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The fish fauna of streams in the Madeira-Purus interfluvial region, Brazilian Amazon

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Abstract: Small headwaters streams of the Neotropical region usually have high species richness and diversity. This study aimed to investigate the species composition and abundance of fish fauna in the headwaters streams of the Madeira-Purus interfluvial plain in the Brazilian Amazon. A total of 22 streams of 1st to 3rd order were sampled during two expeditions at two separate locations in April-May and July of 2007. A total of 5508 fishes were captured using hand and small seine nets, belonging to 78 species, 22 families and six orders. Characiformes was the most diverse taxonomic group in the samples, followed by Gymnotiformes and Siluriformes. Our findings indicate that the fish fauna of streams in the Madeira-Purus interfluvial plain is both rich and diverse and should be considered during the implementation of strengthened environmental conservation strategies in this region.

Introduction

The Neotropical region harbors a high diversity of freshwater fish, which includes almost 4500 already described species and nearly 1550 species still waiting for a scientific description (Reis *et al*. 2003). The Amazon basin is considered to shelter most of this diversity; however knowledge about the ichthyofaunal composition of this region is concentrated in the most accessible areas near large urban centers (Lowe-McConnell 1999). Furthermore, information about fish has been obtained mostly from the main tributaries of the Amazon River, and primarily targeting medium- to large-sized species of commercial value (Böhlke *et al*. 1978; Rapp Py-Daniel and Leão 1991).

Small streams, of the 1st (no tributaries), 2nd (two first order streams join) and 3rd order (two second order streams join), have a unique species pool, and contribute significantly to regional diversity (*e.g.* Espírito-Santo *et al.* 2009). Furthermore, because of the isolated condition of the streams, they are considered important for evolutionary processes, such as speciation (Barthem 2004). However, studies in these environments are limited because of their remoteness (and hence difficult access) and because they shelter small bodied species that are of no commercial interest for use as human food (Lowe-McConnell 1999).

The interfluvial plain between the Madeira and Purus Rivers is one of the most pristine parts of the Amazonian region, but is also one of the least studied with a small amount of protected area coverage. In addition, the Brazilian Federal Government development policies for this region include paving an existing road and the opening of hydroways, dam construction and gas transportation systems. The implementation of such actions is likely to have a major impact to the region, through the encroachment of human settlements, pollution, and deforestation (Fearnside and Graça 2006). Hence there is serious concern for the conservation of small streams and forested environments, which are particularly vulnerable to human occupation/activities and its impacts (*e.g.* Dias *et al*. 2009).

This study presents the first standardized survey conducted in the interfluvial plain of the Madeira and Purus Rivers. The study aims to contribute to existing knowledge of the fish fauna of small Neotropical streams, comparing our findings to similar studies in other regions in the Brazilian Amazon, and consider the conservation importance of this remote area of the basin.

Materials and Methods

Study area

The study was conducted in the area surrounding the BR-319 highway (connecting Porto Velho, in Rondonia state, to Manaus, in the Amazonas state), between the Madeira and Purus Rivers, in southwestern Brazilian Amazon. Two sites were selected for data collection: the first in the southern part of the intefluvial plain near to Porto Velho (Rondônia state) and the second in the northern part, near to Manaus municipality (Amazonas state).

A total of 22 small streams of 1st to 3rd order were sampled, in two separate expeditions; 11 during the first trip between April and May 2007 to the southern part of the region, and 11 streams during the second trip in July 2007 in the northern part of the region. In the first expedition all sampled streams were in close proximity to site #1 and belong to the Purus river basin, and in the second expedition three streams were sampled near site #2, four near site #3, and four near site #4, all draining into the Madeira river (Figure 1). The duration of each expedition was approximatedly 20 days. Both expeditions were conducted at the beggining of the dry season with the southern part being visited first due to the rain stopping earlier than at the northern part.

The geology of the region is primarily comprised by Cenozoic deposits, with sediments from the Tertiary and early Quaternary periods, which make up the Solimões Formation. The relief is classified as one of the morpho-structural units of the "lowered Amazonian tableland" (Radambrasil 1978). Soils are mostly red-yellow podzols, but there are also patches of red-yellow latosols, yellow latosols and hydromorphic laterites (Radambrasil 1978).

The climate is equatorial, warm and humid, including the categories of 'tropical monsoon' (Am), 'tropical rainforest' (Af), and 'tropical wet and dry' (Aw) based on the Köppen climate classification system (Radambrasil 1978). The mean annual temperatures ranges between 24 °C and 26°C. The wet season usually starts in October, with the highest volume of rain falling from January to March. Vegetation cover is dominated by dense and open tropical forests (Radambrasil 1978).

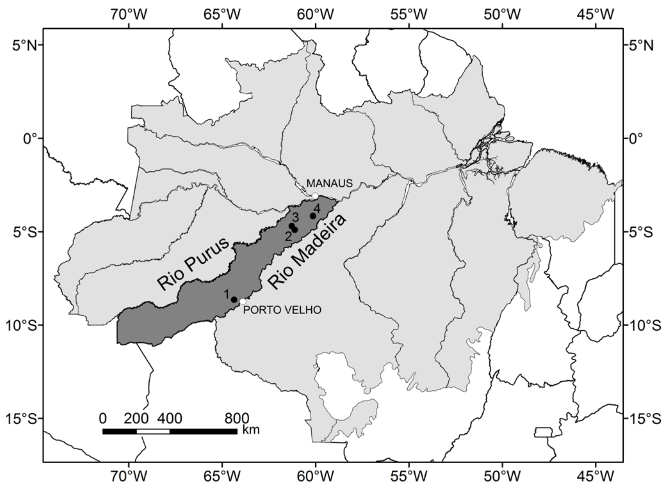

Figure 1. Study area at the interfluvial region of Madeira and Purus Rivers (dark gray) in the Brazilian Amazon biome (light gray). The numbers indicate the sampling sites at the southern (site #1, 11 streams sampled; Purus basin, near to Porto Velho, Rondônia state) and northern (sites #2, three streams; #3, four streams; and #4, four streams; Madeira basin, near to Manaus, Amazonas state) portions of the interfluvial plain.

Fish sampling

The fish sampling protocol used in this study follows Mendonça *et al.* (2005), for the purposes of comparative analysis with similar studies (*e.g.* Dias *et al*. 2009; Espírito-Santo *et al*. 2009). In each stream that was surveyed, a 50 m long section was delimited for the collection of fish. The two extremities of the section were blocked using a fine-mesh net (5 mm between opposite knots) with the aim to prevent the escape of fishes during capture. Fish were captured using a purse seine of 2 m length (mesh size= 2 mm) and hand nets. Capture was conducted during daylight hours only and always in in the same direction; from downstream to upstream. Sampling effort was standardized as much as possible with three collectors working for a 2 h period in each 50 m section.

The collected specimens were sacrificed in a solution of clove oil (Eugenol, 2 drops per litre; *cf.* American Veterinary Medical Association 2001), and fixed in 10% formalin solution. All fish collected in this study were transported to the Instituto Nacional de Pesquisas da Amazônia (INPA) in Manaus. The fish species were separated, and identified by the research team, with the aid of taxonomic literature, and identification keys (*e.g.* Weitzman 1960; 1978; Géry 1977; 1993; Kullander 1986; 1989; 1995; Vari and Ortega 1986; Lucena 1987; Weitzman and Vari 1987; Burgess 1989; Kullander and Ferreira 1991; Huber 1992; Vari 1992; Buckup 1993; Silfvergrip 1996; Reis 1997; Schaefer 1997; Zarske and Géry 1997; Lima and Toledo-Piza 2001; Römer 2002; Crampton *et al.* 2003; Crampton and Albert 2003; Costa 2004; Crampton *et al.* 2004; Crampton and Albert 2004; Mago-Leccia 1994; Crampton *et al.* 2005; Favorito *et al.* 2005; Lundberg 2005; Reis *et al.* 2005; Sousa and Py-Daniel 2005; Thacker *et al.* 2006; Zarske and Géry 2006; Rocha *et al.* 2008; Sarmento-Soares and Martins-Pinheiro 2008; Oyakawa and Mattox 2009; Marinho and Langeani 2010). Samples of the collected specimens were subsequently deposited in the INPA Fish Collection (Table 1). Fishes were collected under the IBAMA license # 10199-1.

Results and Discussion

A total of 5508 fishes were collected belonging to 78 species, 22 families and six orders. The distribution of most species was related to drainage basins. Of the total species collected, 25 were found in both basins, 19 were collected only in the Purus basin, and 34 only in the Madeira basin (Table 1). Of the 78 species, 12 were identified to the genus level only, with an additional three requiring confirmation of identification to the species level. In other words, the taxonomic status of 19.2% of the collected species was undefined and may possibly be revealed as new species following review by taxonomists.

Characiformes was the most diverse and abundant order, with 39 species and 81.6% of all collected specimens. Based on species number, the second most represented order was Gymnotiformes (n = 15), followed by Siluriformes (n = 12), Perciformes (n = 8), Cyprinodontiformes (n = 2), and Synbranchiformes (n = 2). Based on sample abundance, the second most represented order was again Gymnotiformes (6.3% of sampled specimens), followed by Perciformes (4.8%), Siluriformes (4.2%), Cyprinodontiformes (2.7%), and Synbranchiformes (0.4%). Furthermore, three families represented almost 80% of sampled individuals (Table 1), comprising Characidae with 56.4% of the total abundance, followed by Lebiasinidae (18.1%), and Crenuchidae (5.2%).

Overall, five species comprised 56.7% of the total abundance; these included *Hyphessobrycon heterorhabdus* Ulrey, 1894 (20.4%), *Hemigrammus vorderwinkleri* Géry, 1963 (11.8%), *Copella nattereri* (Steindachner, 1876) (11.3%), *Hemigrammus schmardae* (Steindachner, 1882) (6.9%), and *Hemigrammus belottii* (Steindachner, 1882) (6.3%). A further six species were found in over 60% of the sampled streams (Table 1); these included *Apistogramma agassizi* (Steindachner, 1875) (77.3%), *Hyphessobrycon heterorhabdus* (Ulrey, 1894) (72.7%) and *Pyrrhulina brevis* Steindachner, 1876 (72.7%), *Rivulus* sp. (68.2%), *Erythrinus erythrinus* (Bloch and Schneider, 1801) (63.6%) and *Gymnotus coropinae* Hoedeman, 1962 (63.6%).

Existing research has indicated a large diversity in South American freshwater fish fauna, with Characiformes and Siluriformes usually being most dominant (Castro 1999; Lowe-McConnell 1999; Reis *et al*. 2003; Buckup *et al*. 2007). These observations have been further supported by studies in a number of Brazilian Amazon streams (Sabino and Zuanon 1998; Araújo-Lima *et al.* 1999; Bührnheim and Cox-Fernandes 2001; Dias *et al*. 2009; Espírito-Santo *et al.* 2009; Oliveira *et al.* 2009). In this study, Characiformes was also the most diverse order. However, the second order in species richness was Gymnotiformes, rather than Siluriformes as was found in the the above mentioned studies. In this study, Gymnotiformes represented both a relatively high proportion of species (19.2%), and a relatively high abundance (6.3%). The reason for this may have been due to the high proportion of litter banks in sampled streams, a substrate on which individuals of this order were collected. The species of this order usually inhabit slow moving or lentic (*i.e.* lake, pond or swamp like) environments (Fink and Fink 1978), which explain our results. On the other hand, the Perciformes, Cyprinodontiformes and Synbranchiformes all represented small proportions of the overall species abundance and richness, which was similar to that found in previous studies (Silva 1995; Mendonça *et al.* 2005; Espírito-Santo *et al.* 2009; Oliveira *et al.* 2009) and other freshwater environments of South America (Lowe-McConnell 1999).

The present study found very high fish species richness (78 spp.) when compared to existing studies of streams in the Brazilian Amazon (*e.g.* Araújo-Lima *et al*. 1999; Bührnheim and Cox-Fernandes 2001). For example, in the studies by Mendonça *et al.* (2005) and Espírito-Santo *et al.* (2009), in which 38 sections and 31 sections of creeks of 1st to 3rd order were sampled respectively, both following the same methodology used in this study, a total of 49 and 53 fish species were detected respectively. In addition to the relatively high species richness recorded in this study, there is other evidence of high species diversity in the Madeira-Purus interfluvial region, and hence its conservation importance. Field studies in the Amazonian region have uncovered about 4-5% of previously unnamed species (Peres 2005), which is much smaller than the 19.2% of species with undefined taxonomic status found in this study. Further analysis of the fish collected in this study, that do not match species found in biological collections and/or the specialised literature, may result in the classification of new species. Such species are likely to be of restricted distribution, enlarging the list of endemic fish proposed by Nogueira *et al* (2010). In conclusion, the results of this study reinforce the requirement for more targeted surveys on the distribution of Amazonian freshwater fish fauna in remote areas. The acquisition of such scientific information is essential to improve knowledge on distribution patterns of fish species; to monitor the impacts of anthropogenic activities, which can possibly threat species survivorship (Peres *et al*. 2010); and for implementation of effective conservation strategies for ecosystems supporting the fish fauna of Neotropical streams.

Table 1. Composition of the fish fauna sampled in 22 streams of the Madeira-Purus interfluvial plain (Rondônia and Amazonas states, Brazilian Amazon). Purus/Madeira= number of individuals captured in each drainage basin; N = total abundance; FR%= relative frequency of the species in relation to the total number of collected specimens; FO%= frequency of occurrence in the sampled streams.

TAXON	BASINS		N	FR (%)	FO (%)	INPA #
	PURUS	MADEIRA				
CHARACIFORMES						
Characidae						
Amazonspinther dalmata Bührnheim, Carvalho, Malabarba and Weitzman, 2008	8	4	12	0.22	18.2	28659, 28660, 28662, 28663, 28665
Aphyocharacidium bolivianum Géry, 1973	0	52	52	0.94	4.5	35819
Bario steindachneri (Eigenmann, 1893)	3	0	3	0.05	9.1	35772, 35784
Bryconops aff. *magoi* Chernoff and Machado-Allison, 2005	28	0	28	0.51	9.1	35801
Charax caudimaculatus (Lucena,1987)	0	2	2	0.04	4.5	35827
Gnathocharax steindachneri Fowler, 1913	0	8	8	0.15	4.5	35887
Hemigrammus belottii (Steindachner, 1882)	0	349	349	6.34	27.3	35888
Hemigrammus gracilis (Lütken, 1875)	1	0	1	0.02	4.5	35806
Hemigrammus ocellifer (Steindachner, 1882)	179	42	221	4.01	31.8	35788, 35847, 35889
Hemigrammus schmardae (Steindachner, 1882)	0	380	380	6.90	18.2	35829, 35875
Hemigrammus vorderwinkleri Géry, 1963	649	0	649	11.78	27.3	35766, 35792
Heterocharax sp. (juvenile)	0	1	1	0.02	4.5	35900
Hyphessobrycon cf. *tukunai* Géry, 1965	0	16	16	0.29	9.1	35849, 35876
Hyphessobrycon heterorhabdus (Ulrey, 1894)	763	362	1125	20.42	72.7	35769, 35807, 35864
Iguanodectes geisleri Géry, 1970	7	3	10	0.18	9.1	35808
Iguanodectes variatus Géry, 1993	0	9	9	0.16	18.2	35832, 35865, 35891
Moenkhausia mikia Marinho and Langeani, 2010	0	1	1	0.02	4.5	35893
Moenkhausia chrysargyrea (Günther, 1864)	1	0	1	0.02	4.5	35815
Moenkhausia cotinho Eigenmann, 1908	0	2	2	0.04	9.1	35894, 35910
Moenkhausia cf. *diktyota* Lima and Toledo-Piza, 2001	0	12	12	0.22	9.1	35855, 35863
Moenkhausia oligolepis (Günther, 1864)	7	0	7	0.13	4.5	35791

Table 1. *Continued.*

TAXON	BASINS		N	FR (%)	FO (%)	INPA #
	PURUS	MADEIRA				
Priocharax ariel Weitzman and Vari, 1987	0	173	173	3.14	18.2	35825
Tyttocharax madeirae Fowler, 1913	12	33	45	0.82	13.6	35811
Crenuchidae						
Crenuchus spilurus Günther, 1863	0	93	93	1.69	36.4	35871
Elachocharax junki (Géry, 1971)	0	29	29	0.53	13.6	35885
Elachocharax pulcher Myers, 1927	0	1	1	0.02	4.5	35845
Microcharacidium weitzmani Buckup, 1993	6	126	132	2.40	36.4	35774, 35833, 35877
Odontocharacidium aphanes (Weitzman and Kanazawa, 1977)	0	31	31	0.56	22.7	35823, 35834, 35896
Curimatidae						
Cyphocharax pantostictos Vari and Barriga S,, 1990	1	0	1	0.02	4.5	35813
Erythrinidae						
Erythrinus erythrinus (Bloch and Schneider, 1801)	13	18	31	0.56	63.6	35767, 35821, 35854, 35914, 35920
Hoplias malabaricus (Bloch, 1794)	1	8	9	0.16	31.8	35814, 35830, 35848, 35890, 35922
Hoplerythrinus unitaeniatus (Spix and Agassiz, 1829)	7	0	7	0.13	22.7	35768
Gasteropelecidae						
Carnegiella marthae Myers, 1927	0	1	1	0.02	4.5	35883
Carnegiella strigata (Günther, 1864)	19	38	57	1.03	45.5	35906
Lebiasinidae						
Copella nattereri (Steindachner, 1876)	0	623	623	11.31	50.0	35820, 35838, 35844, 35860, 35907, 35919
Copella nigrofasciata (Meinken, 1952)	80	0	80	1.45	22.7	35778
Nannostomus eques Steindachner, 1876	0	1	1	0.02	4.5	35895
Pyrrhulina brevis Steindachner, 1876	63	62	125	2.27	72.7	35818, 35824, 35835, 35841, 35851, 35857, 35867, 35879, 35911, 35924
Pyrrhulina zigzag Zarske and Géry, 1997	170	0	170	3.09	27.3	35794
CYPRINODONTIFORMES						
Rivulidae						
Rivulus kirovskyi Costa, 2004	22	3	25	0.45	27.3	35775, 35852, 35869
Rivulus sp.	85	36	121	2.20	68.2	35770
GYMNOTIFORMES						
Gymnotidae						
Gymnotus carapo Linnaeus, 1758	3	3	6	0.11	13.6	35787, 35804, 35872
Gymnotus coatesi La Monte, 1935	0	1	1	0.02	4.5	35921
Gymnotus coropinae Hoedeman, 1962	19	41	60	1.09	63.6	35797, 35861, 35873, 35916
Gymnotus sp.1	2	1	3	0.05	13.6	35771, 35805, 35917
Gymnotus sp.2	0	15	15	0.27	9.1	35846, 35862
Hypopomidae						
Brachyhypopomus brevirostris (Steindachner, 1868)	0	5	5	0.09	9.1	35843, 35904
Brachyhypopomus sp.1	0	54	54	0.98	18.2	35882, 35905, 35913
Brachyhypopomus sp.2	19	1	20	0.36	31.8	35777, 35785, 35793, 35796, 35870
Brachyhypopomus sp.3	1	0	1	0.02	4.5	35816
Hypopygus lepturus Hoedeman, 1962	14	89	103	1.87	40.9	35789, 35831, 35840, 35923
Microsternarchus bilineatus Fernández-Yépez, 1968	0	28	28	0.51	18.2	35850
Microsternarchus sp.	2	46	48	0.87	22.7	35856, 35866, 35878
Steatogenys duidae (La Monte, 1929)	0	1	1	0.02	4.5	35826
Rhamphichthyidae						
Gymnorhamphichthys petiti Géry and Vu-Tân-Tuê, 1964	1	0	1	0.02	4.5	35803
Sternopygidae						
Sternopygus aequilabiatus (Humboldt, 1805)	0	1	1	0.02	4.5	35836
PERCIFORMES						
Cichlidae						
Acaronia nassa (Heckel, 1840)	0	1	1	0.02	4.5	35902
Aequidens sp.1	6	2	8	0.15	22.7	35781, 35842
Aequidens sp.2	0	2	2	0.04	4.5	35859
Apistogramma agassizi (Steindachner, 1875)	67	149	216	3.92	77.3	35782, 35881, 35903

Table 1. *Continued.*

TAXON	BASINS		N	FR (%)	FO (%)	INPA #
	PURUS	MADEIRA				
Apistogramma regani Kullander, 1980	15	0	15	0.27	9.1	35783
Crenicara punctulatum (Günther, 1863)	0	1	1	0.02	4.5	35884
Crenicichla inpa Ploeg, 1991	1	0	1	0.02	4.5	35812
Gobiidae						
Microphilypinus ternetzi Myers, 1927	0	18	18	0.33	9.1	35892
SILURIFORMES						
Auchenipteridae						
Tatia brunnea Mees, 1974	0	1	1	0.02	4.5	35880
Tatia gyrina (Eigenmann and Allen, 1942)	1	3	4	0.07	13.6	35799, 35899, 35912
Callichthyidae						
Megalechis picta (Müller and Troschel, 1849)	3	6	9	0.16	18.2	35790, 35909
Cetopsidae						
Helogenes marmoratus Günther, 1863	10	40	50	0.91	50.0	35779, 35822, 35828, 35839, 35874
Doradidae						
Physopyxis ananas Sousa and Rapp Py-Daniel, 2005	0	11	11	0.20	4.5	35897
Heptapteridae						
Gladioganis conquistador Lundberg, Bornbusch and Mago-Leccia, 1991	26	109	135	2.45	45.5	35786, 35802, 35886, 35908, 35915
Rhamdia quelen (Quoy and Gaimard, 1824)	0	3	3	0.05	13.6	35858, 35868, 35898
Loricariidae						
Ancistrus sp.	2	0	2	0.04	4.5	35800
Otocinclus caxarari Schaefer, 1997	4	0	4	0.07	4.5	35809
Pseudopimelodidae						
Batrochoglanis raninus (Valenciennes, 1840)	1	0	1	0.02	4.5	35773
Trichomycteridae						
Ituglanis amazonicus (Steindachner, 1882)	6	0	6	0.11	13.6	35780
Trichomycterus hasemani (Eigenmann, 1914)	0	5	5	0.09	9.1	35901
SYNBRANCHIFORMES						
Synbranchidae						
Synbranchus madeirae Rosen and Rumney, 1972	2	0	2	0.04	9.1	35795, 35817
Synbranchus sp.	2	20	22	0.40	40.9	35798, 35810, 35853, 35918, 35837
N = 78	**2332**	**3176**	**5508**			

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