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Distribution and morphological diversity of *Astyanax rivularis* Lütken, 1874 (Teleostei Characiformes) in the upper São Francisco River basin, Brazil

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ABSTRACT *Astyanax* S.F. Baird et Girard, 1854 (Teleostei Characiformes) is one of the most well characterized of the neotropical ichthyofauna and is composed of fish with great ability to adapt to different environmental conditions and a wide spectrum of interaction in fish assemblages due to its structure and population density. This study presents the geographical distribution and morphological diversity of *Astyanax rivularis* Lütken, 1874, a fish historically complex and extremely diverse, in tributary streams of the left side of upper São Francisco River.

KEY WORDS Brazil; Neotropical Fish; Brazilian Savannah; Characidae.

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INTRODUCTION

Although the genus *Astyanax* Baird et Girard, 1854 is one of the most well characterized of the neotropical ichthyofauna, perhaps for its easy capture, certain biological characteristics of this fish indicate that further studies are necessary for better understanding its natural history. The formation of structured populations, combined with evolutionary processes, such as vicariance, certainly plays a key role in the diversity of the group, which emerges as a genus where allopatric speciation has probably occurred. However, it is very difficult to determine specific limits in the group. There are at least four groups of cryptic species proposed in the genus, where different taxa with diagnostic characters (usually chromosomal) are observed sharing the same specific denomination. These cases involve both morphological characteristics and chromosomal or molecular aspects.

The genus *Astyanax* is composed of fish with great ability to adapt to different environmental conditions and a wide spectrum of interaction in fish assemblages due to its structure and population density (Orsi et al., 2004). This is demonstrated by the wide geographical distribution of the group, which covers almost the entire neotropical region (Eigenmann, 1921) and comprises about 150 species distributed from southern United States to northern Argentina (Eschmeyer & Fong, 2019).

Garutti (1995) states that the genus *Astyanax* has a structured distribution, which suggests a high level of endemism: even within a single basin, there are multiple forms with relatively restricted geographic distribution. Therefore, it is assumed that *Astyanax* do not form a uniform group, but present variations between populations, probably because this group inhabits many different microenvironments (Garutti & Britski, 2000). However, they are more successful in the best preserved habitats (Orsi et al., 2004). In fact, it is observed that populations of *Astyanax* present genetic structure along a river (Moysés & Almeida-Toledo, 2002; Prioli et al., 2002; Leuzzi et al., 2004; Paiva et al., 2006).

Astyanax rivularis (Fig. 1) was described by Lütken (1874) as *Tetragonopterus rivularis* from the collections of Reinhardt of the mid-nineteenth century in the Velhas River, a major tributary of the São Francisco River. Later, it was considered a subspecies of *A. scabripinnis* Jenyns, 1842: *A. scabripinnis rivularis* (Eigenmnann, 1921). Chromosomal and morphometric characteristics led Moreira-Filho & Bertollo (1989) to conclude that *A. scabripinnis* is a species complex of which about 14 are currently recognized (Bertaco & Lucena, 2006). According to the "Catalog of Fishes" (Eschmeyer & Fong, 2019), *A. rivularis* Lütken, 1874 (Characidae Stethaprioninae) is currently accepted as a valid species with distribution in São Francisco River basin.

Figure 1. Sample of *Astyanax rivularis* (80 mm standard length).

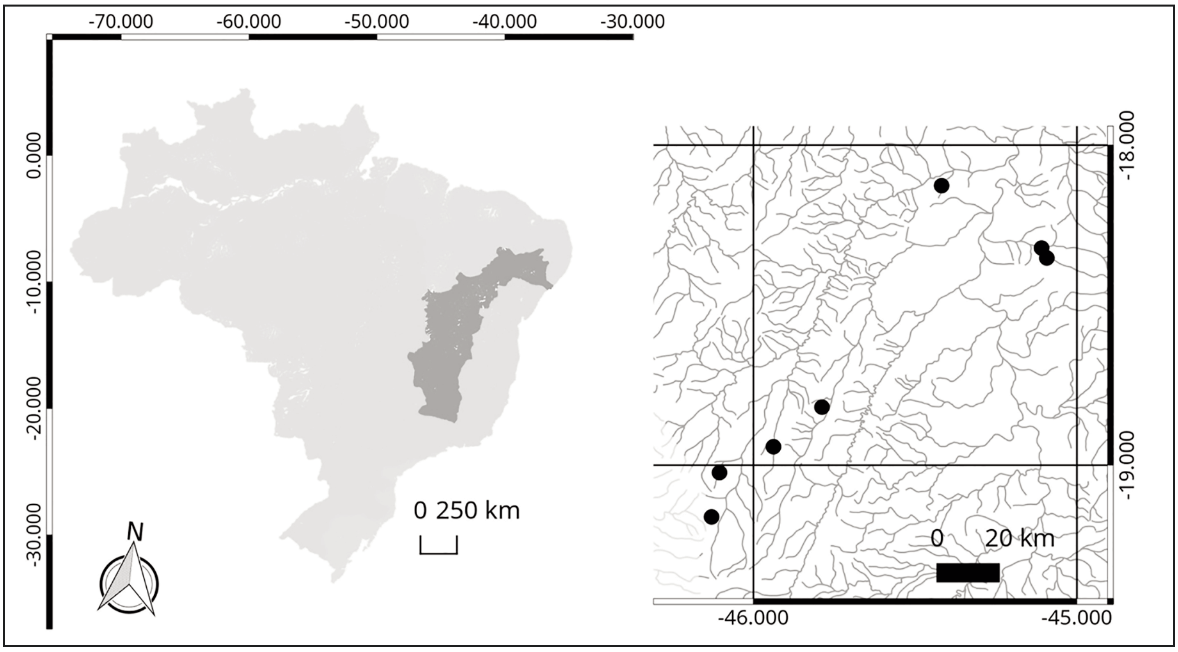

Figure 2. Map of Brazilian hydrographic basins with São Francisco river basin in dark gray (left); distribution of the samples in left tributaries of the Upper São Francisco river basin (right).

Here we present the morphometric data of seven populations of *A. rivularis*, with the purpose to better understand the distribution and diversity of the species.

MATERIAL AND METHODS

Seven population of *A. rivularis* were sampled totaling 69 individuals collected in tributaries of the left margin of Upper São Francisco River basin (Fig. 2), increasing the range of distribution of this species to Upper São Francisco River basin. Sampling and euthanizing of specimens were carried out in accordance with the recommendations of the Conselho Nacional de Controle de Experimentação Animal (CONCEA).

The specimens were deposited in the Collection of Vertebrates of the UFV Laboratory of Ecological and Evolutionary Genetics, at Rio Parnaíba Campus - CV-LaGEEvo. The identification was made according to Britski et al. (1988) and Lütken's description. The morphometric characters were obtained in millimeters (mm) with the help of a digital caliper with a 0.01 mm resolution.

All the data were obtained only from the left size of the sample considering the following measurements: standard head length, predorsal distance, prepelvic distance, preanal distance, height of dorsal origin, height of tail peduncle, length of anal basis, length of dorsal basis, length of pelvic basis, length of pectoral basis, head height, snout length, eye diameter, interorbital distance and jaw length.

RESULTS

All analyzed individuals were identified as *A. rivularis* according to available literature.

The standard length was between 41.44 cm to 82.73 cm (Tables 1 to 7). The highest standard length mean was found in Borrachudo stream population (70.36 cm), and the lowest was in Curral das Éguas stream (44.94 cm). The snout length and head height were the most variable characteristics, meanwhile the length of pectoral basis and the length of head were the less ones (Fig. 3). The scales in the lateral line range from 32 to 39, and the branched anal-fin rays range from 16 to 24 (see the tables).

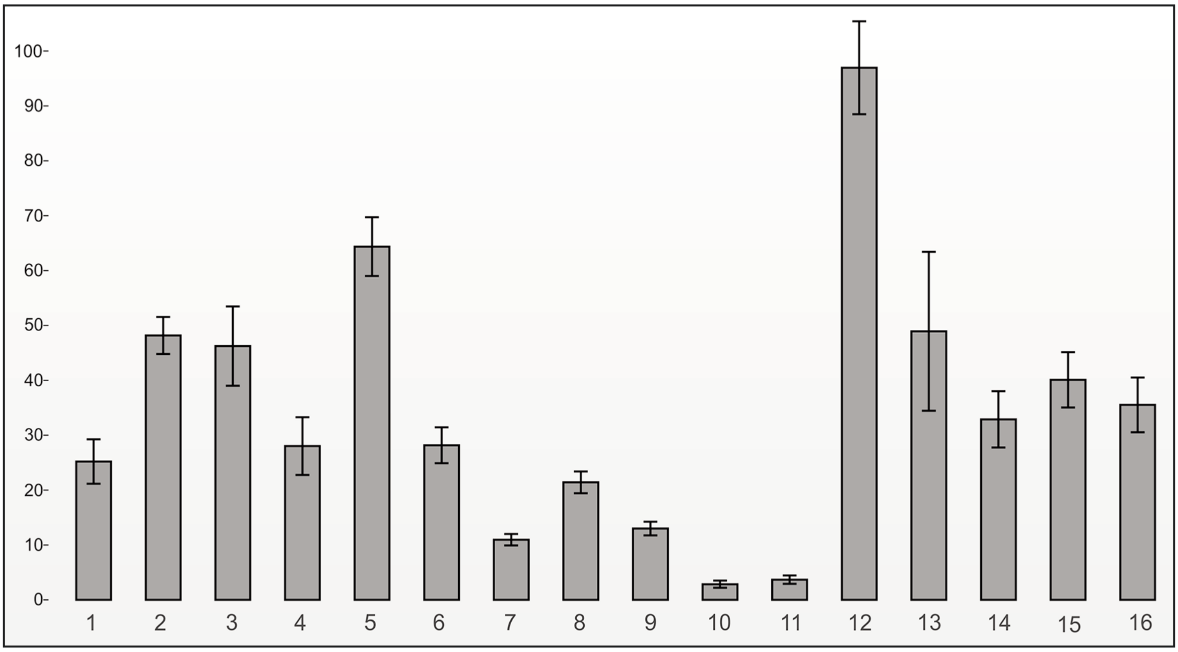

Figure 3. Graphic with mean and standard deviation of morphometric data from seven *Astyanax rivularis* populations. 1: predorsal distance; 2: prepelvic distance; 3: prepectoral distance; 4: preanal distance; 5: height of dorsal origin; 6: height of tail peduncle; 7: length of anal basis; 8: length of dorsal basis; 9: length of pelvic basis; 10: length of pectoral basis; 11: length of head; 12: head height; 13: snout length; 14: eye diameter; 15: interorbital distance; 16: jaw length.

1

Morphometrics	Range	Mean	SD
Standard length	41.44 – 80.07	63.90	12.19
	% of standard length		
predorsal distance	44.38 – 51.49	47.93	1.53
prepelvic distance	45.76 – 63.61	48.82	4.03
prepectoral distance	24.36 – 48.29	29.07	5.08
preanal distance	53.7 – 67.05	63.31	3.01
height of dorsal origin	23.21 – 33.07	26.37	2.50
height of tail peduncle	9.40 – 11.66	10.19	0.65
length of anal basis	19.36 – 26.69	22.36	2.25
length of dorsal basis	10.41 – 16.55	12.96	1.33
length of pelvic basis	2.34 – 4.28	2.89	0.49
length of pectoral basis	3.24 – 6.49	4.02	0.69
length of head	23.37 - 27.03	25.27	0.96
	% head length		
head height	78.97 – 108.94	91.8	6.53
snout length	49.88 – 68.65	58.46	4.56
eye diameter	28.30 – 39.44	32.89	3.52
interorbital distance	31.99 – 41.84	36.00	3.08
jaw length	28.33 – 49.21	37.04	5.04
Meristics	**Range**	**Mean**	**SD**
Scales in Lateral Line	33 - 39	35.63	1.83
Branched anal-fin rays	19 - 23	20.42	1.02

2

Morphometrics	Range	Mean	SD
Standard length	47.08 – 61.58	54.64	5.29
	% of standard length		
predorsal distance	46.65 – 53.22	49.94	2.31
prepelvic distance	43.92 – 48.53	45.04	1.82
prepectoral distance	25.31 – 28.63	28.29	1.40
preanal distance	61.52 – 69.30	65.41	2.69
height of dorsal origin	28.38 – 30.95	30.74	1.01
height of tail peduncle	11.04 – 13.13	11.89	0.84
length of anal basis	18.06 – 23.10	19.97	1.89
length of dorsal basis	11.87 – 14.19	13.62	0.98
length of pelvic basis	1.70 – 3.00	2.05	0.48
length of pectoral basis	3.20 – 4.17	3.87	0.42
length of head	19.55 - 22.60	20.72	1.16
	% head length		
head height	83.92 – 120.35	112.78	12.13
snout length	21.84 – 27.65	26.22	2.20
eye diameter	29.16 – 35.16	32.78	2.24
interorbital distance	32.55 – 50.73	44.14	6.02
jaw length	24.98 – 35.66	30.32	4.06
Meristics	**Range**	**Mean**	**SD**
Scales in Lateral Line	33 - 37	34.83	1.72
Branched anal-fin rays	17 - 20	18	1.10

3

Morphometrics	Range	Mean	SD
Standard length	61.68 - 82.73	70.36	6.84
	% of standard length		
predorsal distance	43.41 - 48.48	46.21	1.99
prepelvic distance	43.44 - 48.43	46.35	1.66
prepectoral distance	21.49 - 29.56	24.47	2.23
preanal distance	63.24 - 67.22	64.56	1.33
height of dorsal origin	22.06 - 28.95	25.16	1.83
height of tail peduncle	8.79 - 11.95	10.28	0.96
length of anal basis	17.67 - 22.58	19.84	1.39
length of dorsal basis	12.04 - 13.75	12.76	0.60
length of pelvic basis	1.85 - 3.86	3.00	0.62
length of pectoral basis	2.95 - 4.30	3.68	0.53
length of head	19.07 - 24.43	21.53	1.70
	% head length		
head height	86.31 - 100.00	93.87	4.79
snout length	42.55 - 58.38	50.55	5.23
eye diameter	22.52 - 35.11	27.63	4.18
interorbital distance	39.30 - 45.15	41.76	2.08
jaw length	33.42 - 40.62	36.21	2.28
Meristics	**Range**	**Mean**	**SD**
Scales in Lateral Line	33 - 39	36.4	1.84
Branched anal-fin rays	16 - 20	19	1.25

4

Morphometrics	Range	Mean	SD
Standard length	58.21 - 62.73	60.47	3.20
	% of standard length		
predorsal distance	54.69 - 57.58	56.14	2.04
prepelvic distance	47.51 - 50.59	49.05	2.18
prepectoral distance	28.33 - 29.46	28.90	0.80
preanal distance	61.87 - 68.65	65.26	4.79
height of dorsal origin	31.79 - 32.16	31.97	0.26
height of tail peduncle	12.53 - 13.06	12.79	0.37
length of anal basis	24.20 - 24.22	24.21	0.02
length of dorsal basis	12.73 - 15.16	13.94	1.72
length of pelvic basis	3.59 - 4.36	3.98	0.55
length of pectoral basis	2.87 - 4.93	3.90	1.45
length of head	28.67 - 28.73	28.70	0.04
	% head length		
head height	89.04 - 91.62	90.33	1.83
snout length	25.04 - 28.52	26.78	2.46
eye diameter	30.97 - 38.47	34.72	5.30
interorbital distance	33.57 - 37.39	35.48	2.70
jaw length	25.97 - 28.52	27.25	1.80
Meristics	**Range**	**Mean**	**SD**
Scales in Lateral Line	33 - 36	34.5	2.12
Branched anal-fin rays	22 - 22	22	0

Table 1. Morphometric and meristic data from Lage stream (n=19). Vouchers 1973, 1974, 1975, 1976, 1977, 1978, 1981, 1982, 1983, 1984, 1985, 1988, 1989, 1991, 1994, 2000, 2016, 2021, 2023. Table 2. Morphometric and meristic data from Açude Lote 94 (n=6). Vouchers 2937, 2938, 2939, 2940, 2941, 2944. Table 3. Morphometric and meristic data from Borrachudo stream (n=10). Vouchers 2048, 2050, 2051, 2052, 2053, 2054, 2069, 2070, 2072, 2073.Table 4. Morphometric and meristic data from Vereda Grande river (n=2). Voucher 2226, 2230.

Morphometrics	Range	Mean	SD
Standard length	34.95 - 56.72	44.94	9.25
	% of standard length		
predorsal distance	47.84 - 52.14	49.85	1.69
prepelvic distance	40.69 - 54.18	48.11	4.24
prepectoral distance	25.30 - 30.58	28.14	2.01
preanal distance	62.50 - 69.08	66.54	2.53
height of dorsal origin	25.19 - 43.89	31.28	5.97
height of tail peduncle	10.11 - 11.09	10.64	0.33
length of anal basis	19.92 - 22.65	21.03	1.03
length of dorsal basis	11.40 - 14.62	12.84	1.27
length of pelvic basis	1.98 - 2.79	2.35	0.26
length of pectoral basis	2.90 - 4.29	3.32	0.48
length of head	27.54 - 43.86	33.23	6.30
	% head length		
head height	83.07 - 105.22	93.46	9.43
snout length	53.91 - 93.42	62.60	13.79
eye diameter	25.71 - 54.39	34.38	9.22
interorbital distance	33.63 - 43.74	38.60	4.07
jaw length	31.29 - 40.16	36.23	3.34
Meristics	**Range**	**Mean**	**SD**
Scales in Lateral Line	30 - 38	34.14	2.67
Branched anal-fin rays	18 - 21	19.43	0.98

5

Morphometrics	Range	Mean	SD
Standard length	49.18 - 69.14	57.41	5.58
	% of standard length		
predorsal distance	29.82 - 51.47	46.48	6.19
prepelvic distance	21.43 - 52.88	36.16	14.18
prepectoral distance	14.59 - 45.80	32.15	10.04
preanal distance	61.74 - 67.61	64.39	2.18
height of dorsal origin	25.88 - 29.80	27.57	1.06
height of tail peduncle	9.83 - 13.91	11.23	1.08
length of anal basis	17.82 - 23.66	20.75	1.59
length of dorsal basis	11.57 - 18.18	13.57	1.90
length of pelvic basis	2.17 - 4.96	3.47	0.81
length of pectoral basis	1.79 - 5.53	3.32	1.33
length of head	19.58 - 27.11	23.25	2.40
	% head length		
head height	86.14 - 111.97	99.35	7.49
snout length	22.78 - 34.13	28.25	3.87
eye diameter	28.63 - 39.09	34.32	2.87
interorbital distance	34.46 - 52.10	43.15	7.00
jaw length	26.54 - 45.47	36.61	6.99
Meristics	**Range**	**Mean**	**SD**
Scales in Lateral Line	34 - 39	36	1.94
Branched anal-fin rays	17 - 23	19.5	1.27

6

Morphometrics	Range	Mean	SD
Standard length	56.6 - 73.16	61.15	4.22
	% of standard length		
predorsal distance	44.43 - 50.05	48.02	1.76
prepelvic distance	45.56 - 52.19	48.15	1.96
prepectoral distance	23.20 - 31.46	26.49	2.16
preanal distance	63.74 - 68.73	66.21	1.94
height of dorsal origin	28.83 - 32.39	30.32	1.11
height of tail peduncle	10.88 - 12.39	11.61	0.44
length of anal basis	18.74 - 24.09	22.13	1.38
length of dorsal basis	15.47 - 17.20	12.80	1.02
length of pelvic basis	1.99 - 3.36	2.56	0.46
length of pectoral basis	2.87 - 4.81	3.65	0.49
length of head	24.06 - 27.91	26.22	1.09
	% head length		
head height	98.03 - 114.11	104.42	4.80
snout length	51.47 - 60.39	55.49	2.77
eye diameter	28.75 - 51.12	34.69	5.35
interorbital distance	38.27 - 47.71	43.48	2.96
jaw length	32.34 - 46.03	35.71	3.34
Meristics	**Range**	**Mean**	**SD**
Scales in Lateral Line	32 - 38	35.2	2.04

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Table 5. Morphometric and meristic data from das Éguas stream (n=7). Voucher 2169, 2170, 2172, 2172, 2173, 2175, 2177. Table 6. Morphometric and meristic data from Tiros stream (n=10). Voucher 2030, 2032, 2033, 2034, 2036, 2037, 2038, 2039, 2040, 2045. Table 7. Morphometric and meristic data from do Boi river (n=15). Voucher 2145, 2147, 2149, 2149, 2150, 2152, 2153, 2154, 2158, 2159, 2161, 2163, 2164, 2165, 2166.

DISCUSSION

Here we describe morphological diversity data from seven populations of *A. rivularis*.

Our data shows that in this region there is a huge diversity in size, shape and meristic counts in this species. Besides being considered a single valid species, separeted from *A. scabripinnis* according to the Catalog of Fishes (Eschmeyer & Fong, 2019), such diversity can indicate a high polymorphic species or we are dealing with a species complex.

Surveys in the Velhas River basin as a whole observed the occurrence of *A. scabripinnis* rather than *A. rivularis* (Alves & Pompeu, 2005) among the 107 species in the watershed, out of the 176 species of the São Francisco River in Minas Gerais (Alves et al., 1998, apud Alves & Pompeu, 2005). Meanwhile, a survey in the Serra do Cipó National Park identified three species of the genus *Astyanax* among the 36 species of fish collected in the Cipó River basin, a tributary of the Velhas River (Vieira et al., 2005). However, the presence of *A. rivularis* or Hasemannia nana was not reported, which led Triques (2006) to record the addition of these species to the list of fishes of the Serra do Cipó National Park. It was speculated that their absence in the first list was due to one of five factors, including that such species were collected but were not taxonomically recognized (Triques, 2006). Indeed, Vieira et al. (2005) reported the presence of *A. scabripinnis*, which suggests that the authors did not consider *A. rivularis* a valid species.

Casatti & Castro (1998) reports an occurrence of *A. rivularis* in the headwaters of São Francisco river. In their identification key for fishes of the São Francisco River basin, Britski and colleagues (1988) present it as *A. scabripinnis rivularis*, but do not record it in the list of the species found in the region of Três Marias - MG. Triques (2006) considers that, among other reasons, it is due to its absence in the region. However, there are reports from cytogenetic studies, where samples are identified as *A. scabripinnis*, in two populations close to the Três Marias (Minas Gerais State) region, with divergent diploid chromosome numbers – 2n=46 at Curral das Éguas populations and 2n=50 chromosomes at Viveiro de Mudas population (Moreira-Filho and Bertollo, 1991). Also in the region of Três Marias, Souza & Moreira-Filho (1995) identified 2n = 50 chromosomes for a population of *A. scabripinnis* from the Barreiro Grande Creek.

Lütken (2001) reports the morphological characteristics of *A. rivularis*, highlighting 33 to 38 lateral line scales; 5 to 6 rows of scales above the lateral line and 6 to 7 below it; on average, the number of ridged striations is high: 07-12-19 in larger specimens, 5 to 10 in smaller; 3 + 16 to 21 (mean 3+18) rays in the anal fin; head length contained 4 times or slightly less in standard length; height contained about 3 times in the standard length; eye diameter of 3 and 1/3 to more than four times in the length of the head; The infra-orbital bones are usually somewhat arched and well-equipped with furrowed grooves; the jawbone usually reaches up to quite below the eyes, more rarely just up the vertical line drawn from its anterior edge; there are 5 intermaxillary teeth in first series and jawbone with 1 to 3 small teeth; the dorsal fin height is generally smaller than its distance from the adipose fin; the tip of the pectoral fin never reaches the ventral fin. Lütken further comments that *A. rivularis* closely resembles *A. fasciatus* (treated by him as *Tetragonopterus cuvieri*) both in body shape and in general appearance.

Therefore, an effort from different areas of science is necessary to better characterize the natural history and geographical distribution of this species in the São Francisco basin, considering that, through DNA “barcoding” technique, Carvalho and colleagues (2011) observed only 0.93% divergence between *A. rivularis* and *A. fasciatus* Cuvier, 1819, another species that has been very difficult to classify, since it was first described in the rivers of Brazil. Besides, different chromosome numbers in the different populations studied suggest that even *A. rivularis* in São Francisco River (data not shown) may represent more than one Operational Taxonomic Unit, thus highlighting the need for further studies in the region.

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