

Longitudinal habitat disruption in Neotropical streams: fish assemblages under the influence of culverts

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This study assessed differences in fish assemblages existing upstream and downstream two types of culverts, one on each of two different Neotropical streams. We analyzed the composition and structure of the ichthyofauna and tested for spatial patterns. Fish sampling was carried out monthly between November 2009 and October 2010 using different fishing gears. We collected 2,220 fish of 33 species; 901 in stretches of the Lopeí stream - circular culvert and 1,310 in stretches of the Pindorama stream - box culvert. Fish abundance was similar in upstream and downstream stretches of the circular culvert, whereas it was slightly higher in the upstream than downstream stretch for the box culvert. Characiformes predominated in the upstream stretch of both culverts. On the other hand, Siluriformes was abundant in the downstream stretch of the circular culvert, with similar abundance in the stretches of the box culvert. Species richness and diversity (Shannon-Weiner Index) were higher in the downstream stretch of the circular culvert, but they were similar in both stretches of the box culvert. The most abundant species were *Astyanax altiparanae*, *A. paranae*, *A. fasciatus*, *Ancistrus* sp., and *Hypostomus* sp. The last two species were more abundant in the downstream stretch of the circular culvert, and similar in stretches of the box culvert. Our study indicated variations in the species abundance, richness, and diversity between upstream and downstream stretches in particular of the circular culvert in the Lopeí stream, suggesting that fish movements are restrained more intensively in this culvert, especially for Siluriformes. The drop in the circular culvert outlet probably created passage barriers especially for those fish that has no ability to jump, where downstream erosion could lead to culvert perching. Studies on appropriate road crossing design or installation are fundamental whereas improvements in these structures can restore the connectivity of fish populations and communities in streams.

Este estudo avaliou diferenças nas assembleias de peixes existentes a montante e a jusante dois tipos de bueiros, um em cada um de dois diferentes riachos Neotropicais. A composição e a estrutura da ictiofauna foram avaliadas e seus possíveis padrões espaciais. As amostragens para a ictiofauna foram realizadas mensalmente, entre novembro de 2009 e outubro de 2010, com diversos apetrechos de pesca. Durante o período foram coletados 2.220 indivíduos, sendo 901 peixes nos trechos do riacho Lopeí - bueiro circular e 1.310 peixes nos trechos do riacho Pindorama - bueiro quadrado, pertencentes a 33 espécies. As capturas foram similares nos trechos de montante e jusante no bueiro circular, enquanto que para o bueiro quadrado a abundância de peixes foi um pouco superior no trecho a montante em relação à jusante. Os Characiformes predominaram no trecho a montante de ambos os bueiros. Por outro lado, os Siluriformes foram abundantes no trecho a jusante do bueiro circular, com abundâncias similares entre os trechos do bueiro quadrado. A riqueza e a diversidade de espécies diferiram entre os trechos do bueiro circular (maior valor a jusante), enquanto que os valores foram similares para os trechos do bueiro quadrado. As espécies mais abundantes foram *Astyanax altiparanae*, *A. paranae*, *A. fasciatus*, *Ancistrus* sp. e *Hypostomus* sp., porém com diferenças constatadas na ocorrência das duas últimas espécies: estas foram mais abundantes a jusante do bueiro circular, e similares nos trechos do bueiro quadrado. As variações na abundância, riqueza e diversidade constatadas

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entre trechos a montante e a jusante, em particular do bueiro circular no riacho Lopeí, sugerindo que os movimentos de peixes são restritos de forma mais intensa neste bueiro, especialmente para Siluriformes. A queda de água na saída do bueiro circular provavelmente cria barreira à passagem dos peixes, especialmente para aqueles peixes que não tem capacidade de saltar, onde a erosão a jusante pode levar a empoleiramento. Estudos sobre projetos de bueiro ou instalações apropriadas são fundamentais considerando que a melhoria destas estruturas pode restaurar a conectividade de populações e comunidades de peixes em riachos.

Key words: Fish passage, Fish population, Habitat fragmentation, Road crossings.

Introduction

In South America, knowledge of the stream ichthyofauna is poor as a consequence of the large number of species, small number of taxonomists, and mainly sampling complexity due to the geographic diversity of sites, as well as the selectivity of capture devices. This geographic diversity is characterized by linear lotic environments, continuous and unidirectional water flow, habitat variations, and unstable stream beds (Uieda & Castro, 1999), exhibiting environmental heterogeneity (Bührnheim, 2002), such as shallow and deep stretches, waterfalls, rapids, backwaters, exposed or shaded areas, and sandy or muddy substrate (Fitzpatrick *et al.*, 1998).

Variations in habitat diversity and physicochemical characteristics make streams susceptible to changes, affecting the distribution of the aquatic fauna, as well as the structure of fish assemblages. Moreover, these conditions are favorable for the initial development of eggs, larvae and juvenile, providing them with food and shelter, which are essential for preservation and maintenance of species (Nakatani *et al.*, 2001).

River ecosystems and adjacent areas depend strongly on each other, and the slightest modification (natural or anthropic) in processes related to this relationship may lead to drastic changes in biotic and abiotic dynamics (Naiman *et al.*, 2005). Changes are intensified by human activities, caused by dam construction, improper land use, removal of riparian forest, industrial expansion, and discharge of effluents that change physical and chemical characteristics of the water, water quality, and sediment distribution (Callisto *et al.*, 2002; Corgosinho *et al.*, 2004; Tundisi & Tundisi, 2008). Urbanization also results in increased road density and, consequently, in an increase in the number of streams crossed by roads (Wheeler *et al.*, 2005), which may lead to severe impacts, such as habitat destruction resulting from the implementation of poorly designed culverts. These structures canalize water from upstream and transpose it downstream; they can be circular or box-shaped, varying in size, length, slope, and quantity, according to DNIT (2004a, 2004b, 2006).

Several culverts may have drops inlet and outlet, hanging culverts; 90% of them are found in first or second order streams, reducing fish movements between upstream and downstream stretches (Park *et al.*, 2008). They may alter the water flow and also reduce the transversal area and channel depth, resulting in an increase in water velocity and turbulence (Metsker, 1970) in stretches where the water flow is frequently contrary to the ichthyofauna's needs (McKinley & Webb, 1956). In recent years,

biologists and engineers in recognition the problems from decades past on population of salmon have designed and installed culverts that have little effect on fish, and several state fish and wildlife agencies in California, Oregon and Washington, USA (*i.e.* CDFG, 2002; WDFW, 2003; ODFW, 2004) have published design criteria to minimize the occurrence of adverse conditions that block migratory fish (Kemp & Williams, 2008).

Conditions imposed by culverts may restrict the ascending and descending movements of fish (Zrinji & Bender, 1995), preventing them from reaching important areas for reproduction, such as small streams, channels, and floodplain areas (Katopodis, 1993). The implementation of a culvert can cause habitat disruption and changes in patterns of species migration and dispersal, reducing biodiversity over time and favoring fragmentation, which could lead to extinctions (Forman & Alexander, 1998).

In the past few years, several studies have been carried out in Neotropical streams to describe the composition and structure of fish assemblages, most of them in Brazil streams such as Uieda (1984), Garutti (1988), Agostinho & Penczak (1995), Abes & Agostinho (2001), Pavanelli & Caramaschi (2003), Castro *et al.* (2004), Cunico *et al.* (2006), and Perez Jr. & Garavello (2007). However, there are no studies that assessed the influence of culverts on the ichthyofauna of Neotropical streams in despite of several studies conducted in the other regions, such as those carried out by McKinley & Webb (1956), Metsker (1970), Katopodis *et al.* (1978), Dane (1978), Zrinji & Bender (1995), Forman & Alexander (1998), Wheeler *et al.* (2005), Hotchkiss & Frei (2007), Foltz *et al.* (2008), Morrison *et al.* (2009), Nislow *et al.* (2011), and others.

The poorly constructed culverts may alter structural characteristics of streams, fragment habitats (Forman & Alexander, 1998; Langill & Zamora, 2002; Gibson *et al.*, 2005; Park *et al.*, 2008; Benton *et al.*, 2008), and affect fish movement through them. Thus, this study was designed to see if differences in fish assemblages existing upstream and downstream two types of culverts, one on each of two different Neotropical streams. Any differences in fish assemblages were hypothesized to result from changes in fish passage through culverts. However, the actual passage through the culverts was not tested.

Material and Methods

Study area

Sampling was carried out in the two streams: Pindorama and Lopeí; both are second order streams and tributaries of

the São Francisco Verdadeiro River (Fig. 1), Paraná River Basin, southern Brazil.

These streams were chosen because they have two distinct type of drains along their course where each intercepts with roads: OT-525 (Pindorama stream) close to the district of Bom Princípio - PR (city of Toledo) and BR317 (Lopei stream), between the cities of Toledo and Ouro Verde - PR. In both streams the culverts are multiple (triple): box in the Pindorama stream and circular in the Lopei stream (Fig 2). The characteristics of culvert engineering are presented in Table 1.

In these areas, stretches of 200 meters were standardized, above (upstream) and below (downstream) of the culvert, totaling 400 meters of sampling in each stream (Fig. 3), a procedure modified from Burford *et al.* (2009).

Data collection

Fish collection was conducted monthly from November 2009 to October 2010. Several fishing gears were used for fish

catching at specific times. The gears used were rods, sieves, gill nets, and cast nets, as these devices have different selectivity (Uieda & Castro, 1999), and also to assure sampling in all environments, since the stream is stratified and has pools, currents, and runs. Details of the description of the sample design are in Celestino *et al.* (2012).

A cast net, with a mesh of 1.5 cm and an area of 12 m, was cast 20 times at 11 a.m. and 10 p.m. Two rectangular sieves, with metallic frames of 1.2 x 0.80 m and netting meshes of 0.5 cm, were cast 20 times at 7 a.m. and 6 p.m., mainly in locals with marginal vegetation. A hook-and-line with live bait was also operated by two samplers at the streams' margins for 30 minutes at 10 a.m., 3 p.m. and 7 p.m. Lastly, a gill net, with an area totaling 28.55 m² and a mesh varying in distance (2.5, 3, 4, and 5 cm) between nonadjacent knots, was exposed for 24 hours, with periodic inspections every 8 hours. Each sampling event's length of time and use of equipment were standardized.

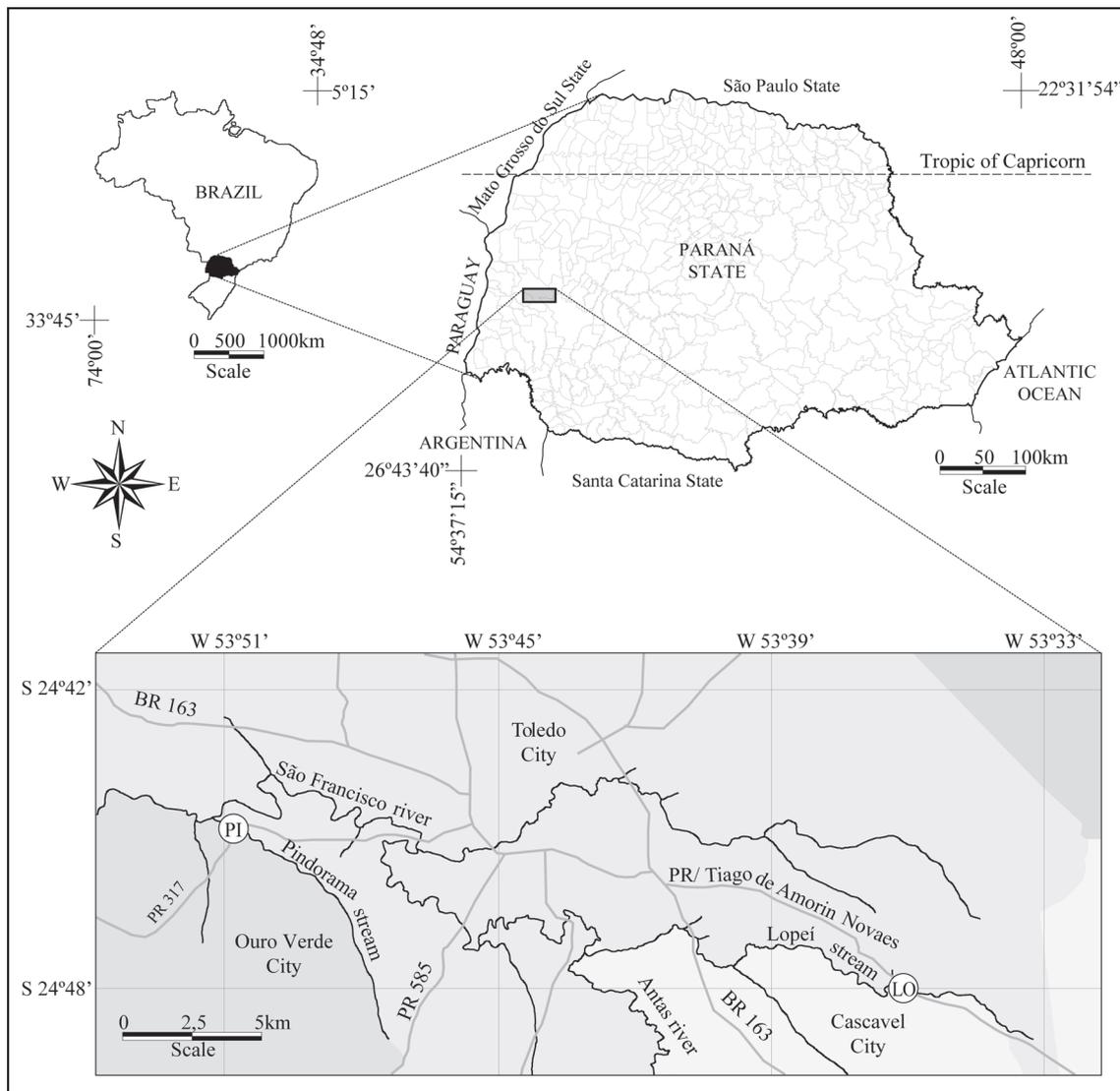


Fig. 1. Sampling sites in the Pindorama (PI) and Lopei (LO) streams, Paraná State, Brazil.

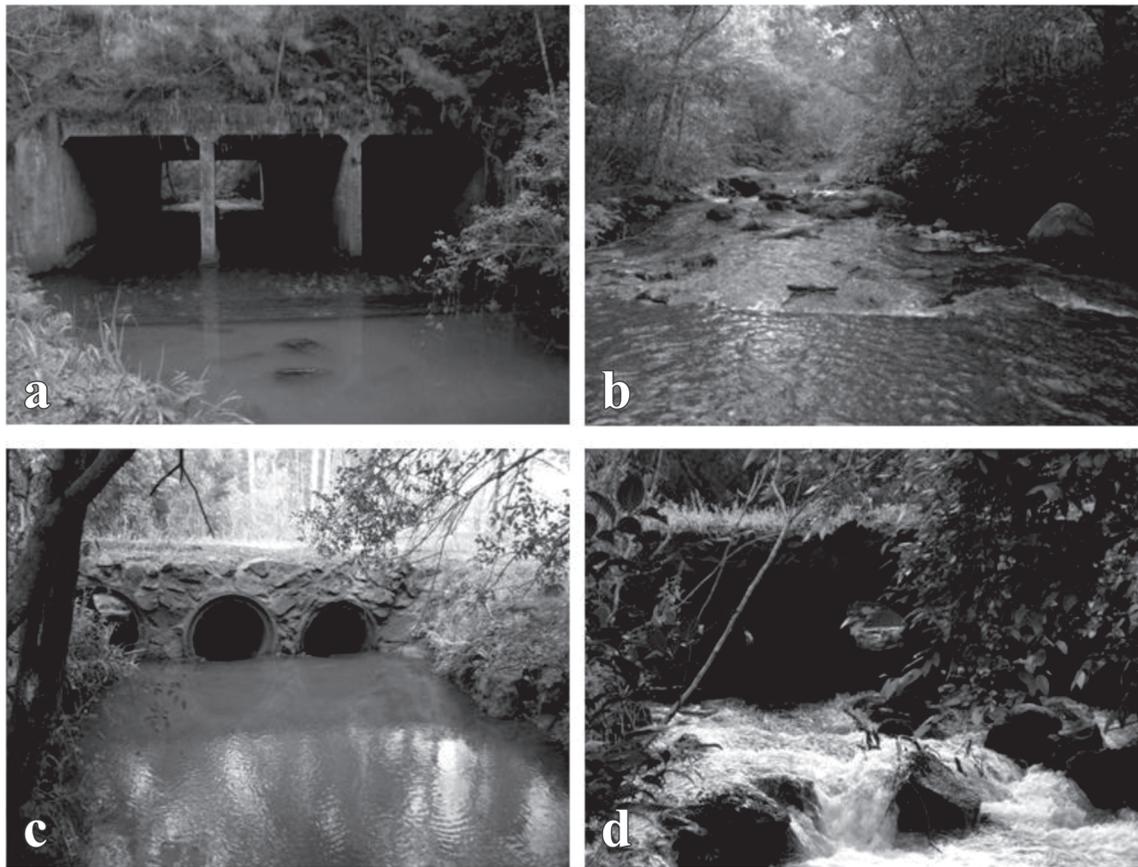


Fig. 2. Sampled stretches: Pindorama stream: **a)** upstream and **b)** downstream from box culvert, and Lopei stream: **c)** upstream and **d)** downstream from circular culvert.

The collected fishes were euthanized by benzocaine at a concentration of 250 mg/l per 10 minute of exposure, according to the approved protocol of the Ethics Committee in Animal Experimentation and the practical classes of Unioeste Protocol n^o 4109. The specimens were then fixed in formaldehyde 10%, and identified following Graça & Pavanelli (2007).

For each specimen, data on the standard length (cm) and the total weight (with a precision of 0.1 g) were recorded, and the voucher specimens were deposited in the collection of the Museu de Ictiologia do Nupélia, Universidade Estadual de Maringá, Paraná State, Brazil.

Sampling area was calculated based on the distance and average width of each stream stretch. To calculate the

average width, stretches were divided in plots of 10 m. In each plot, three measurements were taken to calculate the average width.

Data analysis

The composition of fish species, families, and orders of each stretch sampled in the streams was analyzed. The index of constancy (C) (Dajoz, 1978) was used to determine which species were constant at a given time scale, using the formula $C = n/N * 100$, where: n = number of catches in which the species was captured, and N = total number of catches carried out in the sampled stretches. Values were categorized following Dajoz (1978) as: constant = $C > 50\%$, accessory = $25\% > C < 50\%$, and accidental = $C < 25\%$.

Table 1. Characteristics of study area. SH = Shape of the culverts, C = circular, B = box, Year = year of the roads construction, CA = cross-section area, U = upstream and D = downstream areas of culverts, LC = length of culverts, V = mean flow velocity (V), DF = mean depth of flow, S = slope, OP = outlet perch.

Streams	Latitude	Longitude	SH	Year	CA (m ²)	Area (m ²)		LC (m)	V (m/s)	DF (cm)	S (%)	OP (cm)
						U	D					
Lopei	24°47'47.6"S	53°36'17.1"W	C	1995	1.17	908	1124	7.0	0.97	16.0	1.86	40.0
Pindorama	24°44'44.6"S	53°50'48.5"W	B	1979	9.30	1180	1386	26.6	1.56	9.3	1.09	15.0

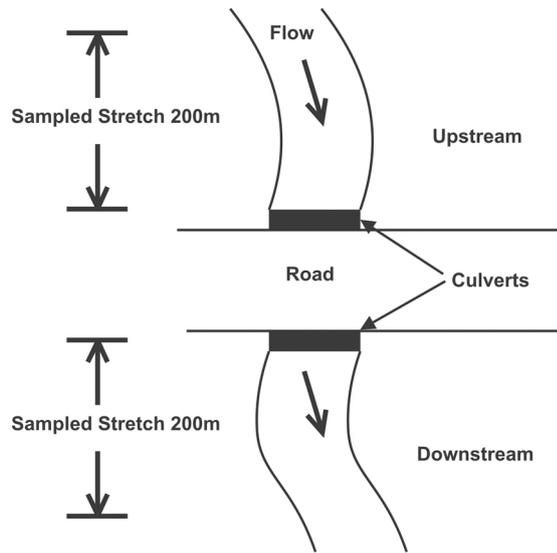


Fig. 3. Diagram showing the design of fish sampling in the streams.

To evaluate the mean standard length of fish between the sampled streams and the stretches of different culverts were used the one-way ANOVA to test for differences.

To analyze the species composition and the temporal-spatial relative abundance (number of individuals square-root transformed) (Magurran, 1988; Winemiller, 1996) of the fish assemblage in each stretch (upstream and downstream) and sampling month, a data matrix was built (using number and biomass of individuals, square-root transformed). This data matrix was used to calculate community parameters, such as species abundance, richness (S) (Magurran, 1988), species diversity (H' Shannon-Weiner), and evenness (E) for each stretch (upstream and downstream) and type of culvert (factors). Two-way ANOVAs were used to test for differences.

The pattern of temporal persistence was assessed as the frequency of occurrence of each species in the catches (y), plotted against the logarithm of the mean abundance (x) (Winemiller, 1996). Spatial aggregation was assessed with a linear regression between the logarithm of the mean abundance (x) and the logarithm of the variance (y) (Taylor, 1961; Maurer, 1994).

For analyzing the structure of the fish community we used the capture matrix in absolute values, which were square-root transformed to avoid a bias caused by very abundant species (Winemiller, 1996). Next, the data matrix of the fish assemblage was used in a Correspondence Analysis (CA) (Gauch Jr., 1986; Ludwig & Reynolds, 1988). To test for the significance of the relationships observed, a Kruskal Wallis test was applied on the axis 1.

Normality and homogeneity were tested using data of community parameters and the axis 1 generated by the CA. Statistical analyses were performed in Statistica 7.0. The significance level used was $p < 0.05$.

Results

During the study period, 2,220 fish were collected; 901 in the Lopeí stream - circular culvert (412 in the upstream and 489 in the downstream stretch) and 1,319 in the Pindorama stream - box culvert (721 in the upstream and 598 in the downstream stretch). These fish belong to five orders and 11 families (Table 2). A total of 33 species were sampled; 27 species occurred in the Lopeí stream (18 in the upstream and 22 in the downstream stretch of the circular culvert), and 25 species occurred in the Pindorama stream (20 in the upstream and 19 in the downstream stretch of the box culvert).

The orders Characiformes and Siluriformes had the largest numbers of families, 36.4% each (Fig. 4a). The Characiformes were more frequent in the upstream stretches of both culverts (Fig. 4b). Differences were observed for the Siluriformes between stretches of the circular culvert, with a larger number of catches in the downstream stretch. However, catches were similar for this order between stretches of the box culvert (Fig. 4b).

The most common families (Fig. 5a) were Loricariidae (11 species) and Characidae (7 species). The tendency in differences between stretches of the culverts observed for Characiformes and Siluriformes was also observed for these two families (Fig. 5b).

Among the captured species, 66% are small (smaller than 10 cm in standard length). The evaluation of the mean standard length of fish between stretches of different culverts showed that larger fish were caught in both stretches (upstream and downstream) of the Lopeí stream - circular culvert (Fig. 6), but this difference was not significant. The difference between stretches was also not significant for the Pindorama stream - box culvert.

Eight species were common to both streams, five species were exclusive of the Pindorama stream - box culvert, and eight species were exclusive of the Lopeí stream - circular culvert.

In the upstream stretch of the Lopeí stream (circular culvert), there was a low number of constant species (11%), 1% of accessory species, 23% of accidental species, and 52% of absent species. In the downstream stretch of this stream, 17% of the species were constant, 1% accessory, 38% accidental, and 32% absent. However, in the upstream stretch of the Pindorama stream (box culvert), 26% of the species were constant, 11% accessory, 17% accidental, and 41% absent. In the downstream stretch of this stream, 23% of the species were constant, 1% accessory, 14% accidental, and 50% absent (Table 2).

The most abundant species in number and biomass in both stretches in the Lopeí stream - circular culvert were *Astyanax fasciatus*, *A. paranae*, *A. altiparanae*, and *Rhamdia quelen*, whereas *Ancistrus* sp. was also abundant in the downstream stretch together with species of *Astyanax* and *R. quelen* (Fig. 7). For the stretches in the Pindorama stream - box culvert, the high values of number of individuals and biomass were different of the pattern found in the Lopeí stream

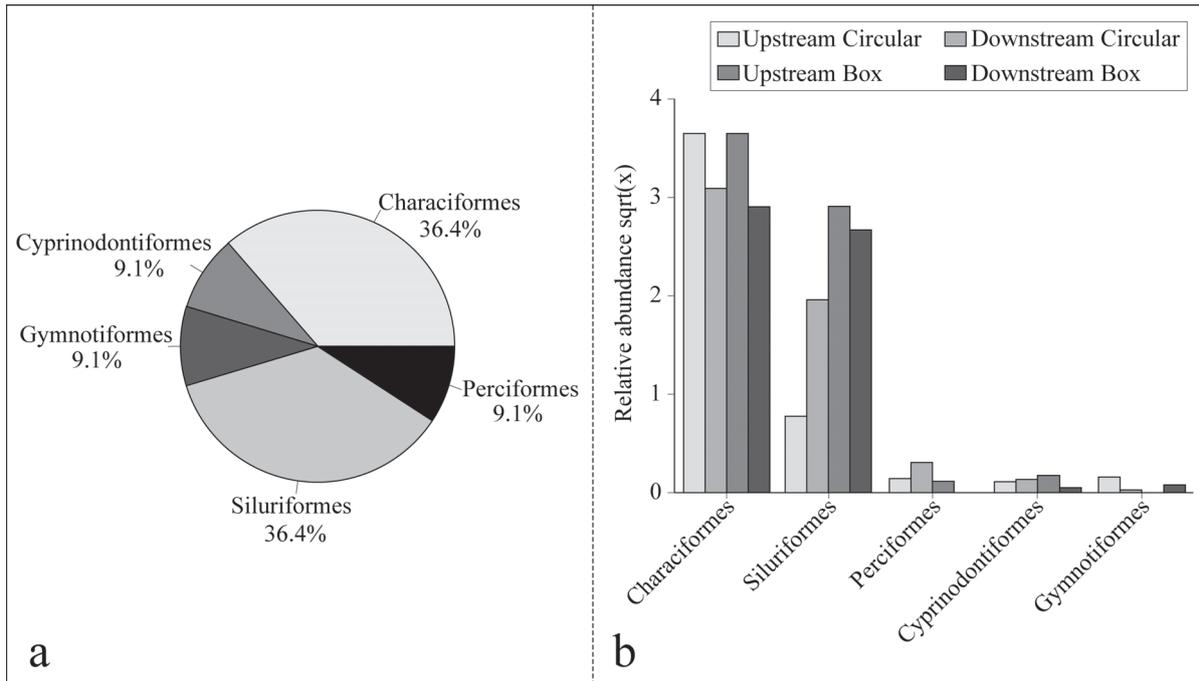


Fig. 4. Relative frequency of number of fish sampled by Order (a), and relative frequency of the number of fish by Order in the sampled stretches of the Lopeí stream - circular culvert and Pindorama stream - box culvert (b).

- circular culvert, considering that in both upstream and downstream stretches Siluriformes such as *Ancistrus* sp. and *Hypostomus* sp. were abundant, as well as the ‘lambaris’, including *Heptapterus mustelinus*, in the downstream stretch.

Species richness was higher in the stream with a box culvert, Pindorama stream (Fig. 8a), as evidenced by

interactions in two-way ANOVA ($F = 4.9551$; $p = 0.031$), showed different between the upstream and downstream stretches in this stream. In the Lopeí stream - circular culvert, richness was higher in downstream stretch (Fig. 8a). The interaction (two-way ANOVA) between culvert type and stretch ($F = 3.0497$; $p = 0.087$) was not significant for evenness

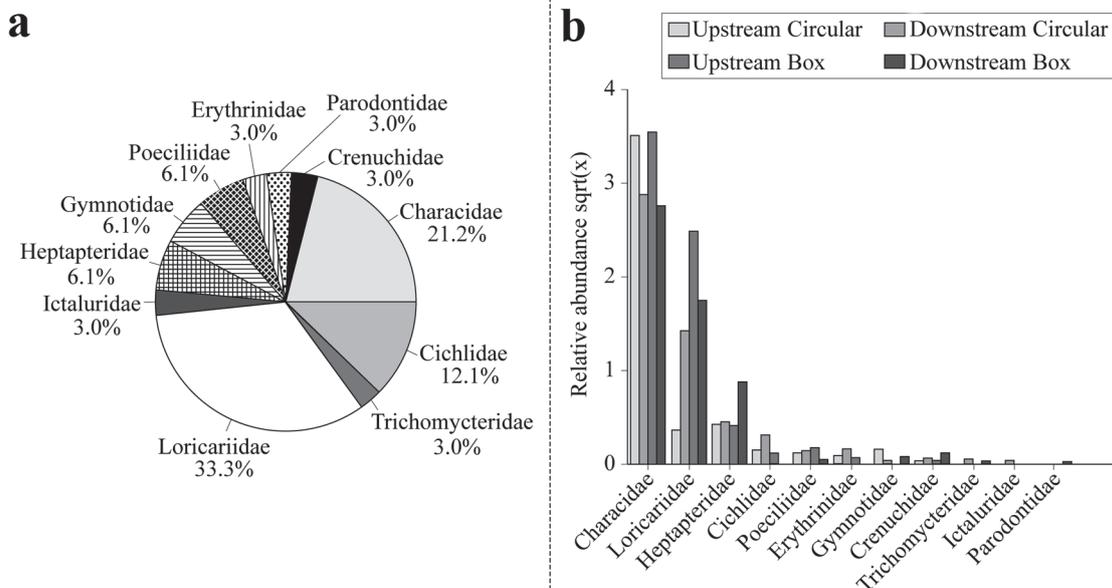


Fig. 5. Relative frequency of number of fish sampled by Family (a), and relative frequency of the number of fish by Family in the sampled stretches of the Lopeí stream - circular culvert and Pindorama stream - box culvert (b).

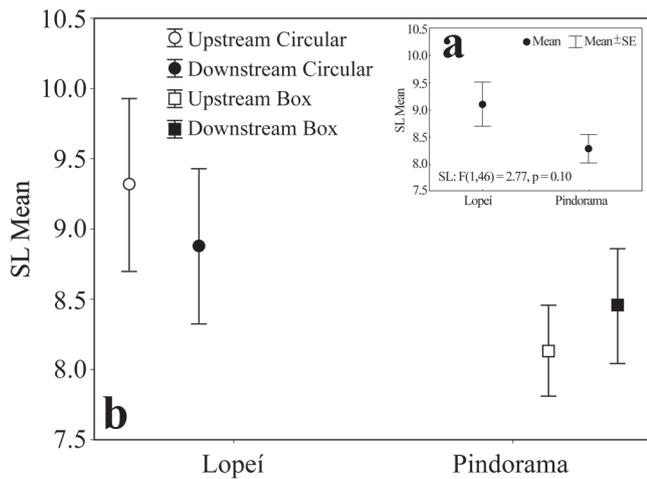


Fig. 6. Standard length of fish (mean \pm standard error) in the Lopeí and Pindorama streams (**a**), and in the sampled stretches (**b**) of the Lopeí stream - circular culvert and Pindorama stream - box culvert.

(Fig. 8b). The Shannon-Weiner diversity index (H') followed that same pattern as species richness (Fig. 8c).

The interaction of two-way ANOVA ($F = 10.230$, $p = 0.002$) among the factors evaluated (culverts and stretches) was significant, indicating differences between the culverts and stretches. The figure 8c shows the highest values for stream with box culvert and the largest discrepancy is between stretches in the stream with circular culvert.

The correspondence analysis (CA) calculated with data on composition, distribution, and abundance (Fig. 9) was represented in the axes 1 and 2. These axes were chosen based on their eigenvalues; the eigenvalue of axis 1 was 0.20, whereas the eigenvalue of axis 2 was 0.17, which is considered as low. Hence, only the axis 1 was retained for statistical analysis and interpretation, following Matthews (1998), who stated that below 0.20 the responses to gradients start to be linear.

The KW test applied on this axis showed spatial dissimilarity between streams with culvert of different shapes ($H = 35.27$; $p < 0.0001$), and the upstream and downstream stretches of the culverts. The streams with different types of culvert were clearly separated in the axis 1. This difference may result from the specificity of the fish assemblages of each stream, especially in terms of rare species (Fig. 9).

High abundance occurred in downstream stretch in the Lopeí stream - circular culvert between January and June (Fig. 10a), during the transition period between the rainy and dry season as well as in the dry season. However, the most abundance of fish has been obtained in the stream with a box culvert between December and April, mainly in the upstream stretch (Fig. 10b) during rainy season (high pluviosity).

The analysis of persistence showed that the dominant species in terms of abundance (*A. fasciatus*, *A. paranae*, and *A. altiparanae*) were also constant in all samples during the

study period, exhibiting higher persistence than other species in all stretches of culverts (Fig. 11). The species with low abundance were also the rarest (less persistent).

The general pattern of aggregation of fish communities in streams with different culverts did not differ from random, and so the community can be characterized as sparsely distributed (Fig. 12). Although fish species were captured several times (see results on persistency), they occurred in low abundance in some months (random pattern).

Discussion

The effects of culverts on stream fish communities can be difficult to detect, because fish abundance and richness are highly heterogeneous in space and time (Nislow *et al.*, 2011). The abundance observed in the present study, with a larger number of fish in the upstream stretch of the box culvert, contrary to what was observed in the circular culvert, which exhibited lower values, mainly in the upstream stretch, may be explained by the conditions imposed by culverts that restrict the fish movements and habitat occupation. According to Benton *et al.* (2008), culverts are potential barriers to connectivity and, with rare exceptions, hardly accomplish the function of allowing fish passage, what may affect fish occurrence and relative abundance upstream of culverts.

The predominance of Characiformes, especially Characidae, in upstream and downstream stretches of both culverts suggests that these fish may have higher mobility between their stretches. However, for Siluriformes, mainly Loricaridae, the circular culvert seems to limit habitat occupation, since the most catches occurred in the downstream stretch of this culvert. Nevertheless, the similar values observed between stretches of the box culvert for this fish group suggest that its movements are probably not hindered in this place. Benton *et al.* (2008) stated that box and circular culverts reduce significantly the movement frequency between upstream and downstream stretches, probably in response to differences in water depth and velocity.

The movement limitation of Siluriformes in relation to Characiformes previously mentioned may also be associated with the swimming capacity of the species. According to Hoffman & Dunham (2007), the ability of fish to pass through culverts is affected by behavioral and physiological factors and by the physical conditions created by culverts. Studies carried out with *Pimelodus maculatus* (Siluriformes) showed that this species swims slower (Santos *et al.*, 2006) than species of Characiformes, in the case of species considered as migratory, such as *Leporinus reinhardti* (Anostomidae) (Santos *et al.*, 2007), and small-sized species, such as *Bryconamericus stramineus* (Characidae) (Castro *et al.*, 2010). These characteristics can improve the Characiformes' ability to transverse obstacles, such as high water flows, which are frequently found in culverts. On the other hand, the Siluriformes may have difficulty in these obstacles, since their swimming ability is inferior. These differences can

Table 2. Fish species collected in the stretches of Lopeí (Upstream Circular Culvert - UC, Downstream Circular Culvert - DC) and Pindorama (Upstream Box Culvert - UB, Downstream Box Culvert - DB) streams. SL = mean standard length of fish species (SL) (cm). Rating scales of constancy in color: dark gray (constant), gray (accessory), light gray (accidental), and white (absent). NUP - Museu de Ictiologia do Nupélia, Universidade Estadual de Maringá, Paraná State, Brazil.

Species	Vouchers (NUP)	Acronym	LS	Occurrence				Constancy						
				Circular		Box		Circular		Box				
				UC	DC	UB	DB	UC	DC	UB	DB			
CHARACIFORMES														
Characidae														
<i>Astyanax altiparanae</i>	9284	Astyanal	6.9	+	+	+	+	[Dark Gray]						
<i>Astyanax fasciatus</i>	9305	Astyanfa	6.6	+	+	+	+							
<i>Astyanax paranae</i>	9285	Astyanpa	7.1	+	+	+	+							
<i>Bryconamericus</i> sp.		Bryconsp	4.1											[Light Gray]
<i>Leporinus elongatus</i>		Leporiel	6.7	+								[Light Gray]		
<i>Moenkhausia</i> aff. <i>sanctaeofilomenae</i>		Moenkhsa	2.3	+		+		[Light Gray]						
<i>Serrapinnus notomelas</i>		Serrapno	3.2		+		+		[Light Gray]					
Crenuchidae														
<i>Characidium</i> aff. <i>zebra</i>	9298	Characze	3.7	+	+	+	+	[Light Gray]		[Dark Gray]				
Parodontidae														
<i>Apareiodon affinis</i>		Apareiaf	11							[Light Gray]				
Erythrinidae														
<i>Hoplias</i> aff. <i>malabaricus</i>		Hoplisp3	18	+	+	+	+	[Dark Gray]	[Light Gray]					
Cyprinotiformes														
Poecillidae														
<i>Phalloceros harpagos</i>	9292	Phalloha	2.2	+	+	+	+	[Dark Gray]	[Light Gray]	[Dark Gray]				
<i>Poecilia reticulata</i>	9301	Poecilre	2.9		+		+		[Light Gray]					
GYMNOTIFORMES														
Gymnotidae														
<i>Gymnotus paraguensis</i>		Gymnotpa	10	+		+		[Dark Gray]		[Light Gray]				
<i>Gymnotus sylvius</i>	9299	Gymnotsy	20	+	+	+	+		[Light Gray]	[Light Gray]				
SILURIFORMES														
Heptapteridae														
<i>Heptapterus mustelinus</i>		Heptapmu	13		+		+		[Light Gray]	[Dark Gray]				
<i>Rhamdia quelen</i>	9286	Rhamdiqu	17	+	+	+	+	[Dark Gray]	[Light Gray]	[Dark Gray]				
Ictaluridae														
<i>Ictalurus punctatus</i>		Ictalupu	14		+		+		[Light Gray]	follows				
Loricariidae														
<i>Ancistrus</i> sp. A	9287	AncisspA	5.6	+				[Light Gray]		[Dark Gray]				
<i>Ancistrus</i> sp.	9302	Ancistsp	4.8	+	+	+	+	[Light Gray]		[Dark Gray]				
<i>Hisonotus</i> sp.	9294	Hisonosp	3.1	+	+	+	+	[Light Gray]		[Dark Gray]				
<i>Hypostomus albopunctatus</i>	9474	Hypostal	9.3							[Dark Gray]				
<i>Hypostomus ancistroides</i>	9282	Hypostan	12	+	+	+	+	[Light Gray]	[Dark Gray]	[Dark Gray]				
<i>Hypostomus</i> cf. <i>strigaticeps</i>	9475	Hypostst	11							[Dark Gray]				
<i>Hypostomus regani</i>		Hypostre	6.5	+	+	+	+	[Light Gray]	[Dark Gray]	[Dark Gray]				
<i>Hypostomus</i> sp.		Hypostsp	15		+		+			[Dark Gray]				
<i>Hypostomus</i> sp. A		HypoospA	7.4		+		+		[Light Gray]	[Dark Gray]				
<i>Loricaria</i> sp.		Loricasp	4.2		+		+			[Dark Gray]				
<i>Neoplecostomus</i> sp.	10779	Neoplesp	5.9		+		+		[Light Gray]	[Dark Gray]				
Trichomycteridae														
<i>Trichomycterus</i> sp.		Trichosp	4		+		+	[Light Gray]						
PERCIFORMES														
Cichlidae														
<i>Cichlasoma paranaense</i>		Cichlapa	6.6		+		+		[Light Gray]					
<i>Crenicichla britskii</i>		Crenicbr	13							[Light Gray]				
<i>Oreochromis niloticus</i>	9306	Oreochni	9.8	+	+	+	+	[Dark Gray]	[Dark Gray]	[Light Gray]				
<i>Tilapia rendalli</i>		Tilapire	4.2	+		+		[Light Gray]						

explain the similar abundance of Characiformes in different culverts and stretches, as well as the lower abundance of Siluriformes in the upstream stretch of the circular culvert.

This tendency was evidenced when we analyzed species abundance and constancy. The most abundant species were *Astyanax altiparanae*, *A. paranae*, *A. fasciatus*, *Ancistrus* sp., and *Hypostomus* sp., but with differences

observed in the occurrence of the last two species: they predominated in the downstream stretch of the circular culvert, and occurred in similar abundance in the stretches of the box culvert. Hence, the effects of culverts on the fish assemblage may vary depending on the species and are related to culvert characteristics, which can make culverts impassable to some fish.

The streams that have culverts with higher slope increase water velocity and the possibility of forming rungs at the exit of the culvert (Poplar-Jeffers, 2005), what may cause disruption in fish communities. According to the authors,

the most common problems observed in culverts are related to the depth of the water column at the entrance and exit, when it is lower than 0.15 m, and to the lack of continuity of substrate along the culvert. In addition, Benton *et al.* (2008)

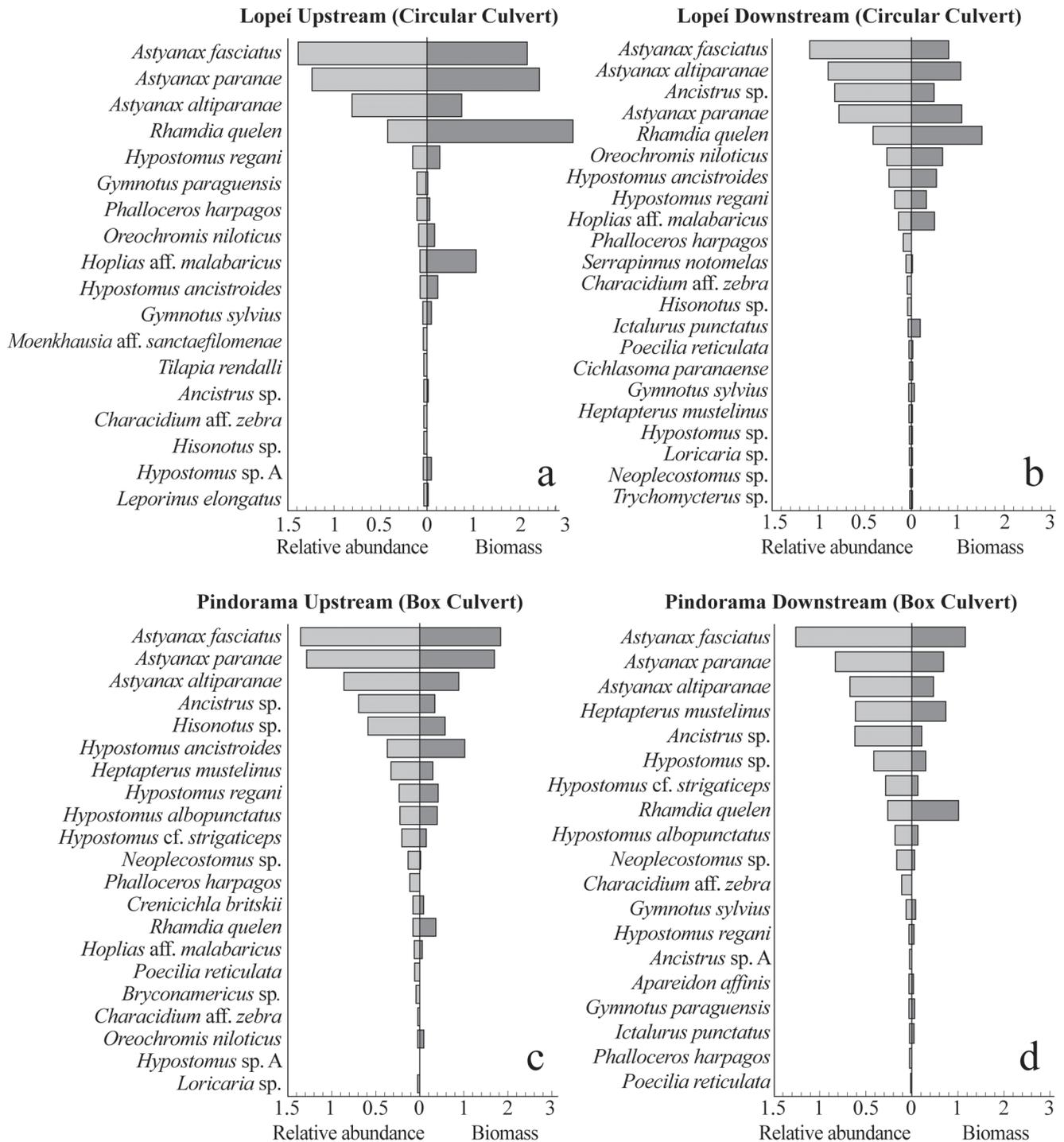


Fig 7. Relative abundance and biomass (square-root transformed) of fish species in the sampled stretches of the Lopeí stream - circular culvert (a - b) and Pindorama stream - box culvert (c - d).

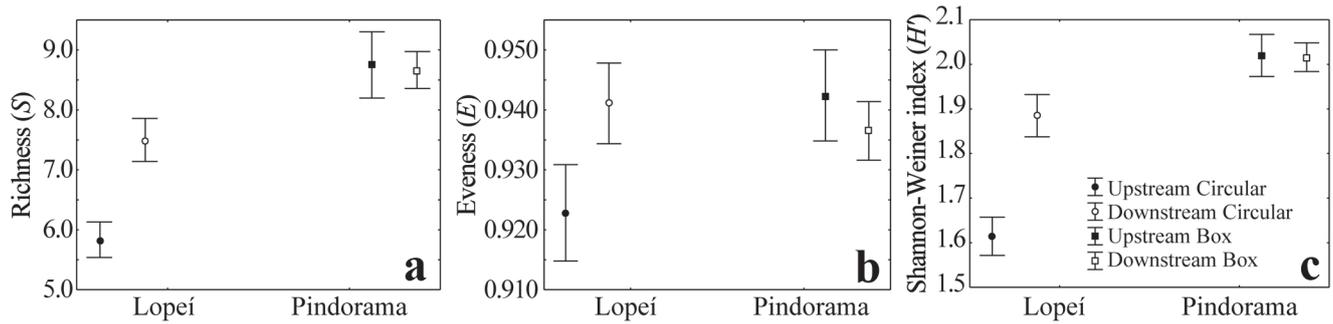


Fig. 8. Species richness (S) (a), evenness (E) (b), and species diversity (Shannon-Weiner Index - H') (c) in the sampled stretches of the Lopei stream - circular culvert and Pindorama stream - box culvert.

stated that poorly designed culverts may cause direct changes in stream morphology in upstream stretches. According to the British Columbia Ministry of Transportation and Highways (2000), it is fundamental to line up the culvert with the existing channel, in order to minimize changes in the direction of water flow; ponds can also be placed at the entrance and exit of the culvert, and chicanes can be placed inside them, facilitating fish passage. Water velocity should respect the limits of each species (Cahoon *et al.*, 2007), not exceeding 55 cm/s (Gardner, 2006). The roughness of the culvert should also be observed as well as the model of the chicanes (Hoffman & Dunham, 2007).

The loss of natural structural complexity in the substrate and in the water flow is other side effect of stream culverts, as the natural conditions are replaced by the uniformity of a culvert, which alters fish habitats and changes the hydraulic capacity of the channel, usually creating rapids (Dane, 1978). In the present study, box and circular culverts seemed to have different influence on the structuring of upstream and

downstream habitats. The most abundant species, *A. fasciatus*, *A. paranae*, and *A. altiparanae* prefer habitats such as ponds and backwaters (Langeani *et al.*, 2005), which are present in the four stretches sampled, whereas *Heptapterus mustelinus* prefers shallow (Becker, 2002) and shady habitats, with rapids and rocky bottom (Dala-Corte *et al.*, 2009), characteristics observed in the downstream stretch of the box culvert, where the abundance of this species was three times higher. According to Tundisi & Tundisi (2008), changes in natural habitat characteristics can alter the distribution of some species; these changes can be caused by culverts (Forman & Alexander, 1998).

The culvert length and water flow may lead to differences in species richness between stretches (Poplar-Jeffers, 2005). In this study, although the circular culvert had a shorter length and lower velocity than the box culvert, it seems to have higher impact on the fish assemblage than the box culvert. We observed higher richness and diversity values in the downstream stretch than in the upstream stretch of the circular

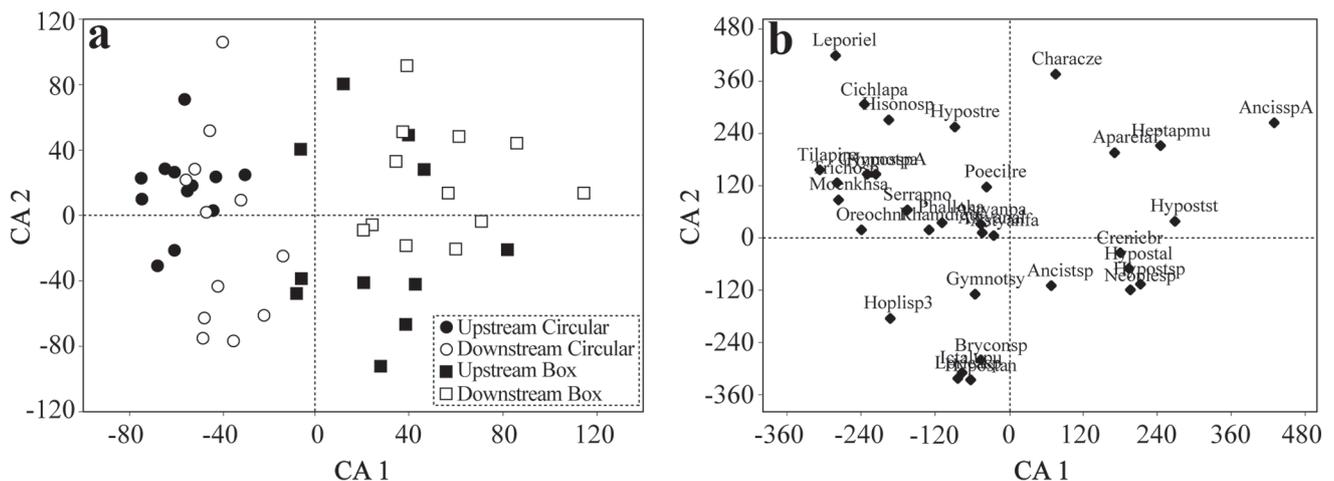


Fig. 9. Results of Correspondence Analysis (CA) between the sampled stretches of the Lopei stream - circular culvert and Pindorama stream - box culvert (a), and species distribution scores (b).

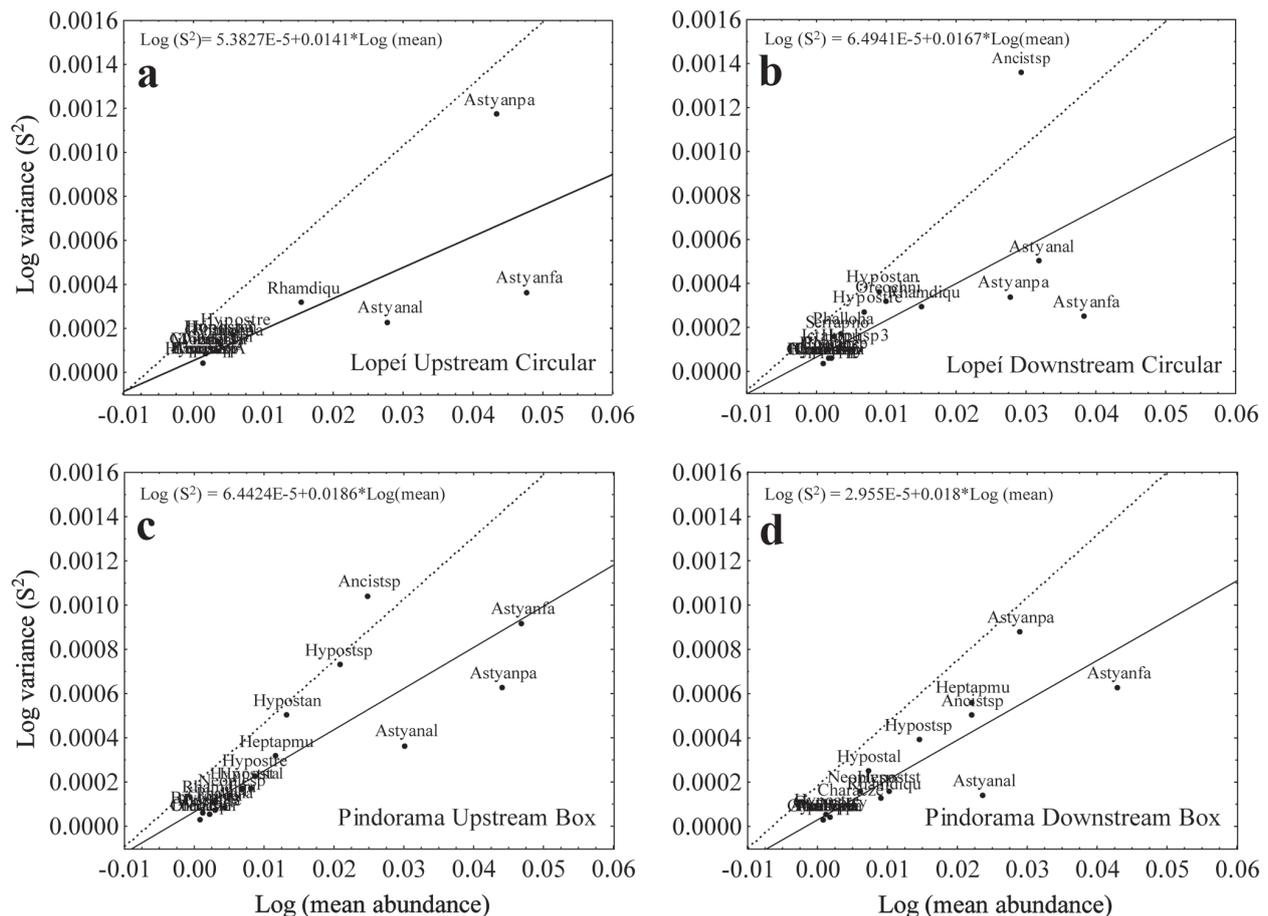


Fig. 12. Spatial aggregation of fish species in the sampled stretches of the Lopeí stream - circular culvert (**a - b**) and Pindorama stream - box culvert (**c - d**).

culvert. These values were similar between stretches of the box culvert. Nislow *et al.* (2011) observed that in culverts considered as impassable to fish in the USA, species richness and abundance were lower in the upstream stretch, whereas in passable culverts they were similar between stretches. However, Pluym (2006) observed that species richness in controlled water flows did not vary with the type of structure of water passage. Wellman *et al.* (2000), in Tennessee (USA), also observed that diversity, abundance, and richness were not different between upstream and downstream stretches, or between culverts and sites of free passage.

Variations in the composition of fish assemblages between upstream and downstream stretches of the culverts, in particular of the circular culvert, indicate that it can be affecting the distribution of the ichthyofauna and altering its composition (Newbrey *et al.*, 2001). The culverts used extensively for water passage and fluvial drainage in the crossings of small streams (Kapitzke, 2010) create potential problems for the passage of fish, and culvert installations can significantly decrease the probability of fish movement between habitat patches (Schaefer *et al.*, 2003).

Our study although limited to two culverts, one of each type (one box and one circular) indicated variations in the species abundance, richness, and diversity between upstream and downstream stretches of the circular culvert in the Lopeí stream, suggesting that fish movements are restrained more intensively in this culvert, particularly for Siluriformes. The drop in the circular culvert outlet probably created passage barriers especially for those fish that has no ability to jump, where downstream erosion could lead to culvert perching. Studies on appropriate crossing design or installation are fundamental whereas improvements in these structures can restore the connectivity of fish populations and communities in streams (Nislow *et al.*, 2011). The longitudinal connectivity in streams is essential for the maintenance of healthy environments, pointing out to the need of further studies in Neotropical streams intercepted by culverts focused on fish assemblages and their movement. Such studies may help the sectors responsible for implementing road crossings in order to propose possible solutions to improve the habitat conditions.

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