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Fishes of Alto Jacuí sub-basin: a poorly studied sub-basin of northwestern Rio Grande do Sul, Brazil

Karine O. Bonato* and **Clarice B. Fialho**

Universidade Federal do Rio Grande do Sul, Instituto de Biociências, Departamento de Zoologia, Programa de Pós-Graduação em Biologia Animal, CEP 91501–970, Porto Alegre, RS, Brazil

* Corresponding author. E-mail: kakabio2005@yahoo.com.br

Abstract: The streams in the state of Rio Grande do Sul (mainly in the Alto Jacuí sub-basin belonging to the Laguna dos Patos system) have scarce information about their ichthyofauna. Thereby for providing information about stream species, the purpose of the present study was to inventory the ichthyofauna of the streams of the Alto Jacuí sub-basin, located in northwestern state of Rio Grande do Sul. The samples were taken bimonthly from June 2012 to June 2013 using electrofishing technique in 10 streams. A total of 13,247 specimens were collected belonging to 42 species, 10 families and six orders. We report the occurrence of five new species that have not yet been described by researchers.

Key words: stream; Alto Jacuí sub-basin; Laguna dos Patos system; ichthyofauna inventory

INTRODUCTION

Fish are considered the most diverse group of vertebrates (Lowe-MacConnell 1999), with an estimated richness of 32,900 species (Froese and Pauly 2014). By December 2013, Pelayo-Villamil et al. (2014) had found 14,782 described species of fish that occur only in freshwater. Although there is a lack of a complementary information, current estimates of the icthyofauna in the Neotropical region are that there are about 6,000 to 8,000 species, totaling 13% of the vertebrate biodiversity in aquatic ecosystems worldwide, with Brazilian continental waters showing 21% of global diversity (Reis et al. 2003; Agostinho et al. 2005).

There is still a lack of knowledge of fish richness, mainly in South America, Africa and Asia, whichis due to a lack of sampling and databasingPelayo-Villamil et al. 2014). Brazil has the largest river networks in the world (Galves et al. 2009); however, many Brazilian basins and sub-basins have not yet been sampled (Agostinho et al. 2005), or there exists little information about their fish fauna, especially with medium-sized and small water bodies such as streams (Castro 1999). According to Langeani et al. (2007) streams are the environments that have the highest number of new species still to be discovered. But the small size of streams and headwater environments makes these places more susceptible to anthropogenic action and they may experience significant change in their population structure, leading to the disappearance of the most sensitive species (Galves et al. 2009). This situation makes it difficult to understand ecological, biological and biogeographical processes (Barletta et al. 2010).

Although the situation has been changing in the last two decades with an increase of studies (biological, ecological and systematic studies) in streams, there is a lack of knowledge in some regions such as in southern Brazil. Most studies in the state of Rio Grande do Sul refer to large rivers, lagoons or estuarine areas (Fialho et al. 1998; Garcia and Vieira 2001; Bastos 2002; Garcia et al. 2003; Majolo 2005; Maltchik et al. 2005; Dufech and Fialho 2006; Garcia et al. 2006; Petry and Schulz 2006; Ribeiro and Köhler 2007; Dufech and Fialho 2009; Flores-Lopes et al. 2010; Saccol-Pereira and Fialho 2010). The only stream environment studies from Rio Grande do Sul are: Tagliani (1994), Becker (2002), Bozzeti and Schulz (2004), Vilella et al. (2004), Hirschmann (2009), Silva (2009), Winkler-Sosinski et al. (2009), Costa and Schulz (2010) and Volcan et al. (2011).

Little information are available about sampling and studies of the ichthyofauna in streams for the Jacuí river basin and no studies of the upper region of the basin, called the Alto Jacuí sub-basin. Malabarba (1989) showed a list of freshwater fish present in the Laguna dos Patos system and cited species found in Jacuí River and its tributaries. Alves and Fontoura (2009) identified the distributive pattern of migratory fish of the Jacuí River basin, but the data were obtained through interviews, collections, literature and technical studies (EIA-RIMA

Estudo e Relatório de Impacto Ambiental) developed in the study region. Additionally there are some taxonomic reviews and descriptions of new species that are distributed on this drainage (Ottoni and Cheffe 2009; Menezes and Ribeiro 2010; Carvalho and Reis 2011).

We emphasize that to understand the ecological mechanisms in these little-explored environments we must use many tools, including ichthyofaunal studies. Streams are highly heterogeneous environments (Winemiller et al. 2008) and this allows for the establishment of numerous species of fish. Further, more studies of streams in south Brazil are necessary because some basins are not as well explored as the Alto Jacuí sub-basin. Therefore, the aim of this study is to inventory and provide more information about distribution and species richness of ichthyofauna in the Alto Jacuí sub-basin located in northwestern Rio Grande do Sul.

MATERIALS AND METHODS

Study site

The Alto Jacuí sub-basin belongs to the large Laguna dos Patos system and is located in the state of Rio Grande do Sul in the northwestern Middle Plateau and Central Depression region. The Alto Jacuí has its headwaters located in the municipality of Passo Fundo and occupies an area of 16,062 km^2 with its rivers flowing into the Lago Guaíba (COAJU 2009). The basin's vegetation consists of Seasonal Deciduous Forest and some areas of Subtropical Ombrophilous Forest. The economy is based on agriculture (soybeans, corn, wheat and rice) and livestock. The basin is drained by the Jacuí, Jacuí-Mirim, Jacuizinho, Caixões, Ivaí and Soturno rivers (SEMA 2010). The Jacuí River is the main tributary of the basin and it is responsible for 85% of the waters forming the Lago Guaíba (FEPAM 2011).

Thus, this study was conducted in 10 streams (Figures 1 and 2–11) in northwestern Rio Grande do Sul, which corresponds to the Alto Jacuí sub-basin (Table 1). All streams flow into the Jacuí River, which is one of the main tributaries to the Laguna dos Patos system.

Data collection

Fish samples were collected with authorization number 34940 from register number 3196382 from Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio). This study was approved by the Ethics Committee on Animal Use of the Universidade Federal do Rio Grande do Sul (permit number 24434) and was conducted in accordance with protocols in their ethical and methodological aspects for the use of fish.

The fish were collected in June, August, October and December 2012; February, April and June 2013. Each sampling event lasted four days. For the sampling, we used electrofishing with three stages of 30 min each, in stretches of 50 m per sampling stream. After sampling, fish were euthanized with 10% eugenol (Vidal et al. 2008; Lucena et al. 2013a), fixed in 10% formalin

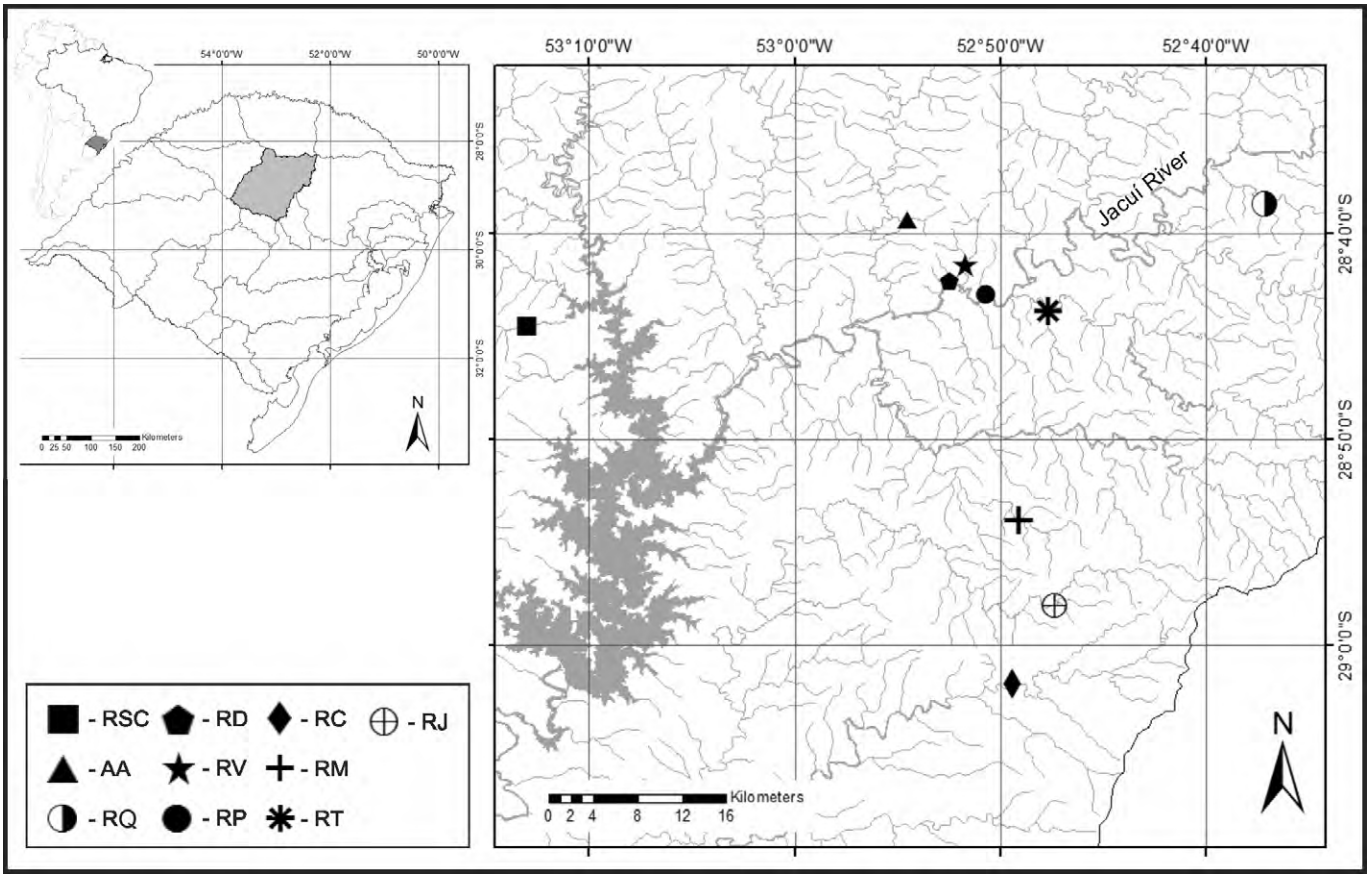


Figure 1. Sampling streams in the Alto Jacuí sub-basin. For stream code see Table 1.

and then transferred to 70% alcohol for conservation. The taxonomic identification was carried out in the laboratory using Rodriguez and Reis (2008), Bertaco and Lucena (2010), Ferrer and Malabarba (2013), Lucena et al. (2013b), Lucena and Soares (2016) and additional literature cited herein. Classification and nomenclature follows Reis et al. (2003), with additional changes made by Thomaz et al. (2015) for Characidae. The nomenclature for Cichlidae followed the new classification of bony fishes proposed by Betancur et al. (2013) that include this family in the order Cichliformes. The voucher specimens were deposited in the fish collection of the Departamento de Zoologia at Universidade Federal do Rio Grande do Sul (UFRGS; Table 2).

Figures 2–11. General view of the sampled streams in the Alto Jacuí sub-basin, Rio Grande do Sul, Brazil: **2**: AA; **3**: RP; **4**: RD; **5**: RC; **6**: RJ; **7**: RM; **8**: RQ; **9**: RSC; **10**: RT; **11**: RV. For stream code see Table 1.

RESULTS

A total of 13,247 specimens belonging to 42 species, ten families and six orders (Table 2 and Figures 12–32) were collected. The most significant orders were Characiformes (36%), Cichliformes (24%) and Siluriformes (14%), with 15, 10 and six species, respectively. Cyprinodontiformes was represented by two species, and both Gymnotiformes and Synbranchiformes were represented by only one species. The predominant families were Characidae (12 species, 29%), Loricariidae (nine species, 21%), Cichlidae (seven species, 17%) and Heptapteridae (four species, 10%), followed by Crenuchidae, Poeciliidae and Trychomycteridae with two species (5% each). Erythrinidae, Pimelodidae, Gymnotidae and Synbranchidae showed one species, corresponding to 2% each of the total richness.

Five species are identified only to genus level and correspond to undescribed species: *Australoheros* sp. (Rícan and Kullander 2008), *Bryconamericus* sp. b (Silva 1998), *Heptapterus* sp. (Bockmann 1998), *Ituglanis* sp. (J. Ferrer, personal communication) and *Bryconamericus* sp. a which also seem to be a new species but, could not be described because it may just be a variation (as color and body shape) of *Bryconamericus iheringii*. According to Bonato and Ferrer (2013), the individuals of *Phalloceros spiloura* Lucinda, 2008 collected in the Alto Jacuí sub-basin during the present study represent the first record of this species to the Laguna dos Patos system.

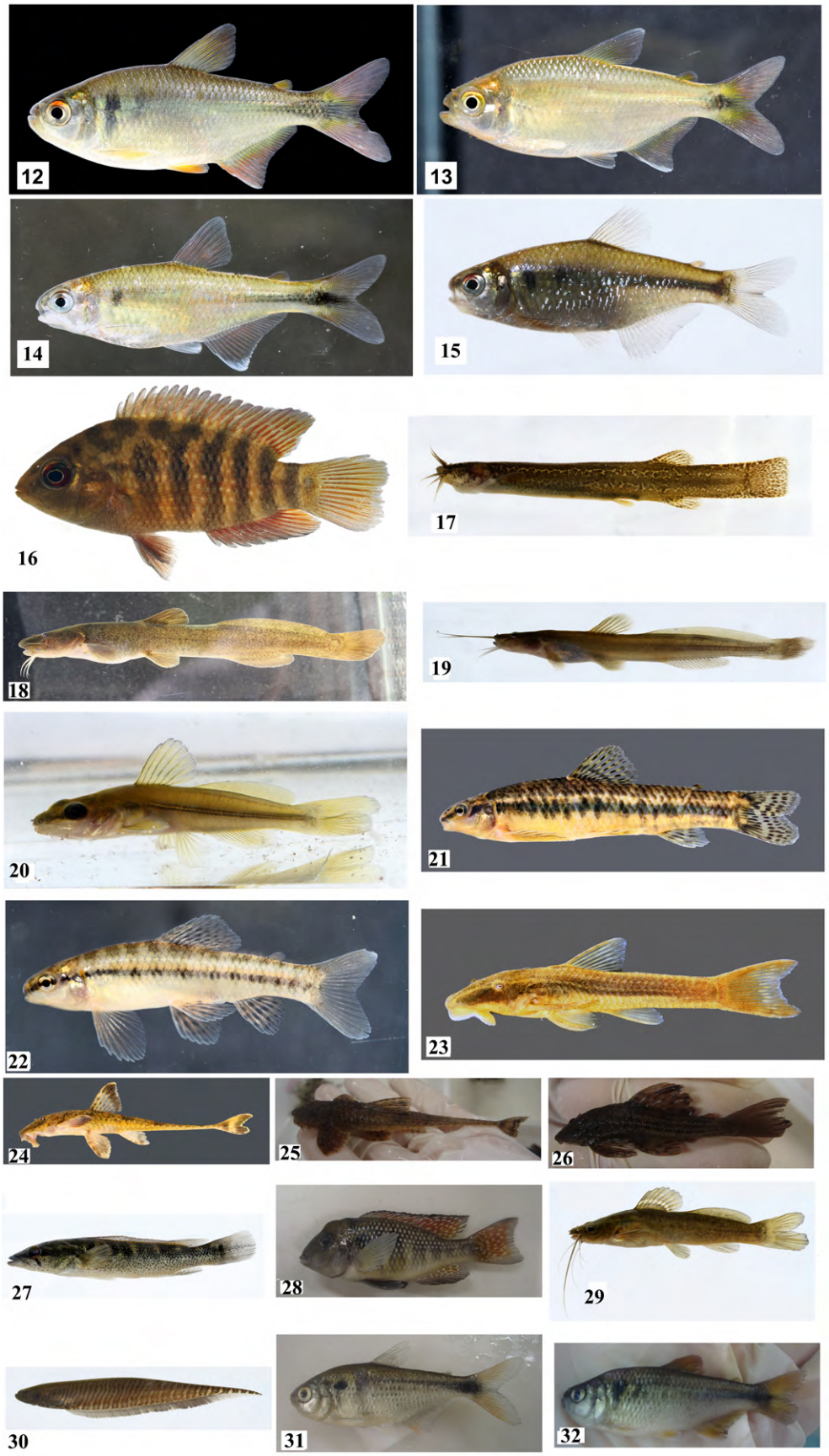
The highest species richness was found in RP, RT, RC and RQ with 28 species, 27 species, 25 species and 21 species, respectively. RM and RSC showed the lowest species richness with only 15 and 14 sample species.

Table 1. Geographic coordinates, elevation and localization of the sampled streams and their respective codes in the Alto Jacuí sub-basin.

Stream	Code	Geographic coordinates	Elevation (m)	Locality
Caixões River	RC	29°01′54.4″ S, 052°49′25.1″ W	420	Guanxuma, Espumoso
Jacuizinho River	RJ	28°58′02.9″ S, 052°47′20.3″ W	513	Depósito, Espumoso
Morcego River	RM	28°53′55.0″ S, 052°49′05.6″ W	461	São Domingos, Espumoso
Turvo River	RT	28°43′47.0″ S, 052°47′40.4″ W	351	Santo Antônio, Espumoso
Quati River	RQ	28°38′31.8″ S, 052°37′07.9″ W	439	Mormaço
Santa Clara River	RSC	28°44′30.1″ S, 053°13′03.0″ W	439	Santa Clara, XV de Novembro
Valoroso Stream	RV	28°41′32.0″ S, 052°51′41.5″ W	376	Teutônia, Tapera
Divinéia Stream	RD	28°42′16.7″ S, 052°52′25.9″ W	350	Teutônia, Tapera
Paz Stream	RP	28°42′57.3″ S, 052°50′41.7″ W	378	Vila Paz, Tapera
Angico Stream	AA	28°39′17.9″ S, 052°54′31.1″ W	368	São Rafael, Tapera

Table 2. List of fish species collected at each sampled stream in the Alto Jacuí sub-basin. See Table 1 for stream names. Asterisk indicates the endemic species to Laguna dos Patos system.

	Streams										
Taxa	**RC**	**RJ**	**RM**	**RV**	**RD**	**AA**	**RSC**	**RQ**	**RP**	**RT**	**Voucher (UFRGS)**
CHARACIFORMES											
Characidae											
Astyanax lacustris (Lütken, 1875)	X			X	X	X		X	X	X	19977
Astyanax laticeps (Cope, 1894)					X		X			X	19327
Astyanax obscurus (Hensel, 1870) *	X						X		X		19329
Astyanax procerus Lucena, Castro & Bertaco, 2013 *	X	X	X	X	X	X	X	X	X	X	19323
Astyanax xiru Lucena, Castro & Bertaco, 2013	X		X		X	X			X	X	19325
Bryconamericus iheringii (Boulenger, 1887)	X	X	X	X	X	X	X	X	X	X	19974
Bryconamericus sp. a	X	X									19975
Bryconamericus sp. b *	X										19980
Diapoma alburnus (Hensel, 1870)	X	X	X					X	X	X	19976
Diapoma dicropotamicus (Malabarba & Weitzman, 2003) *			X					X			19952
Oligosarcus jacuiensis Menezes & Ribeiro, 2010	X	X			X	X	X	X	X	X	19978
Oligosarcus jenynsii (Günther, 1864)				X		X		X	X	X	19979
Crenuchidae											
Characidium orientale Buckup & Reis, 1997	X										19962
Characidium pterostictum Gomes, 1947	X	X	X	X	X	X	X	X	X	X	19973
Erythrinidae											
Hoplias malabaricus (Bloch, 1794)		X	X			X			X	X	19961
SILURIFORMES											
Heptapteridae											
Rhamdia quelen (Quoy & Gaimard, 1824)	X	X	X	X		X	X	X	X	X	19265
Rhamdella eriarcha (Eigenmann & Eigenmann, 1888)	X										19951
Heptapterus mustelinus (Valenciennes, 1835)	X	X					X				19967
Heptapterus sp.	X	X	X	X	X	X	X	X	X	X	19266
Trichomycteridae											
Ituglanis sp.									X		19949
Trichomycterus poikilos Ferrer & Malabarba, 2013 *	X	X	X	X	X	X	X	X	X	X	19267
Loricariidae											
Ancistrus brevipinnis (Regan, 1904)	X	X	X	X	X	X	X	X	X	X	19984
Eurycheilichthys limulus Reis & Schaefer, 1998	X	X	X	X	X	X	X	X	X	X	19985
Hemiancistrus punctulatus Cardoso & Malabarba, 1999 *	X	X		X	X	X		X	X	X	19986
Hisonotus armatus Carvalho, Lehmann, Pereira & Reis, 2008 *	X										19957
Hisonotus brunneus Carvalho & Reis, 2011 *		X						X			19959
Hypostomus commersoni (Valenciennes, 1836)					X				X		19958
Rineloricaria baliola Rodriguez & Reis, 2008		X	X	X	X	X	X	X	X	X	19982
Rineloricaria cadeae (Hensel, 1868) *				X		X		X	X	X	19983
Rineloricaria microlepidogaster (Regan, 1904)	X	X	X								19981
Pimelodidae											
Pimelodus pintado Azpelicueta, Lundberg & Loureiro, 2008									X	X	19960
GYMNOTIFORMES											
Gymnotidae											
Gymnotus aff. *carapo* Linnaeus, 1758	X							X	X	X	19966
CICHLIFORMES											
Cichlidae											
Australoheros sp.	X	X	X					X		X	19968
Crenicichla lepidota Heckel, 1840				X	X				X	X	19969
Crenicichla punctata Hensel, 1870	X			X	X			X	X	X	19972
Geophagus brasiliensis (Quoy & Gaimard, 1824)				X			X		X	X	19965
Gymnogeophagus gymnogenys (Hensel, 1870)									X	X	19964
Gymnogeophagus labiatus (Hensel, 1870)	X										19954
Gymnogeophagus rhabdotus (Hensel, 1870)								X		X	19955
CYPRINODONTIFORMES											
Poeciliidae											
Phalloceros caudimaculatus (Hensel, 1868)				X		X			X	X	19963
Phalloceros spiloura Lucinda, 2008				X	X	X					17827
SYNBRANCHIFORMES											
Synbranchidae											
Synbranchus marmoratus Bloch, 1795									X		19953
Total of Species (*n*= 42)	25	18	15	18	17	18	14	21	28	27	



Figures 12–32. Some species of fishes found in Alto Jacuí sub-basin, Rio Grande do Sul. Photos by L.R. Malabarba. **12**: *Astyanax xiru*, **13**: *Astyanax procerus*, **14**: *Bryconamericus* sp. b (UFRGS 17931), **15**: *Bryconamericus iheringii* (UFRGS 17992), 1**6**: *Australoheros* sp.(UFRGS 17989), **17**: *Trichomycterus poikilos*, **18**: *Heptapterus* sp. (UFRGS 17933), **19**: *Heptapterus mustelinus*,**20**: *Rhamdella eriarcha* (UFRGS 17984), **21**: *Characidium pterostictum* (UFRGS 17826), **22**: *Characidium orientale*, **23**: *Eurycheilichthys limulus* (UFRGS 17986), **24**: *Rineloricaria baliola* (UFRGS 17991), **25**: *Rineloricaria cadeae*, **26**: *Hypostomus commersoni*, **27**: *Creniciclha punctata* (UFRGS 17990), **28**: *Gymnogeophagus gymnogenys*, **29**: *Rhamdia quelen*, **30**: *Gymnotus* aff. *carapo* (UFRGS 17989), **31**: *Astyanax laticeps*, **32**: *Astyanax obscurus*.

DISCUSSION

According to Pelayo-Villamil et al. (2014) an average of 240.2 species of fishes were described per year in the last ten years worldwide. The five new species uncovered by this inventory (*Australoheros* sp., *Heptapterus* sp., *Bryconamericus* sp. a and b, and *Ituglanis* sp.) support the importance of this type of study. In addition, inventories are important in extending the distributional range of some species, such as *Phalloceros spiloura* that was previously only known from the coastal drainages of states of Rio Grande do Sul and Santa Catarina, Iguaçu and Uruguay river basins, and as part of this study, was found in the Alto Jacuí sub-basin representing a new record for the Laguna dos Patos system (Bonato and Ferrer 2013).

Malabarba (1989) registred 25 species of the 42 species sampled in this study to Laguna dos Patos system. The most recent literature indicates a total of 160 species to the Laguna dos Patos system (Malabarba et al. 2009) including 35 species that were new species and yet not described in 2009. Of these 35 species listed by Malabarba et al. (2009), we have sampled five species that were described in recent years (*Oligosarcus jacuiensis* Menezes & Ribeiro, 2010; *Hisonotus brunneus* Carvalho & Reis, 2011; *Astyanax procerus* Lucena, Castro & Bertaco, 2013; *Astyanax xiru* Lucena, Castro & Bertaco, 2013; *Trychomycterus poikilos* Ferrer & Malabarba, 2013), indicating that a representative amount of the ichthyofauna of the upper Jacuí River was described in recent years. There are no comparable studies for the Alto Jacuí sub-basin. We can only make comparisons with other basins belonging to the Laguna dos Patos system. For stream environments Bozzeti and Schulz (2004) found 57 species in the Gravataí and Sinos sub-basins, Hirschmann (2009) found 55 species in the Forqueta sub-basin (Taquari-Antas basin), and Becker et al. (2013) found 119 species for the Taquari-Antas basin but in respect to the last study, the high number of captured species is likely due to their larger sampling of 519 sites.

The number of species found in this study is lower compared to those cited by other studies mainly because it was conducted in streams from a headwater region and many of the streams (of lower species richness) are first-order. The highest occurrence of the orders Characiformes, Cichliformes and Siluriformes in studies is also well documented for the Laguna dos Patos system and for the Neotropical region (Castro 1999; Garcia et al. 2003; Buckup et al. 2007; Lévêque et al. 2008; Costa and Schulz 2010). Headwater streams do not have an exclusive fish fauna but, species that form populations residing in streams and also that occur in larger bodies of water with different characteristics (Castro 1999). The fish fauna of streams is based on small species and according to Castro (1999) it seems to be the only general pattern with real diagnostic value for stream environments. In this study, the streams with lower species richness are the first-order streams, which have a habitat of lower complexity as RD, RV and AA streams (see Table 1 for stream codes). This situation is expected in accordance with the River Continuum Theory (Vannote et al. 1980). Thus, the larger streams, with greater width between banks, areas with and without shading, and more heterogeneous environment showed the highest species richness (Fereira and Casatti 2006; Súarez and Petrere-Junior 2005) as occurred in the RT, RP and RC streams.

Despite the fact that we did not evaluate the degree of anthropic influences in the sampled streams, all streams sampled here showed some kind of human interference. Most streams are very close to agricultural areas with the presence of dairy cattle or pig livestock. In stream RP there was a considerable amount of waste coming from homes and sometimes we found dead animals within the stream. Probably the residents of the region slaughter animals for their own consumption and discard the remains of the animal in the river. However, this stream had considerable marginal vegetation and a heterogeneous environment with changing pools and areas of rapids, which led to the high amount of richness observed.

Due to a lack of data for streams of the studied sub-basin it is difficult to say that the number of species found is representative of the streams belonging to Laguna dos Patos system. The checklist showed 42 species representing 26% of the species mentioned for the Laguna dos Patos system. This study is an important record for the region of the Alto Jacuí sub-basin due to the lack of extensive collecting effort in the region. The expansion of the sampled streams in Jacuí River basin may increase the records of species and information about endemic species.

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