PRIMARY RESEARCH PAPER



The trophic structure of fish communities from streams in the Brazilian Cerrado under different land uses: an approach using stable isotopes

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Received: 15 April 2015/Revised: 23 January 2017/Accepted: 20 February 2017/Published online: 7 March 2017 © Springer International Publishing Switzerland 2017

Abstract The aim of this study was to evaluate how distinct land uses can alter the trophic structure of fish communities in streams. For this purpose, nine streams under the influence of three distinct land uses (pasture, sugarcane, and natural cover) were evaluated. The structure and isotopic niche of the fish communities were investigated by calculating descriptive community-wide metrics based on stable isotopes of δ^{13} C and δ^{15} N. The largest isotopic niche was observed in fish communities in pasture streams, and the smallest in sugarcane streams. Pasture streams exhibited greater ranges of carbon sources exploited by fishes, higher

Handling editor: Luiz Carlos Gomes

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Laboratório de Ecologia Isotópica, Centro de Energia Nuclear na Agricultura - CENA, Universidade de São Paulo, Av. Centenário, 303, Caixa Postal 96, Piracicaba, SP CEP 13400-970, Brazil trophic diversity, and lower trophic redundancy. In contrast, sugarcane streams had greater ranges of nitrogen exploited by fishes and showed the smaller trophic diversity, higher trophic redundancy, and uniformity. Sugarcane was also the only land use that exerted a negative influence on community isotopic niche width. Natural cover streams in turn, showed lower trophic uniformity and exhibited intermediate values for all remaining metrics. We conclude that fish communities residing in streams influenced by pastures displayed characteristics that led to greater trophic diversity, and fish communities influenced by sugarcane plantations were more negatively affected by this land use.

Keywords Carbon \cdot Nitrogen \cdot Food webs \cdot Food resources

Introduction

Streams are important components of the landscape in the neotropical savanna ("Brazilian Cerrado"), and they are home to a large aquatic biodiversity. This biome, which was in the past occupied by sparse indigenous populations, is now under intense pressure as a result of increased anthropogenic activities (Ratter et al., 1997; Diniz-Filho et al., 2009). This change, which began in the 1950s, can be mainly attributed to the extensive conversion of natural areas into pasture for livestock or arable land for crops (Diniz-Filho et al., 2009) such as sugarcane, soybean, and maize. The transformation of natural areas into pastures and crop fields alters the physical structure and energy flow in aquatic environments (Silva et al., 2007), through modification of channel morphology (Medeiros et al., 2008), substrate type (Beltrão et al., 2009), water quality (Ometto et al., 2000), and quality of the riparian zone (Allan, 2004). Moreover, various land uses can alter the biodiversity (Angermeier & Karr, 1994), which can consequently alter the structure of the aquatic communities.

Niche theory can explain many of the patterns of assemblage and community structure, and can be used for understanding the effects of land uses changes on aquatic communities. Niche is a term with a variety of meanings related to the behavior of species living under specific environmental conditions. One of the dimensions of a species' niche is the "trophic niche", which can be defined as the sum of trophic interactions that link it to other species in an ecosystem and can be differentiated into distinct partitions or use of resources (Begon et al., 2007). Ecologists have recently developed renewed interest in the concept, and technological advances now allow us to use stable isotope analyses to quantify these niche dimensions (Newsome et al., 2007).

Stable isotopes, particularly carbon and nitrogen, are widely used to examine structural features of food webs and they permit a representation of the ecological niches occupied by species (Jepsen & Winemiller, 2002; Lujan et al., 2011; Perkins et al., 2014). Isotopic niche has been represented as an area (in δ space) with isotopic values $(\delta^{15}N \text{ and } \delta^{13}C)$ as coordinates. This "δ space" is comparable to the n-dimensional space that contains what ecologists refer to as the niche, because an animal's chemical composition is directly influenced by what it consumes as well as the habitat in which it lives (Newsome et al., 2007). The nitrogen isotope (δ^{15} N) is a powerful tool for estimating the trophic positions of organisms because it exhibits a gradual enrichment from one trophic level to another (DeNiro & Epstein, 1981; Vanderclift & Ponsard, 2003). In contrast, the carbon isotope varies little between trophic levels but exhibits substantial variation among primary producers that use different photosynthetic pathways (C3, C4, and CAM) and carbon substrates such as CO₂ and HCO₃⁻. Therefore, carbon isotopes have been widely used as a tool for identifying carbon sources used in the diets of aquatic consumers (Araújo-Lima et al., 1986; Benedito-Cecílio et al., 2000; Ferreira et al., 2012).

The isotopic composition varies systematically between biotic and abiotic components in an ecosystem (e.g., metabolic pathway, isotopic fractionation), and such variations are reflected in the resources and dynamics of energy and nutrient transfer through food webs (Fry, 2006). The isotopic signature of consumers is closely related to temporal and spatial variation in the isotopic signatures of food resources, especially basal resources with high turnover rates (Post, 2002), which may affect the positions occupied by consumers within the niche space. In aquatic environments, the isotopic signatures of consumers can vary due to changes in riparian zones, mainly because these areas can provide much of the carbon used by aquatic communities and function as a filter that prevents the excessive input of nutrients (from manure and fertilizers used on crops) into water bodies (Gregory et al., 1991; Pusey & Arthington, 2003; Meynendonckx et al., 2006; Salemi et al., 2012). These variations in vegetation cover can influence the dynamics and structure of aquatic communities, thus altering the isotopic composition of resources and consumers. Therefore, the use of isotopes of $\delta^{13}C$ and $\delta^{15}N$ becomes an auxiliary tool in the study of anthropogenic impacts on aquatic environments.

Understanding the factors that can shape the structure of food webs has been the goal of many recent studies (Layman et al., 2007; Schmidt et al., 2007; Lujan et al., 2011; Layman et al., 2012; Perkins et al., 2014). For this purpose, new approaches using dual isotope data have been suggested, including the use of metrics that provides quantitative information from stable isotope datasets, describing trophic structure at the species or community level (Layman et al., 2007). However, the metrics initially proposed by Layman et al. (2007) are subject to criticism mainly because (i) those metrics are sensitive to the sample size and may not be comparable between studies and different sites; (ii) the metrics, when applied to an assemblage, do not incorporate any natural variability within the system and, thus, (iii) provide only a point estimate of each metric (Jackson et al., 2011). Recently, Jackson et al. (2011) proposed a new method based on Bayesian inference techniques for propagating sampling error on the estimates of the means of community members to provide measures of uncertainty surrounding the metrics proposed by Layman et al. (2007), which allows for robust statistical comparisons to be made among communities. Although this methodology was developed a few years ago, it is possible to observe an increase in the number of studies applying Bayesian analysis to evaluate aspects of trophic structure (e.g., Abrantes et al., 2014; Pasotti et al., 2015; Castro et al., 2016).

Considering the effects of anthropogenic activities on aquatic ecosystems, this study used carbon and nitrogen stable isotopes to assess how distinct land uses in the vicinity of streams in the Brazilian Cerrado alter aspects of the trophic structure of the fish community. Bayesian stable isotope-based community-wide models were used to describe and compare the trophic structure of fish communities of streams located in areas surrounded by natural vegetation, sugarcane plantation, and pasture. In addition, we aimed to answer the following questions: Do the streams physical habitat characteristics vary among land uses? Is the fish community able to use the full range of resources available? Does the proportion of each feeding guilds differ among land uses? Protocols of physical habitat assessment and scientific literature were used to access the information about streams physical habitat characteristics and fish feeding guilds, respectively.

Materials and methods

Study area

The study was conducted in tributary streams of the São Simão reservoir, located in the Paranaíba River, southeastern Brazil. The Paranaíba River Basin is the second largest drainage unit of the Paraná Basin, accounting for 25.4% of its area, which corresponds to a 222.8 Km² drainage area covering parts of the states of Goiás (65%), Minas Gerais (30%), Federal District (3%), and Mato Grosso do Sul (2%). The hydrological regime of the rivers in this basin is governed by the rainy season, which is well defined in this part of Brazil. The rainy season occurs between October and March, and rains are rare in the remaining months of the year (CBH—Paranaíba, 2012).

Nine second- and third-order streams located in the states of Minas Gerais and Goiás were selected from 110 candidate streams sorted following the methodology proposed by Olsen & Peck (2008), wherein the streams were defined by a spatially balanced and ranked selection algorithm. The nine streams were selected according to the different types of land use in which they were located: three located in pastures, three in sugarcane cultivation areas, and three selected as references (natural cover category) for having representative riparian vegetation and good water quality (Brazilian Water Quality Resolution, CONAMA 357/2005, Brazilian National Environmental Council). The habitat evaluations concurrent with biological sampling increase the sampling efficiency. Generally, the most advantageous time for biological sampling in regional scale monitoring programs was identified as a low flow season, and not closely following a major flood event (Kaufmann et al., 1999). Therefore, each stream was sampled once during the dry season in September 2012, when physical habitat data were collected and the available resources and the aquatic community were sampled (Fig. 1, Table 1).

Methodology

The land use surrounding the sampled streams was evaluated according to the oriented mapping method described in Lima et al. (2010), in eight multi-spectral RapidEye images of September and October of 2011, with five spectral bands. The percentage cover of natural vegetation, pasture, and sugar cane plantation was determined for the nine streams accordingly (Table 1), in a 150 m radius buffer, around the upstream limit of the sampled stretch. Orthorectified and atmospherically corrected images were obtained through a partnership between the Federal University of Lavras (UFLA) and The Ministry of Environment (MMA). Acquisition errors, clouds, and shadows were removed in the pre-processing phase (Coppin et al., 2004), which also included visual evaluation of image registration. To validate the classification results, an array of errors, measuring the global and kappa accuracy was generated (Shanmugam et al., 2006). Primary field data collected in September 2012 were used to verify the accuracy of mapping. The mapping resulted in a high kappa and global accuracy with values from 96 to 98%, respectively.

A methodology based on the procedures used by the U.S. Environmental Protection Agency (US-EPA) and in protocols for evaluating physical habitats created by



Fig. 1 Location of the nine tributary streams of the São Simão reservoir where sampling was performed in September 2012

its Environmental Monitoring & Assessment Program (EMAP) was used to assess the physical structure of streams in the three land-use categories. The length of the stretch sampled in each stream was proportional to its width, defined as 40 times the mean width of the stream and subject to a minimum of 150 m of sampling. Each sampling stretch was divided into 11 equidistant transects (10 sections) (Kaufmann et al., 1999; Peck et al., 2006).

The following physical habitat variables were assessed in this study: the percentage of fine substrate, canopy cover over the stream (shading), fast water flow and presence of algae, macrophytes, and CPOM (coarse particulate organic matter). These variables were selected because they reliably show the impacts of different land uses on the physical habitat of streams, especially in terms of resource availability. The instream physical habitat was measured as described in Peck et al. (2006) and the metrics were calculated (condensed values from the observations) for each stream from the data obtained by completing the protocol for assessing the physical habitat (see more in Kaufmann et al., 1999). The metrics were calculated for each transect and/or cross-section in streams, and the final value was converted to a percentage (see more details in Kaufmann et al., 1999). The substrate was visually categorized according to the granulometry and was considered as fine substrate where the sediment was smaller than 2 mm (sand, silt, clay and mud). The canopy cover over the stream was estimated through a densiometer, which consists of a convex spherical mirror (Lemmon, 1957). Six measurements were taken: four positioned in the center of the channel (upstream, downstream, right, and left) and a measurement on each margin of the stream (right and left). The measurement of fast flow was done along cross-sections and was considered as the sum of observations of falls, cascades, rapids, and

Table 1 Physical characteristics and land use (%) surrounding the nine tributary streams of the São Simão reservoir sampled inSeptember 2012

Streams	Geographic coordinates	Character	ristics of	streams		Land use			
		Alt. (m)	Order	Mean depth (m)	Mean width (m)	Natural cover (%)	Pasture (%)	Cane (%)	Others (%)
Natural cover 1	18°47′19.49″S 50°39′40.86″W	482	2 ^a	0.20	3.42	53.14	0	46.86	0
Natural cover 2	18°30′56.82″S 50°31′51.62″W	434	3 ^a	0.19	7.29	39.13	57.87	0	3.00
Natural cover 3	18°24′20.08″S 50°39′49.89″W	509	3 ^a	0.19	7.35	50.86	49.14	0	0
Sugarcane 1	18°22′51.60″S 50°39′42.74″W	516	2 ^a	0.23	3.98	14.05	36.56	45.81	3.59
Sugarcane 2	18°36′28.65″S 49°35′09.14″W	441	3 ^a	0.19	1.85	14.63	0	85.37	0
Sugarcane 3	18°40′41.51″S 49°36′46.50″W	463	2 ^a	0.27	1.27	0	43.39	56.61	0
Pasture 1	19°03′03.40″S 50°20′06.81″W	425	3 ^a	0.64	3.49	8.57	62.35	0	29.08
Pasture 2	19°01′38.55″S 49°54′32.40″W	461	3 ^a	0.13	2.00	0	97.69	0	2.31
Pasture 3	18°42′59.17″S 50°46′52.77″W	479	2^{a}	0.17	4.80	16.41	65.35	0	18.24

riffles. The percentage of algae, macrophytes, and CPOM was visually estimated by observing how much of the water surface was covered in each section. The physical and chemical characteristics of the water were also measured in the field for each site, and included temperature, turbidity, pH, and dissolved oxygen (OD).

Fish were collected in a downstream to upstream direction with sieves made from mosquito net (80 cm in diameter, 1-mm mesh) and seine net (3-m long, 5-mm mesh). Each stream was divided into 10 sections for ichthyofauna collection, with a sampling time of 12 min per section, totaling 2 h of sampling per stream. The collected samples were frozen for later analysis of the isotopic composition. In the laboratory, the organisms collected were taxonomically identified using identification keys for fishes of the Paraná Basin. Larger specimens had part of the muscle removed for isotopic analysis, and smaller fish were analyzed whole with only the digestive tract removed. Then, fish samples were lyophilized for 24 h and ground to a fine homogeneous powder using a mortar and pestle. The feeding habits of fish species were determined using the existing scientific literature and classified into the following guilds: invertivorous (include insectivorous species), herbivorous, algivorous (include periphytivorous species), detritivorous (include iliophagous species), piscivorous, and omnivorous.

Samples of benthic macroinvertebrates and basal resources were collected. Basal resources consisted of periphyton, filamentous algae, macrophytes, suspended matter, coarse (CPOM), fine particulate organic matter (FPOM), and riparian producers (vegetation of riparian forest, grasses, sugarcane, bamboo, and leaf litter). Five samples of each resource were collected per stream.

The periphyton and suspended matter were processed similarly. Periphyton was sampled by scraping and washing rocks with distilled water and then storing collected materials in a plastic bottle. The suspended matter was collected with a phytoplankton net (0.045-mm mesh) fixed for 1 min at a point upstream of each sampled stretch. After collection, samples were immediately frozen to preserve the material. In the laboratory, samples were filtered using a filtration apparatus coupled to a vacuum pump and previously calcined 45-micron Millipore glass fiber filters. The filamentous algae samples were manually collected, stored in plastic bottles and immediately frozen. Samples of fine particulate organic matter (FPOM) were collected from sediment in the stream beds and then stored in plastic bottles and immediately frozen. Samples of vegetation, leaf litter, and CPOM were collected at different points in the streams, packed in paper bags, and kept in plant presses until processing in the laboratory. Benthic macroinvertebrates were qualitative collected using Kicking nets (0.5-mm mesh size) along the streams.

In the laboratory, all of the samples were kept in a 60°C oven for 48 h, then immediately ground to a fine homogeneous powder using a mortar and pestle and stored in Eppendorf tubes. Approximately 2–5 mg of dry animal tissue was selected for isotopic analysis, while approximately 5–10 mg was required for the

plant samples. After completing the material preparation, samples were sent for isotopic analysis at the Laboratory of Isotope Ecology, which is linked to the Center for Nuclear Energy in Agriculture (Centro de Energia Nuclear na Agricultura-CENA) at the University of São Paulo (Universidade de São Paulo-USP), Piracicaba. All samples were analyzed for the isotope ratios $({}^{13}C/{}^{12}C$ and ${}^{15}N/{}^{14}N)$ of the total carbon and nitrogen content. Mass spectrometry (Continuous-flow-Isotope Ratio Mass Spectrometry-CF-IRMS) with a Carlo Erba elemental analyzer (CHN 1110) coupled to a Delta Plus mass spectrometer from Thermo Scientific was used to determine the isotope ratios. Results were expressed as relative difference of international reference standards, in the delta notation (δ %), and calculated using the following formula:

$$\delta \mathrm{X} = \left[\left(R_{\mathrm{sample}} / R_{\mathrm{standard}} \right) \, - 1
ight] \, imes \, 10^3$$

where X is ¹³C or ¹⁵N, and R is the isotope ratio ${}^{13}C/{}^{12}C$ or ${}^{15}N/{}^{14}N$ (Barrie & Prosser, 1996).

To verify whether the fish community was able to use the full range of benthic macroinvertebrates and basal resources available, comparisons were made based on the plots generated from the carbon and nitrogen isotopic signature ranges and the fish resources in each category of land use. A fractionation correction was applied in the isotopic signature range (carbon and nitrogen) of macroinvertebrates and fishes to better visualize and interpret which sources were assimilated by the consumers. A fractionation of 0.4‰ for ¹³C and 3.4‰ for ¹⁵N (Post, 2002) was applied to macroinvertebrates, placing this group in a second trophic level. However, it is not feasible to apply the same fractionation correction for the total range of isotopic signatures of fishes, because the fish have different trophic ecologies, including primary consumers and piscivores. In this study, most species have a tendency for detritivory (second trophic levelcorrection of 0.4‰ for ¹³C and 3.4‰ for ¹⁵N) and omnivory and invertivory (third trophic level-correction of 0.8% for 13 C and 6.8% for 15 N), with few piscivores species. Therefore, we assume an intermediate correction of 0.6% for ¹³C and 5.1% for ¹⁵N to the range of isotopic signatures of fishes.

Five metrics originally proposed by Layman et al. (2007) and reformulated in a Bayesian framework by Jackson et al. (2011) were calculated, enabling a

comparison of the structure and trophic ecology of each land use through the use of the Stable Isotope Bayesian Ellipses package in R (SIBER, Jackson et al., 2011). The δ^{15} N range (NR) provides a vertical representation of the structure of a food web. This value indicates the distance between the most and least enriched values of $\delta^{15}N$ for both resources and for consumers. Generally, a greater $\delta^{15}N$ range suggests the presence of more trophic levels in a community. The δ^{13} C range (CR) represents the horizontal variation and indicates the variety of resources used by the community. An increase in the $\delta^{13}C$ is expected in food webs in which there is a wide variety of resources with different $\delta^{13}C$ signatures and/or if there is an increase in amplitude of the δ^{13} C signatures of the resources. The mean distance to centroid (CD) provides a measure of the average degree of trophic diversity within a trophic web and is calculated from the Euclidean distance of each species to the centroid. The mean nearest neighbor distance (NND) represents the mean of the euclidean distances to the nearest neighbor for each species in the bi-plot space and it is a measure of the total density of the community. Food webs with a large proportion of species with similar trophic ecologies will have a smaller NND (greater trophic redundancy) than webs in which the species are, on average, more divergent in relation to their trophic niche. The standard deviation of the nearest neighbor distance (SDNND) provides a measure of evenness of spatial density and packing of species in the bi-plot space that is less influenced than the NND by the sample size. Low SDNND values suggest a more uniform distribution of trophic niches.

The isotopic niches of fish communities were quantified based on standard ellipse areas (SEA, SEA_c, and SEA_b—expressed in $\%^2$) through use of the Stable Isotope Bayesian Ellipses package in R (SIBER, Jackson et al., 2011). The standard ellipse area (SEA) represents the core isotopic niche space and is a proxy of the richness and evenness of resources consumed by the population (Bearhop et al., 2004). A small sample size correction (indicated by the subscript letter "c") was applied to SEA to increase the accuracy of the comparisons, enabling the comparison of niches of Communities with different sample sizes. The Bayesian estimates of SEA_b (bootstrapped n = 10,000—indicated by the letter "b") were generated to test for significant differences

between fish communities isotopic niche widths by comparing their confidence intervals (Jackson et al., 2011). The metrics SEA, SEA_c, and SEA_b were calculated for both the nine streams and for the three categories of land use (combining the three streams in each category). Lastly, the relationship between each land use (and their interaction) and isotopic niche area (SEA_c) was tested using factorial regression. For this analysis, the percentage of each land use and the values of SEA_c generated for each of the nine streams were considered.

Results

Differences in the percentage of each environmental variable were observed among the three land-use categories (Table 2). The percentage of fine substrates was higher in streams influenced by pasture and lower in streams with natural cover. Canopy cover over the stream (shading) was higher in streams with natural cover and those with influence of sugarcane. In contrast, the streams with influence of pasture had less than 40% shading of the channel. The percentage of fast flow did not show much variation among the categories. Only streams with influence of pasture showed higher percentages (>10%) of aquatic plants and filamentous algae channel coverage. In contrast, the percentage of CPOM was higher in natural cover and sugarcane streams and almost absent in pasture streams.

A total of 838 samples were isotopically analyzed, including 341 fish samples and 497 samples of food resources (basal resources and benthic macroinvertebrates). Thirty-eight fish species were identified, 26 were found in streams influenced by pasture, 20 species were found in natural cover streams and 19 species were found in streams influenced by sugarcane. Some of these species have previously been classified in more than one trophic guild (Table 3). Most of the species presented a tendency for invertivory, and 17 of which were found in pastures, and ten in natural cover and sugarcane streams, respectively. Species with a tendency for omnivory were more abundant in pastures (9 species), followed by natural cover streams (7 species), and sugarcane streams (6 species). The same pattern was observed for species with a tendency for herbivory, with six species in pasture streams, four in natural cover streams, and only two in sugarcane streams. The number of species with a tendency for piscivory was low in all land-use categories, with three species sampled in natural cover streams and two species in streams considered in the sugarcane and pasture land-use categories. The number of detritivorous or algivorous fish species was the same in all streams (7 and 5 species, respectively) (Table 3).

The δ^{15} N and δ^{13} C ranges for the basal resources, macroinvertebrates, and fishes were visually different among the three categories of land use (Fig. 2). After the fractionation correction, it was possible to observe that in all three categories of land use, the range of δ^{15} N of fishes matched with the range of δ^{15} N of basal resources and macroinvertebrates (Fig. 2a). The basal resources of streams with natural cover showed a higher range of δ^{15} N (-2.15 to 11.53‰); nevertheless, it was possible to observe that fish had a higher assimilation of sources with more depleted isotopic signatures of $\delta^{15}N$ (between 1.46 and 6.37‰). In pastures and sugarcane streams, the range of $\delta^{15}N$ assimilated by fishes was more enriched (between 2.14 and 8.02‰ and 2.99 and 9.30‰, respectively). In streams influenced by pastures, the nitrogen assimilated by fishes was probably coming directly from more enriched δ^{15} N basal resources (Fig. 2a).

Greater δ^{13} C ranges for basal resources and benthic macroinvertebrates were observed in the streams influenced by pasture, followed by sugarcane and natural cover streams, respectively (Fig. 2b). The range of fish carbon signatures was also higher in stream influenced by pastures (-18.36 to -42.21%), followed by natural cover streams (-19.09 to)-35.22%) and sugarcane streams (-20.90 to -29.84%). The δ^{13} C range of fishes of natural cover streams did not completely match with the δ^{13} C range of basal resources and benthic macroinvertebrates, displaying more enriched values than those observed in the available resources (Fig. 2b; Table 4). In contrast, for streams influenced by pasture, the range of δ^{13} C values found in fish followed the isotopic values for basal resources and benthic macroinvertebrates. For sugarcane streams, the δ^{13} C ranges of fishes also matched with the $\delta^{13}C$ ranges of basal resources and benthic macroinvertebrates; however, the fish community exhibited isotopic values representing only a small subset of the δ^{13} C range of these sources (Fig. 2b).

Basal resources with enriched values of ${}^{13}C$ (above approximately -18%) were not reflected in fish

Category	Physical h	abitat variabl	es				Water q	uality		
	Fine substrate (%)	Canopy cover (%)	Rapid flow (%)	Aquatic plant (%)	CPOM (%)	Algae (%)	T (°C)	pН	Turbidity (UNT)	Dissolved oxygen (mg/L)
Natural cover 1	< 0.01	0.94	0.69	<0.01	0.17	< 0.01	24.5	6.6	2.5	8.3
Natural cover 2	< 0.01	0.47	0.46	< 0.01	0.14	< 0.01	22.6	6.6	3.2	7.3
Natural cover 3	< 0.01	0.90	0.51	< 0.01	0.18	< 0.01	20.0	7.0	4.0	11.1
Sugarcane 1	0.01	0.73	0.38	< 0.01	0.11	< 0.01	18.5	6.8	6.1	7.5
Sugarcane 2	< 0.00	0.99	0.17	0.04	0.16	< 0.01	20.0	7.0	14.2	6.8
Sugarcane 3	0.03	1.00	0.67	0.02	0.07	< 0.01	20.0	7.5	4.5	7.0
Pasture 1	0.30	0.33	0.43	0.66	0.02	0.22	19.0	6.5	4.1	7.6
Pasture 2	0.21	0.01	0.45	0.05	< 0.01	0.14	25.0	7.7	15.4	8.2
Pasture 3	0.02	0.38	0.15	0.02	0.02	< 0.01	18.0	6.6	5.3	8.5

Table 2 Physical habitat variables (%) and variables of water quality for the nine tributary streams of the São Simão reservoir sampled in September 2012

isotopic signatures either in the streams influenced by pastures or in the streams influenced by sugarcane (Fig. 2b). Resources with δ^{13} C higher than -18% are represented mainly by C₄ grass ($-17.6\% \pm 4.5$) and sugarcane vegetation ($-13.1\% \pm 0.3$) present in those categories of land use, respectively (Table 4). The fish species with more enriched values of ¹³C (above -23%) were represented in natural cover streams by *Astyanax altiparanae*, *Astyanax fasciatus*, and *Cetopsis gobioides*, in pasture streams by *Astyanax altiparanae*, *Astyanax fasciatus*, Piabina argentea, Rivulus apiamici, and Tatia neivai, and in sugarcane streams by *Astyanax altiparanae*, *Astyanax fasciatus*, and *Hypostomus* sp.4 (Fig. 3).

The isotopic signature of basal resources with depleted carbon signature (below approximately -30%) was not propagated to the fish community in streams influenced by sugarcane, but was assimilated by the fish communities in the other streams (Fig. 2b). On the other hand, basal resources with carbon signatures below -35% were not assimilated by the fish communities of natural cover streams (Fig. 2b), but they were assimilated by Hypostomus ancistroides in pasture streams (Fig. 3f). In streams influenced by sugarcane, depleted carbon signature was mainly represented by the following basal resources: algae $(-30.1\% \pm 2.8)$, bamboo $(-31.6\% \pm 0.7)$, CPOM $(-30.1\% \pm 0.6)$, and riparian forest $(-30.6\% \pm$ 1.8). In natural cover streams, it is mainly represented by the signature of riparian forests $(-33.2\% \pm 2.3)$ and filamentous algae $(-30.0\% \pm 5.4)$, and in streams located in pastures, the lower limit contained mainly filamentous algae $(-32.8\% \pm 5.8)$ (Table 4).

The trophic niche metrics for fish communities varied among land uses (Table 5). Pasture streams exhibited a higher number of total fish species, greater trophic diversity (CD_b), and lower trophic redundancy (NND_b). The pasture streams fish community also had greater ranges of carbon sources exploited (CR_b), but showed smaller ranges of nitrogen (NR_b). In contrast, sugar cane streams had greater ranges of nitrogen (NR_b) and showed the smallest range of exploited carbon sources (CR_b). The sugarcane fish community also showed the smallest centroid distance values (CD_b), mean nearest neighbor distance (NND_b), and standard deviation of mean nearest neighbor distance (SDNNDb), which indicates smaller trophic diversity, higher trophic redundancy, and higher community uniformity, respectively. Natural Cover streams in showed smaller community uniformity turn, (SDNNDb) and intermediate values (between pasture and sugarcane) for all remaining Layman metrics.

The standard ellipses (SEA) based on the isotope ratio of fish communities visually differed in size, shape and position in the δ^{13} C vs δ^{15} N bi-plot space (Fig. 3). The communities with the lowest SEA_b values (consequently smaller isotopic niche) occurred in the streams with sugarcane influence, followed by natural cover and pasture streams, which exhibited the highest SEA_b values (Table 6). Sugarcane, when

1 able 3 Species identified in the nine streams of Sao	Simao, their	respective num	Der of ind	IIVIdual	s for each type of land use and their ree	aing guilds	
Species	Natural cover	Sugarcane	Pasture	Total	Feeding guilds	Number in figures	Reference***
Characiformes:							
Anostomidae							
Leporinus friderici (Bloch, 1794)			1	1	Omnivorous/herbivorous/piscivorous	27	14, 16, 19, 20
Leporinus piavussu Britski, Birindelli, & Garavello, 2012	1			-	Omnivorous/herbivorous/ piscivorous**	28	14, 16, 19, 20
Characidae							
Aphyocharax dentatus Eigenmann & Kennedy, 1903			5	Ś	Invertivorous/piscivorous/ omnivorous	7	15, 16
Astyanax sp.			6	7	Invertivorous/herbivorous/ omnivorous**	9	1, 2, 3, 4, 11, 12
Astyanax altiparanae Garutti & Britski, 2000	6	3	6	21	Invertivorous/herbivorous/ omnivorous	4	3, 11, 12
Astyanax fasciatus (Cuvier, 1819)	9	1	1	8	Invertivorous/herbivorous/ omnivorous	5	1, 2, 4
Hasemania sp.			б	б	Invertivorous/herbívorous**	13	7, 13
Knodus moenkhausii (Eigenmann & Kennedy, 1903)*	18	15	17	50	Omnivorous	25	5
Moenkhausia sanctaefilomenae (Steindachner, 1907)			Э	Э	Invertivorous	29	3, 16
Piabina argentea Reinhardt, 1867	7	1	4	12	Invertivorous/omnivorous	31	6, 14
Serrapinnus sp.1	10		5	15	Algivorous/herbivorous/ invertivorous**	36	4, 16
Crenuchidae							
Characidium zebra Eigenmann, 1909	10	7	10	27	Invertivorous	9	2, 3, 10, 16
Curimatidae							
Cyphocharax gilli (Eigenmann & Kennedy, 1903)*			4	4	Detritivorous (iliophagous)**	11	20, 21, 22
Steindachnerina insculpta (Fernández-Yépez, 1948)	1			1	Detritivorous	37	14
Parodontidae							
Apareiodon ibitiensis Amaral Campos, 1944	L	4	7	13	Detritivorous/omnivorous	1	6, 14
Cyprinouonurionies. Poeciliidae							
Poecilia reticulata Peters, 1859*		5		5	Detritivorous	33	2
Rivulidae							
Rivulus apiamici Costa, 1989			5	5	Invertivorous	35	16

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Table 3 continued							
Species	Natural cover	Sugarcane	Pasture	Total	Feeding guilds	Number in figures	Reference***
Gymnotiformes:							
Sternopygidae							
Eigenmannia trilineata López & Castello, 1966			б	3	Invertivorous	12	16
Perciformes:							
Cichlidae							
Cichlasoma paranaense Kullander, 1983	2	1		С	Piscivorous	10	14
Laetacara araguaiae Ottoni & Costa, 2009			5	5	Invertivorous/omnivorous	26	17
Siluriformes:							
Auchenipteridae							
Tatia neivai (Ihering, 1930)			1	1	Invertivorous	38	8, 14
Callichthyidae							
Aspidoras fuscoguttatus Nijssen & Isbrücker, 1976	8	10	11	29	Invertivorous	Э	6
Cetopsidae							
Cetopsis gobioides Kner, 1858	1			1	Invertivorous	7	6, 16
Heptapteridae							
Cetopsorhamdia iheringi Schubart & Gomes, 1959		1	1	7	Invertivorous	8	2, 14
Imparfinis longicauda (Boulenger, 1887)	2		ю	5	Invertivorous**	23	2, 8
Imparfinis schubarti (Gomes, 1956)	4	4	L	15	Invertivorous	24	2
Phenacorhamdia cf. unifasciata		4		4	Invertivorous**	30	8
Pimelodella gracilis (Valenciennes, 1835)		5		5	Invertivorous	32	8, 16, 20
Rhamdia quelen (Quoy & Gaimard, 1824)	2	7		6	Invertivorous/piscivorous/	34	2, 3, 6, 8, 14
achinerino 1					omnivorous		
Hisomotus niracaniuba Martins & Langeani. 2012	Ś	ŝ	L	17	Algivorous/detritivorous**	14	2.3
Hypostomus ancistroides (Ihering, 1911)		1	1	0	Algivorous/detritivorous	15	2, 3, 16
Hypostomus cf. paulinus	б			ю	Algivorous/detritivorous**	16	2, 3, 16, 18
Hypostomus cf. topavae	5	4	2	11	Algivorous/detritivorous**	17	2, 3, 16, 18
Hypostomus sp.1			10	10	Algivorous/detritivorous**	18	2, 3, 16, 18
Hypostomus sp.2	16			16	Algivorous/detritivorous**	19	2, 3, 16, 18
Hypostomus sp.3	1		5	9	Algivorous/detritivorous**	20	2, 3, 16, 18
Hypostomus sp.4		16		1	Algivorous/detritivorous**	21	2, 3, 16, 18
Hypostomus strigaticeps (Regan, 1908)		2		7	Algivorous/detritivorous	22	16, 18

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òpecies	Natural cover	Sugarcane	Pasture	Total	Feeding guilds	Number in figures	Reference***
Total richness Total number of individuals	20 118	19 96	26 127	38 341			
² eeding guilds information drawn from studies using a pecies)	analyses of stu	mach contents	. In some	cases v	were considered the information known	to the genus (few	details about the
* Introduced species (according to Langeani et al., 20)07a)						
** Species with few data available in the literature (b:	based on co-ge	neric species)					
*** Reference number: ¹ Esteves (1996), ² Silva et al. Langeani et al. (2007b), ⁸ Casatti et al. (2001); ⁹ Casatti ⁴ Luz-Agostinho et al. (2006), ¹⁵ Duarte et al. (2013), ¹⁰ 1998); ²¹ Corrêa & Piedras (2008); and ²² Höfling et al.	(2012), ³ Cas ti et al. (2009b ¹⁶ Bulla et al. (2 al. (2000)	atti (2002), ⁴ P), ¹⁰ Cetra et al. 011), ¹⁷ Souza	ompeu & (2011), ¹ Filho & C	Godin ¹ Cassen Jasatti (J	ho (2006), ⁵ Ceneviva-Bastos & Casatti niro et al. (2002), ¹² Bennemann et al. (2 2010), ¹⁸ Cardone et al. (2006), ¹⁹ Balass:	i (2007), ⁶ Rondine 011), ¹³ Bertaco & a et al. (2004), ²⁰ H	lli et al. (2011), Carvalho (2010), ahn & Agostinho

Table 3 continued

tested as a pairwise interaction with natural vegetation, was the only significant land-use factor related to the SEA_c (F = 7.37; P = 0.042; $R^2 = 0.37$) metric. The presence of this type of land use was related to a smaller isotopic niche of fish communities.

Discussion

Changes in land use influenced both the physical characteristics of the streams and the trophic structure of the fish communities. The types of resources available to the aquatic community were also different among the categories of land use, as reflected in the carbon and nitrogen isotopic signature ranges of basal resources, benthic macroinvertebrates, and fishes. It was also possible to note that the presence of pasture positively influenced the trophic diversity, while sugarcane plantations had a negative effect on fish communities.

There is a strong relationship between land use and the structure of the physical habitat of streams (Gregory et al., 1991; Pusey & Arthington, 2003). The presence of riparian vegetation in streams favors the stability of the banks and controls the microclimate and sediment transport, in addition to being an important source of resources and providing shelter for aquatic communities (Naiman & Décamps, 1997; Pusey & Arthington, 2003; King & Warbuton, 2007). For example, the presence of fine sediments was greater in streams influenced by pasture, which stresses the importance of riparian vegetation in promoting the stability of banks and diversity of substrates (which influence the complexity of habitats available to the aquatic community), as reported in other studies (Beltrão et al., 2009; Casatti et al., 2009a). Riparian vegetation in streams influenced by pasture was rather limited and directly influenced other variables, such as the presence of macrophytes and filamentous algae, which are abundant in these streams and are virtually absent in more shaded ones (natural cover and sugarcane plantation streams). The same occurred in streams with greater vegetation cover, where there was a greater presence of coarse particulate organic matter (CPOM). Such replacement of allochthonous energy sources by autochthonous ones available in the different land-use categories may be one of the key factors capable of altering the structure of the communities due to the replacement of



Fig. 2 Isotopic signature range for **a** δ^{15} N (‰) and **b** δ^{13} C (‰) of basal resources, benthic macroinvertebrates, and fishes for each category of land use. *Dashed lines* were used to compare the range of isotopic signatures of fish with the range of isotopic signatures of basal resources and benthic macroinvertebrates. A correction fractionation of 0.4‰ for ¹³C and 3.4‰ for ¹⁵N (Post, 2002) was applied to macroinvertebrates, and a correction fractionation of 0.6‰ for ¹³C and 5.1‰ for ¹⁵N was applied to fishes

species (Ferreira & Casatti, 2006). Presently, information on the influence of different land uses on the trophic composition of tropical fish assemblages is scarce, but some of the trends observed in this study have been reported previously (Esteves et al., 2008; Zeni & Casatti, 2014).

In this present study, the range of $\delta^{15}N$ of basal resources was similar among the land-use categories and matched the range of $\delta^{15}N$ of macroinvertebrates and fishes. However, the fish community of streams under anthropogenic influence exhibited enriched ranges of $\delta^{15}N$ when compared with natural streams. Despite the range of $\delta^{15}N$ of basal resources being slightly larger in natural cover streams, all resources

were more enriched in both stream groups under anthropogenic influence, especially those with sugarcane plantations. These changes may have occurred due to the greater influence of chemical and organic fertilizers in these streams. It is known that management practices and the chemical and organic fertilizers applied in these land-use categories can modify the δ^{15} N in the soil available to plants, in the form of nitrate (NO_3^-) , nitrite (NO_2^-) , or ammonium ions (NH_4^+) . Fertilizer waste products may occasionally be carried to waterways. Therefore, a possible nutrient enrichment in streams under the influence of sugar cane cultivations and pastures may be the explanation for the higher nitrogen values observed in the resources and consumer as highlighted in De Carvalho et al. (2015).

Greater δ^{13} C ranges for basal resources and benthic macroinvertebrates were observed in the streams influenced by pasture. The fish community seems to be able to use most of these sources, since the $\delta^{13}C$ ranges of fishes also match with the δ^{13} C ranges of available resources. This is reflected in the space occupied by the communities in the bi-plot space, where it was possible to observe a larger distribution of species along the x axes. The isotopic signatures of the species A. ibitiensis, A. fuscoguttatus, C. iheringi, C. gillii, E. trilineata, H. piracanjuba, H. ancistroides, K. moenkhausii, and L. araguaiae suggest the importance of autochthonous resources in the diet of stream fishes of pasture streams. These species had depleted isotopic values (between -27 and -41%), values which in turn coincide with that exhibited by filamentous algae $(-32.8\% \pm 5.8)$ and macrophytes $(-31.5\% \pm 3.8)$ in this category of land use. This finding is supported by several studies that documented the importance of these basal resources in the fish diet (Benedito-Cecílio et al., 2000; Brito et al., 2006; Hoeinghaus et al., 2007). Factors that influence the productivity and composition of stream microalgae could have a significant impact on stream food webs (Bunn et al., 1999). Therefore, the greater luminosity in streams influenced by pastures can explain differences in trophic structure of the aquatic communities of these streams, through the increase of productivity and richness of resources offered.

On the other hand, in streams influenced by sugarcane, a large part of the resources available was not used by the ichthyofauna. This was also reflected in the space occupied by the communities in the bi-

Resources	δ ¹³ C (‰)			δ ¹⁵ N (‰)			
	Natural cover	Sugarcane	Pasture	Natural cover	Sugarcane	Pasture	
Algae	-30.0 ± 5.4	-30.1 ± 2.8	-32.8 ± 5.8	6.2 ± 2.4	4.5 ± 1.6	6.3 ± 2.0	
СРОМ	-30.1 ± 0.6	-30.1 ± 0.6	-30.2 ± 0.5	0.7 ± 0.6	4.1 ± 2.5	2.2 ± 1.0	
FPOM	-25.5 ± 2.1	-22.3 ± 1.3	-23.8 ± 4.2	4.6 ± 1.8	7.7 ± 0.6	4.6 ± 0.6	
Macroinvertebrates	-27.3 ± 1.6	-25.7 ± 1.7	-28.2 ± 5.4	5.9 ± 1.7	8.0 ± 2.2	7.1 ± 1.5	
Riparian vegetation	-33.2 ± 2.3	-30.6 ± 1.8	-29.8 ± 0.8	1.9 ± 1.9	5.0 ± 1.8	3.1 ± 2.4	
Suspended matter	-27.4 ± 1.1	-26.6 ± 0.9	-24.1 ± 2.9	3.2 ± 0.8	5.4 ± 1.9	3.9 ± 1.1	
Periphyton	-27.2 ± 1.9	-25.8 ± 1.0	-25.9 ± 4.7	4.6 ± 0.9	6.7 ± 1.9	6.2 ± 0.8	
Leaf litter	-30.0 ± 1.0	-29.6 ± 1.5	-29.3 ± 0.9	-0.1 ± 0.9	3.9 ± 3.2	0.6 ± 1.1	
Bamboo	-	-31.6 ± 0.7	-30.3 ± 0.4	-	6.2 ± 0.8	2.8 ± 0.8	
Sugarcane	-	-13.1 ± 0.3	-	-	4.5 ± 0.8	-	
Grasses (pasture)	-	-	-17.6 ± 4.5	-	-	4.8 ± 2.7	
Macrophytes	-	_	-31.5 ± 3.8	_	-	5.6 ± 0.6	

Table 4 Mean and standard deviation of the isotopic signatures of resources sampled in the three land-use categories

plot space, where, in contrast with pasture streams, it was possible to observe a larger verticalization. In these streams, the basal resource with enriched signatures of carbon (sugarcane vegetation) seemed to be assimilated only by Astyanax altiparanae (De Carvalho et al., 2015), and supposedly by Astyanax fasciatus and Hypostomus sp.4. However, shading decreases primary production, resulting in higher fractioning and smaller $\delta^{13}C$ of periphytic algae, closer to or identical to allochthonous material (Ishikawa et al., 2012). Therefore, consumers that assimilate the carbon from small-shaded streams would carry the narrow range of δ^{13} C, but they would not be necessarily trophically narrow. However, this was not the case in the streams under sugarcane influence, since their carbon signatures of periphytic algae and riparian vegetation were similar to those found in streams under pasture influence. Besides that, the fish fauna did not incorporate the isotopic signatures of basal resources with depleted carbon signatures (algae, bamboo, CPOM, and riparian forest). This may have occurred due to the lower abundance of herbivorous and omnivorous species in this category of land use. Furthermore, part of the community may have been locally extinct due, for example, to the greater simplification of the environment (Ometto et al., 2000; Corbi & Trivinho-Strixino, 2008), or the potentially high levels of fertilizer and pesticides used in sugarcane plantations, which are much higher than those used in pastures (Ometto et al., 2000). One factor supporting this hypothesis is the presence of *Poecilia reticulata* only in streams influenced by sugarcane. This exotic species has adaptations that confer great success in colonizing many types of environments, such as a high competitive ability in obtaining resources (since it uses the same resources as native species) and ability to withstand extreme variations in the environment (Souza & Tozzo, 2013). Thus, its presence may be an indication of poor conditions in the streams of this land-use category because this species has been considered an indicator of poor environmental quality by other researchers (e.g., Casatti et al., 2006; Souza & Tozzo, 2013).

In streams surrounded by natural cover, the fish community showed a wider range of δ^{13} C than their potential macroinvertebrate prey and the basal resources. The species with enriched carbon signatures were *Astyanax altiparanae* and *Astyanax fasciatus*, and both present invertivorous/herbivorous/ omnivorous habits. Evaluating the food resources assimilated by the five most abundant species of fish, *Astyanax altiparanae* in the same streams sampled in this study showed the largest variation in diet composition, and consumed especially periphyton in natural cover streams (De Carvalho et al., 2015). Thus, it is possible that *A. altiparanae* and *A. fasciatus* are



Fig. 3 Representation of the trophic structure of fish communities from the nine streams in **a**, **b** natural cover, **c**, **d** sugarcane, **e**, **f** pasture, and **g** considering the three land-use categories together. The *open points* in the figures (letters **a**, **c**, **e**, and **g**) represent the δ^{13} C and δ^{15} N isotopic signatures of each individual in the fish community. The solid points in the figures (letters **b**, **d**, and **f**) represent the mean of δ^{13} C and δ^{15} N isotopic signatures of each species in the fish community. Standard ellipse areas (SEA, *solid lines*), represents the core isotopic niche space of the fish communities and the dashed lines delimit the total area of the fish communities of each stream (**a**, **f**) and each land-use category (**g**). The *numbers* in figures (letters **b**, **d**, and **f**) represent each species of the fish community. Symbols: *Apareiodon ibitiensis* (1); *Aphyocharax dentatus* (2); *Aspidoras fuscoguttatus* (3); *Astyanax altiparanae* (4); *Astyanax*

fasciatus (5); Astyanax sp. (6); Cetopsis gobioides (7); Cetopsorhamdia iheringi (8); Characidium zebra (9); Cichlasoma paranaense (10); Cyphocharax gillii (11); Eigenmannia trilineata (12); Hasemania sp. (13); Hisonotus piracanjuba (14); Hypostomus ancistroides (15); Hypostomus cf. paulinus (16); Hypostomus cf. topavae (17); Hypostomus sp. 1 (18); Hypostomus sp. 2 (19); Hypostomus sp. 3 (20); Hypostomus sp. 4 (21); Hypostomus strigaticeps (22); Imparfinis longicauda (23); Imparfinis schubarti (24); Knodus moenkhausii (25), Laetacara araguaiae (26); Leporinus friderici (27); Leporinus piavussu (28); Moenkhausia sanctaefilomenae (29); Phenacorhamdia cf. unifasciata (30); Piabina argentea (31); Pimelodella gracilis (32); Poecilia reticulata (33); Rhamdia quelen (34); Rivulus apiamici (35); Serrapinnus sp. 1 (36); Steindachnerina insculpta (37); Tatia neivai (38)

Table 5 Layman stable isotope metrics (mean and range) for each land-use category: $NR_b = \delta^{15}N$ range; $CR_b = \delta^{13}C$ range; $CD_b = mean$ distance to centroid; $NND_b = mean$

nearest neighbor distance; and SDNND_b = standard deviation of the nearest neighbor distance, where $_{b}$ = Bayesian implementation of the Layman metrics

6				2	
Category	NR _b	CR _b	CD _b	NND _b	SDNND _b
Natural Cover	2.14 (1.05-3.35)	4.22 (3.30-5.18)	1.99 (1.59–2.35)	2.29 (1.68-2.92)	1.69 (0.97–2.43)
Sugarcane	3.06 (1.77-4.56)	1.45 (0.62-2.78)	1.30 (0.93–1.84)	1.62 (0.90-2.59)	0.57 (0.0001-1.58)
Pasture	0.61 (0.02 - 1.47)	6.61 (5.89-7.46)	2.45 (2.13-2.80)	3.05 (2.61-3.45)	1.05(0.32 - 1.74)

Streams	S	SEA	SEAc	SEA _b
Natural cover 1	4	10.45	10.97	10.99 (6.50–15.84)
Natural cover 2	15	6.46	6.58	6.64 (4.89-8.42)
Natural cover 3	12	4.28	4.39	4.45 (3.13-5.81)
Category "Natural cover"	20	11.80	11.90	11.89 (9.79–14.01)
Sugarcane 1	10	3.74	3.82	3.85 (2.77-4.97)
Sugarcane 2	11	4.68	4.82	4.81 (3.34–6.39)
Sugarcane 3	3	3.64	4.05	4.87 (2.17-7.99)
Category "Sugarcane"	19	8.53	8.62	8.62 (6.92-10.39
Pasture 1	11	15.96	16.42	16.42 (11.22-21.8
Pasture 2	11	9.48	9.70	9.72 (6.93-12.62)
Pasture 3	14	6.45	6.60	6.65 (4.77-8.62)
Category "Pasture"	26	14.47	14.59	14.56 (11.94–17.1

Table 6 SIBER metri each stream and land-u category: S = numberfish species; SEA = standard ellipsarea; SEAc = standardellipse area with correct $SEA_b = Bayesian stan$ ellipse area (mean and credible intervals)

assimilating carbon from sources that were not sampled in this study, such as a periphyton with more enriched values that is not well sampled by scrubbing rocks. From the information of land use in adjacent areas to streams, it is possible to notice that all streams categorized as natural cover are also influenced by sugarcane or pastures (on a smaller scale). Thus, the enriched carbon sources (sugarcane vegetation and grasses) may have drifted into the natural cover streams and were not sampled adequately.

Some studies emphasized the importance of C4 sources in aquatic food webs especially during the wet season (Benedito-Cecílio et al., 2000; Hoeinghaus et al., 2007; Wang et al., 2014). However, C₄ plants are considered of lower food quality than C₃ plants, and many herbivores avoid these types of plant or search for a more nutritious carbon source (Barbehenn et al., 2004a, b). In this study, the isotopic signatures of basal resources with enriched values of ¹³C (represented mainly by C₄ grass and sugarcane) do not match with fish isotopic signatures in either the streams influenced by pastures and sugarcane. However, this may occur because fish species often feed on different carbon sources simultaneously, which results in a mix of isotopic signatures (De Carvalho et al., 2015). Furthermore, the use of C4 sources (sugarcane and grasses) by members of fish communities of pasture and sugarcane streams has already been confirmed in a previous study (De Carvalho et al., 2015).

This difference in resources exploitation in each land use may be the explanation for the difference in trophic diversity observed between these land uses. The trophic structure of fish communities was completely different, and sugarcane plantations seemed to exert more influence on the structure of aquatic communities. In the case of sugarcane, the lower capacity of the species to incorporate the carbon supplied led to a smaller isotopic niche occupied by the community and consequently a smaller trophic diversity, higher trophic redundancy, and uniformity on the trophic niches distribution. Furthermore, sugarcane was the only land use that exerted a negative influence on the isotopic niche of fish communities. Similar results were observed in the macroinvertebrate assemblages of those streams (Castro et al., 2016), which confirm the strong effect of this land-use type on the trophic structure of aquatic communities. In contrast, the range of carbon values used by fish community was much larger in streams influenced by pasture, which was reflected in the larger isotopic niche occupied by the community, higher trophic diversity, and lower trophic redundancy. On the other hand, consumers from streams with natural riparian vegetation displayed less uniformity in trophic niche distribution, which occurs because consumers have more distinct trophic positions (greater distance among consumers in isotopic space) (Layman et al., 2007).

Although there were few significant differences in the species richness among the categories of land use, the composition of the ichthyofauna did change. The streams near sugarcane crops appear to harbor a poorer community with fewer types of consumers despite offering a wide range of carbon sources (greater than those in natural cover streams). The absence of species such as Hypostomus sp. 2, Hypostomus sp. 3, and Steindachnerina insculpta (all detritivorous) in streams influenced by sugarcane (but present in natural cover streams) may be the reason for nonutilization of resources with depleted carbon isotopic signature values (below -30%) in this category of land use. In natural cover streams where these species were present, this same range was reflected in the signatures of the consumers. This result supports the idea that different factors intrinsic to streams near sugarcane plantations may be affecting the fish community and causing changes in the trophic structure of fish communities in such streams.

The findings of the present study demonstrate the relationship between land use and the trophic structure of the fish community, with human activities directly affecting the resources supplied to the aquatic environment. Here, we found that fish communities were strongly negatively affected by sugar cane plantations. Despite the great importance from the point of view of biodiversity, there are at present very few studies on the ichthyofauna in streams that drain areas of the Cerrado. Therefore, we believe that our findings will be of great importance in elucidating the impacts of agricultural and livestock farming activities on fish communities of streams in this biome. However, further studies should be conducted on this topic to understand which factors (such as fertilizers or management practices) may be affecting fish communities in streams located in sugarcane cultivation areas and to assess to what extent this land use may be compromising the structure of aquatic communities. We also recommend further studies to ascertain whether similar results are observed in other hydrological periods, e.g., the wet season, since the findings from this study reflect the trophic dynamics of fish assemblages only during the dry season.

Acknowledgements We thank the National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq), the Coordination for the Improvement of Higher Education Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-CAPES), Minas Gerais Power Company (Companhia Energética de Minas Gerais-CEMIG), and P&D ANEEL/CEMIG GT 487 for the financial support for the project and for the Master's and Doctoral scholarships granted. Thanks to Dra. Ludimilla Portela Zambaldi Lima (UFLA) and Dr. Diego Rodrigues Macedo (UFMG) for the analyses of land use and Federal University of Lavras (UFLA) and The Ministry of Environment (MMA) for granting the RapidEye images. Thanks also to the Benthos Ecology Laboratory (UFMG) and the Laboratory of Fish Ecology (UFLA) for their assistance in the collection and processing of samples, the Center for Nuclear Energy in Agriculture (CENA) for their support and partnership in the isotopic analysis, and Dr. Míriam Pilz Albrecht (UFRJ) and Dr. Lucas Del Bianco Faria (UFLA) for their contributions to the manuscript. MC was awarded a research productivity CNPq (No. 303380/2015-2), research project CNPq (No. 446155/2014-4), and Minas Gerais research grant FAPEMIG PPM-IX - 00525-15. PSP received a research fellowship from the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq No. 306325/2011-0) and the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG No. PPM-00237/13).

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