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The effects of local and regional environmental factors on the structure of fish assemblages in the Pirapó Basin, Southern Brazil

Almir M. Cunico[a,b,*], Eveline A. Ferreira[a,e], Angelo A. Agostinho[c], Antonio C. Beaumord[d], Rodrigo Fernandes[e]

[a] Graduate Course in Ecology of Inland Aquatic Ecosystems, Maringa State University, Av. Colombo, 5790 PEA, Bloco G90, CEP 87020-900 Maringá, Paraná, Brazil
[b] Laboratory of Ecology, Fishing and Ichthyology, Federal University of Paraná, Palotina Campus, Rua Pioneiro, 2153 Jd. Dallas, CEP 85950-000 Palotina, Paraná, Brazil
[c] Department of Biology/NUPELIA, Maringá State University, Av. Colombo, 5790 Bloco H90, CEP 87020-900 Maringá, Paraná, Brazil
[d] Laboratory of Environmental Impact Studies, University of the Valley of Itajaí, Rua Uruguai 458, Sala 139, Bloco 20, Centro, Caixa-Postal: 360, CEP 88302-202 Itajai, Santa Catarina, Brazil
[e] Laboratory of Quantitative Ecology, Rural Federal University of Semi-Arid, Av. Francisco Mota 572, CEP 59625-900 Mossoro, Rio Grande do Norte, Brazil

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ABSTRACT

This study aimed to observe patterns in the structure of fish assemblages in streams with different levels of urbanisation, as well as, relationships of these patterns with local and regional environmental factors. We predicted that regional environmental factors would account for more assemblage variation than local regional environmental factors. Data from 10 streams in a gradient of urbanisation in Maringá County, Brazil, were used to characterize fish assemblages' and environmental factors. Discriminant function analysis was used to test differences between streams and environmental factors. Associations between the structure of fish assemblages and environmental factors in local and regional scales were observed with direct gradient analysis (CCA and pCCA) and relative's contribution quantified by inertia partition techniques. Indicator values were used to find characteristic species in streams with different impacts levels. The environmental factors and structure of fish assemblages were different in streams with different urbanisation levels in regional and local scales. In agreement with the hypothesis tested, the environmental factors as land use, hydrology, geomorphology, chemical and physical habitat characteristics pointed out strong association with structure of fish assemblages in streams with different urbanisation levels. So, the results reveal that the structure of fish assemblages is influenced by environmental factors in different spatial scales in impacted environments, suggesting that efficient management actions should be improved if environmental factors are considered in local and regional scales.

1. Introduction

Land use and occupation by human populations alter the structure and functioning of ecosystems, modifying the interaction of ecological systems (Vitousek, Mooney, Lubchenco, & Melillo, 2008). Together with other forms of land use and human occupation (e.g., agriculture, pasture, and mineral mining), urban development fragments, isolates, and degrades natural habitats, simplifies species composition, disrupts hydrological systems, and modifies the flow of energy and nutrient cycling (Alberti, 2009; Di Giulio, Holderegger, & Tobias, 2009). Additionally, urbanisation-induced disturbances can increase the rates of establishment of non-native species in ecosystems, and this process can have diverse ecological consequences, including a loss of the local diversity and biotic homogenisation (Marchetti et al., 2006; McKinney, 2006). For fish assemblages, changes in the composition, structure and distribution of species have been associated with urbanisation gradients, both in temperate and tropical environments (Alexandre, Esteves, & Moura e Mello, 2010; Brown, Gregory, & May, 2009; Fialho, Oliveira, Tejerina-Garro, & Mérona, 2008; Roy, Freeman, & Freeman, 2007). The pervasive characteristics that are observed include a reduction of the diversity and abundance and an increase in the dominance of the species tolerant to the inhospitable conditions. However, the environmental variables that most affect the structure of assemblages and the spatial extent of the effects associated with these variables have not yet been precisely identified.

Traditionally, studies and projects on stream restoration and conservation have primarily focused on the aspects of vegetation

* Corresponding author at: Laboratory of Ecology, Fishing and Ichthyology, Federal University of Paraná, Palotina campus, rua Pioneiro, 2153 Jd. Dallas, CEP 85950-000 Palotina, Paraná, Brazil. Tel.: +55 44 32 11 85 00; fax: +55 44 32 11 85 70.
E-mail addresses: almircunico@ufpr.br (A.M. Cunico), evebio@gmail.com (E.A. Ferreira), agostinhoaa@gmail.com (A.A. Agostinho), beaumord@gmail.com (A.C. Beaumord), fishfernandes@gmail.com (R. Fernandes).

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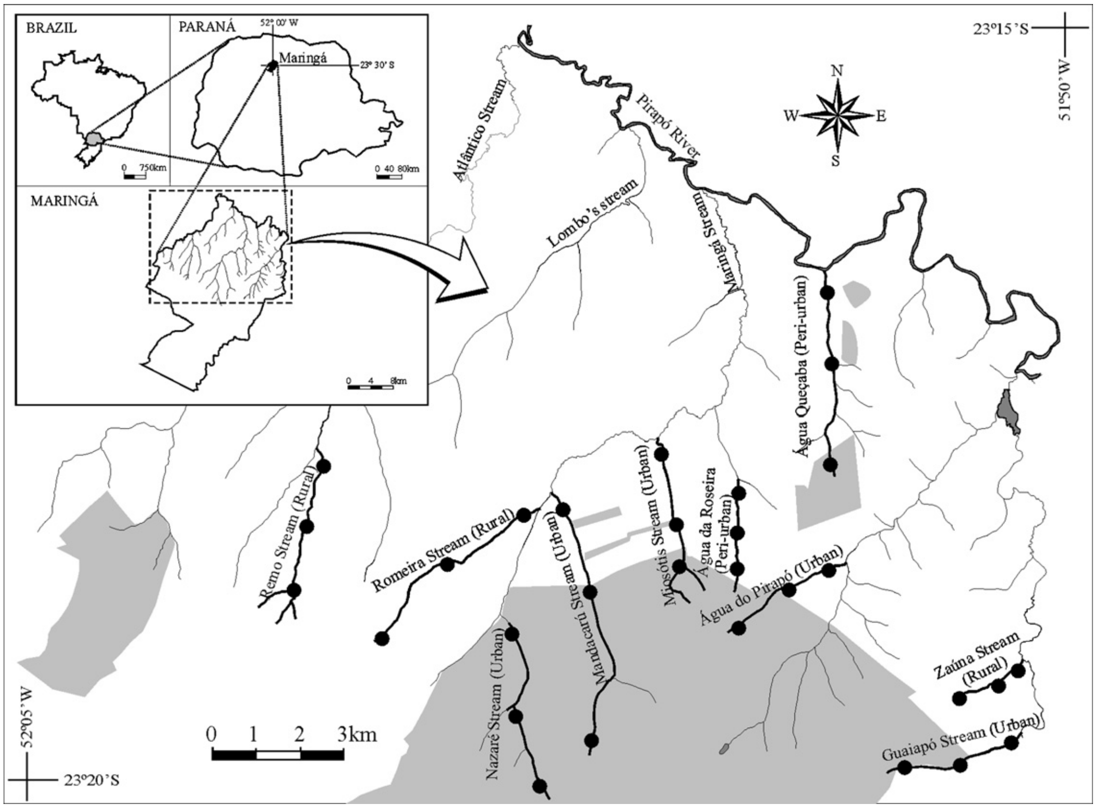

Fig. 1. Study area and sampling sites (●). Shading indicates the urban areas.

cover and the in-stream physical and chemical habitats (Wang, Seelbach, & Lyons, 2006). It is probable that this focus has been chosen because the structure of fish assemblages is directly affected by environmental factors, such as the depth, current velocity, substrate composition, vegetation cover, food sources, temperature, and other physicochemical variables (Wang, Lyons, & Kanehl, 1998; Wang et al., 2006). However, numerous studies illustrate that environmental factors act hierarchically over multiple spatial scales to shape the organisation of the biota (e.g., Wang, Lyons, Kanehl, & Gatti, 1997; Wang, Lyons, Kanehl, & Bannerman, 2001; Wang et al., 2003). This general consensus that the many characteristics of a dynamic fluvial system are mutually adjusted over different spatial extents is particularly relevant to landscapes heavily dominated by anthropogenic land cover types (reviewed in Allan, 2004).

It is probable that human activities that affect the water quality and hydromorphological aspects of the environment will initiate a complex cascade of changes that are ultimately manifested in an altered and possibly degraded stream habitat (Allan, 2004; Gido, Falke, Oakes, & Hase, 2006). Furthermore, large-scale features can affect rivers directly or indirectly by constraining other environmental features over small spatial scales (Frissell, Liss, Warren, & Hurley, 1986; Poff, 1997). According to Weigel, Lyons, Rasmussen, and Wang (2006), an understanding of the influence of environmental variables on fish assemblages over multiple spatial scales can improve our ability to assess the ecological condition of rivers and, subsequently, to target the appropriate spatial scale for management or restoration efforts.

Many studies have investigated how land use and cover on various spatial scales influence the habitat and biota of streams (Allan, Erickson, & Fay, 1997; Alexandre et al., 2010; Esselman & Allan, 2010; Moerke & Lamberti, 2006; Pegg & Taylor, 2007; Sály et al., 2011; Wall & Berry, 2006; Wang et al., 2001, 2006). However, many of these studies have been conducted primarily in temperate regions, whereas studies of this question in tropical regions are scarce (e.g., Alexandre et al., 2010), especially in urban streams (Ramírez, Jesús-Crespo, Martinó-Cardona, Martínez-Rivera, & Burgos-Caraballo, 2009).

Therefore, the objectives of this study were to identify the patterns of species composition and diversity of fish assemblages in 10 streams in the Pirapó Basin, Southern Brazil, in the presence of different levels of urbanisation and to determine which variables best describe the assemblage structure at different spatial scales by evaluating the relationship of these patterns with the local and regional environmental variables. We predicted that regional environmental factors would account for more assemblage variation than local regional environmental factors, because of landscape conversion to human uses.

2. Materials and methods

2.1. Study area

Data were collected at 30 sites on 10 wadable streams (1st- to 3rd-order, sensu Strahler, 1957), in the Pirapó River Basin, which is located in the metropolitan region of Maringá, Southern Brazil. The Pirapó River Basin is located in the northern region of Paraná State (between 22°30′ and 23°30′S; 51°15′ and 52°15′W) and drains approximately 5000 km^2. The dominant landscape in the basin is a mosaic of agricultural and urban habitats, especially in the metropolitan region of Maringá, the third most populous city in Paraná State. With a population of 325,968, this city is an important agro-industrial centre of Southern Brazil.

2.2. Sampling sites

We selected three sites for each of the 10 streams studies, and samples were collected every 2 months from July 2007 through June 2008 along a longitudinal gradient (Fig. 1). The reach length sampled was determined by multiplying the mean wetted channel width by 20 because, in meandering streams, 20 times the channel width typically encompasses at least one complete meander wavelength. This approach ensures that all of the habitat types are represented within the reach (Hauer & Lamberti, 2007).

2.3. Fish sampling

Fishes were sampled using three-pass electrofishing depletion surveys in the blocked reaches. We used a full-wave rectified pulsed DC electroshocker (2.5 kW, 400 V, 2 A) operated through two anode dipnets. The fishes captured were anaesthetised and euthanised with an overdose of benzocaine and then fixed in 4% formalin. In the laboratory, the individuals were identified following Graça and Pavanelli (2007); voucher specimens were deposited in the ichthyological collection of Nupélia at the Universidade Estadual de Maringá (http://www.nupelia.uem.br/colecao).

2.4. Local environmental factors

Environmental variables, including the cross-sectional channel dimensions, substrate characteristics (including structure) and canopy cover, were measured along transects at 10-m intervals over the reach selected for electrofishing. The measures of width, depth and current velocity were obtained at the endpoint of each transect. The depth and current velocity were measured near the channel banks (right and left) and in the middle of the channel. We ensured that the eddies around the legs of the current meter did not disturb the activity of the device and estimated the current velocity according to a current meter protocol for velocity (Hauer & Lamberti, 2007). The current velocity was measured using a JDC electronic flowmeter, model Flowatch FL-K2. The discharge was calculated using the equation $Q = A \times v$, where (A) represents the cross-sectional area of the stream channel and (v) represents the current velocity in m/s (Hauer & Lamberti, 2007). The calculation of the Froude number (FR), which describes different regimes of the hydric flow along the fluvial channel, was made using the Froude equation ($\mathrm{FR} = V/[g \times H]^{0.5}$), where V = the current velocity, H = the depth and g = the acceleration of gravity at sea level at latitude 45°S (Lamouroux, Poff, & Angermeier, 2002).

The benthic substrate and habitat structures were quantified using quadrats (0.50 m × 0.50 m), with a grid that was 0.25 m^2 in area and consisted of 1-in. PVC tubing fitted with nylon lines spaced 10 cm apart to form a square grid with 25 subsections. Visual observation was used in each subsection to identify the presence or absence of benthic substrate categories (silt, sand, fine gravel, coarse gravel, cobble and boulder) and habitat structures (stable debris, litter and artificial substrate). The relative frequencies of the substrate and habitat-structure categories were calculated from the number of subsections in which a specific category occurred and the total number of subsections sampled. The relative frequencies were used as a measure of the coverage of the benthic substrate and habitat structures. The total coverage of a specific category in each stream reach was calculated as the percentage of the total number of subsections observed that included that category. The same protocol was used to measure the percentage of water covered by shade from the periphery of the stream or by the natural spread of foliage from plants (canopy cover).

Data on the physicochemical characteristics of the water, including the pH (DIGIMED, model DM-22), electrical conductivity (μS/cm—DIGIMED, model DM-32), dissolved oxygen (mg/L and % saturation), water temperature (°C), and air temperature, were collected in the field using portable analytical equipment (YSI, model 55D). To determine the total nitrogen concentration, total phosphorus concentration, chemical oxygen demand (COD) and biochemical oxygen demand (BOD), water samples were collected and analysed in the laboratories of Sanitation and Agrochemistry at the Universidade Estadual de Maringá. The methods used for the determination of these parameters are described in APHA (2000).

2.5. Regional environmental factors

Regional environmental variables, including catchment area (m^2), percentage of impermeable surface in the catchment (%), percentage of urbanisation (%) and spatial locations variables (latitude and longitude), were measured using high-resolution satellite images (Quickbird—Pancromatic, year 2005) and the vectorial edition tool of the Spring 4.3.2 software (Camara, Souza, & Freitasum, 1996) for classification. To measure the percentage of urbanisation, we first measured the drainage area of each stream with overlapping high-resolution satellite images (Quickbird—Pancromatic) and altimetric charts. Using the vectorial edition tool of the Spring 4.3.2 software, we classified the urban area and calculated the percentage of urbanisation as the ratio of urban area to the total drainage area of each stream.

The influence of rainfall was quantified as the frequency of the rain peaks at the sampling sites. The rainfall at each sampling site was measured with an individual pluviometer, and the annual average rainfall of the Maringá region was obtained from the meteorological station of the Universidade Estadual de Maringá. We observed the number of days with precipitation to be higher than the annual average recorded by the meteorological station during periods of 7, 15 and 30 days before sampling in each stream. With this information, we calculated the relative frequency of the rain peaks for each environmental category (urban, peri-urban and rural) using the equation: $\mathrm{Frequency} = (Ps/Py) \times 100$, where Ps represents the number of days with precipitation higher than the annual average in a period of 7, 15 or 30 days before the sampling in each stream and Py represents the number of days in the year with precipitation higher than the annual average in the city of Maringá. Because the number of sampling sites in the urban, peri-urban and rural categories was unbalanced and to reduce the amplitude of the variation, which influences the multivariate analysis, we converted the continuous data into ordinal data using the following categories: category ***0*** for a relative frequency ≤1%, category ***1*** between 1% and 10%, and category ***2*** between 10% and 50%.

2.6. Data analysis

2.6.1. A priori sampling design

According to the percentage of urbanisation in the catchment area of each stream, we grouped the environments into urban (urbanisation more than 50%), peri-urban (between 5 and 20%) and rural (below 1%) (Table 1). To validate the classification, the differences between the groups were tested with a discriminant analysis using the abiotic data matrix. The critical values of the Wilks Lambda statistic were used to determine the differences between the groups and variables that contributed most strongly to the formation of the discriminant functions.

2.6.2. Influence of spatial autocorrelation on fish assemblage structure

To evaluate the influence of the spatial autocorrelation on the fish assemblage structure, we applied a Mantel test to a Bray–Curtis similarity matrix containing the relative abundance of species and a matrix of Euclidean distances (km) among the sampling sites. The intersite distances were calculated from the geographic coordinates. We performed a separate Mantel test for each sampling period. The significance of the Mantel test was calculated with 5000 permutations.

Table 1
Sampling locations and catchment characteristics for each stream studied. Urb% = percentage of urbanisation; % IS = percentage of impervious surfaces.

Stream	Code	Latitude	Longitude	Catchment (ha)	% Urb	% I.S.
Nazaré	NAZ	23°24′04,64″S	51°58′03,57″W	867.928	100.0	34.8
Mandacarú	MAN	23°23′05,24″S	51°56′49,85″W	1504.896	82.5	30.8
Guaiapó	GUA	23°24′44,54″S	51°51′13,83″W	1596.792	73.6	33.4
Miosotis	MIO	23°21′54,50″S	51°55′37,35″W	1213.855	56.7	9.3
Agua do Pirapó	API	23°22′24,31″S	51°53′48,58″W	431.125	56.6	5.0
Agua da Roseira	ROS	23°20′56,30″S	51°54′52,31″W	867.504	18.8	1.2
Agua Queçaba	AQU	23°19′04,41″S	51°53′29.35″W	984.687	5.2	1.6
Remo	REM	23°21′39,26″S	52°01′02,48″W	792.325	0.5	0.5
Romeira	ROM	23°22′04.05″S	51°58′43,50″W	895.986	0.0	0.5
Zaúna	ZAU	23°23′47,36″S	51°51′02,09″W	297.486	0.0	1.6

2.6.3. Assemblage parameters

The abundances of the species collected by electrofishing were estimated using the Zippin maximum-likelihood method for three catches (Zippin, 1956). If the Zippin method was not applicable, density was calculated by multiplying the total number of fish caught (C_s) by a N/C_s ratio, estimated for species with the lowest catch efficiency (p) at a given site. Absolute estimates (=total catch) were used for a population in which the total number of fish captured in a given site did not exceed three individuals in three catches. If it was not possible to use this method, the fish density was calculated by multiplying the total number of fish caught (C_s) by an N/C_s ratio that was estimated for the species with the lowest catch efficiency (p) at a given site (Agostinho & Penczak, 1995).

Two assemblage parameters (Ludwig & Reynolds, 1988), species richness (S) and species diversity (Shannon–Wiener index, H') (Magurran, 1988), were estimated, and rarefaction (Hurlbert, 1971) was also used to compare the species richness between the environmental categories following Gotelli and Graves (1996) and Krebs (1999).

The indicator value (IndVal) of Dufrêne and Legendre (1997) was used to identify the most important species for the environmental groups. This value was obtained for each species from the original untransformed data matrix. The values with type I error probabilities <5% ($p < 0.05$; result of a Monte Carlo test based on 5000 permutations) served to identify the potential indicator species.

2.6.4. Relationships between fish assemblage structure and environmental factors

The relationships between the environmental data and the fish assemblage structure in the groups determined a priori were tested with a canonical correspondence analysis (CCA). CCA is an ordination method recommended for use with relative species abundance data that follow a unimodal (normal or Gaussian) distribution related to an environmental gradient. Detrended correspondence analysis (DCA) can be used to examine the unimodal or linear species distribution related to an environmental gradient by evaluating the length of the first axis with a standardised dispersion measure, such as the standard deviation (SD). A DCA axis longer than 3 SDs indicates a unimodal distribution pattern of species abundance that is related to an environmental gradient. In contrast, an axis shorter than 3 SDs indicates a linear association between the species abundance and environmental gradient (Jongman, ter Braak, & Van Tongeren, 1995). Previously, we tested the matrix of relative species abundance with a DCA and found an SD value of 3.13.

Separate CCAs were performed to relate the taxonomic structure of the fish assemblage to the local and regional environmental factors. In this way, we could identify the local and regional environmental variables that explained a significant part of the taxonomic structure of the fish assemblages. For this analysis, the data on species abundance were transformed using a logarithmic function (base 2). The variables of latitude and longitude were transformed according to the formula $Y = X - X_{min}/X_{max} - X_{min}$, where X is the value of the variable to be transformed, X_{min} is the smallest value of the variable in the dataset and X_{max} is the maximum value of the variable. The percentages were transformed to the arcsine of the square root of the variable. The association between the matrices (the structural matrix for the assemblages and the environmental matrix) and the significance of each axis were tested using a Monte Carlo procedure (999 permutations; $p = 0.05$). Only the associations and the significant axes were interpreted. To select the significant variables ($p = 0.05$) in the final model, we used the forward selection option. The variables with variance inflation factors (VIF) greater than 20 were considered redundant (ter Braak & Smilauer, 1998) and, thus, excluded from the analysis. Subsequently, the CCAs were reperformed using the structural data and this subset of significant and non-redundant variables.

2.6.5. Relative importance of the spatial scale

We used a partial canonical correspondence analysis (pCCA) to test the hypothesis that the influence of environmental factors on the variation in fish assemblage structure depends on the spatial scale (Borcard, Legendre, & Drapeau, 1992). In this analysis, the total variation in the assemblage data was partitioned as follows: (i) variation explained exclusively by the local and regional variables (the pure effect of each spatial scale) and (ii) variation explained by the interaction between the local and regional variables (shared effects). All of the ordination analyses were performed using CANOCO® 4.02 (ter Braak & Smilauer, 1998).

3. Results

3.1. Groups determined a priori

The discriminant analysis was based on the predefined groups that were established according to the percentage of urbanisation in each catchment area analysed (Wilks Lambda = 0.102; $F = 12.463$, $p < 0.001$). The variables associated with the channel morphology, habitat complexity and chemical characteristics of the environment significantly influenced the group separation (Table 2).

The urban streams had a wider stream channel and a higher total nitrogen concentration and electrical conductivity (Fig. 2). The peri-urban and rural streams had a higher habitat complexity, as demonstrated by the presence of litter (LT), overhanging vegetation (OV), and a higher canopy cover. Higher concentrations of coarse gravel (CG) and silt (ST) were found in the peri-urban streams. A higher dissolved oxygen concentration (O_2) was observed in the rural environments, and a higher chemical oxygen demand (COD) was observed in the rural and peri-urban environments (Fig. 2).

Table 2
Results of the discriminant analysis with the environmental variables. Values in bold are significant ($p < 0.05$).

	Axis 1	Axis 2	*Wilks Lambda*	*F*	*p*
Width (m)	**0.038**	**−0.956**	**0.107**	**3.745**	**0.026**
Canopy cover	**−0.609**	**0.031**	**0.1107**	**6.216**	**0.002**
Open canopy angle	0.320	−0.299	0.1057	2.366	0.097
Stable debris	−0.045	−0.114	0.1027	0.416	0.660
Litter	**−0.350**	**−0.429**	**0.112**	**7.230**	**0.001**
Overhanging vegetation	**−0.499**	**−0.070**	**0.117**	**11.515**	**0.000022**
Current velocity (m/s)	−1.127	−0.069	0.103	1.344	0.263
Depth (m)	0.321	0.400	0.103	1.102	0.334
Discharge (m^3/s)	−0.112	0.630	0.103	1.193	0.306
Froude number	1.179	0.158	0.104	1.766	0.174
Silt	**0.355**	**0.236**	**0.109**	**5.636**	**0.004**
Sand	−0.463	−0.100	0.105	2.935	0.056
Fine gravel	0.178	0.059	0.103	1.137	0.323
Coarse gravel	**0.357**	**0.469**	**0.110**	**6.255**	**0.002**
Cobble	−0.027	−0.173	0.102	0.497	0.609
Boulder	0.075	−0.276	0.102	0.699	0.498
Artificial structures	0.007	−0.2136	0.102	0.632	0.532
Water temperature (°C)	−0.030	−0.159	0.102	0.700	0.497
pH	−0.103	0.125	0.103	0.949	0.389
Conductivity (μS/cm)	**0.753**	**0.507**	**0.148**	**34.568**	**0.000**
Dissolved oxygen (mg/L)	**−0.373**	**−0.135**	**0.110**	**6.109**	**0.003**
Total phosphorus (mg/L)	−0.075	−0.165	0.103	0.862	0.424
Total nitrogen (mg/L)	**0.267**	**−0.404**	**0.110**	**6.552**	**0.002**
COD (mg/L)	**−0.470**	**0.428**	**0.107**	**3.723**	**0.026**
BOD (mg/L)	0.410	−0.309	0.105	2.679	0.072
Oil and grease (mg/L)	0.151	0.181	0.104	1.835	0.163
Eigenvalues	4.898	0.663			
%	88				

3.2. Spatial autocorrelation of the fish assemblage structure

The similarity matrices for the fish assemblages were not significantly correlated with the distance matrix of the sampling sites for any of the time periods studied (July 2007, $R = -0.015$, $p = 0.592$; September 2007; $R = -0.030$, $p = 0.650$; December 2007, $R = 0.077$, $p = 0.091$; February 2008, $R = 0.490$, $p = 0.187$; April 2008, $R = 0.032$, $p = 0.294$; June 2008; $R = 0.004$, $p = 0.431$). Thus, we considered that the fish assemblages of each sample were spatially independent based on the initial statistical analysis (Legendre, 1993).

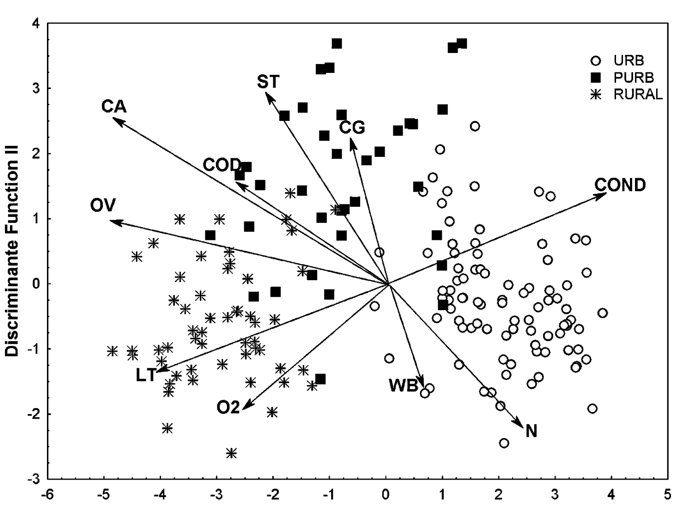

Fig. 2. Discriminant analysis according to the percentage of urbanisation in the catchment area (URB = urban; PURB = peri-urban; RURAL = rural) and the environmental variables that contributed most to the discrimination between the groups (O_2 = dissolved oxygen; LT = litter; OV = overhanging vegetation; CA = canopy; COD = chemical oxygen demand; ST = silt; CG = coarse gravel; COND = conductivity; N = total nitrogen concentration; WB = width of the stream channel).

3.3. The ichthyofauna

A total of 38 species from 27 genera, 12 families and 6 orders were collected. The values of species richness, as estimated with rarefaction curves (Fig. 3), and the mean values of the Shannon–Wiener index indicated a higher species diversity in the peri-urban ($H' = 2.15 \pm 0.66$ SE) and rural ($H' = 1.66 \pm 0.46$ SE) environments than in the urban environments ($H' = 1.32 \pm 0.68$ SE). The species with a higher frequency of occurrence in the urban environments were *Poecilia reticulata* (97%), *Rhamdia quelen* (80%), *Hypostomus* aff. *ancistroides* (79%) and *Cetopsorhamdia iheringi* (46%). In the peri-urban environments, the most frequent species were *Imparfinis mirini* (97%), *Hypostomus* aff. *ancistroides* (92%), *Astyanax* aff. *fasciatus* (81%) and *Rhamdia quelen* (80%). In the rural environments, the most frequent species were *Poecilia reticulata* (100%), *Hypostomus* aff. *ancistroides* (85%), *Rhamdia quelen* (61%) and *Astyanax* aff. *fasciatus* (72%). However, the combination

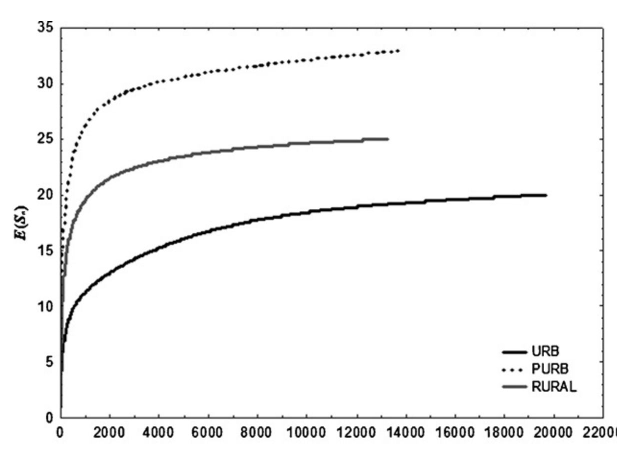

Fig. 3. Rarefaction curves for the groups of environments. E (Sn) denotes the expected number of species. URB = urban; PURB = periurban; RURAL = rural.

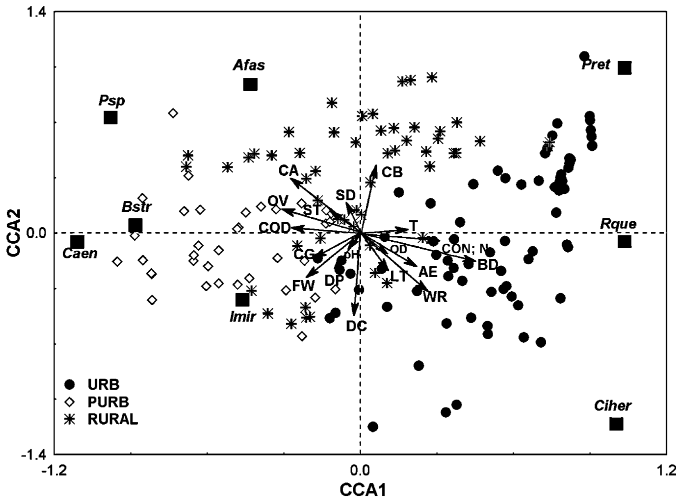

Fig. 4. Canonical correspondence analysis (CCA) applied to the relationship between the fish assemblage structure and the local spatial scale (OD = dissolved oxygen; LT = litter; OV = overhanging vegetation; SD = Stable debris; CA = canopy cover; COD = chemical demand oxygen; ST = silt; CG = coarse gravel; CB = cobble; BD = boulder; AE = artificial structures; DC = discharge; FW = current velocity; DP = depth, pH = pH, T = water temperature; COND = conductivity, N = total nitrogen concentration and WR = width of the stream channel) in the groups of environments examined (URB = urban; PURB = peri-urban; RURAL = rural). Emphasis is placed on the distribution of the species identified by IndVal (Afas = *Astyanax* aff. *fasciatus*; Bstr = *Bryconamericus stramineus*; Caen = *Corydoras aeneus*; Ciher = *Cetopsorhamdia iheringi*; Imir = *Imparfinis mirini*; Psp = *Piabina* sp.; Pret = *Poecilia reticulate*; Rque = *Rhamdia quelen*).

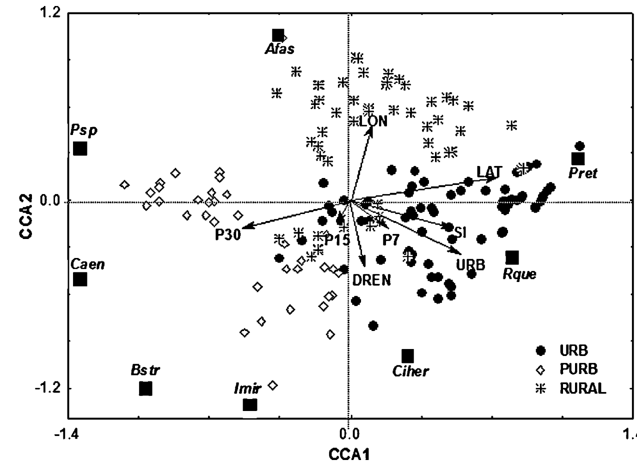

Fig. 5. Canonical correspondence analysis (CCA) applied to the relationship between the fish assemblage structure and regional spatial scale (LAT = latitude; LON = longitude; IS = impervious surfaces; URB = percentage of urbanisation; DREN = catchment area; P7 = rain peaks 7 days before sampling; P15 = rain peaks 15 days before sampling; P30 = rain peaks 30 days before sampling) in the groups of environments examined (URB = urban; PURB = peri-urban; RURAL = rural). Emphasis is placed on the distribution of the species identified by IndVal (Afas = *Astyanax* aff. *fasciatus*; Bstr = *Bryconamericus stramineus*; Caen = *Corydoras aeneus*; Ciher = *Cetopsorhamdia iheringi*; Imir = *Imparfinis mirini*; Psp = *Piabina* sp.; Pret = *Poecilia reticulate*; Rque = *Rhamdia quelen*).

of information on the occurrence frequency and relative abundance represented by the indicator value (IndVal) identified three species with a high (>35%) and significant ($p < 0.05$) score for the urban environments: *Poecilia reticulata* (62%), *Rhamdia quelen* (50%) and *Cetopsorhamdia iheringi* (38%). Similarly, four species were identified for the peri-urban environments, *Imparfinis mirini* (83%), *Bryconamericus stramineus* (70%), *Piabina* sp. (51%) and *Corydoras aeneus* (44%), whereas one species, *Astyanax* aff. *fasciatus* (41%), was identified for the rural environments.

3.4. Relationships between fish assemblage structure and environmental factors

Associations between the fish assemblage structure and the local and regional environmental variables were identified with a canonical correspondence analysis (CCA) (Monte Carlo test with 1000 permutations, $p < 0.05$). In the analysis of the local environmental variables, the Froude number showed a variance inflation factor (VIF) greater than 20 and was excluded from the analysis. All of the VIF values were less than 20 for the regional variables, indicating no colinearity in this group.

The CCA_{local} explained 53.7% of the total variation in the fish species abundance and indicated a relationship between the fish assemblage structure and the hydrogeomorphological and physicochemical habitat characteristics. The urban environments were affected by the stream channel width and the presence of cobble, boulders and artificial structures and by the nitrogen concentration, electrical conductivity, temperature, and dissolved oxygen (Fig. 4). In the peri-urban and rural environments, the canopy cover and the presence of litter and overhanging vegetation and the presence of silt in the streambed were related to the fish assemblage structure. Hydrogeomorphological variables, such as the discharge, current velocity, depth and presence of coarse gravel, in addition to chemical variables, such as the chemical oxygen demand and pH, were related to the peri-urban environments and to inferior segments of the longitudinal gradient in the rural and urban environments (Fig. 4). The species ordination in the CCA indicated a relationship between the local environmental factors and indicator value (IndVal) for the urban (*P. reticulata*, *R. quelen* and *C. iheringi*), peri-urban (*I. mirini*, *B. stramineus*, *Piabina* sp. and *C. aeneus*) and rural environments (*A.* aff. *fasciatus*) (Fig. 4).

The $CCA_{regional}$ explained 51.7% of the total variation in the fish species abundance. The fish assemblage structure was related to the latitude and longitude of the sampling sites and to the urbanisation and impermeable surface, catchment area and rainfall peaks (Fig. 5). The rainfall peaks that occurred 7 days before the sampling were related to those environments with a high level of urbanisation and large impermeable surfaces (urban environments). The fish assemblage structure in the peri-urban environments with 19% urbanisation indicated a relationship with the rainfall peaks that occurred 15 days before the sampling, and those environments with 5% urbanisation indicated a relationship with the monthly rain peaks. The latitude explained the variations in the longitudinal gradient of the sampling sites in the urban and rural environments, whereas the longitude was related to the position of the rural environments within the study area. The urban and peri-urban environments were also related to the catchment area of the streams. The ordination of species relative to the $CCA_{regional}$ indicated that the species with high indicator values (IndVal) were related to the regional factors, as previously observed for the CCA_{local} and local factors (Fig. 5).

3.5. Relative importance of the spatial scale

The partial CCA indicated that the local and regional environmental factors explained 37% of the variation in the fish assemblage structure. These factors explained 51% of the variation in the fish assemblage structure with the interaction among the variables included (Fig. 6). The influence of the pure local factors explained 19% of the variation in the fish assemblage structure, whereas the pure regional factors explained 18%. The interaction between the local and regional variables explained 14% of the variation.

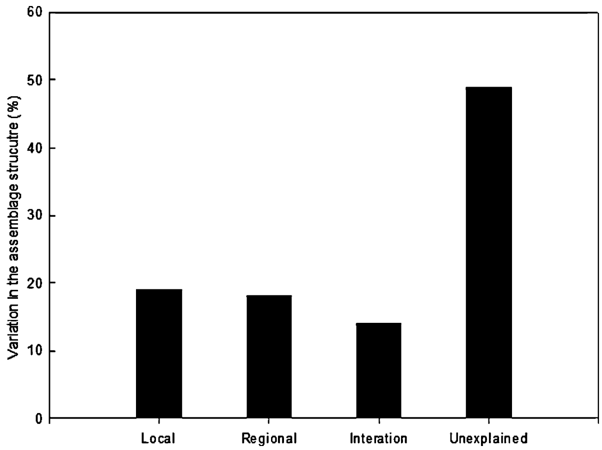

Fig. 6. Percentage of the variance of the fish assemblage structure explained by the local spatial scale, regional spatial scale and their interaction.

4. Discussion and conclusions

Over the urbanisation gradient assessed in the present study, the results indicated that environmental variables influence the structure of fish assemblages at multiple spatial scales and that fish assemblages are influenced similarly by local and regional factors. This finding contrasts with the results of studies in other geographical settings. For example, studies have shown that landscape factors often have less explanatory power than the in-stream characteristics (Johnson, Furse, Hering, & Sandin, 2007; Lammert & Allan, 1999; Lyons, 1996; Wang et al., 2003), whereas other studies have found that landscape-scale factors seem to have a stronger relative influence on assemblages than the environmental conditions at the reach scale in watersheds with relatively little or increasing land cover conversion (Esselman & Allan, 2010; Wang et al., 2006; Weigel et al., 2006). We have shown that the pure regional and local environmental factors seem to have a similar influence on the assemblages in the disturbed catchment areas in the present study. These results suggest that the characteristics of fish assemblages are a direct reflection of the in-stream conditions and that the influences of the catchment conditions on fishes are expressed both directly and indirectly through their influence on the in-stream factors.

Unlike natural or minimally disturbed systems, the regional characteristics, e.g., the amount of impervious surface within the watershed, have been a key environmental indicator of urban land use in anthropogenically disturbed catchments (Arnold & Gibbons, 1996; Wang et al., 2001; Schueler, 1994). The strong influence of such characteristics on the pattern and magnitude of precipitation infiltration and surface runoff reduces the time required for the drainage subsequent to rainfall events and causes remarkable hydrological alterations, with direct and indirect influences on the structure of the fish assemblages (Finkenbine, Atwater, & Mavinic, 2000; Roy et al., 2005; Wenger, Peterson, Freeman, Freeman, & Homans, 2008). We have presented evidence of a direct influence in the form of a relationship between heavy rainfall during the week before sampling and the assemblage structure in environments with high urbanisation. The increase in the surface runoff causes a rapid, intense increase in the water volume and the downstream displacement of fish species by the current; however, this result does not imply that the indirect effects are weak. Indeed, the amount of impervious surface has effects on the water quality and on the morphological changes shown by the channels. It is probable that these effects decrease the occurrence of habitats that are suitable for fish species (Booth & Jackson, 1997; Casatti & Ferreira, 2009).

The relationships between the fish assemblages along the urbanisation gradient and the conductivity, nitrogen concentration and dissolved oxygen demonstrated the effects of the chemical changes caused by the local urban organic effluents and surface runoff. Aquatic environments in urban regions had higher concentrations of nutrients, particularly nitrogen, due to inefficient sewage treatment and illegal effluent discharge (Alexandre et al., 2010; Paul & Meyer, 2008). Similarly, residues generated by human activities have diffuse effects on water bodies in association with the surface runoff in the catchment areas. The nutrient concentrations within watersheds with amounts of impervious surface > 5% often exceeded those in other watersheds during both baseflow and storm flow (Schoonover, Lockaby, & Pan, 2005). According to Alberti (2005), the higher concentrations of nutrients generally found in urban drainage areas produce unsuitable conditions for certain fish species.

It is well known that the substrate, depth and current are among the most important physical habitat features that determine the distribution of fishes in stream communities (Angermeier & Karr, 1983; Angermeier & Schlosser, 1989; Gorman & Karr, 1978; Schlosser, 1982) and that urban environments have homogeneous habitats (McKinney, 2006). The reduction of the canopy cover increases the temperature of the aquatic environment due to the reduced shading and intensifies the channel erosion, but it also limits the natural replacement of such structures as trunks, branches and leaves. These structures are important for increasing the spatial heterogeneity because they create shelters and provide substrate for foraging, reproduction and spawning. In this context, we indicated that the urban streams had a higher concentration of artificial structures, especially wastes from civil construction and trash, and that these structures contributed to habitat homogenisation and, as a result, to changes in the processes that determine the composition, diversity and abundance of fish assemblages, thus increasing the frequency of "urban-adaptable species".

The lower species richness and diversity and higher abundance of tolerant species (*P. reticulata*) observed in the urban streams is consistent with the results of studies in North America (Onorato, Angus, & Marion, 2000), Asia (Gafny, Goren, & Gasith, 2000) and Europe (BoeCyut, Belliard, Berrebi-Dit-Thomas, & Tales, 1999): the peri-urban and rural environments exhibited a higher richness and species diversity. However, the richness values in the peri-urban environments were affected by the Água Queçada stream in which 31 species occurred. The Água Queçaba stream is closer to the Pirapó River than the other sampling sites, and the addition of new species in successive stream sections that are increasingly close to a large river is a natural phenomenon observed in many South American streams. This phenomenon is explained by the addition of micro-habitats, food availability, and shelters (Abes & Agostinho, 2001; Meyer et al., 2007). However, no barriers are present to prevent the dispersal of fish from the Pirapó River to the other streams sampled. Thus, the interconnection of the entire ecosystem shows that environmental factors can be the main influence on the structure of the assemblages.

Our study found species that suggested a high potential as indicator species. The high abundance and frequency of *P. reticulata* in the most urbanised areas show that this species can potentially indicate urbanisation. Although these species also occur in rural streams, *P. reticulata* and others of the same genus have been found to be abundant in highly degraded environments (Casatti & Ferreira, 2009; Cunico, Agostinho, & Latini, 2006; Dyer et al., 2003). Indeed, *Poecillia* species are common indicators of environmental quality, especially in indexes of biological integrity (Casatti & Ferreira, 2009; Ferreira & Casatti, 2006; Pinto & Araújo, 2007), and individuals of this species are capable of surviving under abrupt temperature changes (Chung, 2001), in low-quality habitats (Casatti, Langeani, Silva, & Castro, 2006) and under hypoxia (Kramer & Mehegan, 1981). Based on these findings, *P. reticulata* can be considered to be an indicator of anthropogenic impacts (Kennard, Arthington, Pusey, & Harch, 2005). In fact, *P. reticulata* is frequent in small water bodies, regardless of the conservation status. It is probable that the dominance of *P. reticulata* grants it the status of an indicator species. Similarly, although Siluriformes, such as *R. quelen* and *C. iheringi*, are commonly found in small streams, they demonstrate such biological characteristics as a high production of gametes, external fertilisation and high fertility and trophic plasticity (Gomiero, Souza, & Braga, 2007), which may represent an effective strategy in disturbed habitats.

In summary, our study has important implications for catchment research and management. We found that the fish assemblages were influenced similarly by pure regional and local factors. These findings suggested that the characteristics of fish assemblages are directly influenced by regional and local factors and that regional factors influence in-stream factors indirectly. These results shed new light on the ways in which stream environments and their associated fish assemblages are influenced by land use patterns at different spatial scales. We suggest that the regional and local factors should be emphasised to develop management or restoration efforts aimed at improving stream quality in degraded catchments.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.landurbplan.2012.01.002.

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