Taking into consideration that the city of Altamira is the beginning of the wild specimen trafficking route and that up

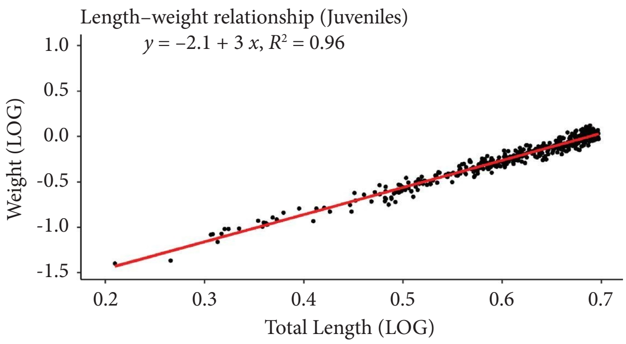

Figure 4: Weight-length relationship (WLR) of juvenile *Hypancistrus zebra* based on the equation $y = (\text{LOG}\ (W)) = \text{LOG}\ (a) + (b)\ x = (\text{LOG}\ (L))$, where ($a$) is the intercept, ($b$) is the angular coefficient, and R^2 is coefficient of determination. (L) is the LOG of total length in cm, and (W) is the LOG of weight in g.

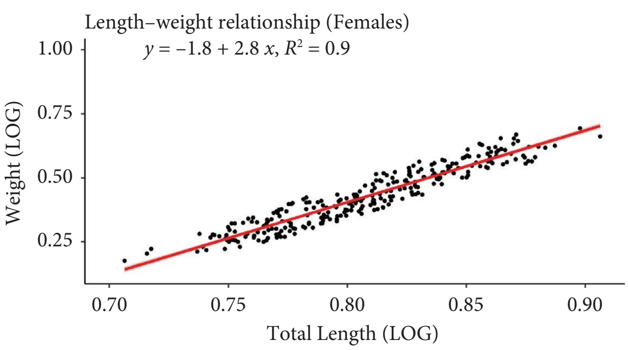

Figure 5: Weight-length relationship (WLR) of female *Hypancistrus zebra* based on the equation $y = (\text{LOG}\ (W)) = \text{LOG}\ (a) + (b)\ x = (\text{LOG}\ (L))$, where ($a$) is the intercept, ($b$) is the angular coefficient, and R^2 is coefficient of determination. (L) is the LOG of total length in cm, and (W) is the LOG of weight in g.

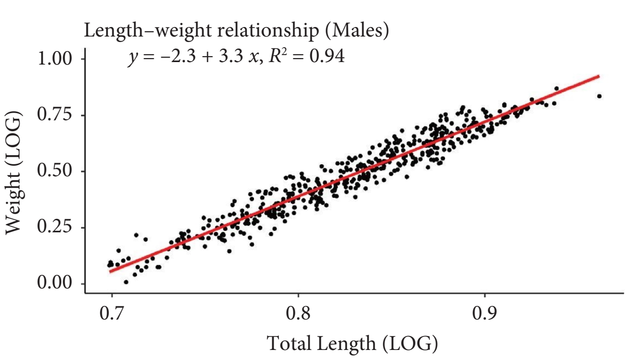

Figure 6: Weight-length relationship (WLR) of males of *Hypancistrus zebra* based on the equation $y = (\text{LOG}\ (W)) = \text{LOG}\ (a) + (b)\ x = (\text{LOG}\ (L))$, where ($a$) is the intercept, ($b$) is the angular coefficient, and R^2 is coefficient of determination. (L) is the LOG of total length in cm, and (W) is the LOG of weight in g.

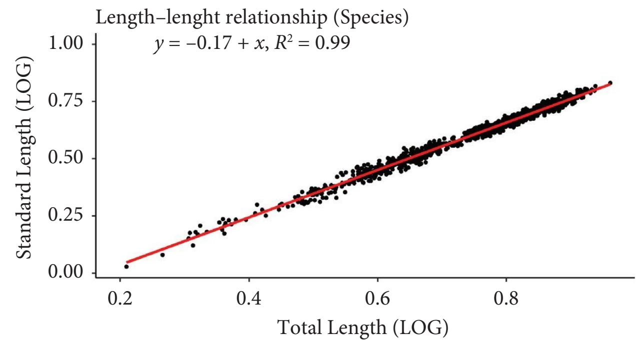

Figure 7: Length-to-length ratio (LLR) of *Hypancistrus zebra* based on the equation $y = (\text{LOG}\ (\text{SL})) = \text{LOG}\ (a) + (b)\ x = (\text{LOG}\ (\text{TL}))$, where ($a$) is the intercept, ($b$) is the angular coefficient, and R^2 is coefficient of determination. (SL) is the LOG of standard length in cm, and (TL) is the LOG of total length in cm.

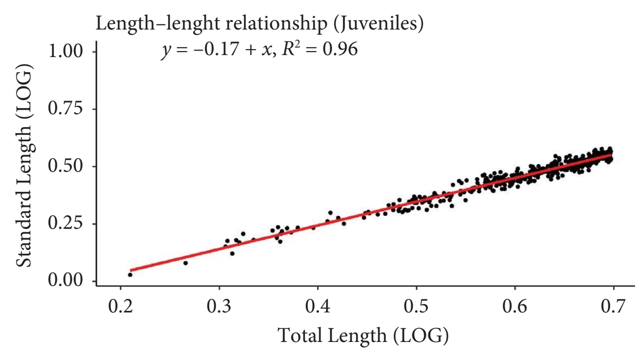

Figure 8: Length-to-length ratio (LLR) of juvenile *Hypancistrus zebra* based on the equation $y = (\text{LOG}\ (\text{SL})) = \text{LOG}\ (a) + (b)\ x = (\text{LOG}\ (\text{TL}))$, where ($a$) is the intercept, ($b$) is the angular coefficient, and R^2 is the coefficient of determination. (SL) is the LOG of standard length in cm, and (TL) is the LOG of total length in cm.

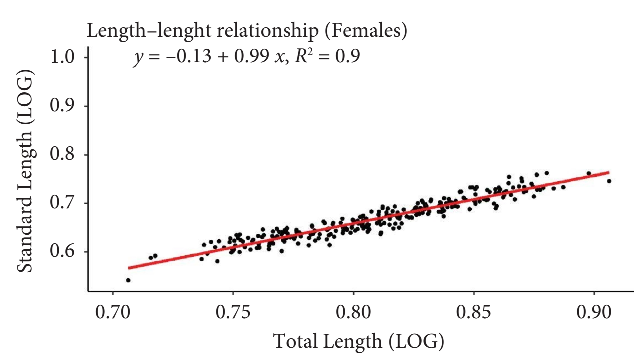

Figure 9: Length-to-length ratio (LLR) of female *Hypancistrus zebra* based on the equation $y = (\text{LOG}\ (\text{SL})) = \text{LOG}\ (a) + (b)\ x = (\text{LOG}\ (\text{TL}))$, where ($a$) is the intercept, ($b$) is the angular coefficient, and R^2 is coefficient of determination. (SL) is the LOG of standard length in cm, and (TL) is the LOG of total length in cm.

to 70% of all trafficked animals are sent to China in suitcases for a long period of time [3], it is likely that 54.74% of the animals were at risk of death or would arrive very weak to their final destination, and probably 13.16% would not arrive alive.

According to [3], the mortality rate of trafficked *H. zebra* is highest during the first stages of the journey, which goes from capture to arrival in Bogotá (Colombia) or Iquitos (Peru). These animals are usually packed in bags with low oxygen or adequate insulation and can reach temperatures

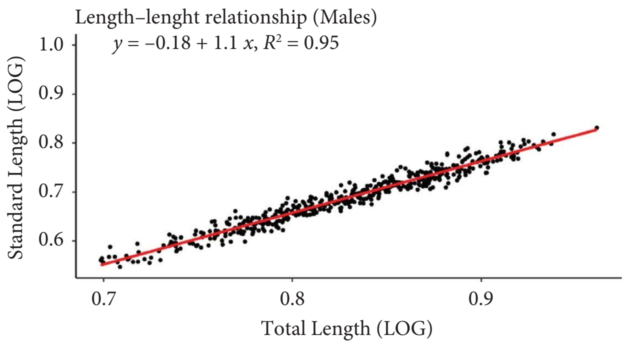

FIGURE 10: Length-to-length ratio (LLR) of males of *Hypancistrus zebra* based on the equation $y = (\text{LOG (SL)}) = \text{LOG } (a) + (b)$ $x = (\text{LOG (TL)})$, where (a) is the intercept, (b) is the angular coefficient, and R^2 is coefficient of determination. (SL) is the LOG of standard length in cm, and (TL) is the LOG of total length in cm.

above 32°C. In addition, the animals that die midway through the journey can increase the amount of ammonia in the enclosed environment.

A condition factor with $K < 1$ may indicate inadequate nutrition or unbalanced homeostasis; thus, fish with K below the expected level are more susceptible to death or suffering irreparable physical injuries [13]. Sousa et al. [3] reported that the average mortality of trafficked *H. zebra* is 50%; this data corroborate with the sampled data of 54.74% of animals below the expected condition factor.

5. Conclusions

Hypancistrus zebra is considered critically endangered in Brazil and by the IUCN, and the results obtained in this study will be useful for work related to the conservation of the species. The WLR, besides facilitating the conversion of length into weight, allows the calculation of the condition factor (K) of animals in *in situ* and *ex situ* environments, helping in the environmental monitoring of the species and the management of these animals in artificial biotopes. Furthermore, this study presents the LLR of the species, enabling the conversion of standard length into total length, and establishes a new maximum length for the species from a measured marker of 9.30 cm.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

This study was part of Fábio Barros's PhD thesis.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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References

[1] H. Evers, J. K. Pinnegar, and M. I. Taylor, "Where are they all from?–sources and sustainability in the ornamental freshwater fish trade," *Journal of Fish Biology*, vol. 94, no. 6, pp. 909–916, 2019.

[2] F. C. P. Dagosta, M. Pinna, C. A. Peres, and V. A. Tagliacollo, "Existing protected areas provide a poor safety-net for threatened Amazonian fish species," *Aquatic Conservation: Marine and Freshwater Ecosystems*, vol. 31, no. 5, pp. 1167–1189, 2021.

[3] L. M. D. Sousa, O. Lucanus, J. P. Arroyo-Mora, and M. Kalacska, "Conservation and trade of the endangered *Hypancistrus zebra* (Siluriformes, Loricariidae), one of the most trafficked Brazilian fish," *Global Ecology and Conservation*, vol. 27, Article ID e01570, 2021.

[4] F. M. Ramos, L. B. Recuero, T. V. N. Silva, R. Y. Fujimoto, J. T. Lee, and M. Ferreira Torres, "Shelter selection in the amazonian zebra pleco, *Hypancistrus zebra* isbrücker & nijissen, 1991 (siluriformes: Loricariidae): requirements in rearing conditions," *Journal of Applied Ichthyology*, vol. 29, no. 4, pp. 927–929, 2013.

[5] I. J. H. Isbrücker and H. Nijssen, "Hypancistrus zebra, a new genus and species of uniquely pigmented ancistrine loricariid fish from the rio xingu, brazil (pisces: siluriformes: loricariidae)," *Ichthyological Exploration of Freshwaters*, vol. 1, 1991.

[6] Mapa, "Ministerio do Estado do Meio Ambiente (Mapa), *Instrução Normativa MMA No 05, de 21 de Maio de 2004*, Ministerio do Estado do Meio Ambiente (MAPA), Brasilia, Brazil, 2004.

[7] ICM de C da B (Icmbio) and H. zebra, *The IUCN Red List of Threatened Species*, Instituto Chico Mendes de Conservação da Biodiversidade, 2022.

[8] A. C. Lees, C. A. Peres, P. M. Fearnside, M. Schneider, and J. A. S. Zuanon, "Hydropower and the future of Amazonian biodiversity," *Biodiversity & Conservation*, vol. 25, no. 3, pp. 451–466, 2016.

[9] J. S. Caldas, A. L. da Silva, L. M. de Sousa et al., "Effects of hormonal treatment on induced spermiation and semen quality in the endangered Amazonian fish *Hypancistrus zebra* (Siluriformes, Loricariidae)," *Aquaculture*, vol. 533, Article ID 736140, 2021.

[10] T. Giarrizzo, R. R. de Sena Oliveira, M. Costa Andrade et al., "Length-weight and length-length relationships for 135 fish species from the Xingu River (Amazon basin, Brazil)," *Journal of Applied Ichthyology*, vol. 31, no. 2, pp. 415–424, 2015.

[11] R. Froese, "Cube law, condition factor and weight-length relationships: history, meta-analysis and recommendations," *Journal of Applied Ichthyology*, vol. 22, no. 4, pp. 241–253, 2006.

[12] V. Lugert, G. Thaller, J. Tetens, C. Schulz, and J. Krieter, "A review on fish growth calculation: multiple functions in fish production and their specific application," *Reviews in Aquaculture*, vol. 8, no. 1, pp. 30–42, 2016.

[13] N. Jisr, G. Younes, C. Sukhn, and M. H. El-Dakdouki, "Length-weight relationships and relative condition factor of fish inhabiting the marine area of the Eastern Mediterranean city, Tripoli-Lebanon," *The Egyptian Journal of Aquatic Research*, vol. 44, no. 4, pp. 299–305, 2018.

[14] R. G. A. Reis, R. S. Oliveira, I. K. Da Silva Viana et al., "Evidence of secondary sexual dimorphism in king tiger plecos *Hypancistrus* sp, Loricariidae, of the Amazon river basin," *Aquaculture Research*, vol. 53, no. 10, pp. 3718–3725, 2022.

[15] A. P. O. Roman, *Biologia reprodutiva e dinâmica populacional de Hypancistrus zebra Isbrücker & Nijssen, 1991 (Siluriformes, Loricariidae), no rio Xingu, Amazônia brasileira*, Universidade Federal do Pará, Instituto de Ciências Biológicas, Belém, 2011.

[16] T. Barnett and V. Lewis, *Outliers in Statistical Data*, Wiley, Chichester, England, 1994.

[17] Q. M. Dinh, T. H. D. Nguyen, L. Nguyen-Ngoc, and T. T. K. Nguyen, "Temporal variation in length-weight relationship, growth and condition factor of Acentrogobius viridipunctatus in the Mekong Delta, Viet Nam," *Regional Studies in Marine Science*, vol. 55, Article ID 102545, 2022.

[18] A. T. İlkyaz, G. Metin, O. Soykan, and H. T. Kinacigil, "Length-weight relationship of 62 fish species from the central aegean sea, Turkey," *Journal of Applied Ichthyology*, vol. 24, no. 6, pp. 699–702, 2008.