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Riparian coverage affects diets of characids in neotropical streams

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Abstract – Aquatic ecosystems are influenced by the surrounding terrestrial environment. This work studied the influence of vegetation of riparian zones on the feeding patterns of two nektonic characids, *Astyanax paranae* and *Bryconamericus iheringii*, in a basin surrounded by an agricultural area. Nine streams within the Corumbataí River basin (São Paulo State, Brazil) with varying proportions of adjacent riparian forest (RF) and pastures were set apart in three arbitrary categories: Riparian Forest (>90% RF), Mixed Coverage (banks covered by 30–60% RF; MC) and Pasture (<29% RF, PA); resident characids were sampled in the dry and rainy seasons and evaluated in regard to composition of diets. *Astyanax paranae* fed on allochthonous food sources in RF and MC, and on autochthonous food sources on PA streams; *B. iheringii* fed on autochthonous food sources in RF streams and in mixed resources (detritus and sediment) in PA streams. Selection of food source was related to, and altered by, stream channel structure and composition of substratum. Preservation and restoration of native riparian vegetation is key to preservation of resident characids in small streams of this river basin.

Key words: riparian buffer; agro-ecosystem; stream habitat; stream fish; land use

Introduction

Riparian zones are areas of transition and interaction between aquatic and terrestrial ecosystems, ordinarily influencing lotic systems (Naiman et al. 2005). Forests in these areas directly influence the starting point of stream food chains: the regulation of primary production and the influx of allochthonous resources to aquatic environments (Vannote et al. 1980). Alterations of riparian ecosystems not only alter food chains in the aquatic system, but also break the structure of stream canals and further negatively influence stream equilibrium. This phenomenon has been solidly demonstrated for temperate regions (Sponseller et al. 2001; Growns et al. 2003; Meador & Goldstein 2003; Diana et al. 2006; Rios & Bailey 2006; Bonada et al. 2008), but scarce information is available for tropical streams, mainly in regard to fish assemblages (Bojsen & Barriga 2002; Casatti et al. 2009).

The Corumbataí River basin, southeastern Brazil, has a long history of anthropogenic occupation and alteration. The current degree of fragmentation of the basin is high, with the main fragments composed of pastures and sugarcane crops (Koffler 1993; Valente & Vettorazzi 2002). The riparian landscape in the Corumbataí River basin is no exception; the riparian zone in the region as a whole has been frequently altered by agricultural and industrial activity, farming of animals and urban development (Silva et al. 2007a).

In the Corumbataí River basin, the characids *A. paranae* and *B. iheringii* are amongst the most numerous fish species (Gerhard 2005). Characidae is a

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conspicuous fish family in Neotropical streams, comprising 12 subfamilies, 88 *incertae sedis* genera and at least 1,300 species (Buckup 1999; Castro et al. 2003; Reis et al. 2003). Nectonic characids are small, sight-dependent fish, exploring the whole water column and relying on various feeding tactics (Casatti & Castro 2006). Little is known on characids auto-ecology, especially in regard to anthropogenic impact on use of food sources and survival (Bojsen 2005; Ceneviva-Bastos & Casatti 2007). Therefore, expanding the core of knowledge of the feeding ecology of these characids represents an important step towards understanding the relationship between these fish and their habitat, eliciting and designing future strategies for their conservation management. Basic information on fish diets can be drawn from analysis of stomach contents. Alterations of feeding habits and tactics can be connected to altered environmental conditions, caused by both natural phenomena and anthropic activities. For instance, alterations in riparian coverage interfere with streams trophic webs and lead to simplification of food chains (e.g., Bojsen & Barriga 2002; Bojsen 2005; Casatti et al. 2009; Lorion & Kennedy 2009). Stream ecosystems are not closed environments and are strongly influenced by their terrestrial surroundings, especially considering the lateral dimension of the system, that is, land-water interactions (Ward 1989). Consequently, this work that investigated the influence of the composition of the riparian vegetation on the feeding patterns of stream characids in an agricultural landscape addressed the following questions: (i) how does the riparian coverage influence the diet of *A. paranae* and *B. iheringii*?; (ii) how similar or dissimilar have the species diets become locally? and (iii) besides riparian coverage, which other abiotic variables, e.g., water chemistry and stream canal structure, influence species diets locally?

Material and methods

The Corumbataí River basin encompasses 170 km^2 on the right banks of the Piracicaba River, Midwest State of São Paulo (Brazil), 22°04″46″S to 22°41′28″S; 47°26′23″W to 47°56′15″W (Fig. 1), a region with subtropical climate with rainy summers and dry winters (CWa climate by Köppen's classification). The rainy season – October to February – concentrates 70% of annual rainfall, coinciding with the period of the highest temperatures. The dry period, when the lowest temperatures are recorded, occurs from March to September (Koffler 1993).

The basin is fragmented as a result of anthropogenic activities, predominantly by cattle pastures (44% of total area) followed by sugarcane (26%), fragments of native vegetation (11%) and planted forests (7%) (Valente & Vettorazzi 2002). Brazilian environmental laws require this legally protected area to be covered by 35% native vegetation instead of just 11% as is currently; consequently, land-use practices in the study area seriously flout these laws.

Selection and description of the studied areas

The study area included nine streams in the Corumbataí River basin (Table 1), and their corresponding catchments, with registered occurrence of both *A. paranae* and *B. iheringii*. The streams were selected to display different percentages of remaining

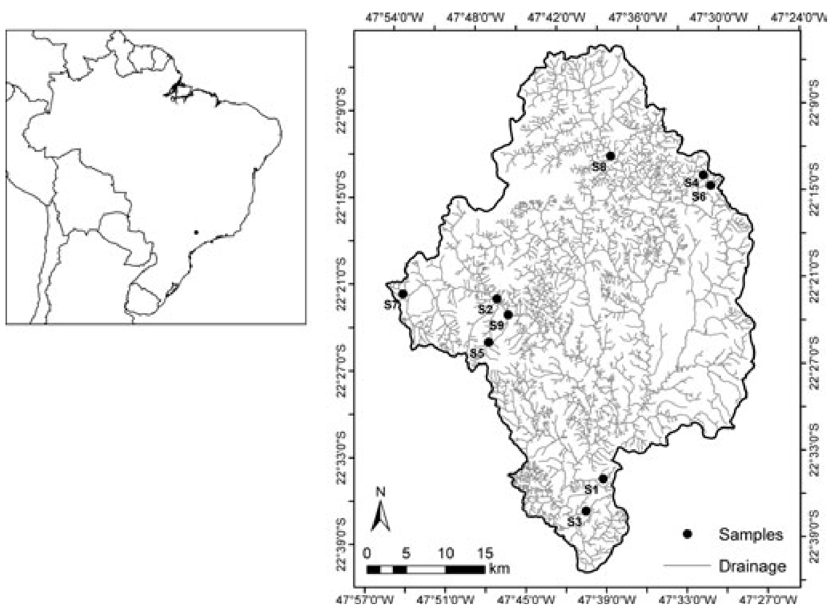

Fig. 1. Location of the Corumbataí River basin in the State of São Paulo (Brazil) and of the selected sampled stream stretches. Coordinates in UTM projection, Zone 23S, datum Córrego Alegre.

Table 1. Location and environmental characteristics (mean ± SE) of sampled streams in the Corumbataí River basin, State of São Paulo, Brazil. The substrate represents the main categories found in streams. Coordinates in UTM projection, Zone 23S, datum Córrego Alegre.

Code	Location	Coordinates† x	Coordinates† y	Altitude (m)	Slope (%)	Width (m)	Depth (m)	Substrate
S1	Córrego Tamandupá	227.346	7.500.575	585	1.37	1.69 ± 0.52	0.08 ± 0.06	Gravel/sand
S2	Córrego Paredão	213.780	7.523.554	585	2.75	2.22 ± 0.83	0.11 ± 0.11	Sand/boulder
S3	Córrego Barro-Frio	226.971	7.505.548	529	0.46	2.15 ± 0.65	0.12 ± 0.09	Sand/pebble
S4	Tributary of the Córrego do Jacú	240.713	7.538.579	650	1.82	2.40 ± 1.44	0.07 ± 0.08	Sand/bedrock
S5	Córrego da Lapa	212.406	7.517.643	698	2.81	2.37 ± 0.84	0.13 ± 0.11	Pebble/boulder
S6	Tributary of the Córrego do Jacú	240.907	7.538.304	648	0.25	2.43 ± 1.52	0.13 ± 0.17	Sand/boulder
S7	Córrego do Anzol	202.183	7.524.105	674	5.60	3.13 ± 1.58	0.09 ± 0.08	Sand/block
S8	Tributary of the rio Corumbataí	228.240	7.541.731	500	1.20	2.44 ± 1.34	0.19 ± 0.19	Sand/vegetable matter
S9	Córrego do Rochedo	215.151	7.521.401	578	1.91	1.93 ± 0.86	0.31 ± 0.24	Sand/vegetable matter

†Coordinates refer to the downstream end of the sampled section.

native forests in the riparian zone, as determined by the forest covering a 30-m buffer strip along all channels of each catchment. No catchment with 100% of native forests along the riparian zone could be located to elicit comparisons of data between the nonforested and forested catchment area.

Land cover in the selected catchments was dominated by grasslands and sugarcane crops, differing only in percentage of coverage of riparian zones. Fish and abiotic variables were sampled along 500-m stream stretches in which 30-m-wide riparian buffer zones could be identified in each bank.The riparian buffer zone width stipulated by Brazilian Federal Law # 4771, 1965, defining Permanent Preservation Area (APP) and determining 30-m riparian buffer strips for streams narrower than 10 m. The 500-m stretch was randomly chosen as sufficient for sampling enough specimens needed for analysis.

The detailed characterisation of the land use and cover, both at catchment and riparian zone spatial scales, was obtained from the interpretation of orthorectified, digital aerial photographs (year 2000, scale 1:30,000) and topographic maps (year 1979, scale 1:10,000) by the Cartographic and Geographic Institute of the State of São Paulo. The interpretation was carried out in a Geographic Information System (GIS) developed for the studied area, using both ArcView 3.3© and ArcGIS© 9.1 tools (Environmental Systems Research Institute, Redlands, CA, USA). This GIS enabled the georeferencing of aerial photographs, scanning and defining the boundaries of each catchment and the hydrographic network, classification of land cover polygons and calculating landscape metrics.

Landscape index and composition

Catchment areas and the percentages of each land cover calculated from land use and cover map are presented in Table 2. The main land covers in the studied area included pasture, sugarcane crops and native forest fragments. These are the three sole cover types occurring in the riparian zones of each 500-m sampled stretch (Table 2).

Table 2. Categories of land cover (%) and total surface area (ha) of Corumbataí River basin and categories of riparian coverage (%) along stream sampling stretches.

	Catchment					Stretches		
	Forest	Pasture	Sugarcane	Other	Total area	Forest	Pasture	Sugarcane
S1	26.4	14.4	56.0	3.2	256.2	100	0	0
S2	40.1	59.0	0.0	0.9	229.7	99	1	0
S3	43.0	19.5	37.5	0.0	586.7	95	0	5
S4	25.3	73.2	1.5	0.0	98.9	94	6	0
S5	37.8	43.6	17.2	1.4	1086.1	52	48	0
S6	19.7	57.1	22.3	0.9	299.1	43	57	0
S7	22.5	68.9	8.1	0.5	289.0	34	66	0
S8	8.5	89.2	0.0	2.3	216.0	21	79	0
S9	23.0	68.0	4.6	4.4	694.4	0	100	0

The cluster analysis of Un-weighted Pair-Group Average (UPGMA) was used to identify the occurrence of conspicuous groups in terms of percentage of riparian forest (RF) cover along the 500-m sampling stretch. Three groups of streams were identified and tagged: (i) 'Riparian Forest' streams (RF), which presented between 90 and 100% riparian zone covered by native forest fragments (sampling sites S1, S2, S3, S4); (ii) 'Mixed Coverage' streams (MC), presenting between 30 and 60% of the riparian zone covered by native forest fragments (sampling sites S5, S6, S7) and (iii) 'Pasture' streams (PA), presenting between 0 and 20% of the riparian zone covered by native forest fragments (sampling sites S8, S9). The arbitrary classification was tested through a one-way ANOVA, which identified differences between the stream categories ($F = 83.53$, $P < 0.01$); all categories differed from each other (Tukey test; $P < 0.05$). The grouping was also used as a categorical variable in subsequent exploratory analysis and statistics.

Characterisation of the habitat

Stream habitat was described following Fitzpatrick et al. (1998). Stream widths, stream depth (Table 1) and substrate particle size – bedrock, block, boulder, pebble, gravel, sand, silt, vegetable matter, trunk and clay [Wentworth scale (Cummins 1962)] – were measured at regular intervals along 25-m stretches (Appendix 1).

Five measurements of dissolved oxygen saturation and water temperature (YSI-95 oxygen meter) were also taken at each stream stretch. A 1.0-l water sample was stored on ice and taken to laboratory for analysis of acidity, alkalinity, CO_2 contents, pH, total suspended solids, apparent colour, turbidity and conductivity (Appendix 1).

Fish sampling and diet analysis

Fish were sampled during the months of July and August 2005 (dry season) and January and February 2006 (rainy season). Fish were collected using seine nets and small plastic traps lured with plastic-coloured beads. Captured specimens were placed in plastic bags kept in an ice box and later identified in the laboratory by comparing to voucher specimens of the collection of Department of Zoology and Botany, Universidade Estadual Paulista (DZSJRP) (São José do Rio Preto, SP, Brazil). Fish had their guts removed and stomachs preserved in 4% formaldehyde and subsequently transferred to 70% alcohol.

For dietary analysis, only the largest individuals of each species per stream were selected. A total of 312 stomachs of *A. paranae* and 360 *B. iheringii* (Table 3) were examined. Stomach contents were analysed under stereomicroscope and microscope, and food items were identified to the lowest possible taxonomic level. The volume of each food item was determined by compressing the material with a glass plate to a known height (1 mm), the result converted into millilitres (1 mm^3 = 0.001 ml) (Hellawell & Abel 1971). Fish diets were first summarised by the methods of frequency and volume (Hyslop 1980) and later evaluated by Food Index (IA_i %) (Kawakami & Vazzoler 1980):

$$\mathrm{IA}_i = \frac{F_i \times V_i}{\sum F_i \times V_i} \times 100$$

where F_i is the relative frequency of occurrence of item i (%) and V_i is the relative volume of item i (% total).

Food items were grouped into broad food categories and according to their origin. Allochthonous resources included terrestrial insects (TIN), terrestrial invertebrates (TIV) (other invertebrates than insects) and terrestrial plants (TPL). Autochthonous resources included aquatic insects (AIN), aquatic invertebrates (AIV), fish (FIS) and algae (ALG). Detritus and sediment (DET) were deemed of mixed origin.

Data analysis

The principal component analysis (PCA) (Pearson 1901; Gauch 1986) was used with the objective of summarising the dimensionality of environmental variables (Appendix 1) and ranking the of collection points and identifing which environmental characteristics influence the ordination. To determine which axes of principal components (PC) would be retained, the eigenvalues of the axes were compared with the eigenvalue generated within the hypothesis of randomness obtained from the model of 'broken-stick' (Jackson 1993), and only PCs with higher values than the 'broken-stick' were used for interpretation.

To define spatial (streams) and temporal (dry and wet) patterns for the species diet, data on the feeding ecology were analysed and explored in tables and graphs. Correspondence analysis with removal of the effect of arc (Detrended correspondence analysis; DCA) (Gauch 1986; Jongman et al. 1995) was used to summarise fish diet data. This analysis was carried out using the volumes of food items consumed by each

Table 3. Number of stomachs (n), mean of standard length (SL ± SE; cm) of analysed individuals per stream in dry and rainy seasons.

	Astyanax paranae				*Bryconamericus iheringii*			
	Dry		Rainy		Dry		Rainy	
Code	*n*	SL	*n*	SL	*n*	SL	*n*	SL
S1	20	5.91 ± 0.39	20	5.31 ± 0.72	20	4.46 ± 0.29	20	4.66 ± 0.33
S2	20	5.16 ± 0.69	20	4.49 ± 0.42	20	4.35 ± 0.38	20	4.56 ± 0.35
S3	04	3.88 ± 0.75	2	4.87 ± 0.45	20	4.38 ± 0.38	20	4.27 ± 0.35
S4	20	5.74 ± 0.67	20	5.70 ± 0.59	20	4.58 ± 0.28	20	4.43 ± 0.23
S5	20	5.46 ± 0.71	20	5.69 ± 0.85	20	5.10 ± 0.41	20	4.84 ± 0.48
S6	20	3.79 ± 0.53	20	5.12 ± 0.60	20	4.72 ± 0.29	20	4.76 ± 0.24
S7	20	5.96 ± 0.59	20	5.06 ± 0.52	20	5.05 ± 0.41	20	4.97 ± 0.25
S8	20	3.40 ± 0.68	11	3.05 ± 0.57	20	4.33 ± 0.25	20	4.51 ± 0.25
S9	20	3.59 ± 0.41	15	3.80 ± 0.45	20	3.83 ± 0.45	20	3.76 ± 0.31
Total	164		148		180		180	

species in each stream and time. All calculations were done using the PC-ORD 4 tool (McCune & Mefford 1997).

To determine whether the scores generated by the ordinations (DCA and PCA) presented different patterns, multivariate analysis of variance (MANOVAS) between PCA scores in relation to physico-chemical data and DCA, based on the species diet, were performed. The collection period (dry and wet) and stream categories (RF, MC and PA) were considered categorical variables for PCA axes. As for the axes of the DCA, sampling periods (dry and wet) and species (*B. iheringii* or *A. paranae*) were considered the main factors. Relationships between streams categories and DCA axes were tested by one-way ANOVA. Differences between mean scores defined by MANOVA and one-way ANOVA were detected by Tukey test. To identify which environmental variables influenced the diet of the species, a correlation analysis between PCA and DCA axes was performed. The assumptions of normality and homoscedasticity were all previously tested. All statistical analyses were performed at $\alpha = 0.05$.

Canonical correspondence analysis (CCA) was used to measure the relationships between diets of the species and environmental variables (Ter Braak & Smilauer 2002). CCA is a multivariate direct gradient analysis technique in which a multiple linear least-squares regression is performed with the biotic data as the dependent variable and the environmental characteristics as the independent variables (Palmer 1993). Categories of streams (Riparian Forest; Mixed Coverage; Pasture) were used as covariates in the CCA, and environmental variables used in this analysis were the variables with eigenvalues >0.260 from PCA performed earlier. CCA was performed for each species separately. Ordination diagrams are presented to illustrate the relationship of diets of species and environmental variables. In these diagrams, the environmental variables are represented by arrows along with the species and site scores. The arrow length indicates the importance of the environmental variable, the direction indicates how well this gradient is correlated with the species composition axes, whereas the angle between arrows indicates the species' environmental preferences, the location of site scores relative to arrows indicates the environmental characteristics of the sites, and the location of species scores relative to the arrows indicates the environmental preferences of each species (Palmer 1993). The statistical significance of the correlations between environmental characteristics and biotic variables extracted from the CCAs was determined by the Monte-Carlo test, based on 5000 permutations ($\alpha < 0.05$); only the first axis of this analysis was interpreted.

Results

Environmental characteristics

Axes PC1 and PC2 (Fig. 2), which together explain 37.4% of total data variability (PC1 20.5% and PC2 16.9%), were considered for analysis. The eigenvalues estimated for the first two axes higher than 0.260 influenced the ordination (Appendix 2).

The variable Sand was positively correlated with PC1, and variables Pebble, Bedrock and Block were negatively correlated with these axes. PC2 separated variables vegetable matter and depth positively, and variables turbidity, apparent colour and total suspended solids, negatively. Through the components PC1 and PC2 of the ordination graph, pasture streams were separated from other stream categories.

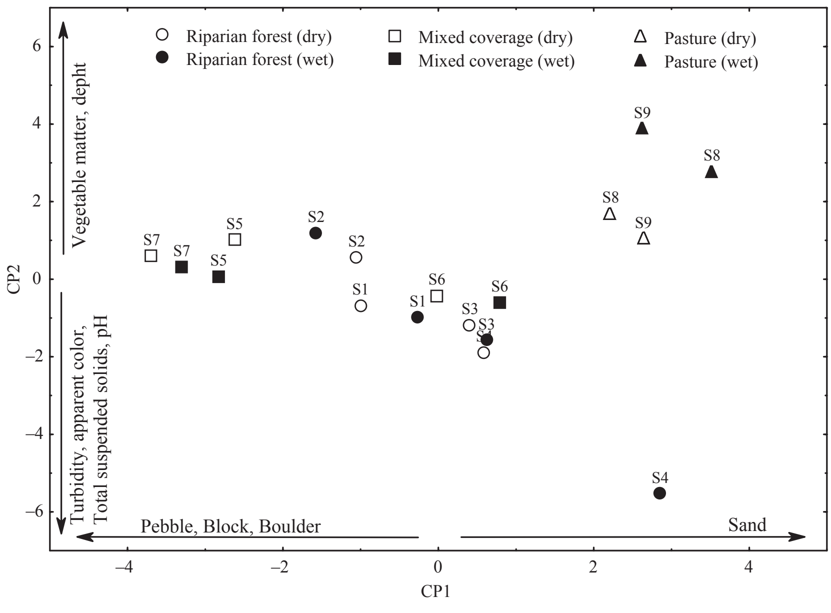

Fig. 2. Scores derived from the principal component analysis (axes 1 and axes 2) involving the variables of physical-chemical analysis of water and channel structure for the studied streams.

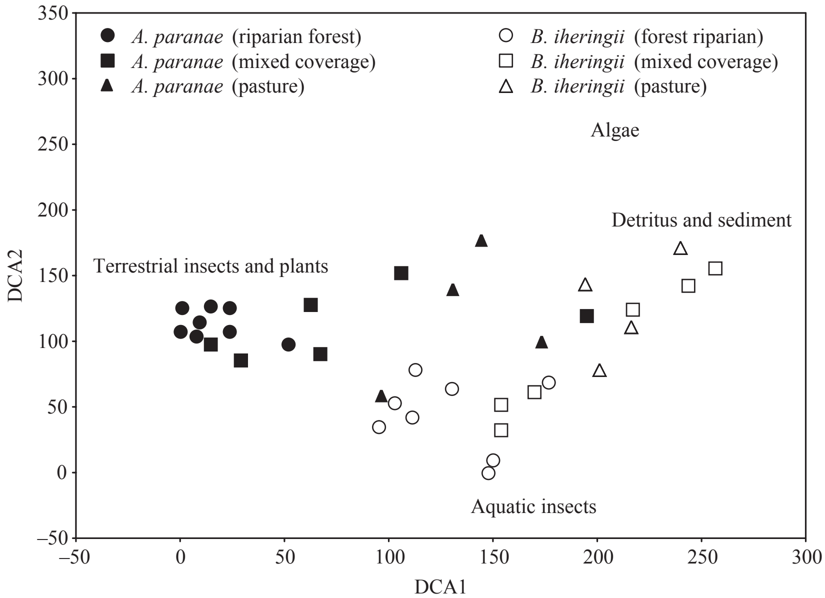

Fig. 3. Ordination of diets of *Astyanax paranae* and *Bryconamericus iheringii* by location, dry and wet periods, highlighting main food consumed by the species in Corumbataí River basin streams.

A MANOVA detected differences between means of abiotic variables within stream categories ($F = 14.76$, $P < 0.001$). The variables related to seasonality, i.e., dry and rainy seasons, did not differ for both axes; only Pasture streams differed significantly from other stream categories (Tukey test; $P < 0.05$).

Diet composition

Patterns of species diet composition in the dry and rainy periods, and spatial variations for stream categories, were summarised by correspondence analysis with arc effect removal (DCA) (Fig. 3). Axes 1 (A1; eigenvalue = 0.51) and 2 (A2; eigenvalue = 0.18), which together concentrated the highest variation, were retained for score analysis. Assuming species and seasonality as categorical factors, MANOVA applied for scores of A1 and A2 of DCA detected no differences between diet of species diet as related to seasonality; that is, seasonality did not significantly affect consumption of food resources. However, the diets of the two species differed in the sense that preferred items were not the same. ($F = 60.18$; $P < 0.001$). Diets of species also differed relative to stream categories, for both A1 ($F = 22.11$; $P < 0.001$) and A2 ($F = 4.56$; $P < 0.02$). The Tukey test separated diets of *A. paranae* and *B. iheringii* at different stream categories in which RF differed from other categories, both for A1 and A2.

Because there were no seasonal variations between species' diet, food items were grouped and the main items consumed are shown in Fig. 4. Food items such as aquatic and terrestrial macro invertebrates and fish represented <1% of all food encountered in the stomachs of both species, so they were not included in Fig. 4.

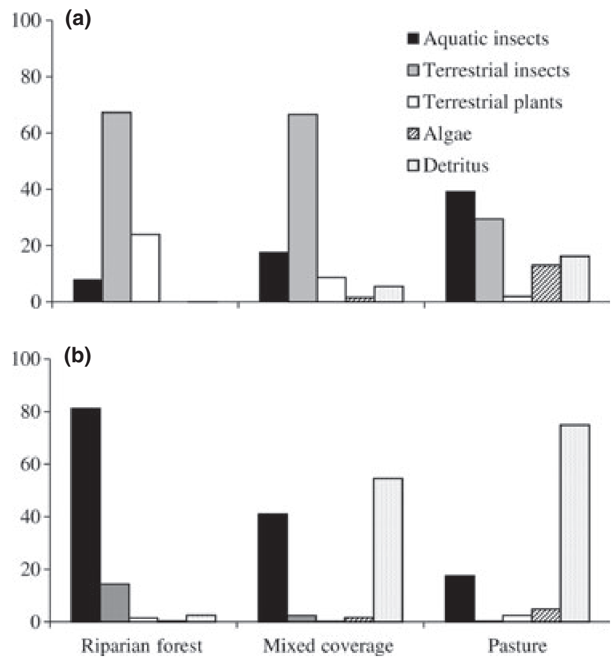

Fig. 4. Percentage (IAi%) of the main food resources consumed by *Astyanax paranae* (a) and *Bryconamericus iheringii* (b) in the categories of streams in the Corumbataí River basin, State of São Paulo, Brazil.

The main food sources of *A. paranae* were terrestrial and aquatic insects (Fig. 4a). However, specimens inhabiting streams bordered by RF and MC consumed more terrestrial insects compared with specimens inhabiting streams where the riparian zone was dominated by pasture. The opposite was observed for *B. iheringii*, which reduced the consumption of aquatic insects with the substitution of RF by pastures (Fig. 4b).

Foods such as terrestrial plants (mainly leaf fragments and seed), algae and detritus were relatively less important for *A. paranae*; however, some trends were registered among individuals of streams with different covering vegetation in the riparian zone. There was a progressive decrease of terrestrial plants as a food source and increased consumption of algae and detritus in streams with dominance of pasture along riparian stretches (Fig. 4a).

Terrestrial plants and algae were also less important in the diet of *B. iheringii*. Detritus became the main food item of this species in streams where the riparian zone was covered by pasture. In these cases, detritus represented the main food source for the species, accounting for almost 80% of the Feeding Index (Fig. 4b).

Therefore, allochthonous items were the main food source of *A. paranae* in streams with RF and MC, unlike the streams with pasture, where the species consumed chiefly autochthonous resources. On the other hand, *B. iheringii* shifted from autochthonous resources to mixed (detritus and sediment) food resources in streams with pasture predominance.

The CCA for all samples combined showed the overall relationships between diets of the species and environmental variables (Fig. 5a,b; Appendix 3). The cumulative percentage variance of relation of diet species and environmental variables to the first axis CCA were about 49% for *A. paranae* and 72% for *B. iheringii*. The correlations between fish species and environmental characteristics were high and significant (Monte-Carlo test with 5000 permutations, along the first canonical axis) for *A. paranae* ($P = 0.01$) and *B. iheringii* ($P = 0.05$). The CCAs identified environmental variables related to categories of streams and the diets of species. Depth, vegetable matter and sand were positively correlated with Axis 1, while block and pebble were negatively correlated with Axis 1. Therefore, these variables formed two main groups along the first CCA axis, where the streams with forest coverage occupied the negative side of the ordination, while the streams of pasture coverage were on the positive side.

Additionally, the rankings showed a pattern similar to the DCA regarding the diet of the species. For streams in RF, *A. paranae* consumed mainly allochthonous resources (see Fig. 4a), and in streams with pasture covering, a greater intake of aquatic insects, detritus and sediment and algae (see Fig. 4b) was registered. *Bryconamericus iheringii* consumed higher proportions of aquatic insects in streams with RF, and detritus and sediment in streams with pasture coverage. These results reinforce the influence of riparian coverage changes in the characteristics of channels and the diet of these species.

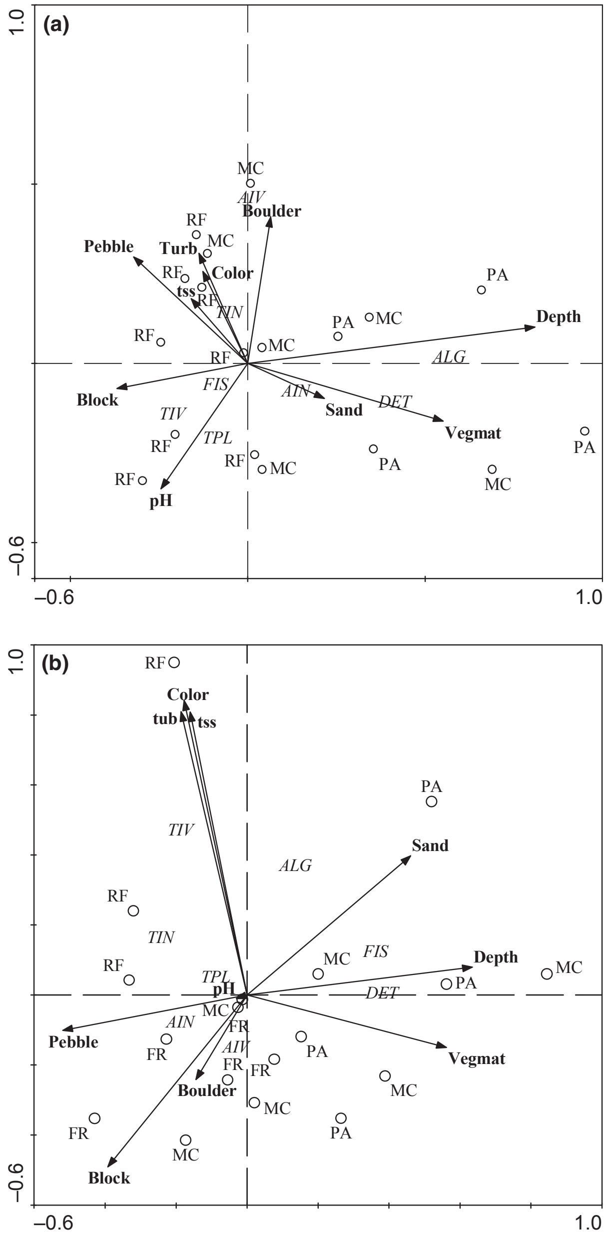

Fig. 5. Ordination diagram produced by canonical correspondence analysis (axis 1 and 2, *x* and *y*, respectively) for *Astyanax paranae* (a) and *Bryconamericus iheringii* (b). Vectors of environmental variables (vegmat = vegetable matter; acolour = apparent colour; turb = turbidity, tss = total suspended solids) are represented by arrows and categories of streams by circles. Abbreviations of categories of food items and streams are found in material and methods section.

Discussion

Diets of *A. paranae* and *B. iheringii*

The main food resources consumed by *A. paranae* switched from terrestrial insects in the streams of RF and MC to a greater variety of categories consumed in Pasture streams, mainly aquatic insects, detritus and sediment, terrestrial insects and algae. Changes were also observed for *B. iheringii*, featuring a diet of aquatic insects in streams of RF and detritus and sediment in Pasture streams. Some authors described for *A. paranae* a diet based on allochthonous resources (Uieda et al. 1987; Roque et al. 2003; Ferreira 2007) and for *B. iheringii* a diet consisting of mixed resources (Oricolli & Bennemann 2006) and autochthonous food items (Pinto & Uieda 2007).

Through the modification of their diet in response to changes in riparian coverage, the species showed opportunistic behaviour. This behaviour is common in small nektonic characids (Ferreira et al. 2002; Rezende & Mazzoni 2003; Ceneviva-Bastos et al. 2010), which can use their morphological and behavioural characteristics to obtain alternative food resources in the face of environmental change. They can also demonstrate trophic adaptability, by altering their diet because of changes in resource availability in the face of heterogeneous environments, resulting from either natural or human-induced changes. It is otherwise remarkable that even having different diets and being able to change their eating habits in response to changes in the land covering of riparian zones, diets of the species do not overlap.

According to the diets, the species use distinct compartments of the water column and different tactics to obtain their food. Nektonics characids are active swimmers with typical compressed bodies, laterally positioned eyes, pectoral fins at mid body and extended anal fins (Casatti & Castro 2006). When most of the food resources consumed by *A. paranae* were allochthonous, it is fair to infer that the species foraged on the surface or current-carried food sources. This feeding tactic was also recorded by Sabino & Castro (1990) and Sabino & Zuanon (1998) for other nektonic characids. On the other hand, most food sources exploited by *B. iheringii* were of autochthonous and mixed origin (detritus and sediment), so seemingly the species forage in the substrate and on items carried by the current. Ecomorphological and stomach contents analysis revealed that *B. iheringii* are active swimmers, dwelling on continuous environments associated with flowing, mid water column and raiding the substrate, preying chiefly on aquatic insects but also having a large proportion of detritus and sediment particles in the diet (A. Ferreira, unpublished data).

As a rule, the diets of fish correspond to morphological adaptations in the feeding apparatus and foraging strategies (Labropoulou & Eleftheriou 1997; Freyhof & Herder 2006). Diets and spatial segregation between *A. paranae* and *B. iheringii* may actually be related to the morphology of the species' mouth: with *A. paranae* having a terminal mouth and a diet based on terrestrial insects, while *B. iheringii* presents a subterminal mouth and forages on aquatic insects. These observations confirm data reported by Russo et al. (2004) and Freyhof & Herder (2006).

Influence of soil coverage of riparian zones in the diets of species

There were significant differences between diets of species in relation to categories of streams studied, demonstrating the influence of riparian coverage in the diets of species in these ecosystems. Major changes in RFs can substantially change the structure of the fish community, especially in small rivers (Stauffer et al. 2000; Growns et al. 2003), even taking into account the feeding plasticity of fish (Sabino & Castro 1990). Changes can be of a direct nature, such as a reduction of the plant material input when the RF is removed, and of indirect nature, as a result of changes that occur in light input and channel geomorphology, for instance (Gregory et al. 1991; Hicks 1997; Esteves & Aranha 1999; Rowe et al. 1999; Naiman et al. 2005).

Diets were influenced by characteristics of the channels, especially composition of substrate variations in the depth of channels, as well as turbidity, apparent colour and concentration of suspended solids in the water. In streams having either forest or MC as the main vegetation of riparian zones, the substrate of channels was mostly rocks; streams that had a riparian zone dominated by pasture had sandy, silty substrate and grass sprouted in the channel. The siltation and consequent increased turbidity affect the detection of prey by visually oriented fish (Bonner & Wilde 2002), such as nektonic characids (Casatti & Castro 2006). Changes observed in the diets of *A. paranae* and especially in the diet of *B. iheringii* between different categories of streams showed the effects caused by changes in water features and especially in the channel structure. A significant increase in the occurrence of debris and sediment as part of the diet was registered for both species in streams having pasture-dominated riparian zones. This was especially remarkable for *B. iheringii*, whose diet was virtually devoid of debris and sediment in streams with forested riparian zone, but had debris and sediment accounting for more than 70% of their diet when pastures were prevalent in the riparian zone. While exploring the substrate in search for food (see next item), the observed changes in the substrate in pasture streams had direct effects on the diet. Other studies showed similar results on diet *B. iheringii*. In streams undergoing anthropogenic interference (rural and urban areas), the species showed a diet of detritus (Oricolli & Bennemann 2006), while in stretches of streams with dense vegetation cover and the other with open land (herbaceous), both having rock as substrate, the species consumed aquatic insects (Pinto & Uieda 2007).

Aquatic insects are the preferred item in *B. iheringii* diet, which does not mean it is a specialist species. The consumption of detritus and sediment may be explained by factors such as the increased availability of this resource (as also occurs in pasture streams) or accidental ingestion while foraging on the substrate in search for insects. Despite consumption of aquatic insects being energetically advantageous in comparison to detritus and sediments, detritus is an abundant and passive food, and its nutritional capacity has been demonstrated in the diets of trophic specialists, such as Curimatidae and Prochilodontidae (Abelha et al. 2006). Even without showing morphological adaptations in the digestive tract, such as in detritivores (mechanical stomach or long intestine, for example), or expelling much of the fine sediment through the gills (such as cichlids and some loricariids), *B. iheringii* may be somehow taking advantage of the energy obtained from this resource. To validate these premises, further studies detailing ecomorphological, anatomical and nutritional aspects of *B. iheringii* biology are required.

Removal of forest from the riparian zone increases the light input to a stream system, and as a consequence, primary productivity also significantly increases in the streams (Bunn et al. 1997; Hicks 1997; Luiz et al. 1998). In streams where riparian areas were dominated by pasture, large quantities of both colonies of filamentous algae, either floating or attached to grasses and submerged macrophytes, were a relevant feature. This should explain why fish consumed more algae in these streams, and the same trend was not observed in streams shaded by RFs. Increased consumption of filamentous algae was also found in the diet of *Astyanax zonatus* in deforested sites as compared to forested sites (Bojsen 2005). In addition, *A. paranae* is a midwater swimmer, seizing food items at both the surface and midwater. The shading provided by forested riparian zones casts shadow patches on the surface camouflaging the fish, aided by the presence of darkened bedrock which also provides shelter and refuge (Uieda, personal communication).[1] As a result of RF removal, individuals of *A. paranae* lose this protection and become more susceptible to predators. As a result, searching for food items on the surface becomes more risky. Because *A. paranae* feeds mainly on the surface and on resources carried by the current, such as terrestrial insects and plant debris, the removal of the RF was probably the main cause of changes in the diet of this species in pasture streams. In these sites, these species seek for refuge on the margins of streams and obtain most of their food in these places and the substrate. In streams with pasture coverage, there is a simplification of habitat and few species are favoured, in addition, the dominant species are usually opportunistic omnivores with a tendency to be insectivorous and do not necessarily depend on the substrate to be consolidated and diversified (Casatti et al. 2009). It is also possible to connect the diet of the species to the silting of channels, where there are shallow, heavily grassy stretches, thus eliciting the presence of fragments of leaves and grass seeds in the stomach of some specimens sampled at these sites.

Concluding remarks and management implications

The importance of land cover of stream riparian zones for Neotropical nektonic characids has been herein demonstrated. In addition to presenting different diets, species responded differently to riparian land cover, indicating that these species have flexible diets and may be able to adjust to riparian alterations. Removal or fragmentation of RF can affect the abiotic characteristics of streams, especially the composition of substrates, disrupt food chains and not only alter fish diets, but also lead to the differentiation of diets in different streams. Results herein reported emphasise the complex interactions between riparian zones and stream ecology, and also that the recovery and preservation of RFs are essential to maintain the integrity and environmental quality of these ecosystems. This is especially important, considering two aspects: Firstly, back in 1997, only 25% of riparian areas of the seven major river basins of São Paulo were covered by native forests, the remaining 75% were already covered by pastures and sugar cane (Silva et al. 2007b); and last but not least, the current efforts by corporate agribusiness in altering environmental legislation aimed at agricultural use of preserved riparian zones. Therefore, continued efforts aimed at recovering and preserving riparian zones are key for conservation of stream fish and shall be on the agenda of public and private affairs regulating these areas.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix 1. Environmental characteristics (means and ranges) measured in the categories of streams of the Corumbataí River basin.

Appendix 2. Loadings derived from principal component analysis of abiotic variables (physicochemical water and channel structure) measured in streams of the Corumbataí River basin, Brazil.

Appendix 3. Results of canonical correspondence analyses of diets of species and physicochemical characteristics in streams of the Corumbataí River basin, Brazil.

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