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Structure and integrity of fish assemblages in streams associated to conservation units in Central Brazil

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This study aims to characterize the spatial and seasonal distribution of the fish assemblage and evaluate the integrity of streams in a sustainable use area that includes integral protection conservation units in Distrito Federal, Central Brazil (Cerrado biome). For the study, 12 stretches of 8 streams were sampled in 2008 (dry season) and 2009 (wet season). For that evaluation was estimated the Physical Habitat Index (PHI), vegetation cover (VC), pH, dissolved oxygen, turbidity, and conductivity. We recorded 22 species, about eight undescribed species, by a total of 2,327 individuals. The most representative families in number of species were Characidae (31.8%), Loricariidae (31.8%), and Crenuchidae (13.6%). *Knodus moenkhausii* was the most abundant species with 1,476 individuals, added to *Astyanax* sp., *Phalloceros harpagos*, and *Hasemania* sp. they represent over 95% of the total abundance. The species *Astyanax* sp. (occurring in 79.2% of the stretches) and *K. moenkhausii* (50.0%) were considered constant in both seasons. The longitudinal gradient (River Continuum) exerts a strong influence on the studied assemblage. According to CCA, the variables that structure the fish assemblage are based on aspects related to water volume and habitat complexity. No seasonal variation in richness, diversity, abundance, and mass were detected. A cluster analysis suggests a separation of species composition between the stretches of higher and lower orders, which was not observed for seasonality. The streams were considered well preserved (mean PHI $82.9 \pm 7.5\%$), but in some stretches were observed anthropogenic influence, detected in the water quality and, mainly, on the riparian vegetation integrity. The exotic species *Poecilia reticulata* was sampled in the two stretches considered most affected by anthropogenic activities by PHI, conductivity, and VC.

Esse estudo teve como objetivo caracterizar a distribuição espacial e sazonal da taxocenose de peixes e avaliar a integridade dos córregos de uma área de uso sustentável que inclui unidades de conservação de proteção integral no Distrito Federal, Brasil Central (bioma Cerrado). Para o estudo, foram amostrados 12 trechos de oito cursos d'água em 2008 (estação seca) e 2009 (estação chuvosa). Para essa avaliação foram utilizados o Índice Físico do Habitat (IFH), cobertura vegetal (CV), pH, oxigênio dissolvido, turbidez e condutividade. Foram coletadas 22 espécies, sendo oito não descritas, em um total de 2.327 indivíduos. As famílias mais representativas em número de espécies foram Characidae (31,8%), Loricariidae (31,8%) e Crenuchidae (13,6%). *Knodus moenkhausii* foi a espécie mais abundante, com 1.476 indivíduos, que juntamente com *Astyanax* sp., *Phalloceros harpagos* e *Hasemania* sp. representaram mais de 95% da abundância total. As espécies *Astyanax* sp. (ocorrendo em 79,2% dos trechos) e *K. moenkhausii* (50,0%) foram consideradas constantes nas duas estações. O gradiente longitudinal (rio Contínuo) exerce forte influência na taxocenose estudada. De acordo com a CCA, as variáveis que estruturam a taxocenose íctica se baseiam em aspectos relacionados ao volume e complexidade dos habitats. Não foi detectada variação sazonal na riqueza, diversidade, abundância e massa. Uma análise de agrupamento sugere uma separação na composição de espécies entre trechos de maiores e menores ordens, o que não foi observado para a sazonalidade. Os córregos da APA encontram-se relativamente bem preservados (IFH médio de $82,9 \pm 7,5\%$), porém em alguns trechos foi observada certa influência antrópica, detectada na qualidade da água e, principalmente, na integridade da vegetação ripária. A espécie exótica *Poecilia reticulata* foi coletada nos dois trechos considerados mais afetados por atividades antrópicas de acordo com o IFH, condutividade e CV.

Key words: Cerrado, Habitat quality, Headwaters, Upper Paraná river.

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Introduction

Fishes of small size streams exhibit strong dependence of structural characteristics of the environment (Gorman & Karr, 1978; Poff, 1997). Its distribution is influenced by hydrogeological variables in detriment to biological interactions (Peres-Neto, 2004). In headwaters streams, as a result of shading caused by riparian vegetation, the primary production is usually extremely deficient, unlike larger rivers, where is possible the establishment of algae and macrophytes in larger proportion (Vannote *et al.*, 1980). Consequently, the ichthyofauna of these systems, as well as the whole community, are extremely dependent of allochthonous input from the riparian vegetation (*e.g.*, leaves, twigs, flowers, fruits, and terrestrial arthropods that fall into the water) to feed, shelter and reproduce (Lowe-McConnell, 1987; Castro, 1999). Castro (1999) emphasizes the small size as a general pattern of headwaters fish fauna. Among other things, this pattern exists due the low productivity of these systems (Vannote *et al.*, 1980) and the small size prey that compose their diets (Castro, 1999).

As a result of human actions, the headwater streams ichthyofauna is suffering strong pressure, mainly by the indiscriminate use of pesticides, construction of dams, deforestation and changes in riparian vegetation, introduction of exotic species and siltation (Castro & Menezes, 1998; Casatti *et al.*, 2006b). The Paraná basin, also characterized by having intense agricultural activity, contains the areas with the highest population densities and the most industrialized region of Brazil (Agostinho *et al.*, 2007). Because of the high diversity and the threats resulted by agricultural expansion, the Brazilian Savanna (Cerrado) is rated as one of 25 global hotspots. Estimates predict that there is only 20% of the original biome preserved, with only 6.2% destined to conservation areas (Myers *et al.*, 2000), some of them classified as of sustainable use. In this case, human occupation, presence of private lands, and extractivism are allowed (Sistema Nacional de Unidades de Conservação - SNUC, Law 9985/00).

The Brazilian fish fauna stands out for its richness and diversity. Currently, there are 2,587 species described for freshwater ecosystems, representing about 55% of freshwater fish species of the Neotropical Region (Buckup *et al.*, 2007). According to Langeani *et al.* (2007), 310 fish species are recorded for upper Paraná, in which 236 (76.1%) are considered native (autochthonous), 67 (21.6%) are species introduced from other basins of the Neotropical Region (allochthonous) and seven (2.3%) are exotic from other continents. About 65% of these species are small sized (≤ 21 cm) and most of them occur exclusively in headwaters streams (Langeani *et al.*, 2007).

According to Aquino *et al.* (2009), despite of recent efforts, the Center-West region of Brazil still faces a shortage of data involving fish assemblages in streams of upper Paraná. Is worthwhile to mention some studies conducted in the States of Goiás (Benedito-Cecilio *et al.*, 2004; Fialho *et al.*, 2007; Araújo & Tejerina-Garro, 2007) and Mato Grosso do Sul (Súarez, 2008; Suárez & Lima-Júnior, 2009). In the Distrito Federal should be

emphasized the studies of Viana (1989), Ribeiro (1994), and Aquino *et al.* (2009). The high endemism and, in consequence of the absence of studies, the high number of undescribed species are constantly cited in the researches conducted in the region. This fact, coupled with several environmental problems resulting from uncontrolled human occupation and mismanagement of water resources, make these studies become ever more urgent.

Due to the need of information about fish assemblages in Central Brazil, extremely important data for watercourses management and conservation, this study aimed to evaluate the integrity of streams and characterize the spatial and seasonal distribution of the fish assemblage inside and outside integral protection conservation units of a sustainable use area in Distrito Federal, upper Paraná Basin, Cerrado biome.

Material and Methods

The study was conducted in a sustainable use area, the APA (in English Environmental Protection Area) Gama and Cabeça de Veado, which includes the Gama sub-basin and Cabeça de Veado stream (Fig. 1). Inside the APA, there are three integral protection conservation units: Estação Ecológica da Universidade de Brasília (EE UnB), Estação Ecológica do Jardim Botânico de Brasília (EE JBB), and Reserva Ecológica do IBGE (RE IBGE) (Fig. 1). The APA was created in 1986 (Decree 9,417/86) in order to protect watercourses and Cerrado biodiversity, and to promote scientific researches (Felfili & Santos, 2002). The climate is classified as tropical wet-dry (Köppen, 1948), characterized by a severe dry season (April to September) and a wet season (October to March). Even the APA is considered a conservation unity of sustainable use, the area suffers some environmental impacts, mainly by the occupation of Permanent Preservation Areas (APPs), especially around wetlands and water courses, trash dumping, deforestation, forest fires and unrestricted use of pesticides.

Nine stretches were sampled from Gama sub-basin and three stretches from Cabeça de Veado stream (Table 1 and Fig. 1). To standardize the sampling, during the daytime, 30 m stretches were sampled in the dry season, between August 13 and September 19, 2008, and the wet season, March 23 to April 10, 2009. For fish samples, because of some restrictions on the efficiency of some fishing techniques, a combination of sieves (30 cm radius and 2 mm mesh) and seines nets (3 × 1 m and 2 mm mesh) was used according to stretches characteristics, aiming to capture all individuals in each sample units. For deeper stretches (stretch 1), gill nets were placed for 24 h just to species inventory, but there was no captures with this method. Captured fishes were anaesthetized in a solution 4.5 mg/mL of lidocaine hydrochloride and then kept in a cooler with ice. This method of euthanasia is acceptable for fish according to the American Veterinary Medical Association (AVMA, 2007). Thereafter, fish were fixed in formalin solution 10% and after 48 h, transferred to ethanol 70% solution (Vanzolini & Papavero, 1967; Uieda & Castro, 1999). Voucher specimens are listed in Appendix 1. In laboratory, the weight and standard length (SL) were measured

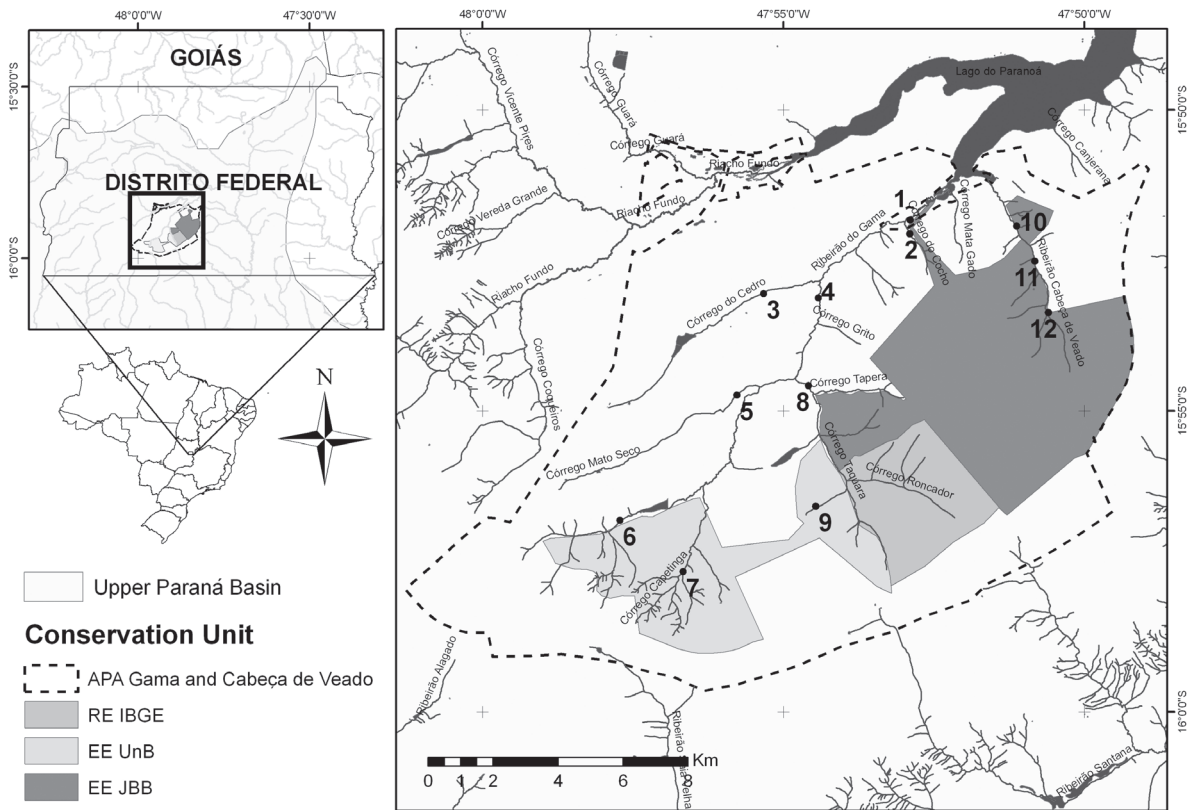


Fig. 1. Location of sampled stretches in the Gama sub-basin (1 to 9) and Ribeirão Cabeça de Veado (10 to 12). Represented in gray scales are the main integral protection conservation units (RE IBGE - Reserva Ecológica do IBGE, EE UnB - Estação Ecológica da UnB, EE JBB - Estação Ecológica do Jardim Botânico de Brasília) of APA Gama and Cabeça de Veado.

at least for 50 individuals of each species per sample unit. For *Gymnotus carapo* by the absence of caudal fin, was adopted the total length. Furthermore, the total mass per species in each sample unit was measured with a precise balance Marte® A200, except for individuals with more than 100 g, that were measured with the balance Urano® UD 6000/1L.

For each 30 m stretch mean depth, width, water velocity (time traveled by a float at 3 m with three repetitions), and vegetation cover (spherical forest density measurer) were determined in three sections (downstream, 0 m; middle, 15 m; upstream, 30 m). Water temperature, air temperature, dissolved oxygen (Winkler modified by Pomeroy & Kirschman, 1945), pH (Schott® Handlab1), turbidity (Quimis®) and water conductivity (Analion® C-702) were measured downstream of the stretches. The mesohabitats types were visually classified according to Rincón (1999) and the presence of substrate types (sand, silt, gravel, pebble, and litter) were described for each sample unit. The environment physical integrity was also determined visually, according to the Physical Habitat Index (PHI) proposed by Casatti *et al.* (2006a, 2006b). In this index, nine items that describe the riparian conditions, stream characteristics (*e.g.*, combinations of substrate types, micro and mesohabitats) and margins stability (*e.g.*, erosion and siltation presence) are visually evaluated. The habitat can be classified as good (PHI higher than 75%), regular (75-50%), poor (50-25%) or very poor (under 25%).

The occurrence constancy was determined by the Dajoz (1978) formula ($C = p/P \times 100$, which C is the species constancy, p is the number of stretches with the species presence and P is the total number of stretches sampled). A species was considered constant when $C > 50\%$. If $50\% \geq C \geq 25\%$, it was considered accessory and accidental when $C < 25\%$. The fish fauna diversity of each stretch and season was calculated by the Shannon Diversity Index (Magurran, 2004).

A species accumulation curve, expressed by the number of individuals sampled, was generated to assess the efficiency of fish sampling methodology (Gotelli & Colwell, 2001). The curve was generated with 1,000 random permutations without replacement. To assess the inventory efficiency, the richness extrapolation estimators Chao 1 (Chao, 1987) and ACE (Abundance-based Coverage Estimator, Lee & Chao, 1994) estimators were used. A cluster analysis was performed to observe stretches similarity according to species occurrence (Jaccard coefficient) and UPGMA linkage method (Van Tongeren, 1995). The cophenetic coefficient was generated to verify the correlation between the similarity matrix and dendrogram. To compare the stretches richness, abundance, mass, and diversity seasonality, Wilcoxon paired test (Quinn & Keough, 2002) was used. To check the influence of the distance between the stretches sampled on the fish species composition a Mantel test (999 random permutations) (Legendre & Legendre, 1998) was carried out. A Canonical

Table 1. Sample units located in the APA Gama and Cabeça de Veado with their respective watercourses names, coordinates, altitude (Alt), integral protection conservation units (Cons*), Physical Habitat Index (PHI), and classification (Class), exotic plant species that compose the riparian vegetation, types of mesohabitats (Meso**), and main substrate types (Sub***). * EE JBB (Estação Ecológica do Jardim Botânico de Brasília), EE UnB (Estação Ecológica da UnB); **run (Ru), riffle (Ri), pool (P); ***sand (Sd), silt (Si), gravel (G), pebble (Pe), and litter (Li).

Stretch	Watercourses	Latitude (S)	Longitude (W)	Alt (m)	Cons*	PHI (%)	Class	Exotic plants	Meso**	Sub***
Gama sub-basin:										
1	Rib. do Gama	15°51'49.62"	47°52'53.68"	1007	EE JBB	77.5±1.2	Good	-	Ru	Sd
2	Córr. do Cocho	15°52'03.43"	47°52'54.08"	1014	EE JBB	76.4±2.7	Good	<i>M. indica</i>	Ru, P	Si
3	Córr. do Cedro	15°53'03.07"	47°55'19.74"	1020	-	75.0±6.3	Good	<i>P. aquilinum</i>	Ru	Si
4	Rib. do Gama	15°53'07.61"	47°54'25.15"	1023	-	77.5±0.4	Good	<i>P. aquilinum</i> , pasture	Ri, Ru, P	Sd, G
5	Córr. do Mato Seco	15°54'44.46"	47°55'46.37"	1041	-	70.6±3.9	Regular	Pasture	Ru	Sd, Si, G
6	Rib. do Gama	15°56'49.00"	47°57'43.00"	1090	EE UnB	88.9±4.7	Good	-	Ri, P	Sd, G
7	Córr. Capetinga	15°57'40.00"	47°56'40.00"	1097	EE UnB	87.5±2.0	Good	-	Ri, P	G, Pe
8	Córr. Taquara	15°54'35.00"	47°54'35.00"	1076	-	85.6±0.8	Good	<i>P. aquilinum</i> , <i>M. minutiflora</i>	Ri, Ru, P	Sd, G, Pe
9	Córr. da Onça	15°56'35.00"	47°54'28.00"	1063	EE UnB	84.7±2.7	Good	-	Ru, P	Si, Li
Cabeça de Veado stream:										
10	Rib. Cab. de Veado	15°51'55.91"	47°51'07.42"	1025	EE JBB	89.4±1.6	Good	-	Ri, Ru, P	Sd, G, Pe
11	Rib. Cab. de Veado	15°52'31.06"	47°50'49.51"	1051	EE JBB	86.9±2.0	Good	-	Ru	Sd, Pe
12	Rib. Cab. de Veado	15°53'22.02"	47°50'35.78"	1078	EE JBB	95.0±1.6	Good	-	Ri, Ru	G, Pe, Li

Correspondence Analysis (CCA, Ter Braak, 1986) was used to detect variation patterns in the fish composition assemblage along environmental gradients. The abundances of species that occurred in more than two samples were used as dependent variables. These abundances were square root transformed to reduce the effect of the most representative species, and environmental variables were logarithm transformed to reduce the effects of different scales of the measures. The influence of each environmental variable was quantified by its maximum correlation with the occurrences of the species. All analyses were performed in the statistical program R (R Development Core Team, 2010) with 0.05 as significance level.

Results

The mean PHI was $82.9 \pm 7.5\%$ ($n = 24$). Only the stretch 5 showed a mean PHI lesser than a 75%, being classified as regular. The remaining stretches were classified as good (Table 1). Exotic plant species were registered composing the riparian vegetation in some stretches (Table 1). Particularly, *Pteridium aquilinum* (L.) Kuhn. (locally called "samambaião"), *Melinis minutiflora* P. Beauv. (locally called "capim-gordura"), pasture and some fruit trees such as mango (*Mangifera indica* L.).

The species accumulation curve for the total of sampled individuals is shown in Fig. 2. Although the curve is still growing, there is a tendency towards stabilization, demonstrating good sampling efficiency. The richness estimators Chao1 showed 25 ± 8 and ACE 25 ± 2 fish species for the streams. A total of 2,327 individuals were sampled (1.787 kg), distributed in four orders, seven families, 16 genera, and 22 species (Table 2). In the dry season were sampled 1,176 individuals (0.775 kg) and in the wet 1,151 (1.012 kg). Among the species sampled, 50% belong to the order Characiformes, 31.8% to the order Siluriformes, 13.6% to the order Cyprinodontiformes, and 4.5% to the order Gymnotiformes. The more specious families were Characidae (31.8%), Loricariidae (31.8%), and Crenuchidae (13.6%) (Table 2).

Fish fauna was characterized by small-sized specimens.

Standard length (SL) ranged from 1.0 to 20.5 cm (Table 2), with a mean of 3.4 cm. About 77% had average SL lower than 5 cm, and only two species showed average SL higher than 15 cm (*G. carapo* and *Hoplias malabaricus*). Among the 22 sampled species, eight are still taxonomically undefined (36.4%) and four were recently described (see Lucinda, 2008; Silveira *et al.*, 2008; Zawadzki *et al.*, 2008; Calegari & Reis, 2010). The exotic species *Poecilia reticulata* was sampled in the stretches 4 and 5 during the wet season, for a total of four individuals. *Knodus moenkhausii* was the most abundant species with 1,476 individuals (63.4% of the total abundance), followed by *Astyanax* sp. (19.4%), *Phalloceros harpagos* (6.6%), and *Hasemania* sp. (5.8%) (Table 2). Constant species during the wet and dry seasons were *Astyanax* sp. and *K. moenkhausii*. *Hasemania* sp., *Hypostomus* sp.2, and *P. harpagos* were considered accessories. The remaining species fall into the accidental category (Table 2). For mass, *K. moenkhausii* had the highest participation with 755.7 g (42.3% of the total mass), followed by *Astyanax* sp. (35.2%), *H. malabaricus* (10.5%), and *Hypostomus* sp. 2 (4.9%) were also representative (Table 2).

Between seasons (Table 3), no significant differences in species richness ($W = 75$; $p = 0.88$), diversity ($W = 72$; $p = 0.99$),

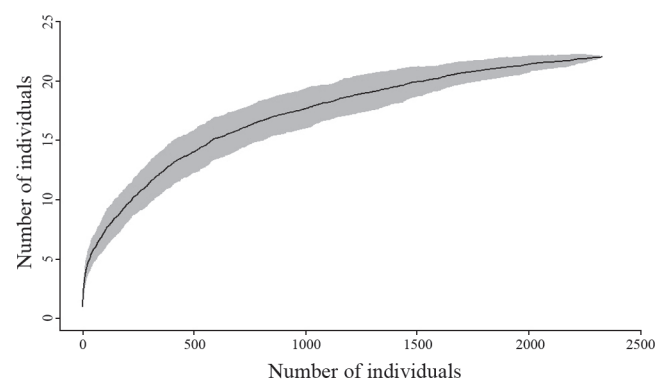


Fig. 2. Species accumulation curve and standard error (gray) generated from permutations of sampled individuals in streams of the APA Gama and Cabeça de Veado.

Table 2. Fish species sampled in the APA Gama and Cabeça de Veado with their number of individuals (N) and mass (M) of each species in total (T), dry (D), and wet (W) seasons, occurrence constancy (C), and standard length (SL) range. *Exotic species, **total length. Family group names follow Reis *et al.*, 2003).

Taxon	N			M(g)			C (%)	SL (cm)
	T	D	W	T	D	W		
Order Characiformes								
Family Crenuchidae								
<i>Characidium</i> sp.	18	11	7	14.1	8.2	5.9	8.3	3.4-4.9
<i>Characidium xanthopteron</i> Silveira, Langeani, Graça, Pavanelli & Buckup, 2008	5	5	-	2.9	2.9	-	8.3	3.2-3.8
<i>Characidium zebra</i> Eigenmann, 1909	4	3	1	0.9	0.5	0.4	8.3	1.9-3.0
Family Characidae								
Subfamily Glandulocaudinae								
<i>Planaltina myersi</i> Böhlke, 1954	5	2	3	2.8	1.3	1.5	16.7	3.4-4.1
Genera incertae sedis								
<i>Astyanax</i> sp.	451	174	277	629.9	293.8	336.2	79.2	1.0-8.3
<i>Bryconamericus stramineus</i> Eigenmann, 1908	3	-	3	4.0	-	4.0	4.2	4.5-5.2
<i>Hasemania</i> sp.	136	56	80	23.4	5.8	17.6	29.2	1.1-3.1
<i>Knodus moenkhausii</i> (Eigenmann & Kennedy, 1903)	1,476	786	690	755.7	349.3	406.4	50.0	1.1-4.8
<i>Moenkhausia</i> sp.	7	4	3	5.3	1.9	3.5	12.5	2.1-4.2
<i>Piabina argentea</i> Reinhardt, 1867	14	14	-	19.1	19.1	-	8.3	4.0-4.7
Family Erythrinidae								
<i>Hoplias malabaricus</i> (Bloch, 1794)	1	-	1	187.0	-	187.0	4.2	20.5
Order Siluriformes								
Family Loricariidae								
Subfamily Hypoptopomatinae								
<i>Microlepidogaster longicollis</i> Calegari & Reis, 2010	4	4	-	1.9	1.9	-	4.2	2.4-3.7
Subfamily Hypostominae								
<i>Hypostomus ancistroides</i> (Ihering, 1911)	3	3	-	0.9	0.9	-	4.2	2.3-2.8
<i>Hypostomus</i> sp.1	1	1	-	6.3	6.3	-	4.2	6.5
<i>Hypostomus</i> sp.2	34	29	5	87.7	63.4	24.3	25.0	1.6-7.4
<i>Hypostomus</i> sp.3	1	1	-	1.7	1.7	-	4.2	4.3
<i>Hypostomus</i> sp.4	1	-	1	9.6	-	9.6	4.2	7.3
Subfamily Neoplecostominae								
<i>Neoplecostomus corumba</i> Zawadzki, Pavanelli & Langeani, 2008	2	-	2	5.8	-	5.8	4.2	4.8-6.8
Order Gymnotiformes								
Family Gymnotidae								
<i>Gymnotus carapo</i> Linnaeus, 1758	1	1	-	7.5	7.5	-	4.2	15.9**
Order Cyprinodontiformes								
Family Rivulidae								
<i>Rivulus pictus</i> Costa, 1989	2	1	1	1.5	0.6	0.9	8.3	3.4-3.4
Family Poeciliidae								
<i>Phalloceros harpagos</i> Lucinda, 2008	154	81	73	19.1	10.1	9.0	25.0	1.2-2.9
<i>Poecilia reticulata</i> Peters, 1859*	4	-	4	0.4	-	0.4	8.3	1.5-2.0

abundance ($W = 72.5$; $p = 0.99$), and mass ($W = 74$; $p = 0.93$) were recorded. No influence in the distances between the sampled stretches on the fish species composition (Mantel test; $r = 0.09$; $p = 0.06$) was observed.

The cluster analysis showed a more marked spatial differences in species composition than seasonal differences, with groups representing stretches located farther (A) and closer (B) of headwaters (Fig. 3). Abundant and frequent species as *K. moenkhausii* and *Hasemania* sp. were absent in B stretches (*i.e.*, absent in headwaters). In contrast, *Astyanax* sp. was present in all B stretches, but absent or rare in A group. Similar pattern was observed in Ribeirão Cabeça de Veado, where more upstream stretches (*i.e.*, 11 and 12) showed higher similarity with Gama sub-basin headwaters than with its own downstream stretch (*i.e.*, with stretch 10). Between seasons only sites 2 and 12 demonstrated little variation.

The Canonical Correspondence Analysis (CCA) showed that the environmental variables (Table 4) explained 64% of the variation in the fish species abundance (25% in the first and 16% in the second canonical axis). The most important variables in fish assemblage were altitude, water velocity, PHI,

pebble, sand, width, riffle, and silt (Table 5). The species *Planaltina myersi*, *Bryconamericus stramineus*, *Moenkhausia* sp., *Hasemania* sp., *G. carapo*, *Hypostomus* sp.3, *P. reticulata*, *K. moenkhausii*, *H. malabaricus*, *Hypostomus* sp.4, and *Hypostomus ancistroides* were present, especially, in low altitude and deeper stretches (Fig. 4). Despite having a wide distribution in APA, *Astyanax* sp. and *Rivulus pictus* demonstrated preferences for shallower stretches (Fig. 4). *Neoplecostomus corumba*, *Characidium* sp., *Hypostomus* sp.1, *Microlepidogaster longicollis*, *Piabina argentea*, *Hypostomus* sp.2, and *Characidium xanthopteron* occurred primarily in stretches with higher water velocity and altitude. *Phalloceros harpagos* occurred in narrow stretches with lower water velocity and presence of silt. *Characidium zebra* was correlated with wide stretches with higher water velocity and presence of sand (Fig. 4). *Characidium xanthopteron* was strongly correlated to PHI, in contrast to *P. myersi*, *B. stramineus*, *Moenkhausia* sp., *Hasemania* sp., *G. carapo*, *Hypostomus* sp.3, *P. reticulata*, *K. moenkhausii*, *H. malabaricus*, *Hypostomus* sp.4, and *H. ancistroides*, which were negatively correlated with that variable (Fig. 4).

Table 3. Species richness, Shannon diversity (H'), abundance and mass of fish sampled in dry (D) and wet (W) seasons in stream stretches of the APA Gama and Cabeça de Veado.

Stretch	Richness		H'		Abundance		Mass (g)	
	D	W	D	W	D	W	D	W
1	4	4	0.40	0.14	295	248	85.7	91.7
2	2	2	0.69	0.65	138	108	118.3	71.4
3	4	3	0.41	0.28	69	74	44.8	55.4
4	6	8	0.65	0.83	300	265	116.1	333.1
5	5	7	0.19	0.59	122	80	66.0	51.7
6	2	1	0.13	0.00	34	12	75.7	8.5
7	1	1	0.00	0.00	6	168	7.0	164.0
8	8	6	1.85	1.02	74	62	101.3	64.0
9	2	2	0.33	0.69	10	2	17.2	0.9
10	2	2	0.27	0.39	78	99	59.9	93.2
11	1	1	0.00	0.00	19	7	13.9	11.8
12	2	2	0.38	0.16	31	26	69.1	66.8
Total	17	15	-	-	1,176	1,151	775	1,012

Discussion

The orders Characiformes and Siluriformes totaled 81.8% of APAs fish species. This fact is also widely observed in streams of the upper rio Paraná system (Castro *et al.*, 2003; Langeani *et al.*, 2007), which reflects the patterns of Brazil and the Neotropics (Lowe-McConnell, 1987; Castro, 1999; Reis *et al.*, 2003; Buckup *et al.*, 2007). As the pattern also found in the APA, the small size is a general characteristic of headwaters stream fishes of South America (Castro, 1999). This fact allows these species to colonize environments with specific microhabitats and reduced physical dimensions, spending all their life cycle in a geographically restricted area. One consequence of this process would be the high rate of allopatric speciation (Castro, 1999). This idea is supported by the high number of undescribed species or in undefined taxonomic situation (Castro *et al.*, 2003; Buckup *et al.*, 2007; Langeani *et al.*, 2007; Valério *et al.*, 2007; Aquino *et al.*, 2009).

As well as in other studies in upper rio Paraná system, including Distrito Federal (Aquino *et al.*, 2009) and São Paulo State (Casatti *et al.*, 2006b; Ceneviva-Bastos & Casatti, 2007), *K. moenkhausii* was registered as the most abundant species. According to Langeani *et al.* (2007), this species is not originally from the upper Paraná drainage, and its introduction may be related to Itaipu dam construction, finished in 1982 (Agostinho *et al.*, 2007). The dominance of the species *K. moenkhausii*, adapted to tolerate sites where the riparian vegetation is not preserved, primarily without feeding preferences between allochthonous and autochthonous items, can be explained by its large feeding plasticity (Ceneviva-Bastos & Casatti, 2007). The second representative species in terms of abundance was *Astyanax* sp., similarly to that observed by Ribeiro (1994) and Aquino *et al.* (2009). This species has a great colonization capacity, and in some headwater stretches was the unique species sampled. Although more frequent in headwaters, it was also present, even unrepresentative, in larger water volume stretches. Moreover, *Astyanax* sp., classified as omnivorous with herbivory tendency, has great feeding plasticity, consuming materials from animal origin and mainly superior plants parts with allochthonous origin (Schneider, 2008).

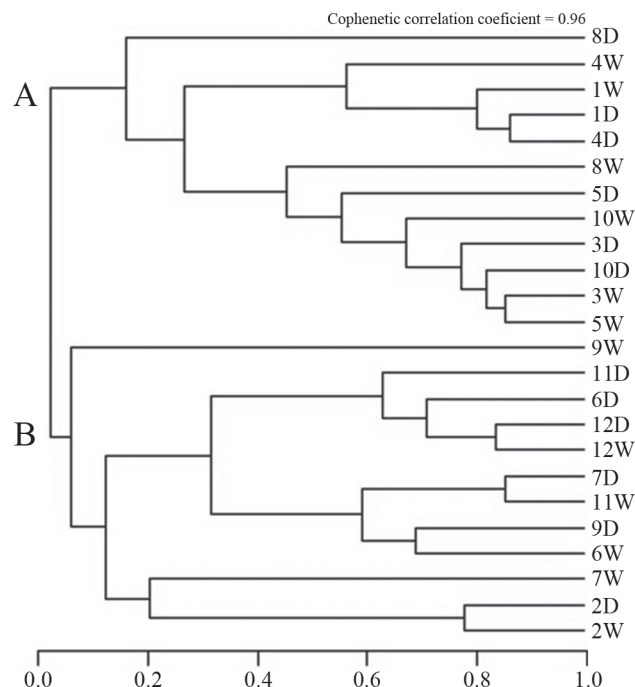


Fig. 3. Similarity dendrogram of stretches based on fish species occurrence from dry (D) and wet (W) seasons in streams of the APA Gama and Cabeça de Veado. Note the two groups that represent farther (A) and closer (B) of headwaters.

Despite the rainfall influence on the migratory cycles targeted to feeding sites, and specially to reproductive activities in fish assemblages (Agostinho, 2004), the low seasonal influence on headwater streams ichthyofauna has been observed in upper Paraná basin studies, where spatial variation are more relevant to species distribution than seasonal variations, at least for most species (Langeani *et al.*, 2005; Valério *et al.*, 2007; Aquino, 2008; Suárez, 2008; Suárez & Lima-Júnior, 2009). The low seasonal variation in fish assemblages of headwaters can be related to the higher stability (*i.e.*, tendency to reduce fluctuations in the energy flow) in these systems when compared to high order streams. Systems physically more stable, as headwaters (*e.g.*, low radiation incidence, clear and cold waters, and allochthonous organic matter input relatively constant during all the year), tend to have a minor contribution of the biota on ecosystem stability, maintaining favorable conditions for few species in both seasons (Vannote *et al.*, 1980). This fact may be related to the perennial riparian vegetation dynamics, which hold stream characteristics with low seasonal influence (Ribeiro & Walter, 1998).

According to Poff (1997), hydrological variables act as filters in lotic environments for species able to colonization, unlike biotic relationships that, generally, do not exert much influence on the composition of ichthyofauna in headwaters when compared to habitat specializations and colonization-extinction dynamics (Peres-Neto, 2004). For some species of the APA, as *K. moenkhausii* and *Hasemanina* sp., it is evident that those filters were directly related to water volume and habitat complexity, however, for *Astyanax* sp., they were inversely related.

Table 4. Environmental variables sampled in the streams of the APA Gama and Cabeça de Veado during dry (D) and wet (W) seasons. Width, depth, vegetation cover (VC), water velocity (Vel), air temperature (Ta), water temperature (Tw), pH, water conductivity (Cond), dissolved oxygen (DO), and turbidity (Turb).

Stretch	Width (cm)		Depth (cm)		VC (%)		Vel (m/s)		Ta (°C)		Tw (°C)		pH		Cond (µS/cm ²)		DO (mg/L)		Turb (NTU)	
	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W
1	686	702	92	129	63.9	72.2	0.2	0.4	19.5	23.0	16.0	22.0	7.4	5.0	20.2	12.1	7.4	7.9	7.4	33.0
2	91	137	45	71	80.6	60.4	0.1	0.0	23.0	26.0	17.0	23.0	5.5	4.8	5.5	6.3	7.4	7.8	9.0	4.0
3	108	173	49	44	87.5	88.9	0.4	0.4	23.0	25.0	19.0	23.0	5.7	5.3	15.0	17.8	6.8	7.9	9.8	4.1
4	689	741	80	117	45.8	53.5	0.5	0.6	23.0	25.0	17.0	22.0	5.8	5.0	19.1	14.5	7.5	5.7	5.9	8.5
5	139	183	49	73	76.4	86.1	0.2	0.5	25.0	26.0	21.0	23.0	6.5	5.2	80.8	36.5	5.4	6.7	7.9	5.2
6	278	435	37	36	80.6	71.5	0.4	0.7	22.0	22.0	19.0	21.0	5.3	6.1	4.5	8.7	5.6	6.7	7.7	5.2
7	215	404	23	26	63.9	73.6	0.3	0.4	21.0	24.5	19.0	22.0	5.3	6.2	3.7	2.7	5.5	8.4	3.9	6.0
8	397	422	47	56	48.6	69.4	0.7	0.9	29.0	23.0	20.0	21.5	5.6	6.6	3.1	3.3	6.9	7.1	6.1	4.0
9	202	198	47	52	93.1	91.7	0.4	0.4	23.0	22.0	20.0	22.0	5.3	6.3	2.3	2.7	6.3	6.0	2.5	2.5
10	341	363	61	63	90.3	90.3	0.2	0.2	24.0	23.5	16.0	21.0	6.3	4.9	9.3	5.8	7.3	8.1	4.3	7.9
11	235	253	83	90	87.5	72.9	0.1	0.1	18.0	20.4	16.5	22.0	6.6	4.9	10.8	5.6	7.8	8.3	6.5	1.6
12	271	274	25	21	93.1	93.1	0.4	0.5	21.0	22.0	18.0	21.0	5.5	4.9	4.3	3.2	6.9	7.9	3.4	2.2

Apparently, natural seasonal changes in APA do not exert major alterations in these filters. However, little seasonal influence may be scale dependent (see Fig. 3), in which fluctuations in similarity between stretches within each subdivision A and B could be observed. As a consequence of small scale alterations of mesohabitats, mainly by natural hydrological changes related to seasons or not, short movements of fishes due habitat preference can be stimulated. Small changes in depth, water flow and substrates (*i.e.*, riparian roots, macrophytes, litter) to feed, shelter, and reproduce can stimulate these short movements for sites that remain more favorable characteristics.

In natural lotic environments, along its longitudinal gradient (*i.e.*, for downstream), there is an increase in water volume and, consequently, in habitat complexity and food availability, that support more species (Vannote *et al.*, 1980). Therefore, we expect lower richness and higher dependence of allochthonous input in headwaters when compared to downstream waters (Vannote *et al.*, 1980). In fact, more complex stretches presented higher richness in the study, which was also reported by several studies (Viana, 1989; Aquino, 2008; Hitt & Angermeier, 2008; Ibañez *et al.*, 2009). Through the CCA, variables that more influenced species distribution patterns in the APA were related directly or indirectly to the water volume and habitats complexity. Several studies point out the altitude and hydrological variables (*i.e.*, depth, width, and water velocity) as the those that best describe the distribution patterns and assemblage structure of headwaters fishes of Central Brazil (Valério *et al.*, 2007; Aquino, 2008; Suárez & Lima-Júnior, 2009). In addition to these, riparian vegetation characteristics and the combination of types of mesohabitats and substrates should be emphasized according to their importance documented in several studies (Jones *et al.*, 1999; Casatti *et al.*, 2006a; Ferreira & Casatti, 2006; Teresa & Romero, 2010). As an example of mesohabitat influences, Langeani *et al.* (2005) compared the ichthyofauna between a riffle and a pool from a Tietê river tributary and concluded that the pool was the more diverse mesohabitat. The authors attributed this fact to the habitat complexity (*e.g.*, presence of submerged vegetation and substrates combination) and the higher water volume that contribute to greater food availability and, consequently, niches to be explored.

In general, the APA streams are relatively well preserved

Table 5. Results of Canonical Correspondence Analysis (canonical coefficients [CCA1 and CCA2] and squared correlation coefficients [r^2]), of fish assemblages and environmental variables in streams of the APA Gama and Cabeça de Veado. *Significant for $\alpha \leq 0.05$, **significant for $\alpha \leq 0.01$, ***significant for $\alpha \leq 0.001$.

Variables	CCA1	CCA2	r^2
Season	0.681	0.732	0.005
pH	0.962	-0.274	0.036
Dissolved oxygen	-0.957	0.292	0.033
Conductivity	0.838	0.546	0.347
Cover	-0.671	0.741	0.169
Width	0.919	-0.393	0.336*
Depth	0.948	0.318	0.371*
Velocity	0.324	-0.946	0.601***
Turbidity	0.932	0.362	0.122
Water temperature	-0.268	-0.963	0.014
Air temperature	0.107	-0.994	0.123
Physical habitat index	-0.685	-0.728	0.520**
Run	0.972	0.236	0.237
Riffle	-0.075	-0.997	0.415*
Pool	-0.753	-0.658	0.214
Sand	0.879	-0.477	0.533**
Silt	-0.285	0.959	0.359*
Gravel	0.209	-0.978	0.300
Pebble	-0.446	-0.895	0.513**
Litter	-0.926	-0.378	0.164
Altitude	-0.593	-0.806	0.734***
Conservation units	-0.920	-0.392	0.327

(mean PHI $82.9 \pm 7.5\%$), but in some stretches anthropogenic influences were registered, notably in water quality and riparian vegetation integrity and composition. According to Esteves (1998), water conductivity can detect pollution sources in aquatic ecosystems. If compared to other sub-basin stretches, outliers were recorded on Córrego Mato Seco (stretch 5) conductivity, indicating an over input of allochthonous organic matter, possibly by domestic sewage and by agricultural activities. The invasive plants *Pteridium aquilinum* ("samambaião") and *Melinis minutiflora* ("capim-gordura") compete assiduously with native species, thus reducing plant diversity (Pivello *et al.*, 1999; Marrs & Watt, 2006). The presence of these two species composing the riparian vegetation in some stretches is probably related to forest clearing (*i.e.*, increase of light availability), strong evidence of forest fires and other human activities (Pivello *et al.*, 1999; Mistry & Berardi, 2005).

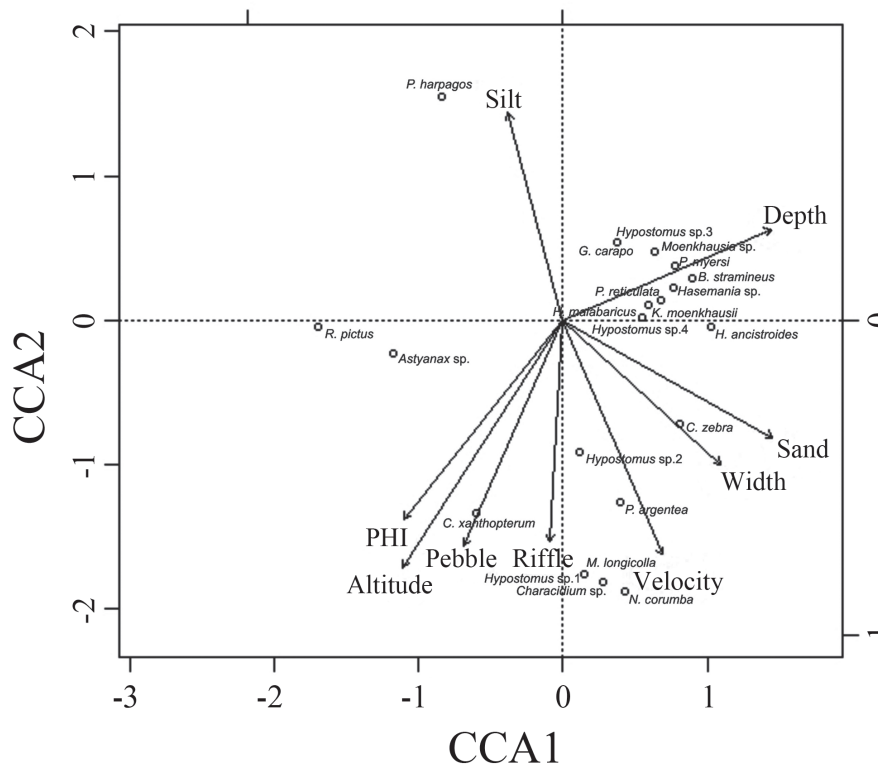


Fig. 4. Biplot of the two first axis resulting from Canonical Correspondence Analysis (CCA) showing fish species scores (open circles) and significant environmental variables (arrows) in streams of the APA Gama and Cabeça de Veado.

The misuse of land and the riparian vegetation deforestation contribute to a marked habitat quality loss in aquatic ecosystems, which leads the dominance of generalist fish species (Casatti *et al.*, 2006a). Continuous physical and chemical alterations of natural conditions of streams caused by human activity support the establishment of exotic fish species. In minimally disturbed habitats, the most successful fish invaders tend to be omnivores/detritivores or piscivores (Moyle & Light, 1996). As observed in this study, Casatti *et al.* (2006a, 2006b) showed that the structure of fish assemblage has strong correlation with the habitat physical conditions. The presence of the exotic species *P. reticulata*, tolerant to hypoxia and detritivorous species (Casatti *et al.*, 2009), is strongly correlated with variables of degraded habitats, primarily associated with streams siltation. In extremely impacted stretches, this species is able to hold more than 50% of fish fauna abundance (Casatti *et al.*, 2006a, 2006b; Cunico *et al.*, 2006; Casatti *et al.*, 2009). Fitzgerald *et al.* (1998), studying Canadian impacted streams, suggests that changes in structure of fish assemblage and replacement of species do not happen immediately and may take many years. The four *P. reticulata* individuals sampled only during the wet season in sample units 4 (middle Ribeirão do Gama) and 5 (Córrego Mato Seco), showed that the species is not well established in the area yet, but it's starting to colonize some stretches, especially those with low habitat quality. Other species, such as *G. carapo* and *H. ancistroides*, sampled in stretches 4 and 5, are also reported as common in degraded habitats, especially due to their tolerance to hypoxia (Cunico *et al.*, 2006; Casatti *et al.*, 2009). According to

Casatti *et al.* (2006b), *K. moenkhausii* can also be benefited by siltation, mainly by its preference for habitats with particulate substrate (*i.e.*, silt and sand) due to its generalist feeding habit. Ribeiro (1994) compared the biotic integrity of fish fauna in Gama sub-basin between the years 1986 and 1991, and concluded that there was a generalized depletion of the fish fauna throughout the sub-basin. Like the present study, he emphasized the Ribeirão do Gama and Córrego Mato Seco as the watercourses most affected by human activities. Based on data from the present study, *C. xanthopterygum* can be considered as indicator of physically preserved habitats.

The APA Gama and Cabeça de Veado streams are relatively well preserved, despite some human activities, mainly outside the integral protected areas. Among these activities, clearing of riparian vegetation deserves attention, since its integrity is a remarkable component for the maintenance of the ichthyofauna structure. The high number of undescribed fish species sampled in this and other studies corroborate that more samples in Central Brazil streams are extremely necessary.

Despite the study limitations, mainly the number of samplings, it is evident that there is an enormous amount of basic information to be known which is essential for understanding, managing and for stream fishes and aquatic resources from Cerrado biome conservation. The large number of endemic species and the rapid habitat loss in this biome make necessary urgent efforts, notably long-term studies, taxonomic inventories, and species biology studies (*e.g.*, feeding, reproduction).

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Appendix 1. Voucher specimens deposited in Coleção Ictiológica da Universidade de Brasília (CIUnB): *Astyanax* sp. CIUnB 474-492; *Bryconamericus stramineus* CIUnB 450; *Characidium* sp. CIUnB 468, 469; *Characidium xanthopterygum* CIUnB 470, 471; *Characidium zebra* CIUnB 472, 473; *Gymnotus carapo* CIUnB 439; *Hasemanina* sp. CIUnB 456-462; *Hoplias malabaricus* CIUnB 467; *Hypostomus ancistroides* CIUnB 435; *Hypostomus* sp.1 CIUnB 434; *Hypostomus* sp.2 CIUnB 428-433; *Hypostomus* sp.3 CIUnB 425; *Hypostomus* sp.4 CIUnB 436; *Knodus moenkhausii* CIUnB 493-504; *Microlepidogaster longicollis* CIUnB 437; *Moenkhausia* sp. CIUnB 451-453; *Neoplecostomus corumba* CIUnB 438; *Phalloceros harpagos* CIUnB 442-447; *Piabina argentea* CIUnB 454, 455; *Planaltina myersi* CIUnB 463-466; *Poecilia reticulata* CIUnB 448, 449; *Rivulus pictus* CIUnB 440, 441.