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Landscape effects on the occurrence of ichthyofauna in first-order streams of southeastern Brazil

Efeito da paisagem na ocorrência da ictiofauna em rios de primeira ordem da região sudeste do Brasil

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Abstract: Objective: In this study we aimed to understand how extrinsic environmental factors measured in the watercourses and the surrounding landscape influence the ichthyofauna of first-order streams. **Methods:** Data were collected within the Corumbataí River Basin, São Paulo, southeastern Brazil, during the dry season of 2012. We sampled the ichthyofauna in 13 stretches of streams distributed across four river sub-basins. The stretches differed in relation to the presence/absence of riparian forest, the predominant type of matrix and the percentage of forest. Response variables were species richness and the occurrence of functional groups and explanatory variables include both local and landscape structures from the surrounding environment. Local variables comprised the following water quality and structural attributes: pH, temperature, conductivity, turbidity, flow rate, depth, width, type of substrate. Landscape variables included presence/absence of riparian vegetation, type of vegetation, type of matrix, percentage of forest and canopy cover. **Results:** A total of 268 individuals were recorded, which were distributed among 12 species. The landscape structure influenced the occurrence of functional groups in first-order streams, especially allochthonous-feeders, nektonic and hypoxia-intolerant species. The presence of riparian forest was the most important predictor. Species richness was negatively related to the presence of riparian vegetation, supporting the hypothesis that degraded landscapes lead to a reduction in diversity. **Conclusion:** The protection of riparian vegetation is critical to the maintenance of ichthyofauna diversity in first-order streams. The presence or absence of riparian vegetation differently affected the occurrence of species depending on their functional characteristics, particularly those related to the tolerance to hypoxia, source of alimentary items and the position in the water column.

Keywords: landscape ecology; ichthyofauna; riparian vegetation; ecological groups.

Resumo: Objetivo: Neste estudo buscamos compreender como os fatores ambientais extrínsecos medidos no curso d'água e a paisagem circundante influenciam a ictiofauna em rios de primeira ordem. **Métodos:** Os dados foram coletados na Bacia do Rio Corumbataí, São Paulo, região sudeste do Brasil, durante a estação seca de 2012. A ictiofauna foi amostrada em 13 trechos de riachos distribuídos em quatro sub-bacias. Os trechos diferiam em relação à presença/ausência de mata ciliar, tipo predominante de matriz e porcentagem de cobertura vegetal. A riqueza de espécies e a ocorrência dos grupos funcionais foram as variáveis resposta, enquanto as variáveis explanatórias incluíram tanto estruturas locais como da paisagem do entorno. As variáveis locais foram compostas por pH, temperatura, condutividade, turbidez, vazão, profundidade, largura, tipo de substrato. As variáveis da paisagem incluíram presença/ausência de vegetação ripária, tipo de vegetação, tipo de matriz e cobertura de dossel. **Resultados:** Coletamos 268 indivíduos distribuídos em 12 espécies. A estrutura da paisagem influenciou a ocorrência da ictiofauna em rios de primeira ordem, em especial das espécies de alimentação alóctone, nectônicas e intolerantes a hipóxia. A presença de mata ciliar foi o preditor mais importante. A riqueza de espécies foi negativamente relacionada à presença de vegetação ripária, corroborando a hipótese de que paisagens mais degradadas levam a uma redução na diversidade. **Conclusão:** A preservação da vegetação ripária é fundamental para a manutenção da diversidade da ictiofauna. A presença ou ausência da vegetação ripária pode afetar diferentemente a ocorrência de diferentes espécies, dependendo de suas características funcionais, sobretudo relacionadas à tolerância à hipóxia, entrada de alimento no riacho ou posição na coluna d'água.

Palavras-chave: ecologia da paisagem; ictiofauna; vegetação ripária; grupos ecológicos.

1. Introduction

Freshwater represents less than 0.8% of all the water covering the surface of the planet, however, it houses about 6% of all described species and represents 40% of the diversity of fish in the world (Magalhães et al., 2011). Most of that species richness is concentrated in tropical and subtropical regions (Lévêque et al., 2008), and new species continue to be described (Agostinho et al., 2008; Lévêque et al., 2008). Aquatic fauna is critically endangered due to human-induced changes, which are responsible for rapid and strong disturbances in continental ecosystems (Barili et al., 2011) and which may entail species loss, faunal homogenization and decreased fish biomass (Casatti, 2010).

Among the main changes of anthropogenic origin are the loss and/or fragmentation of habitat (Dudgeon et al., 2006; Cunico et al., 2012), the deforestation of riparian vegetation (Teresa & Casatti, 2010), hydrological changes (Agostinho et al., 2008), overfishing, pollution and the propagation of invasive species (Vitousek et al., 1997; Bifi et al., 2006; Olden et al., 2010). The loss of riparian vegetation, margin erosion and silting of the riverbed leads to a reduced habitat complexity in the watercourses, with a slow flux and homogeneous stretches (Barrella et al., 2000).

The riparian vegetation has as much influence on the terrestrial system as on the aquatic system as it is located in the region of land-water interface, such that its maintenance is a prerequisite for the preservation of the river and the surrounding soil (Cunha & Guerra, 1998). Riparian vegetation also contributes to other ecological roles: it acts in the containment of flash flooding, the infiltration of surface runoff, the absorption of excess nutrients, and the retention of sediment and agrochemicals (Silva et al., 2003). Riparian vegetation play important role on the protection of the drainage network, reducing the silting of the river channel and promoting the increase of flow capacity during drought (Karr & Schlosser, 1978).

The removal of riparian vegetation from the basins, particularly in the headwaters of streams, directly and indirectly influences the composition and the functional structure of fish assemblages (Teresa & Casatti, 2010). Studies have shown that species richness would be lower in more degraded landscapes (Viana & Pinheiro, 1998). Studies have aimed to understand how fish species richness varies in relation to local environmental variables (*e.g.,* pH, temperature, conductivity, turbidity and flow) as well as in relation to landscape-level variables on regional or bioclimatic scales (Balmford & Gaston, 1999; Kautza & Sullivan, 2012). However, few studies aimed to understand how the landscape structure (presence of riparian vegetation, percentage of forest, and the predominant land use type) that surrounds water bodies affects fish assemblages. This is particularly important because the landscape around rivers may influence species composition, trophic structure and the diversity of the local ichthyofauna (Santos et al., 2015). Thus, it is essential to quantify the influence of these surrounding variable local fishes, including both taxonomic and functional aspects.

The aim of this study was to quantify the relative contribution of landscape structure and local variables on fish richness and presence of functional groups in first-order streams within highly fragmented agricultural landscapes. Functional groups were defined by considering ecological attributes important for species survival, such as tolerant or intolerant to hypoxia, source of alimentary items (autochthonous or allochthonous-feeders) and vertical position in the water column (benthic or nektonic). Fish assemblages may be affected by extrinsic factors, represented by environmental variables that can be measured in the watercourse and the surrounding landscape. Thus, we present the premise that, depending on the ecological group, the landscape variables are as important as the environmental variables in explaining the occurrence of the species.

2. Material and Methods

2.1. Study area and sampling methods

The study was conducted in the Corumbataí River Basin, located in the east-central portion of São Paulo State, Brazil, between the coordinates 22° 04' 46" S and 22° 41' 28" S, and 47° 26' 23" W and 47° 56' 15" W (Figure 1). This basin covers 170,000 ha; originally it was covered by semideciduous forest and cerrado, but nowadays it is highly fragmented, containing only 11% native forest and 1.25% cerrado *lato sensu* (Brazilian savanna). The main land use includes pasture (44%) and sugarcane (26%) (Valente & Vettorazzi, 2003).

We collected our data in July 2012, during the dry season. We chose this period for data collection due the strong association between the structure of the fish assemblages and the complexity of the habitat during this season (Willis et al., 2005). We sampled the ichthyofauna in 13 stretches of first-order streams. Around every headwater we draw a 500-m buffer, and calculated landscape metrics for this area. The 13 headwaters (one in each landscape) were distributed among the sub-basin of four rivers: Cabeça (N=4), Corumbataí (N=3), Passa Cinco (N=3) and Ribeirão Claro (N=3). These landscapes differed in terms of the presence/absence of riparian vegetation, the type of predominant matrix (pasture, sugarcane, citrus or native forest) and the percentage of forest (primary and secondary forests) within the 500-m buffer (min=20%, max=70%).

Fish assemblages were collected using electrofishing technique, where pulsed electricity is used to immobilise individuals so that they can be collected using hand or sweep nets (Kelso & Rutherford, 1996). The fishing removal procedure was repeated three times at each studied headwater, summing up 39 removals (3 removals * 13 localities). We applied a constant fishing effort (~30 min for each fishing removal), with a break of half of the time used in the first fish removal. Each sampled stretch was about 50m long.

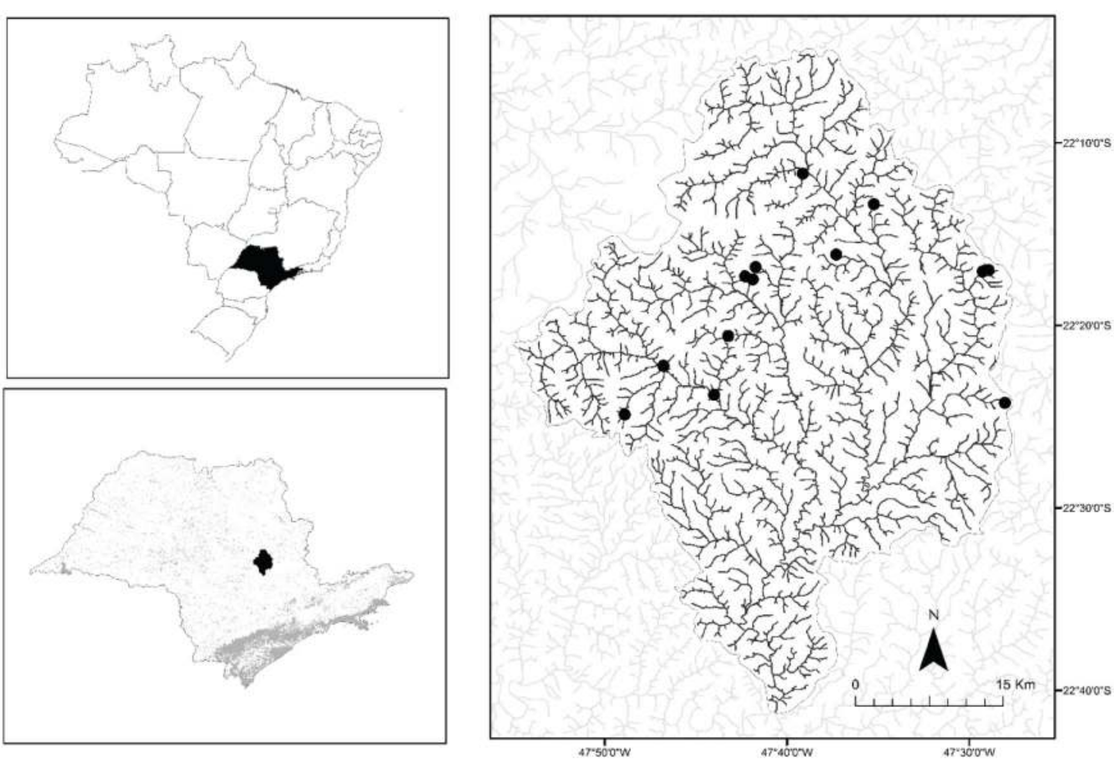

Figure 1. Sampling points of ichthyofauna in 13 headwaters distributed among four rivers: Cabeça, Corumbataí, Passa Cinco e Ribeirão Claro, in the Rio Corumbataí River Basin, São Paulo State, southeastern Brazil. Black dots represent the sampling points.

2.2. Response variables

Species richness and the present/absence of functional groups were the analyzed response variables. The species were categorized into functional groups according to the following classification proposed by Casatti (2002) and Teresa et al. (2015): a) feeding habits (allochthonous or autochthonous-feeders); b) position in the water column (benthic or nektonic) and; c) tolerance to hypoxia (tolerant or intolerant). Species that were not classified in relation to some functional groups were not included in the analyses of functional groups, but were kept for species richness analyzes.

2.3. Explanatory variables

Two groups of explanatory variables were used: 1) local variables and 2) the landscape structure and river surrounding environment. Table 1 presents the list of these variables, as well as the numeric meaning of each. Local variables refers to water quality and structural attributes of the stretches: pH; temperature; conductivity; turbidity; flow; depth; width; and type of substrate. Water quality were measured using a multi-parameter water analyzer - HORIBA, model U-10. To measure the channel depth we used a rod with gradation in centimeters. Channel length and the width were measured using a 30-m tape. The predominant type of substrate were assessed by visual inspection, which were classified into rock, sand or clay.

The second group of variables refers to the landscape and river surrounding environment, and included: the percentage of forest within a 500-m radius around the sampling point; the presence (1) or absence (0) of riparian forests; the type of predominant vegetation composing the riparian zone (a – grass in riparian zone, b – shrubby vegetation up to 1 meter in height, and c – arboreal vegetation over 1 meter); the predominant types of matrix surrounding the rivers (pasture, sugarcane, citrus or native forest); and canopy coverage, measured with a coverage densitometer (varying from 0% to 92%). In some situations the presence of riparian vegetation not imply the presence of a high density of forest (Table 1).

Most of these variables were obtained from satellite images using Google Earth software and QGIS. The vegetation cover was mapped at a scale of 1: 5000 using high resolution images (1 meter) available on Google Earth (http://earth.google.com).

Before analyses we used Pearson's correlation coefficient to identify patterns of collinearity among the explanatory variables ($r < 0.5$ or $r < -0.5$). In the case of collianearity, the most biologically meaningful variables were kept. At the end, nine variables were used to build the models: presence of riparian vegetation, conductivity, stream width, canopy coverage, the predominant types of matrix surrounding the rivers, the percentage of forest, water pH, water temperature and turbidity (Figure 2).

Table 1. Explanatory variables and numeric meaning to explain the occurrence of different ecological groups and species richness of fish in 13 headwaters distributed among four rivers, Cabeça, Corumbataí, Passa Cinco e Ribeirão Claro, in the Rio Corumbataí River Basin, São Paulo State, southeastern Brazil.

Group of variables	Explanatory variables	Numeric meaning
Local variables	**Conductivity**	**Values of water conductivity**
	Stream width Substrate typepH Temperature Turbidity Flow Depth	Average stream width in meters Visual substrate classification into rock, sand or clay Scale to specify the acidity or alkalinity of an aqueous solution Measure of the warmth or coldness of the water in Celsius The cloudiness or haziness of the water caused by large numbers of particles generally invisible to the naked eye Volume and rate of flow of the water in a specific stream site The channel depth measured by a rod with gradation in centimeters
Landscape and surroundings environments	Percentage of forest Riparian forest Type of predominant vegetation composing the riparian zone Type of matrix surrounding the rivers	Percentage of forest (primary and secondary forests) within the 500-m buffer (min=20%, max=70%) 0=absence and 1=presence of riparian forest Grass in riparian zone, shrubby vegetation up to 1 meter in height or arboreal vegetation over 1 meter Pasture, sugarcane, citrus or native forest
	Canopy coverage	Canopy coverage measured with a coverage densitometer (varying from 0% to 92%)
Absence of effect	Null	Only b0 (average) parameter estimated on regression

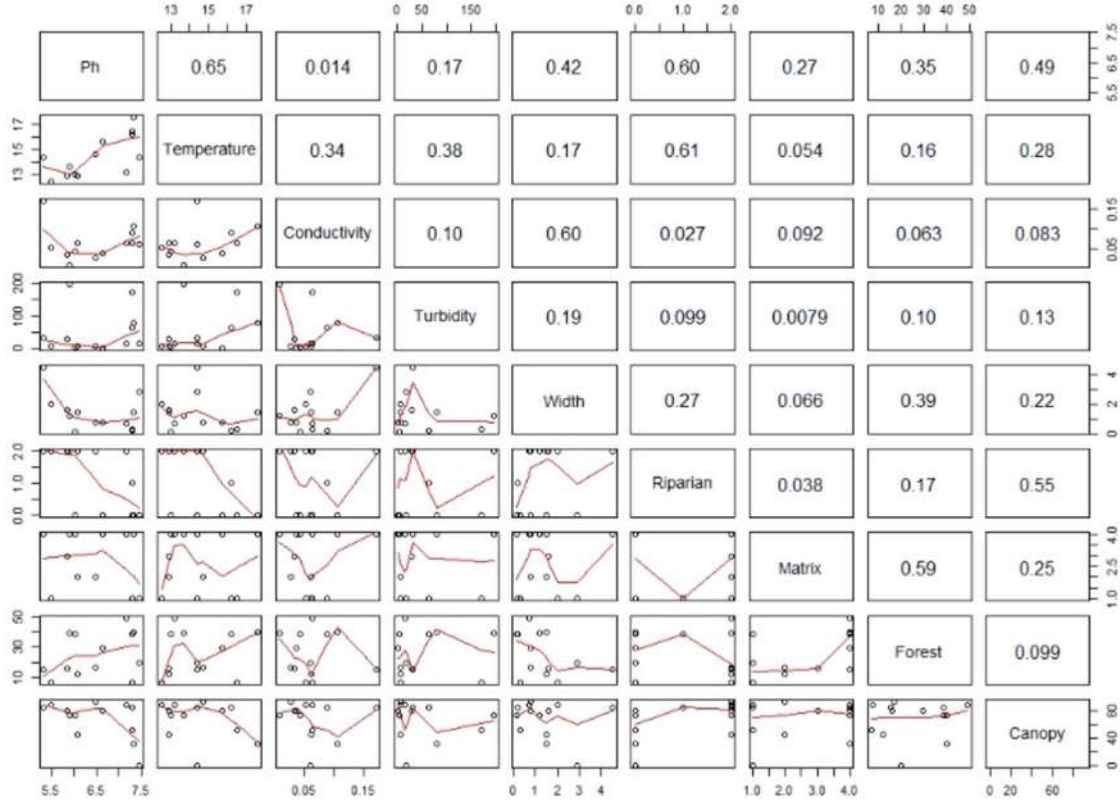

Figure 2. Pearson's correlation analysis among the explanatory variables (riparian vegetation, conductivity, with, canopy coverage, type of substrate, the predominant types of matrix surrounding the rivers, the proportion of forest habitat and turbidity).

2.4. Data analysis

To estimate de contribution of the local and landscape variables on explaining species richness and functional groups, we modeled the response variables using Generalized Linear Models (GLM) implemented in R software (R Development Core Team, 2010). We used the Poisson distribution for species richness and the binomial distribution for the presence of functional groups. We also built a model with the absence of effects (null model) to test whether random effects could also explain the responses variables. For data analysis, we used the 'models with multiple competing hypotheses' approach based on the Akaike Information Criterion (AIC) (Burnham & Anderson, 2002), where the sets of local and landscape variables competed to estimate their potential to explain species richness and the presence of functional groups. Only models containing a single explanatory variable were compared. We calculate the AIC corrected for small samples (AICc) and the difference of the AICc of each model in relation to the best model (ΔAICc*i,* where *i* represents each model). We estimated the Akaike´s weight of evidence (wAICc), which represents the relative contribution of the model *i* towards explaining the observed pattern given the set of competing models (Burnham & Anderson, 2002). Models with ΔAICc<2 or wAICc>0.1 were considered equally plausible to explain the patterns (Zuur et al., 2009).

3. Results

We collected 268 individuals, representing 12 species (Table 2). The species *Astyanax scabripinnis* (Jenyns, 1842) had a high occurrence (N = 197; 73.5%), and were found at nine of 13 points. The species *Tilapia* sp., *Phalloceros* sp., *Geophagus* sp., *Pimelodella* sp. *and Piabina argentea* (Reinhardt, 1867) had a very low occurrence, as they were collected at only one point.

The highest species richness (N=7) was recorded in a landscape with 20-40% forest habitat, with riparian zone composed of arboreal vegetation. In the extremely degraded areas, with only grass in its surrounding area no fish was collected. The species richness found at the collection points were best explained by a model that has the presence/absence of riparian vegetation as an explanatory variable (wAIC = 0.97, Table 3).

Table 2. Fish species collected from 13 headwaters distributed among four rivers, Cabeça, Corumbataí, Passa Cinco e Ribeirão Claro, in the Rio Corumbataí River Basin, São Paulo State, southeastern Brazil.

Species	Vertical position in the water column	Feeding habitat	Hypoxia tolerance	Number of collection points
Astyanax scabripinnis	Nektonic	Allochthonous	Intolerant	9
Tilapia sp.	Benthonic	Autochthonous	Tolerant	1
Phalloceros sp.	Nektonic	Allochthonous/ Autochthonous	Tolerant	1
Geophagus sp.	Nektonic/Benthonic	Autochthonous	Tolerant	1
Trichomycterus sp.	Benthonic	Autochthonous	Intolerant	4
Phalloceros sp. 2	Nektonic	Allochthonous/ Autochthonous	Tolerant	5
Poecilia reticulata	Nektonic	Allochthonous/ Autochthonous	Tolerant	2
Imparfinis mirini	Benthonic	Autochthonous	Intolerant	3
Gymnotos carapo		Autochthonous	Tolerant	2
Characidium zebra	Benthonic	Autochthonous	Intolerant	2
Pimelodella sp.	Benthonic	Autochthonous	Intolerant	1
Piabina argentea	Nektonic/Benthonic	Autochthonous	Intolerant	1

Table 3. Best models to explain the occurrence of different ecological groups (Toler – hypoxia-tolerant; Intol – hypoxia-intolerant; Nekt – nektonic; Bent – benthic; Autoch – autochthonous-feeders; Alloch – allochthonous-feeders) and species richness of fish (Rich) in 13 headwaters distributed among four rivers, Cabeça, Corumbataí, Passa Cinco e Ribeirão Claro, in the Rio Corumbataí River Basin, São Paulo State, southeastern Brazil. *K* – numbers of estimated parameters for each model; ΔAICc – Akaike corrected for small samples; wAICc – Akaike's weight of evidence. Null model represents the absence of effect.

Model	K	ΔAICc	wAICc	Effect
Toler ~ Riparian forest	2	0.0	0.70	
~ Null	1	3.9	0.10	
Rich ~ Riparian forest	2	0.0	0.97	+
~ Null	1	9.6	0.00	
Alloch ~ Riparian forest	2	0.0	0.89	+
~ Null	1	8.2	0.01	
Autoch ~ Null	1	1.1	0.23	
Nekt ~ Riparian forest	2	0.0	0.89	+
~ Null	1	8.2	0.01	
Bent ~ Conductivity	2	1.8	0.12	
~Null	1	0.0	0.28	
Intol ~ Riparian forest	2	0.0	0.77	+
~ Null	1	4.5	0.08	

3.1. Functional groups responses

The occurrence of functional groups varied between streams, and in only four out of the 13 streams had all the groups. With regard to the source of alimentary items, the model that best explains the presence of allochthonous-feeders is the riparian forest model (wAIC = 0.89, Table 3), while the presence of autochthonous-feeders was best explained by both the model containing riparian forest as an explanatory variable (wAIC = 0.41, Table 3) as well as the null model (wAIC = 0.24, Table 3). Regarding the use of the environment, the riparian forest model was the most convenient to explain the presence of nektonic species (wAIC = 0.90, Table 3). The occurrence of benthic species was best explained by the null model (wAIC = 0.28, Table 3) and by the models containing riparian forest (wAIC = 0.22, Table 3) or conductivity (wAIC = 0.12, Table 3). Regarding the tolerance to hypoxia, the presence of tolerant species can be explained by both the riparian forest model (wAIC = 0.70, Table 3) and the null model (wAIC = 0.10, Table 3), while only the riparian forest model explains the presence of intolerant species (wAIC = 0.77, Table 3).

4. Discussion

As expected, the structure of the current landscape influenced species richness and occurrence of functional groups in first-order streams, particularly allochthonous-feeders, nektonic and hypoxia-intolerant species. The presence of riparian forest was the most important predictor factor. The hypothesis that the species richness would be lower in more degraded landscapes has been corroborated, since it was higher in streams with riparian vegetation.

Our results showed that the high species richness found in places with better riparian forest conditions can be related to the hydrological, ecological and limnological functions of riparian forests, which are important for the preservation of the biotic and abiotic integrity of river systems. In stretches where water volumes are relatively low, as is the case in first-order streams, the influence of the forest is great. In these environments, the riparian zone has structural importance as habitat protection, regulating the water flux and flow as well as providing shelter and shade. Riparian vegetation is also an important factor for the maintenance of water quality, filtering out substances from the surrounding area and providing organic material and substrate for the fauna present therein (Barrella et al., 2000).

We showed that several local variables correlated with landscape variables, may influence the structure of aquatic communities. For example, temperature had an inverse correlation to the presence of riparian forest because the presence and structure of riparian vegetation contributes to reducing the incidence of sunlight on the water. The water temperature regulates the metabolic rate of ichthyofauna (ectothermic organisms) and an increase in that rate can mean an increase in energy needs, which is reflected in the quantity of food needed for the organism to function (Magnuson et al., 1979). Therefore, the presence of riparian vegetation can directly and indirectly influence other variables important for maintaining the structure and function of aquatic ecosystems.

The type of vegetation that composes riparian forest was highly correlated with the presence of riparian vegetation, which can be a determining factor in the occurrence of ichthyofauna. We noted an absence of arboreal riparian vegetation, with only grass and isolated trees surrounding the rivers, and also the absence of fish. On the other hand, although highly degraded matrices such as citrus and sugarcane plantations surrounded the river at some points, riparian zone that was composed of arboreal vegetation, favored the occurrence of fish. These results corroborated other studies (Bruschi Junior et al., 2000; Ferreira & Casatti, 2006a; Cetra et al., 2005) that have shown that higher levels of fish diversity are associated with more preserved environments.

With respect to food, we showed that riparian vegetation influences the occurrence of allochthonous-feeders, while for autochthonous-feeders, the model with a riparian vegetation effect had the same explanatory power as the null model. Studies on the diet of tropical freshwater fish show that the ichthyofauna of these environments generally had significant trophic plasticity (Lowe-McConnell, 1999), altering their diet according to spatial and temporal variations in food supply. As the first-order streams have a low primary productivity and the processes are predominantly heterotrophic, the fish in these environments depend on the input of allochthonous-feeders matter for their subsistence (Castro, 1999). In this sense, the riparian zone are of great importance in these systems for food provision, habitat composition and shelter, which are significant factors in the maintenance of aquatic fauna diversity (Crowder & Cooper 1982; Gilinsky, 1984; Gotceitas & Colgan, 1989; Vono & Barbosa, 2001).

The presence of riparian forest influenced the occurrence of nektonic species. The diversity of species with different biological and ecological attributes, such as nektonic species that occupy the water columns, are possibly associated with a greater heterogeneity of available habitat (Ferreira & Casatti, 2006b). Degraded environments have fewer nektonic species because these species are more susceptible to high quantities of suspended solids (Pinto & Araujo, 2007). Thus, the influence of riparian forest on nektonic fishes we found may reflect an indirect effect by mediating the influence of particle entrance, and quantities of suspended soils in the water. Unlike the nektonic species, the occurrence of the benthic species was not influenced by any of the tested variables. The current composition of the communities is low in specialized groups and largely composed by tolerant to hypoxia and generalists species. This may be due to the fact that many anthropogenic changes in the rivers of the region has acted as environmental filters, increasing sedimentation, changing substrate composition and reducing flow levels (Rabeni & Smale, 1995; Casatti et al., 2006). Altogether, these had favored and ichthyofauna composed mainly by less specialist species at the expense of those with more specialized habits, especially those related to colonization of benthonic habitats.

Regarding the tolerance to hypoxia, sampling sites with low percentage of forest, absence or degraded riparian vegetation had few hypoxia-intolerant species. The presence of ichthyofauna can be influenced by the chemical quality of the water (Karr, 1993), which can diminish with the leaching of soils containing pesticides or phosphorus- and nitrogen-based fertilizers (Brodie & Mitchell, 2005). When released into the water, they can decrease the concentrations of dissolved oxygen, thereby causing the death of many fish species less tolerant of such conditions (Eklöv et al., 1998).

4.1. Riparian forests and biodiversity

Although some studies have argued that deforestation can increases species richness due to the appearance of new microhabitats, our results support findings that fragmentation and habitat loss are the main factors that contribute to reduction of fish diversity in both taxonomic and functional aspects. We also found that a disturbed habitat can harbour some species, but they are frequently generalist and less sensitive to environmental changes. In this context, preservation of riparian zone is of great importance not only for the fish community, but also for other organisms. Once preserved or restored, they can fulfill the role of ecological corridor (Uezu et al., 2005), connecting extant forest fragments (Metzger et al., 2008) and contributing to the growth of regional diversity.

Several studies have warned of the impacts of deforestation and the removal of riparian forest (Metzger, 2010; Toledo et al., 2010; Tundisi & Matsumura-Tundisi, 2010), including their effect on the conservation of ichthyofauna (Casatti et al., 2009; Magalhães et al., 2011, Santos et al., 2015). Given the recent changes in the Brazilian forest code (Brasil, 2012) that loosened the rules of protection for forest areas on the banks of watercourses, these studies are a crucial warning of the effects of landscape modification and the reduction of riparian vegetation on the functioning of freshwater aquatic ecosystems and their fauna and flora.

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