Population dynamics of two Andean *Trichomycterus* (Siluriformes: Trichomycteridae) species from Bolivia

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The species of *Trichomycterus* (Siluriformes: Trichomycteridae) are small catfish distributed throughout South and Central America, from Patagonia to Costa Rica, at elevations ranging from sea level to over 4,000 m. In Bolivia, 17 species have been recorded, but information about the status of their populations and their relationship with the environment is unknown. This study addressed the population dynamics of two species (*T.* cf. *corduvensis* and *T. tiraquae*) in an Andean river from the Cochabamba Department in Bolivia, over a hydrological cycle. Monthly abundance, size structure, condition factor (K), and the relationship between abundance and environmental factors were calculated using multiple regressions. Results indicated that *T.* cf. *corduvensis* is more abundant than *T. tiraquae*. The temporal variation in the abundance of both species is related to the hydrological cycle and local factors, without showing a clear habitat preference. Juvenile individuals predominate, and the condition factor did not vary significantly.

Keywords: Andean catfish, Condition factor, Environmental factors, Hydrological cycle, Size structure.

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Las especies de *Trichomycterus* (Siluriformes: Trichomycteridae) son pequeños bagres distribuidos por América del Sur y Central, desde la Patagonia hasta Costa Rica, en elevaciones que van desde el nivel del mar hasta más de 4000 m. En Bolivia se han registrado 17 especies, pero se desconoce información sobre el estado de sus poblaciones y su relación con el medio ambiente. Este estudio abordó la dinámica poblacional de dos especies (*T.* cf. *corduvensis* y *T. tiraquae*) en un río andino del departamento de Cochabamba en Bolivia, durante un ciclo hidrológico. La abundancia mensual, la estructura de tallas, el factor de condición (K) y la relación entre la abundancia y los factores ambientales se calcularon mediante regresiones múltiples. Los resultados indicaron que *T.* cf. *corduvensis* es más abundante que *T. tiraquae*. La variación temporal en la abundancia de ambas especies está relacionada con el ciclo hidrológico y factores locales, sin mostrar una clara preferencia de hábitat. Predominan los individuos juveniles y el factor condición no varió significativamente.

Palabras clave: Bagre andino, Ciclo hidrológico, Estructura de tallas, Factor de condición, Factores ambientales.

INTRODUCTION

The Trichomycteridae family comprises a wide variety of catfish, distributed throughout South and Central America (Arratia, 1990). The genus *Trichomycterus* Valenciennes, 1832, part of the family Trichomycteridae, is the most species-rich and taxonomically complex within the subfamily Trichomycterinae, comprising more than 250 nominal species (Fricke *et al*., 2024). This complexity arises from its broad geographic distribution, non-monophyletic status, and numerous cases of synonym, alongside heterogeneous descriptive methodologies (de Pinna, 1989, 1998; Ochoa *et al*., 2020; Lima *et al*., 2021). Despite these challenges, the integration of morphological and DNA sequence data has enabled the identification and delimitation of at least 14 species in specific basins, including six newly described ones (Reis, de Pinna, 2023). Such integrative approaches are crucial for resolving the taxonomic ambiguity of *Trichomycterus* and advancing our understanding of its diversity. Species of this genus inhabit a broad range of habitats, from Patagonia to Costa Rica, at elevations ranging from sea level to over 4,000 m (Chará *et al*., 2006). This genus is commonly found in neotropical headwater rivers (Pouilly, Miranda, 2003), and around 60 species are endemic to the Andean-draining basins (Alencar, Costa, 2004).

Trichomycterus species have been defined as cold-water torrent-dwelling fish (Ringuelet *et al*., 1967). Some species exhibit habitat preferences that vary with age, influenced by the presence or absence of certain structures (Arratia, 1976). Their distribution in rivers is discontinuous, affected by factors such as substrate type and color, depth, and water speed. They inhabit substrates ranging from muddy to rocky (Arratia, 1983). Most species live in well-oxygenated rivers with rocky substrates (Arratia, 1983; Flórez, Sarmiento, 1991; Bizerril, 1994; Ruiz, Berra, 1994; Román-Valencia, 2001), although they are occasionally found in muddy and sandy substrates with slow currents and variable oxygen levels (Chará *et al*., 2006).

In general terms, *Trichomycterus* species are invertivore, feeding primarily on benthic organisms (Chará *et al*., 2006). Studies have found that their diet predominantly includes macroinvertebrates Diptera (Chironomidae, Culicidae), Ephemeroptera and Plecoptera (Bizerril, 1994; Habit *et al*., 2005; Chará *et al*., 2006; Scott *et al*., 2007; Manoni *et al*., 2009), with some species mainly consuming Chironomidae, Trichoptera, and Oligochaeta (Chará *et al*., 2006). In Chile, was reported Chironomidae as the main food source (Campos, 1985; Ruiz, Berra, 1994; Habit *et al*., 2005; Scott *et al*., 2007). One species exhibited an opportunistic feeding habit, consuming the most abundant macroinvertebrates (Chará *et al*., 2006). In Colombia, the diet was dominated by Elmidae and Diptera (Román-Valencia, 2001). Other studies found that the principal order in the diet was Ephemeroptera (Baskin *et al*., 1980; Arellano *et al*., 1983; Argermeier, Karr, 1983; Ruiz *et al*., 1993; Bizerril, 1994).

The reproduction of some *Trichomycterus* species can be seasonal, coinciding with the onset of the rainy season (Cala, Sarmiento, 1982; Chará *et al*., 2006). In population from Chile, according to Arratia (1983), *Trichomycterus areolatus* Valenciennes, 1846 lacks evident external sexual dimorphism between "pseudoadult" and adult males and females, which is uncommon among siluriform fishes. This species reaches reproductive maturity at a relatively small size, with minimum lengths of 51.1 mm for females with mature oocytes and 56.7 mm for males with spermiation. *Trichomycterus areolatus* demonstrates asynchronous ovarian development, characterized by the presence of immature, previtellogenic, vitellogenic, and mature oocytes within mature gonads (Manriquez *et al*., 1988). This results in an extended reproductive period and the likelihood of multiple spawning events within a single reproductive season. Fecundity in this species correlates more strongly with body weight than with age or length, underscoring its precocial development and variable spawning periods potentially influenced by environmental factors (Arratia, 1983; Manriquez *et al*., 1984, 1988). In a population from the Andes of Colombia, monthly precipitation was found to significantly correlate with the number of small individuals, with peaks observed in October and February, and absence in June, July, and December. This suggests year-round reproduction with peaks in October-November and February-March (Chará *et al*., 2006). In Bolivia, some species exhibit a K-strategy, with larger and fewer eggs, while others follow an r-strategy, with smaller and more numerous eggs, depending on the environmental conditions of the rivers (Miranda, Pouilly, 2001).

A study conducted by Arraya *et al*. (2009) recorded 17 species of *Trichomycterus* and several listed as "sp." (undetermined species following current descriptions for Bolivia) in the Bolivian Andes. Despite their widespread distribution, available information on the status of populations and their relationship with the environment is limited. There are no studies determining the status of their populations and relationship with environmental factors in Bolivia.

The aim of the present study was analyzed the population dynamics of two *Trichomycterus* species, *T.* cf. *corduvensis* Weyenbergh, 1877 and *T. tiraquae* (Fowler, 1940) in the Pucara River (Cochabamba, Bolivia) over a hydrological cycle, by obtaining data on abundance, size structure, condition factor (K), and the influence of environmental factors.

MATERIAL AND METHODS

Sampling sites. The Pucara River is an Andean Mountain River located in the upper Valley of the Cochabamba department, Bolivia (Punata Province, Punata Municipality). It is a tributary of the Rocha River basin, forming part of the hydrological network of the Grande-Mamoré River system (Amazon basin). The sampling section was situated between 2,839–2,846 m of elevation, between -17.503419 and -17.500389 latitude, and -65.798486 and -65.796899 longitude (Fig. 1).

Two habitats were identified in the studied section: fast riffles and slow riffles following the habitat classification of Aadland (1993), where six sampling sites were established (three per habitat). Fish captures were performed using an electric fishing gear, with a configuration of 450 V and 100 Hz (conditions adjusted according to equipment instructions), in spot sampling of 3 m^2 (2 m * 1.5 m) and for 120 s. Samples

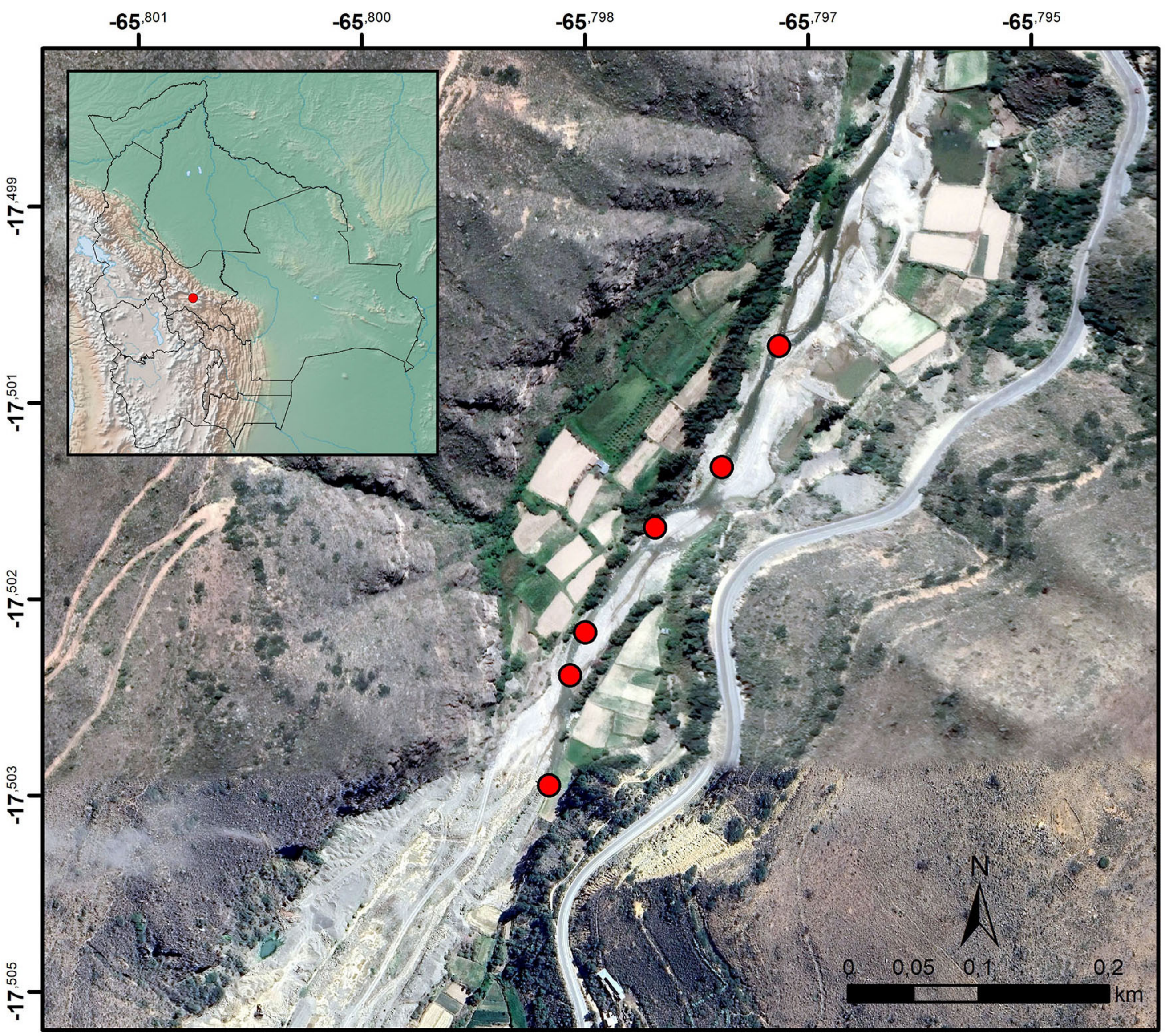

FIGURE 1 | Geographic location of the site of study at the Pucara River, Municipality of Punata, Department of Cochabamba, Bolivia.

of *T.* cf. *corduvensis* and *T. tiraquae* (Fig. 2) were euthanized using clove oil extract and subsequently preserved in 10% formalin and transported to the fish collection of the Unidad de Limnología y Recursos Acuáticos (ULRA), University Mayor de San Simón (UMSS), Cochabamba. During the peak high-water period (December), sampling was not possible due to high discharge and turbulence.

FIGURE 2 | Preserved individuals of *Trichomycterus* cf. *corduvensis* (left column) and *T. tiraquae* (right column) from the Pucara River, Cochabamba, Bolivia. Fish collection codes: **A**. UMSS 18231.1, 95.38 mm SL; **B**. UMSS 18231.2, 66.96 mm SL; **C**. UMSS 18239.1, 53.18 mm SL; **D**. UMSS 18239.2, 42.98 mm SL; **E**. UMSS 18231.3, 26.80 mm SL; **F**. UMSS 18239.5, 12.39 mm SL; **G**. UMSS 18624.1, 57.28 mm SL; **H**. UMSS 18622.1, 50.64 mm SL; **I**. UMSS 18624.2, 26.04 mm SL; **J**. UMSS 18624.3, 23.28 mm SL; **K**. UMSS 18623.1, 21.13 mm SL; **L**. UMSS 18623.2, 18.51 mm SL.

In the collection sites, the following environmental factors were obtained: pH, temperature (°C), electrical conductivity (µS cm^{-1}), dissolved oxygen (mg l^{-1}), substrate type (% of rock, block, stone, gravel, pebble, sand, and silt–clay), full channel width (m), wetted channel width (m), water height (cm), habitat length (m), and water velocity (m s^{-1}), following the techniques of Maldonado, Goitia (2001). This process was carried out every six weeks over a year to know variation in a hydrological cycle. Additionally, benthic macroinvertebrates were collected to assess food availability using a Surber net with a mesh porosity of 250 µm, with three replicates at each of the sites. Macroinvertebrates samples were preserved in 10% formalin.

The summary values of the environmental factors for the Pucara River are presented in Tab. 1. A wide variation was observed in some factors, such as the full channel width, wet channel width, habitat length, and water height, which are related to the average channel size. It was noted that temperature and water velocity showed considerable variation. Water oxygen ranged between 6.1 and 11.9 mg/L. Conductivity indicated that the river is moderately mineralized, with slightly basic waters (pH between 7.2 and 8.9), and a prevalence of coarse substrate. Macroinvertebrates were found to exhibit significant variability in their abundance.

Statistical analyses. Morphological analysis was conducted by measuring standard length (SL) using a precision calipers with a 0.01 mm of accuracy, and weight (W) using a digital scale with a 0.01 g of precision. Macroinvertebrate samples were taxonomically identified at family level and quantified. Fish abundance by species was obtained through the total count of captured individuals, to determine the variation of population abundance in both species throughout the hydrological cycle, categorized

TABLE 1 | Summary values of environmental factors obtained throughout eight samples of the hydrological cycle from the Pucara River between April 2021 and April 2022. Min = Minimum; Max = Maximum; Abun = Abundance.

Environmental factors	Min / Max	Mean
Full channel width (m)	11.8 / 45.3	22.3
Wetted channel width (m)	4.8 / 10.8	7.2
Habitat length (m)	8.7 / 29.2	18.7
Temperature (°C)	16.2 / 22	18.6
Dissolved oxygen (mg l^{-1})	6.1 / 11.9	8.2
Electrical conductivity (µS cm^{-1})	142.9 / 568.5	236.6
pH	7.2 / 8.9	8.2
Water velocity (m s^{-1})	0.4 / 0.8	0.5
Water height (cm)	11.8 / 22.2	17.8
Rock %	0.4 / 7	3.8
Block %	8 / 18.5	12
Stone%	31.7 / 45.1	39.2
Gravel%	31.5 / 48.9	42.6
Pebble%	0.5 / 4.9	2.2
Abun. Macroinvertebrates (m^2)	34 / 9871	4886.75

by months and habitat. To determine the population size structure, size classes were grouped from 0.00 to 100.00 mm, with intervals of 10.00 mm, resulting in a total of 10 classes. This allowed observe the variation of size distribution in each species and the temporal variation throughout the hydrological cycle, categorized by months and capture habitat.

The condition factor (K) was calculated following Vinay *et al*. (2017), categorized by capture months, size class, and habitat. Identification of environmental variables related to the abundance was performed by a correlation tests. High correlation among substrate variables was observed, leading to the selection of the Rock-Block category as the sum of the percentages of both categories. Subsequently, collinearity tests were carried out using the "faraway" program (Faraway, 2004) with the "vif" statement, revealing collinearity between full channel width and wetted channel width, leading to the use of only the latter.

Normality of abundance values in both species was checked using the Shapiro-test (Shapiro, Wilk, 1965), in *T.* cf. *corduvensis* (w = 0.94, p-value = 0.01), in *T. tiraquae* (w = 0.69, p-value = 1.02e-8). As both distributions biased from normality, goodness-of-fit tests were performed for binomial, negative binomial, and Poisson distributions using the "vcd" program (Meyer *et al*., 2007) and the "goodfit" statement. *Trichomycterus tiraquae* data approximated a negative binomial distribution (Chi-Square value = 5.52, df = 12, p-value = 0.93), while *T.* cf. *corduvensis* data did not fitted with any of these distributions. *Trichomycterus* cf. *corduvensis* data was determined to follow a beta distribution using the "fitdistrplus" program (Delignette-Muller, Dutang, 2015) and the "descdist" statement. To compute the model's statistical fit, the Kolmogorov-Smirnov test was performed using the "ks.test" statement, which provided the Kolmogorov-Smirnov parameter D = 0.17, p-value = 0.10.

Subsequently, multiple negative binomial regression was performed for *T. tiraquae* using the "MASS" program (Ripley *et al*., 2013) and the "glm.nb" statement, calculating the McFadden's R^2 value using the "ISLR" program (James *et al*., 2013). For *T.* cf. *corduvensis*, abundance data was adjusted by obtaining the proportion of abundance for each collection in relation to the total, resulting in values between zero and one. Values of zero were replaced with one hundred-thousandth (0.00001) to meet the conditions of "betareg" (Cribari-Neto, Zeileis, 2010) for multiple regression on beta distributions. All the mentioned analyses were conducted using the Rstudio program version 2022.02.1 Build 461.

RESULTS

It was observed, in most of the environmental factors, that the minimum and maximum values obtained were related to the seasonality of the high-water season (November–March) and the low-water season (April–October). The full channel width, wetted channel width, water velocity, water height and gravel% have their maximum values in the high-water season and their minimum values in the low-water season. While, habitat length, pH, rock% and macroinvertebrate abundance presented the reverse case. The values of the other factors were not related to this seasonality, while sand and silt-clay were found in small quantities.

The abundance of both *Trichomycterus* species exhibited considerable variation. *Trichomycterus* cf. *corduvensis* had a minimum of eight individuals (January) and a maximum of 1,084 individuals (August) with average of 537 per collection, totaling 4,294 individuals captured. *Trichomycterus tiraquae* presented a minimum of zero individuals (January) and a maximum of 38 individuals (August) with average of 11 per collection, totaling 88 individuals captured (Fig. 3). Both species were more abundant during low-water periods and lower values during high-water periods. ANOVA analysis revealed no significant habitat preference for either species, with p-values of 0.79 for *T*. cf. *corduvensis* and 0.77 for *T*. *tiraquae* (Fig. 3).

Size class distribution showed that *T*. cf. *corduvensis* was dominated by the third class (20.01–30.00 mm), which represented 74% of total individuals, followed by the fourth and second classes, with the most individuals being found in fast riffles (Tab.2; Fig. 4). *Trichomycterus tiraquae* had a narrower size distribution, with the second and third classes

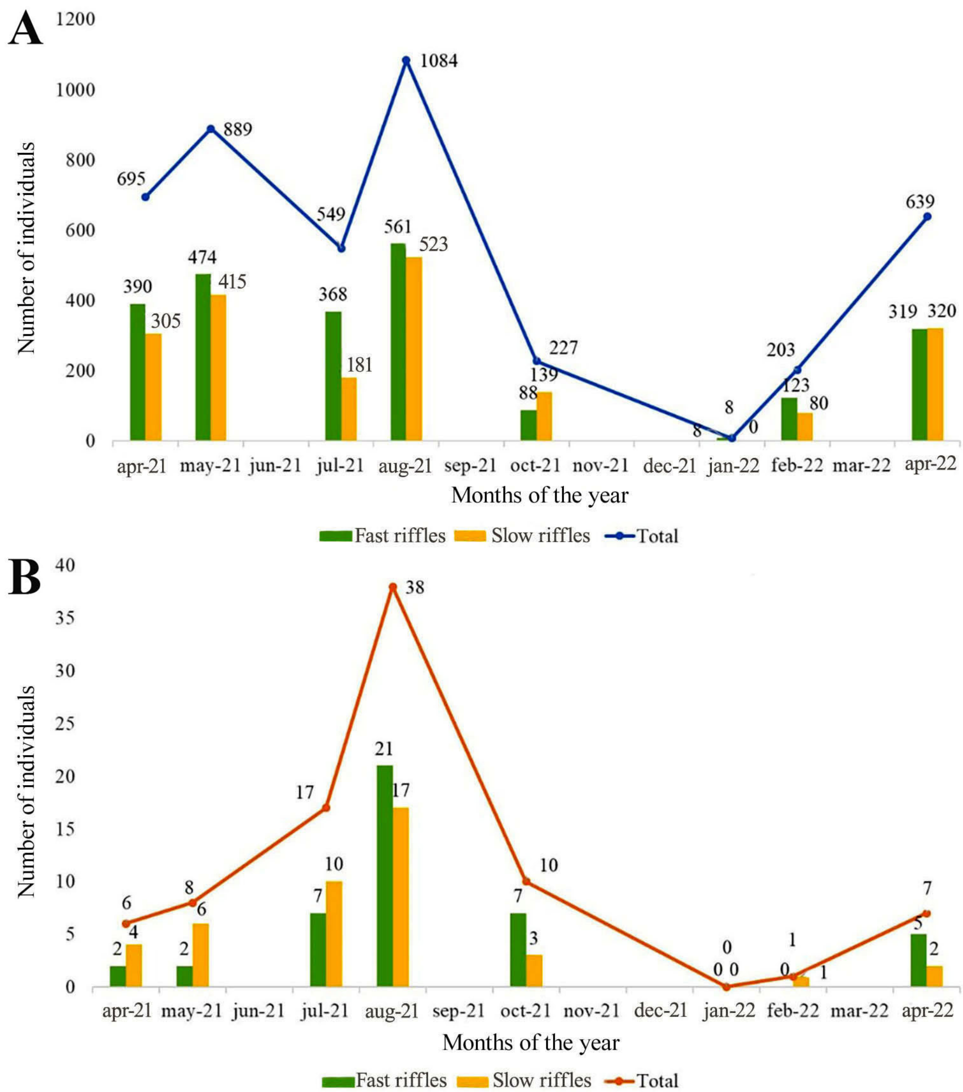

FIGURE 3 | Andean catfish *Trichomycterus* cf. *corduvensis* (**A**) and *T. tiraquae* (**B**) total abundance and by habitat throughout eight samples of the hydrological cycle from the Pucara River, Cochabamba Department, between April 2021 and April 2022.

accounting for 79% of the total individuals, with the most individuals being found in fast riffles (Tab. 2; Fig. 4).

The condition factor analysis indicated that in both species, the monthly values were greater than one and did not show significant variation. Analyzing the factor by habitat, values for *T.* cf. *corduvensis* were similar between fast and slow riffles, while *T. tiraquae* exhibited a clearer difference between habitats.

The lowest value in *T.* cf. *corduvensis* was observed during the high-water period and the highest during the low-water period. In general, the values were above one regardless of the month, size structure, or habitat. Both the lowest and highest values in *T. tiraquae* were observed during the low-water period. The values were above one for the monthly averages, but below one (0.99) for the slow riffles habitat in July.

Trichomycterus cf. *corduvensis* presented monthly values between 1.27 and 1.66, with the lowest value in January 2022 and the highest in April 2022, with an average of 1.49 (Tab. 3). The size structure showed that no value was below one, with higher factors in the larger size classes (> 40 mm) in April 2021, February and April 2022. Regarding habitat, the values were similar in the first five months, regardless of habitat, and in the last three months, the factors in the slow riffles were higher (Tab. 3).

Trichomycterus tiraquae presented monthly values between 1.19 and 1.33, with the lowest value in July 2021 and the highest in August 2021, with an average of 1.26. No individuals were recorded in January 2022 (Tab. 3). The size structure showed that the second size class (10.01–20.00 mm) in July 2021 was the only one with a value (0.97) below one, with the remaining values between 1.15 and 1.45. In terms of habitat, the factor was higher in the fast riffles, except in April 2021 and April 2022, where the slow riffles had a higher factor. The only value (0.99) below one was recorded in the slow riffles in July 2021, and the highest value (1.46) was in the fast riffles in August 2021. No individuals were recorded in January 2022, and in February 2022, individuals were only recorded in the fast riffles, being absent in the slow riffles (Tab. 3).

The beta regression of *T.* cf. *corduvensis* (Tab. 4) explained 54% of the variation, indicating that pH and macroinvertebrate abundance influence significant and positively this species. In the fast riffles habitat, the model explained 56% of the variation, with pH

TABLE 2 | Andean catfish *Trichomycterus* cf. *corduvensis* and *T. tiraquae* means abundance for size classes depending on habitat throughout eight samples of the hydrological cycle from the Pucara River between April 2021 and April 2022. Mf = Means of fast riffles; SD = Standard deviation; Sk = Skewness of the distribution; Ms = Means of slow riffles; "-" = Absence of individuals.

	T. cf. *corduvensis*						*T. tiraquae*					
Size class	Mf	SD	Sk	Ms	SD	Sk	Mf	SD	Sk	Ms	SD	Sk
0.00–10.00	0	0	-	0	0	-	0	0	-	0	0	-
10.01–20.00	8.29	17.37	3.55	6.38	9.34	1.72	0.21	0.51	2.54	0.50	1.29	2.68
20.01–30.00	69.46	61.88	0.34	62.71	60.63	1.14	1.17	2.88	3.46	1.04	1.99	2.47
30.01–40.00	16.25	16.08	1.48	10.67	11.82	1.10	0.13	0.34	2.42	0.04	0.20	4.90
40.01–50.00	0.88	1.39	1.82	1.50	2.38	1.36	0.21	0.51	2.54	0.08	0.28	3.22
50.01–60.00	1.17	1.34	2.03	0.29	0.55	1.80	0.21	0.51	2.54	0.08	0.28	3.22
60.01–70.00	0.67	1.09	1.84	0.13	0.45	3.80	0	0	-	0	0	-
70.01–80.00	0.29	0.69	3.00	0	0.00	-	0	0	-	0	0	-
80.01–90.00	0.04	0.20	4.90	0.13	0.34	2.42	0	0	-	0	0	-
90.01–100.00	0.08	0.28	3.22	0	0	-	0	0	-	0	0	-

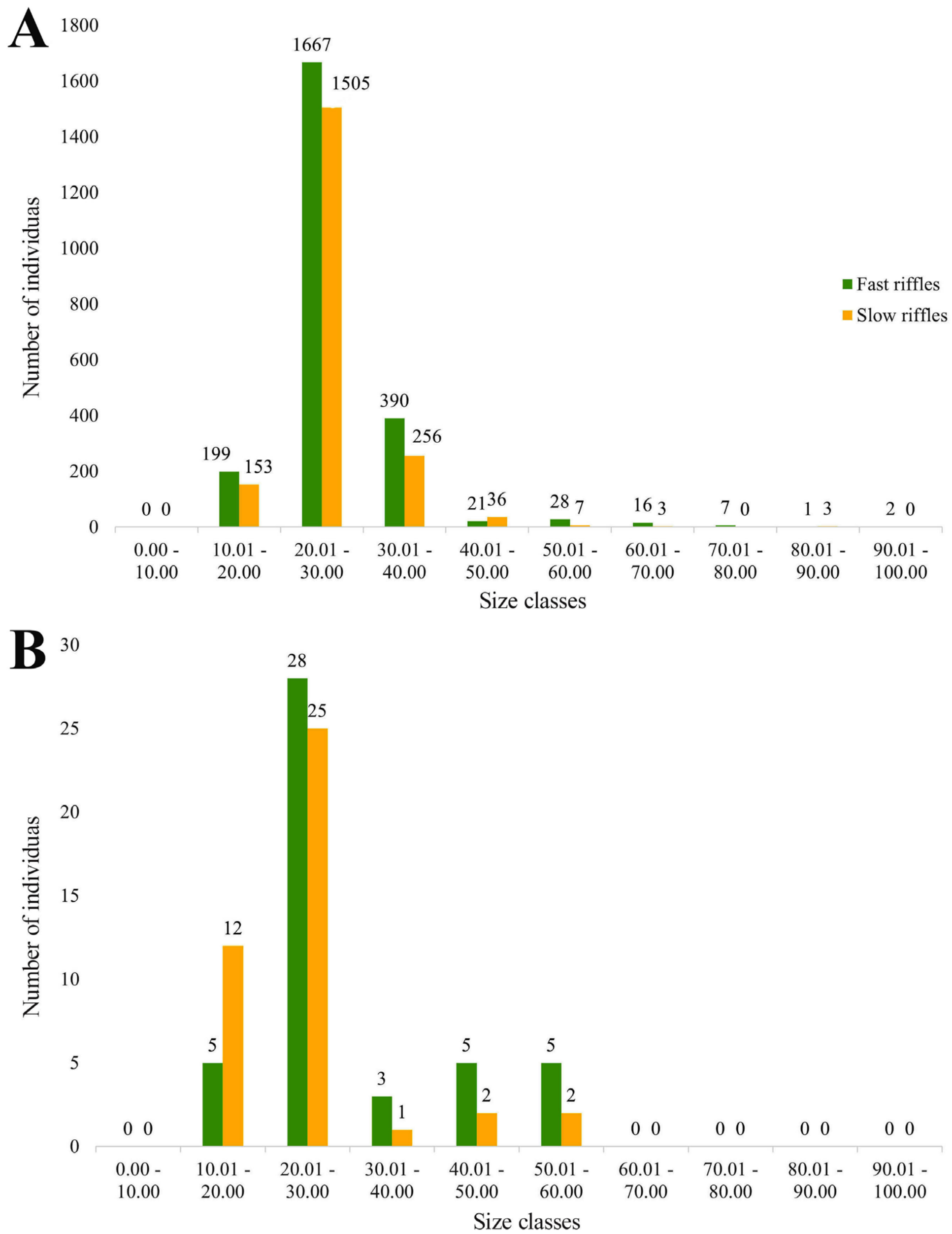

FIGURE 4 | Andean catfish *Trichomycterus* cf. *corduvensis* (**A**) and *T. tiraquae* (**B**) abundance by size classes depending on habitat throughout eight samples of the hydrological cycle from the Pucara River between April 2021 and April 2022.

having a significant positive influence and water height a significant negative influence. In the slow riffles habitat, the model explained 67% of the variation, showing significant positive influences of pH and water height, and significant negative influences of temperature, dissolved oxygen, and velocity.

When analyzing the monthly abundance of *T.* cf. *corduvensis* with macroinvertebrate families, the model explained 35% of the variation, with Chironomidae, Baetidae, and Caenidae having significant positive influences. In the fast riffles habitat, the model explained 56% of the variation, being Chironomidae, Baetidae, Physidae, and Corixidae the most influencing taxa in a positive sense. In the slow riffles habitat, the model explained 39% of the variation, with Caenidae showing a significant positive influence (Tab. 4).

The negative binomial regression analysis of the monthly abundances of *T. tiraquae* and environmental factors (Tab. 5) explained 48% of the variation, with water height having a significant negative influence. In the fast riffles habitat, the model explained 53% of the variation, with the width of the wet channel having a significant positive influence. In the slow riffles habitat, the model explained 76% of the variation, being the velocity a significant factor in a negative sense.

TABLE 3 | Andean catfish *Trichomycterus* cf. *corduvensis* and *T. tiraquae* means condition factor for each month and as a function of habitat for each month throughout eight samples of the hydrological cycle from the Pucara River between April 2021 and April 2022. Km = Condition factor for month; SD = Standard deviation; Kf = Condition factor for fast riffles; Ks = Condition factor for slow riffles; "-" = Absence of individuals.

	T. cf. *corduvensis*						*T. tiraquae*					
Month	Km	SD	Kf	SD	Ks	SD	Km	SD	Kf	SD	Ks	SD
April 2021	1.59	0.13	1.48	0.27	1.46	0.30	1.24	0.08	1.16	0.13	1.30	0.26
May	1.35	0.06	1.38	0.18	1.38	0.19	1.26	0.09	1.37	0.01	1.17	0.29
July	1.39	0.22	1.31	0.19	1.26	0.18	1.19	0.15	1.25	0.13	0.99	0.35
August	1.53	0.11	1.42	0.20	1.44	0.22	1.33	0.11	1.46	0.21	1.41	0.17
October	1.56	0.08	1.50	0.14	1.49	0.17	1.26	0.06	1.27	0.12	1.22	0.13
January 2022	1.27	0.03	1.26	0.08	-	-	-	-	-	-	-	-
February	1.54	0.23	1.24	0.62	1.50	0.70	1.30	0.01	1.30	0.01	-	-
April	1.66	0.21	1.54	0.30	1.66	0.25	1.22	0.08	1.17	0.10	1.29	0.20

TABLE 4 | Multiple beta regressions performed for *T.* cf. *corduvensis* with the data obtained throughout eight samples of the hydrological cycle from the Pucara River between April 2021 and April 2022. Abu. = Abundance; Envi. = Environmental; Macro. inver. = Macroinvertebrate abundance.

Variables	Model	Results
Monthly Abu. *vs.* Envi. factors	p = 7.47e-06 R^2= 54%	-pH: p=0.0010; slope = +0.9327 -Macro. inver.: p= 0.0385; slope = +0.0002
Fast riffles Abu. *vs.* Envi. factors	p= 0.0011 R^2= 56%	-pH: p= 0.0013; slope = +1.148e+00 - Water height: p= 0.0057; slope = -1.230e-01
Slow riffles Abu. *vs.* Envi. factors	p= 0.0010 R^2= 67%	- Temperature: p= 0.0093; slope = -0.2916 - Dissolved oxygen: p= 0.0045; slope = -0.3423 -pH: p= 0.0134; slope = +1.1859 - Water speed: p= 0.0007; slope = -3.8548 - Water height: p= 0.0463; slope = +0.0837
Monthly Abu. *vs.* Macro. inver.	p= 9.62e-06 R^2= 35%	-Chironomidae: p= 0.0081; slope = +0.0007 -Baetidae: p= 0.0235; slope = +0.0011 -Caenidae: p= 7.56e-07; slope = +0.1287
Fast riffles Abu. *vs.* Macro. inver.	p= 0.0011 R^2= 56%	-Chironomidae: p= 0.0033; slope = +0.0013 -Baetidae: p= 0.0054; slope = +0.0014 -Physidae: p= 0.0233; slope = +0.0329 -Corixidae: p= 0.0119; slope = +0.5950
Slow riffles Abu. *vs.* Macro. inver.	p= 0.0019 R^2= 39%	-Caenidae: p= 0.0001; slope = +1.292e-01

TABLE 5 | Multiple negative binomial regressions performed for *T. tiraquae* with the data obtained throughout eight samples of the hydrological cycle from the Pucara River between April 2021 and April 2022. Mc.R^2 = McFadden's R^2; Abu. = Abundance; Envi. = Environmental; Macro. inver. = Macroinvertebrate abundance.

Variables	Model	Results
Monthly Abu. *vs.* Envi. factors	Mc.R^2= 48%	- Water height: p= 0.0137; slope = -1.119e-01
Fast riffles Abu. *vs.* Envi. factors	Mc.R^2= 53%	- Wetted channel width: p= 0.0118; slope = +0.2275
Slow riffles Abu. *vs.* Envi. factors	Mc.R^2= 76%	- Water speed: p= 0.0014; slope = -7.6124
Monthly Abu. *vs.* Macro. inver.	Mc.R^2= 36%	-Caenidae: p= 0.0011; slope = +0.1381
Fast riffles Abu. *vs.* Macro. inver.	Mc.R^2= 55%	-Physidae: p= 0.0174; slope = +7.087e-02 -Corixidae: p= 0.0320; slope = +9.171e-01
Slow riffles Abu. *vs.* Macro. inver.	Mc.R^2= 72%	-Hydropsychidae: p= 0.0316; slope = +0.0144 -Caenidae: p= 1.06e-05; slope = +0.2045

The model explained 36% of the variation analyzing the monthly abundance of *T. tiraquae* in relation to macroinvertebrate families. Caenidae family showed a significant positive influence. In the fast riffles habitat, the model explained 55% of the variation, with Physidae and Corixidae having significant positive influences. In the slow riffles habitat, the model explained 72% of the variation, with Hydropsychidae and Caenidae showing significant positive influences (Tab. 5).

DISCUSSION

The temporal variation in the abundance of these species appears to be primarily influenced by the hydrological cycle. Higher abundances were recorded during the low-water season, while lower abundances were observed during the high-water season. An exception to this pattern was noted in July, where a sudden drop in the abundance of *T.* cf. *corduvensis* was possibly related to the observed sediment removal activities, changes in the river due to aggregate extraction, and agricultural runoff. In October, a decline in the abundance of both species marked the beginning of the high-water period, characterized by increased water velocity and height.

In January, as the water level decreased, *T.* cf. *corduvensis* was the only species observed, likely the first to recolonize the area or those that found refuge during the flood. *Trichomycterus tiraquae* reappeared in February.

The studied populations were dominated by smaller size classes (10–40 mm SL), with larger sizes being rare or absent. This suggests either that individuals do not reach these sizes in this section of the river studied or that larger individuals migrate to other areas, as seen in other species of the genus (Arratia, 1983; Miranda-Chumacero *et al.*, 2015).

The absence of smaller individuals could be due to the sampling method or that these individuals stay in other river areas. Size structure by habitat showed that most sizes are more abundant in fast riffles than in slow riffles, except for some larger sizes which are more abundant in slow riffles; possibly due to habitat preference related to their different sizes, as observed in other species of the genus (Arratia, 1976, 1983).

Regarding the condition factor of *T.* cf. *corduvensis*, the lowest value was recorded in January, likely due to reduced food availability, coinciding with a drop in macroinvertebrate abundance, possibly related to the river flood. In May and July, the condition factor values were below average, and despite a decrease in macroinvertebrate abundance, this does not seem to be the cause. This suggests that the mentioned months might be the reproductive period for this species, during which the condition factor typically decreases (Cifuentes *et al*., 2012). In April 2021, February and April 2022, higher condition factors were observed in larger size classes (> 40 mm), suggesting that the reproductive period might be between May and July and sexual maturity may be reached at sizes over 40 mm SL. This pattern supports two hypotheses: reproduction occurs outside the study area, leading to the absence of adults during reproductive months, following the displacement of fish to suitable breeding sites (Schlosser, 1995), or post-reproduction, adults are swept away or seek refuge in lower river areas, explaining their absence during these months. This indicates a seasonal reproduction period (Chará *et al*., 2006), from May to July. In *T. areolatus*, a longer reproductive cycle has been documented. *Trichomycterus areolatus* shows individuals smaller than 25 mm between September and May, suggesting an extended reproductive period with multiple spawnings episodes (Manríquez *et al*., 1988), in contrast to *T.* cf. *corduvensis*, whose reproduction appears to be concentrated within a shorter seasonal period. This difference reflects distinct reproductive strategies between the two species of the same genus, likely adapted to the specific environmental conditions of their respective habitats.

For *T. tiraquae*, the lowest condition factor value was in July, but given the low abundance of the species in the river, this is not indicative of a reproductive period. The condition factor values did not show high variability or extreme maximum or minimum values, both temporally and by size structure. Generally, the condition factor values were lower in *T. tiraquae* compared to *T.* cf. *corduvensis*.

At a habitat level, both species showed fluctuations between condition factors in fast riffles and slow riffles, but without significant variation. The differences between fast riffles and slow riffles were greater in *T. tiraquae* compared to *T.* cf. *corduvensis*.

The relationship between *T.* cf. *corduvensis* abundances and environmental factors indicates that pH and macroinvertebrate abundance positively influence the monthly abundance of this species. Macroinvertebrate abundance showed a similar trend to *T.* cf. *corduvensis*, with higher values during the low-water season and lower values during the high-water season, suggesting that fish abundance is limited by available resources (Allen, Hightower, 2010). In the fast riffles, water height negatively correlated with abundance, linked to the hydrological cycle. In the slow riffles, water height exhibited a positive correlation, deviating from the expected pattern of the hydrological cycle. Temperature, dissolved oxygen, and velocity correlated negatively to abundance.

The relationship between *T.* cf. *corduvensis* abundances and macroinvertebrate families showed that Chironomidae, Baetidae, Caenidae, Physidae, and Corixidae are probably the principal food items following previous work that suggested to this species is a generalist insectivore, which feeds almost exclusively with the most abundant autochthonous fauna (Ferriz, 1998; Manoni *et al*., 2009), with variation between habitats due to the distribution of these families. The Chironomidae family was identified as food item of *Trichomycterus* species in other studies (Campos, 1985; Bizerril, 1994; Ruiz, Berra, 1994; Habit *et al*., 2005; Chará *et al*., 2006; Scott *et al*., 2007; Manoni *et al*., 2009). Manoni *et al*. (2009) showed that in populations of *T. corduvensis* in Argentina, Chironomidae and Batidae are the main food items, which is consistent with the findings of the present study. A similar preference for these two prey groups was also observed in populations of *T. areolatus* in Chile (Habit *et al*., 2005). These similarities in diet between the two species suggest that some *Trichomycterus* species may share comparable ecological niches, particularly in terms of their feeding strategies, which could be influenced by the availability of similar food resources in their respective habitats.

The relationship between *T*. *tiraquae* abundances and environmental factors indicates that water height negatively correlates with monthly abundance, aligning with the hydrological cycle. In the fast riffles, the width of the wet channel positively correlated with abundance, suggesting more refuges in wider channels. In the slow riffles, velocity negatively correlated with abundance, like the findings for *T*. cf. *corduvensis*.

The population dynamics of the *Trichomycterus* species present in the Pucara River are primarily conditioned by the hydrological cycle, which is mainly reflected in the variation pattern of the physical environmental factors influencing the abundance variation of both species. No habitat preference was identified for both species. The population structure shows that juveniles predominate in both species, suggesting a population recovering from previous environmental events or potential upstream migration, as observed in *T. barbouri* (Miranda-Chumacero *et al*., 2015). Despite this, the condition factor of the species appears relatively constant throughout the year. These assertions should be confirmed with other complementary studies (gonad analysis, stomach contents, etc.) to better understand the ecology of these species, particularly their reproductive cycles.

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REFERENCES

- **Aadland LP.** Stream habitat types: their fish assemblages and relationship to flow. North Am J Fish Manage. 1993; 13(4):790–806. https://doi.org/10.1577/1548-8675(1993)013<0790:SHTTFA>2.3.CO;2
- **Alencar AR, Costa WJEM.** Description of two new species of the catfish genus *Trichomycterus* from southeastern Brazil (Siluriformes: Trichomycteridae). Zootaxa. 2004; 744(1):1–08. https://doi.org/10.11646/zootaxa.744.1.1
- **Allen MS, Hightower JE.** Fish population dynamics: mortality, growth, and recruitment. In: Hubert WA, Quist MC, editors. Inland Fisheries Management in North America. American Fisheries Society; 2010. p.43–79.
- **Arratia G.** Variaciones de las hipurapófisis en algunos peces siluriformes (Familia Trichomycteridae). An Mus Hist Natur Valparaíso. 1976; 9:105–14.
- **Arratia G.** Preferencias de hábitat de peces siluriformes de aguas continentales de Chile (Fam. Diplomystidae y Trichomycteridae). Stud Neotrop Fauna Environ. 1983; 18(4):217–37. https://doi.org/10.1080/01650528309360637
- **Arratia G.** The South American Trichomycterinae (Teleostei: Siluriformes), a problematic group. In: Peters G, Hutterer R, editors. Vertebrates in the Tropics. Bonn: Museum Alexander Koening; 1990. p.395–403.
- **Arraya M, Maldonado M, Carvajal-Vallejos FM, Fernandez LA.** Contribución al conocimiento de los peces del género *Trichomycterus* (Siluriformes: Trichomycteridae) en los Andes de Bolivia. Rev Bol Ecol Conserv Ambient. 2009; 26:45–52.
- **Argermeier P, Karr J.** Comunidades de peces a lo largo de gradientes ambientales en un sistema de arroyos tropicales. Biología ambiental de los peces. 1983; 9:117–35.
- **Arellano M, Huaquín L, Manríquez A.** Aspectos comparativos de dos especies de Siluriformes Chilenos de agua dulce (Pisces, Trichomycteridae). Arch Biol Med Exp. 1983; 16:136.
- **Baskin JN, Zaret TM, Mago-Leccia F.** Feeding of reportedly parasitic catfishes (Trichomycteridae and Cetopsidae) in the Rio Portuguesa Basin, Venezuela. Biotropica. 1980; 12(3):182–86. https://doi.org/10.2307/2387969
- **Bizerril CRSF.** Description of a new species of *Trichomycterus* (Siluroidei, Trichomycteridae) from the State of Santa Catarina, with a synopsis of the composition of the family Trichomycteridae in Eastern Brazil. Arq Biol Tecnol. 1994; 37:617–17.
- **Campos H.** Distribución de peces en los ríos andinos del sur de Chile. Arch Hydrobiol. 1985; 104(2):169–91. https://doi.org/10.1127/archiv-hydrobiol/104/1985/169
- **Cala PC, Sarmiento NG.** Cambios histomorfológicos en el ovario del pez capitán, *Eremophilus mutisii* Humboldt 1805 (Pisces: Trichomyteridae), durante el ciclo reproductivo anual, en la laguna del Muña, sistema río Bogotá. Colombia. Acta Biol Colomb. 1982; 1(1):9–30.
- **Chará JD, Baird DJ, Telfer TC, Rubio EA.** Feeding ecology and habitat preferences of the catfish genus *Trichomycterus* in low-order streams of the Colombian Andes. J Fish Biol. 2006; 68(4):1026–40. https://doi.org/10.1111/j.0022-1112.2006.00984.x
- **Cifuentes R, González J, Montoya G, Jara A, Ortíz N, Piedra P *et al*.** Relación longitud-peso y factor de condición de los peces nativos del río San Pedro (cuenca del río Valdivia, Chile). Gayana (Concepc). 2012; 76:86–100. https://doi.org/10.4067/S0717-65382012000100009
- **Cribari-Neto F, Zeileis A.** Beta regression in R. J Stat Softw. 2010; 34:1–24. https://doi.org/10.18637/jss.v034.i02
- **Delignette-Muller ML, Dutang C.** fitdistrplus: an R package for fitting distributions. J Stat Softw. 2015; 64:1–34. https://doi.org/10.18637/jss.v064.i04
- **Faraway JJ.** Linear models with R. Chapman & Hall/CRC Texts in Statistical Science. Boca Raton, Florida, USA; 2004.
- **Ferriz RA.** Alimentación de *Trichomycterus corduvense* Weyenbergh, 1879 (Teleostei: Trichomycteridae) en dos ríos serranos de San Luis, Argentina. Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" e Instituto Nacional de Investigación de las Ciencias Naturales. 1998.
- **Flórez A, Sarmiento N.** Observaciones ecológicas sobre el pez capitán, Humboldt 1805 (Pisces Trichomycteridae) en los departamentos de Cundinamarca y Boyacá, Colombia. Acta Biol Colomb. 1991; 1:99–115.

- **James G, Witten D, Hastie T, Tibshirani R.** An introduction to statistical learning with applications in R. Springer; 2013; p.180–83. https://doi.org/10.1007/978-1-4614-7138-7
- **Lima SMQ, Berbel-Filho WM, Vilasboa A, Lazoski C, Volpi TA, Lazzarotto H *et al*.** Rio de Janeiro and other palaeodrainages evidenced by the genetic structure of an Atlantic Forest catfish. J Biogeogr. 2021; 48(6):1475–88. https://doi.org/10.1111/jbi.14091
- **Maldonado M, Goitia E.** Correspondencia entre unidades geofísicas – bioclimáticas y patrones espaciales en ecosistemas acuáticos de Bolivia. Rev Bol Ecol Conserv Ambient. 2001; 10:29–58.
- **Manoni RA, Garelis PA, Tripole ES, Vallania EA.** Diet and feeding preferences of *Trichomycterus corduvensis* Weyenbergh, 1877 (Siluriformes, Trichomycteridae) in two rivers of the Quinto River basin (San Luis, Argentina). Acta Limnol Bras. 2009; 21(2):161–67.
- **Manriquez A, Arellano M, Huaquin L.** Antecedentes ecológicos y biológicos de *Nematogenys inermis* (Guichenot, 1848) una especie en extinción. Mem Asoc Latinoam Acuicult. 1984; 5:609–14.
- **Manriquez A, Huaqúin L, Arellano M, Arratia G.** Aspectos reproductivos de *Trichomycterus areolatus* Valenciennes, 1846 (Pisces: Teleostei: Siluriformes) en río Angostura, Chile. Stud Neotrop Fauna Environ. 1988; 23(2):89–102. https://doi.org/10.1080/01650528809360749
- **Meyer D, Zeileis A, Hornik K.** The strucplot framework: visualizing multi-way contingency tables with vcd. J Stat Softw. 2007; 17:1–48. https://doi.org/10.18637/jss.v017.i03
- **Miranda G, Pouilly M.** Morphology and reproductive strategies of cave fish of genus *Trichomycterus* in Torotoro National Park (Potosí, Bolivia). Speleo Brazil. 2001.
- **Miranda-Chumacero G, Álvarez G, Luna V, Wallace RB, Painter L.** First observations on annual massive upstream migration of juvenile catfish *Trichomycterus* in an Amazonian River. Environ Biol Fish. 2015; 98(8):1913–26. https://doi.org/10.1007/s10641-015-0407-3
- **Ochoa LE, Datovo A, DoNascimiento C, Roxo FF, Sabaj MH, Chang J *et al*.** Phylogenomic analysis of trichomycterid catfishes (Teleostei: Siluriformes) inferred from ultraconserved elements. Scient Rep. 2020; 10:2697. https://doi.org/10.1038/s41598-020-59519-w
- **de Pinna MCC.** A new sarcoglanidine catfish, phylogeny of its subfamily, and an appraisal of the phyletic status of the Trichomycterinae. Am Mus Novit. 1989. 2950:1–39.
- **de Pinna MCC.** Phylogenetic relationships of Neotropical Siluriformes (Teleostei: Ostariophysi): historical overview and synthesis of hypotheses. In: Malabarba LR, Reis RE, Vari RP, Lucena ZM, Lucena CAS, editors. Phylogeny and classification of Neotropical fishes. Porto Alegre: Edipucrs, 1998. p.279–330.
- **Pouilly M, Miranda G.** Morfología y reproducción del cavernícola *Trichomycterus chaberti* y el epigean relacionado *Trichomycterus* cf. *barbouri*. J Fish Biol. 2003; 63(2):490–505. https://doi.org/10.1046/j.1095-8649.2003.00171.x
- **Reis V, de Pinna M.** Diversity and systematics of *Trichomycterus* Valenciennes 1832 (Siluriformes: Trichomycteridae) in the rio Doce basin: iterating DNA, phylogeny and classical taxonomy. Zool J Linn Soc. 2023; 197(2):344–441. https://doi.org/10.1093/zoolinnean/zlac018
- **Ringuelet R, Alonso de Aramburu R, Aramburu R.** Los peces de agua dulce de la República Argentina. Com Nac Inv Cient Buenos Aires. 1967; 1–602.
- **Ripley B, Venables B, Bates DM, Hornik K, Gebhardt A, Firth D *et al*.** Package 'mass'. Cran R. 2013; 538:113–20.
- **Román-Valencia C.** Ecología trófica y reproductiva de *Trichomycterus caliense* y *Astroblepus cyclopus* (Piscis: Siluriformes) en el río Quindío, Colombia. Rev Biol Trop. 2001; 49(2):657–66.
- **Ruiz V, Berra T.** Peces del Río Alto Biobio del Centro Sur de Chile con notas sobre la dieta y especulaciones sobre el origen de la ictiofauna. Explor Ictiol Aguas Dulces. 1994; 5:5–18.
- **Ruiz VH, López MT, Moyano HI, Marchant M.** Ictiología del Alto Biobío: aspectos taxonómicos, alimentarios, reproductivos y ecológicos con una discusión sobre la hoya. Gayana Zool. 1993; 57(1):77–88.

- **Schlosser IJ.** Critical landscape attributes that influence fish population dynamics in headwater streams. Hydrobiologia. 1995; 303:71–81. https://doi.org/10.1007/BF00034045
- **Shapiro SS, Wilk MB.** An analysis of variance test for normality (complete samples). Biometrika. 1965; 52(3–4):591–611. https://doi.org/10.1093/biomet/52.3-4.591
- **Vinay VJC, Esqueda VA, Tosquy OH, Ríos A, Vázquez MV, Perdomo C.** Avances en investigación agrícola, pecuaria, forestal, acuícola, pesquería, desarrollo rural, transferencia de tecnología, biotecnología, ambiente, recursos naturales y cambio climático. Inifap: México. 2017; 1125–33.

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