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PRIMARY RESEARCH PAPER

Fish-habitat relationship in a tropical river under anthropogenic influences

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Abstract This study analyzes the interaction of fish assemblages with 14 physicochemical and hydrogeomorphological variables at 31 sampling stations along the watershed of the Meia Ponte River, Upper Paraná Basin, Central Brazil, during low and high water seasons in 2001. This river and its tributaries drain both urban and agricultural areas. Fish were caught with sieves along a 100 m stretch demarcated in every sampling site, where environmental variables were also measured. A total of 3508 individuals belonging to 31 species were collected. Fish abundance and environmental data matrices were submitted to a multivariate analysis of co-inertia. Two axes were retained for interpretation (total variance explained = 63.65%) indicating that pH, water temperature, conductivity, chemical dissolved oxygen, and turbidity, all have an influence on fish assemblage structure. The co-structure found (fish assemblages and physicochemical variables) is correlated in both of the axes considered ($r = 0.73$ and $r = 0.68$, respectively), and is statistically significant (Monte Carlo test, $P < 0.001$). This co-structure is regulated by seasonality, but is influenced by fish habitat preferences, spawning and available food, the extent and effects of anthropogenic activities (domestic sewage, agriculture, ranching, urban areas) and the position of sampling stations along the watershed.

Keywords Fish assemblage · Environmental impacts · Neotropics

Introduction

Neotropical aquatic environments have been intensively used by humans in several ways, such as, consumption, irrigation, hydroelectric dams, sewage, and industrial discharge (Pringle et al., 2000). This situation makes the ecological study of any aquatic ecosystem more complex. Therefore, in addition to the biotic and abiotic interactions and the exchanges between aquatic and terrestrial environments (Lowe McConnell, 1999), it is necessary to consider the influence of anthropogenic activities that may modify the conditions of aquatic habitats. Camargo et al. (1996) and Sabater et al. (2000) indicate that land use

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of a basin modifies physicochemical water characteristics. Leite et al. (2000), Holomuzki & Biggs (2000) and Duarte & Araújo (2001) point out that the amount of solid particles suspended in the water, a condition caused by erosion as a result of anthropogenic activities, modifies turbidity, temperature, hardness, and conductivity.

In turn, alterations of these environmental variables influence fish assemblage structure (Matthews, 1998; Lammert & Allan, 1999; Tejerina-Garro et al., 2005). They may lead to modifications in reproductive patterns, feeding behavior, and growth rates of fish (Böhlke et al., 1978; Gondin-Ferreira, 1993; Araújo, 1996), and predator–prey relationship (Rodríguez & Lewis, 1997; Tejerina-Garro et al., 1998). Fish are considered excellent indicators of the condition or health of ecosystems (Lyons et al., 1995), and are used to evaluate the effects of different types of environmental stressors or pressures on fish assemblages (Karr, 1981), or to evaluate a specific impact using a single species (Schulz & Martins-Junior, 2001).

However, it is necessary to know how the fish-habitat relationship responds to anthropogenic impacts (Barnes, 1998). One approach used to evaluate the effect of environmental modification on fish assemblages (Davis, 1995; Camargo et al., 1996) is to compare the current fish assemblage data with historical data (Paul & Meyer, 2001). But, in many Neotropical rivers, there are no historical fish data available and the fish-habitat relationships are poorly known, although the aquatic environment has already been modified by anthropogenic activities.

The aim of this article is to respond to the following question: which environmental variables among 14 physicochemical and hydrogeomorphological ones structure the fish assemblages in water courses that drain regions under anthropogenic influences in Central Brazil?

Materials and methods

Sampling area

The Meia Ponte River belongs to the upper Paraná River basin. It rises in the Brandões Mountains in the Itauçú Municipality, Goiás State, Central Brazil. The river flows for 480 km, before joining the Paranaíba

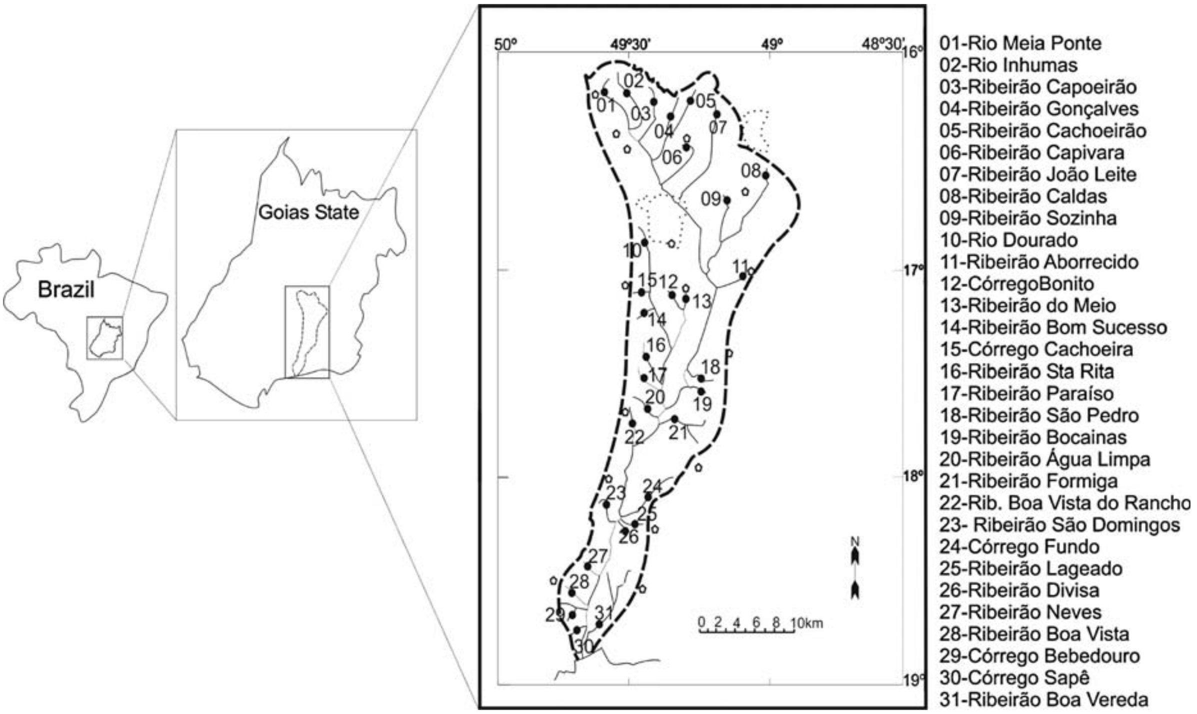

Fig. 1 Sampling sites (black dots) in the Meia Ponte River basin, Central Brazil. Numbers identify sampling sites. Pentagon = cities with 10–40 inhabitants/km^2; dotted line = towns with > 100 inhabitants/km^2; dashed line represents the border of the basin

River, draining an area of 12,350 km^2 in 35 municipalities of the State of Goiás (Fig. 1). Some of the rivers in this basin are used for water supply and irrigation (Fialho & Tejerina-Garro, 2004). The area sampled in the Meia Ponte River basin is located between the 16°16’38” and 18°32’53” S parallels, and the 48°46’38” and 49°44’51” W meridians. In this area, 31 stations located in tributaries and one in the main channel of the Meia Ponte River were sampled (Fig. 1).

Sampling protocols

In each station, 100 m long stretches were randomly selected to collect fish, during high (March 2001) and low (August 2001) water seasons. As the rivers sampled are small (creeks), fish were caught by sieves (3 mm mesh) over a period of 60 min and fixed in 10% formalin. In the laboratory, the fish were identified, measured, and weighed. For each stretch, several environmental variables were measured (channel width, water depth, water velocity—General Oceanics Model 2030 flow meter, pH—pHmeter F-1002, water temperature—Guterm-180 thermometer, conductivity—F-1000 conductivimeter, turbidity—LaMotta 2020 turbidimeter, and dissolved oxygen—F-1001 oxymeter). Water samples were taken to determine the chemical demand of oxygen (CDO—titrametric method with dichromate of potassium in a Tecnal digestor). Hardness was determined using EDTA 0.01 N titrametric, and both phosphate and nitrite were measured using a DREL HACH-2000 spectrophotometer. Sediment residues were determined using a gravimetric method, whereas fecal coliforms were estimated through use of the multiple tubes method. These measurements were all carried out at the Environmental Agency Laboratory of the State of Goiás.

Data analyses

First, we generated a fish abundance data matrix. To eliminate the effects of rare species on the ordination, only the species with more than 10 individuals captured were considered. This matrix was summarized by a factorial analysis of correspondence (FAC) and environmental variables were summarized by a Principal Components Analysis (PCA). The collinearity between environmental variables resulting from the PCA was tested using a Pearson correlation test (Zar, 1998) following the removal of the variable phosphate from the model. Then, a co-inertia analysis was performed using FAC and PCA results to identify a possible co-structure between species abundance and environmental variables (Gauch, 1982). This analysis is powerful even when few samples are available (Dolédec & Chessel, 1994). The co-structure between species abundance and environmental variables resulting from the co-inertia analysis was tested using a Monte Carlo test (1,000 iterations). All analyses were performed using ADE-4 software (Thioulouse et al., 2001).

Several one-way “*t*” tests were also performed to compare the averages of each variable between the high and low water seasons. As this approach can increase the probability of Type I error, we used the protected ANOVA protocol (Scheiner & Gurevitch, 1993) considering that an ANOVA is a generalization of the “*t*” test (two group comparison). In this protocol, a MANOVA is first applied (for the factor water season), and only if it was significant, would a one-way “*t*” test for each variable be conducted separately. Assumptions of “*t*” tests were examined by the Shapiro–Wilk (normality) and Levene (homogeneity of variances) tests. The parametric tests (MANOVA and “*t*” tests) were conducted using Statistica 6.0 software.

Results

A total of 3508 fish individuals of 31 different species were collected. A similar number of fish were sampled in both seasons (high water = 1746; low water = 1762). However, the number of individuals of dominant species, such as *Poecilia reticulata*, *Astyanax eigenmanniorum*, *Bryconamericus stramineus*, *Astyanax fasciatus*, and *Hypostomus ancistroides* varied greatly between seasons (Table 1) and among sampling stations (e.g., *Poecilia reticulata* was absent in sampling station 31, but 181 individuals were collected in sampling station 1).

The co-inertia analysis ordinated fish species and sampling stations according to the environmental variables in two axes (they explained 63.65% of the total variance). Correlation between environmental

Table 1 Number of individuals from each species sampled during high (March, 2001) and low (August, 2001) water periods, in the 31 sampling stations located in the Meia Ponte River Basin, Central Brazil

Order Family Genus and species	Codes	High water *n*	Low water *n*
Characiformes			
Anostomidae			
Leporinus microphthalmus	Lepmic	11	18
Characidae			
Astyanax altiparanae	Astalt	20	15
Astyanax eigenmanniorum	Asteig	111	265
Astyanax fasciatus	Astsp	129	114
Astyanax scabripinnis	Astsca	22	15
Bryconamericus sp.	Brysp1	231	54
Bryconamericus stramineus	Brystr	53	217
Hyphessobrycon sp.	Hyfsp1	0	88
Odontostilbe sp.	Odosp	18	13
Oligosarcus planaltinae	Olipla	28	14
Piabina argentea	Piaarg	58	30
Crenuchidae			
Characidium zebra	Chazeb	46	61
Curimatidae			
Cyphocharax modestus	Cypmod	2	20
Cyprinododontiformes			
Poeciliidae			
Poecilia reticulata	Poeret	350	446
Gymnotiformes			
Gymnotidade			
Gymnotus carapo	Gymcar	8	6
Perciformes			
Cichlidae			
Cichlasoma paranaense	Cicpar	18	7
Siluriformes			
Loricariidae			
Hypostomus ancistroides	Hypanc	185	29
Hypostomus sp. A	Hypsp	149	33
Hypostomus sp. B	Hypsp1	77	42
Hypostomus sp. C	Hypsp2	69	9
Hypostomus sp. D	Hypsp3	0	28
Loricaria sp.	Lorsp	7	3
Neoplecostomus paranensis	Neopar	20	2
Callichthyidae			
Aspidoras fuscoguttatus	Aspfus	32	0
Corydoras sp.	Corsp	30	129
Heptapteridae			
Cetopsorhamdia iheringi	Cetihe	37	42
*Imparfinis schubart*i	Impsch	11	15
Phenacorhamdia tenebrosa	Pheten	4	6
Pimelodella sp.	Pimsp	8	17
Rhamdia quelen	Rhaque	12	13
Rhamdia sp.	Rhasp	0	11
Total		1746	1762

variables and fish abundance in the sampling stations was significant for both axes ($r = 0.73$ and $r = 0.68$, respectively; Monte Carlo test $P < 0.001$; Table 2).

Taking in account the protected ANOVA protocol, the MANOVA was significant for water season (low and high water) (D. F. = 2.62; R of Rhao/F = 108.39; $P = 0.000$) indicating the appropriateness of applying one-way "t" test for each variable. The "t" test indicated significant differences for seven variables (Table 3) that met the assumptions of the "t" test (Shapiro–Wilk > 0.05; Levene > 0.05).

On axis 1, the co-structure of fish species and sampling stations was influenced by pH and water temperature, but regulated by seasonality (all the black circles, indicating high water, are located on the left side of the ordination; Fig. 2). In the low water season, the armored catfish *Hypostomus* sp. B, the characins *Astyanax scabripinis*, *Bryconamericus stramineus*, the catfish *Phenacorhamdia tenebrosa* and *Rhamdia quelen*, and the guppy *Poecilia reticulata* are associated with alkaline water (mean pH = 7.68) and low water temperature (mean = 18.40°C). However, in the high water season, the characin *Bryconamericus* sp. is related to acidic water (average = 6.0) and high water temperature (average = 24.16°C) (Fig. 2). Both, pH and water temperature showed significant differences between low and high water (Table 3).

On axis 2, ordination revealed two groups, one formed by fish assemblages at sampling stations 2–6, 8, 21 and 25 in both seasons. The other group was represented by sampling stations 10–20, 22–24, and 26–31, in both seasons, but more evident during the low water season (Fig. 2). In the first group, characins *Astyanax altiparanae*, *A. eigenmanniorum* and *Cyphocharax modestus*; catfish *Rhamdia quelen* and *Cetopsorhamdia iheringi*; armored catfish

Table 2 Statistics of the co-inertia analyses applied on the factorial analysis of correspondence (FAC; summarized fish abundance data) and on the principal components analysis (PCA; summarized environmental data). Boldface values indicate significant contribution (%) to axes

Item	Absolute contribution (%)	
	Axis 1	Axis 2
Species		
Aspidoras fuscoguttatus	0.01	1.35
Astyanax altiparanae	2.91	4.30
Astyanax eigenmanniorum	3.09	12.15
Astyanax fasciatus	1.42	0.04
Astyanax scabripinnis	17.09	0.00
Bryconamericus sp.	4.07	3.86
Bryconamericus stramineus	6.04	0.23
Cetopsorhamdia iheringi	2.77	5.03
Characidium zebra	0.93	0.11
Cichlasoma paranaense	2.97	8.18
Corydoras sp.	0.10	0.01
Cyphocharax modestus	0.98	12.06
Gymnotus carapo	0.02	0.97
Hyphessobrycon sp.	0.50	10.21
Hypostomus ancistroides	1.67	16.40
Hypostomus sp. A	1.43	0.03
Hypostomus sp. B	12.66	0.05
Hypostomus sp. C	0.88	4.41
Hypostomus sp. D	0.46	2.92
Imparfinis schubarti	2.44	0.91
Poecilia reticulata	7.04	1.96
Leporinus microphthalmus	1.95	0.13
Loricaria sp.	2.69	0.29
Neoplecostomus paranensis	0.00	3.84
Odontostilbe sp.	0.00	0.97
Oligosarcus planaltinae	0.72	0.57
Phenacorhamdia tenebrosa	16.33	0.60
Piabina argentea	0.20	0.00
Pimelodella sp.	0.38	1.25
Rhamdia quelen	4.14	7.00
Rhamdia sp.	3.97	0.00
Environmental parameters		
Conductivity	7.37	33.69
CDO	4.00	19.57
Water hardness	14.65	11.13
Nitrite	0.62	6.81
Dissolved oxygen	4.22	0.15
PH	28.77	2.51
Residual sediment	0.36	0.05
Turbidity	1.41	19.45
Fecal Coliform	6.54	1.16
Water temperature	22.75	1.41
Water depth	0.34	2.15
Water flow	8.06	0.02
Channel width	0.83	1.86
Statistics of axes		
Eingenvalues	6.51	4.59
Explained fraction of co-inertia (%)	37.34	26.31
Correlation (r) between the environmental paameters and fish assemblages	0.73	0.68
Monte Carlo test (1,000 iterations)	$P = 0.000$	

Hypostomus sp. C and *H. ancistroides* were associated to high values of conductivity, CDO, and turbidity in both low (average of 121.20 µS/cm; 9.83 mg/l of O_2; 13.57 NTU, respectively) and high (average of 101.34 µS/cm; 17.46 mg/l of O_2; 72.71 NTU, respectively) water seasons. In the second group, during low water season, the characins *Hyphessobrycon* sp. was related to low conductivity (average = 42.47 µS/cm), CDO (average = 6.08 mg/l of O_2), and turbidity (average = 11.75 NTU).

Discussion

The influence of environmental variables on fish assemblage structure is one approach to understand fish-habitat relationships. Rivers are highly variable environments, and are periodically subjected to

Table 3 Mean and standard deviation (SD) of environmental variables during high and low water periods. Boldface values indicate significant differences between seasons with ''*t*'' test ($P < 0.05$; Shapiro–Wilk > 0.05; Levene > 0.05). In all cases $n = 31$

Environmental parameters	Code	High water		Low water		p
		Mean	SD	Mean	SD	
Conductivity (μS/cm)	CO	59.72	31.62	62.82	41.31	0.735
Chemical demand of oxygen (mg/l of O2)	CDO	13.72	9.35	7.25	5.53	**0.001**
Water hardness (mg/l of CaCO3)	WH	48.86	19.38	68.77	26.47	**0.003**
Nitrite (mg/l of N)	NI	0.01	0.01	0.02	0.00	0.660
Dissolved oxygen (mg/l)	DO	7.21	0.52	6.38	1.33	0.001
pH	pH	6.05	0.28	7.68	0.30	**0.000**
Residual sediment (mg/l)	RS	0.14	0.18	0.05	0.06	**0.004**
Turbidity (NTU)	TU	40.16	40.04	23.68	6.90	**0.000**
Fecal Coliform (NMP/100 ml)	FC	60890.00	49408.50	2645.26	6030.36	0.000
Water temperature (°C)	WT	23.92	1.35	18.73	1.32	**0.000**
Water depth (m)	WD	0.62	0.23	0.49	0.23	0.066
Water flow (m/sec)	WF	0.70	0.33	0.37	0.25	**0.000**
Channel width (m)	CW	5.55	2.31	5.22	2.47	0.285

unpredictable oscillations of their physical and chemical habitat (e.g., flow, temperature, dissolved oxygen, pH, and conductivity), and these fluctuations have been shown to affect the richness and structure of river fish assemblages (Tejerina-Garro et al., 2005). However, in the Neotropical regions alternating high and low water seasons influence habitat (Poff et al., 1997) and fish assemblages (Mérona & Gascuel, 1993) inclusive of the Meia Ponte River tributaries (Fialho et al., 2007). In this case, seasonality can be seen as a key factor switching on/off other environmental variables and increasing or inhibiting environmental modifications (Agostinho & Zalewski, 1995). This seems to be the case in this study, where seasonality regulates the fish-habitat relationship, especially through pH and water temperature.

Despite seasonality the fish-habitat relationship is also influenced by anthropogenic impacts (e. g., Balon, 1993; Penczak et al., 1994; Moyle, 1995; Camargo et al., 1996; Sabater et al., 2000; Wiens, 2002). Agriculture and urbanization are the human activities that threaten aquatic environments in Europe, North America (Paul & Meyer, 2001), and South America. This is the case of the Meia Ponte River basin, where 32.7% of the population of Goiás State (about 1.6 million inhabitants) is concentrated, and the main economic activities are agriculture and cattle raising (Galinkin, 2003). These anthropogenic activities influence the physical (hydrology, geomorphology, and water temperature), chemical (nutrients, metals, and organic compounds), and biological (fauna and flora) characteristics of water courses (Camargo et al., 1996; Paul & Meyer, 2001; Giller & Malmqvist, 2000).

The pH of running waters is influenced by regional seasonality (Soulsby et al., 2001), for example, during the rainy season low pH water conditions can be predominant because of leaching iron by rain from the watershed surfaces (Giller & Malmqvist, 2000). This situation can be found in Central Brazil soils, where the Meia Ponte River watershed is located, because of the predominance of oxisols (ferralitic soils) (Ratter et al., 1997). This can explain the observed significant differences in pH between high (average = 6.0) and low water seasons (average = 7.68). However, water pH also can be influenced by industrial and domestic sewage (Schulz & Martins-Junior, 2001), and by calcium and magnesium washed from urban areas (Ometo et al., 2000; Araújo & Pfrimer, 2005).

The water pH influences fish in key ways. Acidic pH produces osmoregulatory disturbances in fish resulting in significant ion (Na, Cl, K, and Ca) loss (Shuter et al., 1989). Water pH determines habitat preferences for the reproduction of some species (Dei Tos et al., 2002), and affects fish development and growth (Ferreira et al., 2001). It also controls the changes between the harmless ammonium (NH_4^+) and the toxic undissociated ammonia (NH_3) (Lampert & Sommer, 1997).

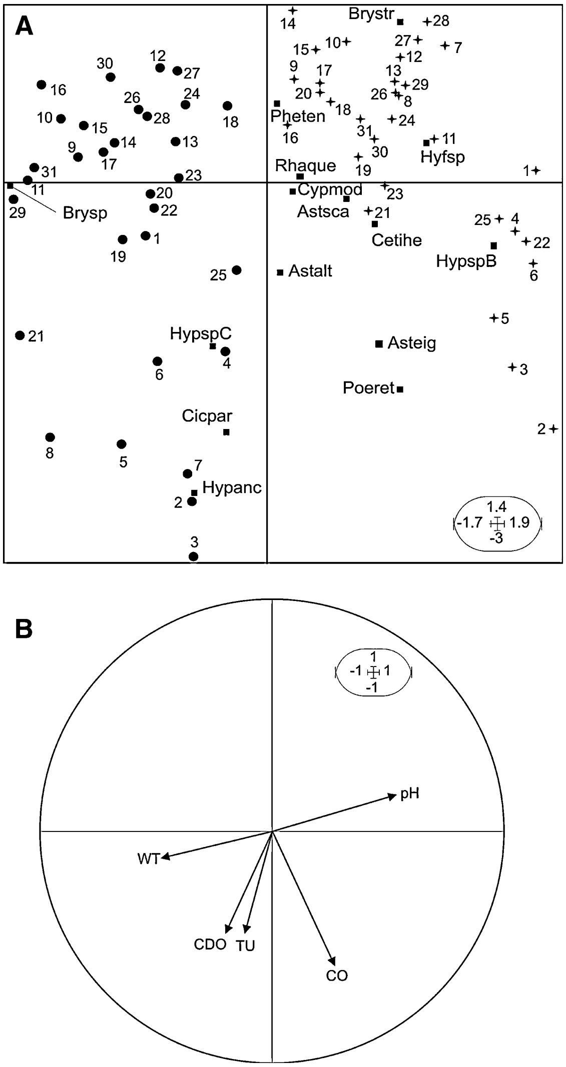

Fig. 2 Discrimination of fish species and sampling sites (**A**) according to environmental variables (**B**). Only species and environmental variables with significant contributions are displayed. Black circles = sampling in high water; crosses = sampling in low water. Numbers correspond to sampling sites. Species codes correspond to those mentioned in Table 1. Code of environmental variables corresponds to those presented in Table 3. Small boxes indicate the graphic scale

In the Meia Ponte River, characins (e. g., *Bryconamericus stramineus*), catfish (e. g., *Phenacorhamdia tenebrosa*), an armored catfish (*Hypostomus* sp. B), and an introduced guppy (*Poecilia reticulata*) were associated with alkaline water. Froese & Pauly (2006) describe similar pH preferences for *Bryconamericus stramineus* (5.5–7.2) and *Poecilia reticulata* (7–8). However, the association we found, could also be related to anthropogenic impacts such as domestic sewage pumped into rivers, which increases the abundance of Chironomids (flies) (deBruyn et al., 2003), one of the food items consumed by *Bryconamericus stramineus* (Casatti & Castro, 1998). On the other hand, the multiple spawning per year displayed by *Poecilia reticulata* (Froese & Pauly, 2006), associated with some habitat characteristics such as low water volume and velocity could also explain the presence of this species during low water.

Water temperature is another environmental variable that influenced fish assemblages in the Meia Ponte River basin (average high water temperature = 23.92°C; average low water temperature = 18.73°C). Although water temperature changes are associated with seasonality in tropical and temperate regions (Tejerina-Garro et al., 2005), other factors can also influence this variable. In water courses with reduced flow, like those sampled in this study, energy exchanges between the water mass, solar radiation, and air conductivity result in rapid oscillations of water temperature (Walling & Webb, 1992) in high and low water seasons. This process can be amplified by the absence of riparian vegetation (Castro & Casatti, 1997), similar to that observed in various water courses sampled. The characins *Bryconamericus* sp. and the armored catfish *Hypostomus ancistroides* and *Hypostomus* sp. C were associated with warm waters during the high water season (average = 23.92°C). However, the presence of bottom-dwelling fish species like the armored catfish of the genus *Hypostomus* (Moyle & Cech, 1996; Santos et al., 2004) could also be related to changes in benthic habitat conditions, because of an increase in water velocity and volume during the high water season. These species are sensitive to benthic habitat changes because they have specific reproduction and feeding requirements (Casatti, 2004).

Sampling sites along the watershed were separated into two groups that were most evident during low water. In both seasons, fish assemblage was related to high values of water conductivity, CDO, and turbidity registered in sampling stations 2–6, 8, 21, and 25.

Increased water volume during high water season favored the redistribution and dispersion of adult and young individuals, larvae, and eggs between sections and compartments (e. g., lake and main channel) of an aquatic ecosystem (Rodríguez & Lewis, 1994), and homogenized water physicochemical characteristics, even in areas subjected to distinct levels of anthropogenic impacts and at different spatial extents (Thomaz et al., 2007). This seems to explain the similar co-structure of fish assemblages and environmental variables observed between sampling sites located in the upper (1–8), middle (19–22) and lower (29) sections of the watershed during the high water season.

However, during low water, differences between sections can be accentuated, not only by natural phenomena such as water volume reduction, but also by the effects of anthropogenic activities. In creeks of the upper Paraná River basin not impacted by anthropogenic activities such as sewage or agriculture, conductivity diminishes from low to high water season, whereas turbidity displays the opposite trend (Carmo et al., 2005). But, this was not the case for conductivity in sampling stations 2–6, 21 and 25 of this study. In the upper section of the Meia Ponte River basin, where sampling stations 2–6 are located, an intensive process of erosion is occurring, associated with the pluvial water waste drainage system, agriculture, ranching, and deforestation (Rubin et al., 2005). These anthropogenic activities may contribute during both seasons to increase conductivity and CDO because of input of organic matter, and its later decomposition by heterotrophic organisms (Matthews, 1998). These environmental conditions appeared to favor the presence of bottom-dwelling (e.g., armored catfish *Hypostomus ancistroides* and catfish *Cetopsorhamdia iheringi*), and benthopelagic species (e. g., characins *Astyanax altiparanae* and catfish *Rhamdia quelen*) (Froese & Pauly, 2006). However, the presence of the two potamodromous characins *Astyanax eigenmanniorum* and *Cyphocharax modestus* (Froese & Pauly, 2006) could be related to migratory patterns.

Conclusion

Among the 14 environmental variables considered in this study, pH, water temperature, conductivity, CDO, and turbidity played important roles in structuring fish assemblages. Contrary to what was expected, this co-structure was regulated by seasonality (low and high water seasons) but influenced by biological patterns (fish habitat preferences, feeding, and spawning) and by anthropogenic activities (domestic sewage, urban areas, ranching,and agriculture). This situation is demonstrated not only by the difference in co-structures (fish assemblage and physicochemical variables) observed during low and high water, but also in the variation among sampling stations along the watershed. The latter suggests that the degree of influence of environmental impacts on fish-habitat relationship depends on duration and position within a watershed.

The findings of this study may be useful in approaches aiming the quantification of the quality of habitats and monitoring programs involving fish fauna. Consequently, they could serve as a support for management and restoration efforts in Neotropical regions.

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