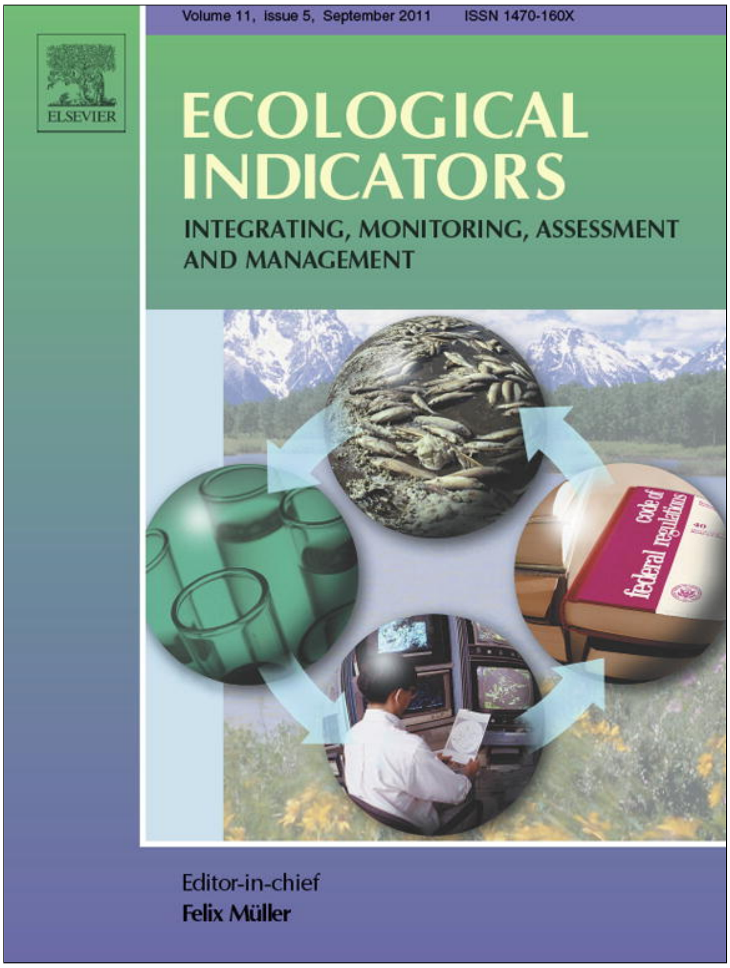
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Original article

Functional convergence of fish assemblages in urban streams of Brazil and the United States

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ABSTRACT

The aim of this study was describe functional faunal assemblages occurring in streams with high influence of urbanization in USA and Brazil to answer the question whether similar biological traits of fish assemblages would be found between streams with high influence of urbanization in USA and Brazil. We compiled data on the structure and composition of freshwater fishes in 46 urban streams in the USA and 10 urban streams in Brazil. Data on functional traits was established in accordance with ordinal data on abundance. Cluster analysis was conducted to examine relationships among species composition across all sites sampled and to uncover patterns in functional traits of the fish assemblages by nonmetric multidimensional scaling (NMS). The cluster analysis separated the biogeographic regions in relation to the fish fauna composition. However, the ordination analysis (NMS) did not reveal differences between functional traits in Brazil and USA urban fish assemblages, suggesting functional similarity of very disparate zoogeographic assemblages.

1. Introduction

Increasing urbanization world-wide and its consequent impacts on ecosystems represents a threat to native species assemblages and a challenge to biological conservation (Vitousek et al., 2008). In 1900, only 10% of the human population lived in cities whereas today half of the world's population dwells in urban areas, a figure expected to exceed 60% by the year 2030 (Cohen, 2003; Population Reference Bureau, 2008). This extensive and ever-increasing urbanization creates new landscapes, alters habitat and facilitates species invasions (McKinney, 2006). Impacts on aquatic ecosystems are profound (Cuffney et al., 2010; Paul and Meyer, 2008; Price et al., 2011).

Because of the well-established dependency of stream biota on the surrounding landscape (Allan, 2004), streams in urban areas are particularly vulnerable to impacts associated with changing landcover (Walsh et al., 2005). Increased areas of impermeable surfaces can increase the frequency and magnitude of storm flows (Campana and Tucci, 2001; Zhou and Wang, 2007), elevate erosive processes, change channel morphology with subsequent effects on streambed composition (Booth et al., 2004; Hancock, 2002; Wood and Armitage, 1997) and elevate concentrations of toxicants and nutrients in urban runoff (Hatt et al., 2004; Mainstone and Parr, 2002). Moreover, the loss of riparian vegetation reduces shade, organic matter inputs and instream habitat diversity, changing trophic processes and the structure of associated biological communities (Quinn et al., 2001). These changes in physical, chemical and biological aspects of urban streams show consistent trends across geographic regions, having the appearance of an urban stream syndrome (Meyer et al., 2005).

This growing evidence that stream ecosystems respond similarly across regions to the pressures of urbanization suggests the hypothesis that biological assemblages will converge in at least some of their functional properties. It is already apparent that a typical response of fish assemblages to urbanization is an increase in the abundance of tolerant species and decrease in sensitive species (Allan, 2004), resulting in shifts in species dominance and in fish assemblages that are functionally less diverse than found in non-urban streams (Weaver and Garman, 1994). Thus it is likely that a more detailed comparison of the functional traits of fish assemblages in urbanized and less altered landscapes will provide additional insight into the response of the biological assemblages to urbanization. Indeed, stream fish are well-suited for testing the hypothesis that traits of communities in distant systems converge in response to a similar environmental constraints because lotic fish population occur in more or less isolated watersheds where they

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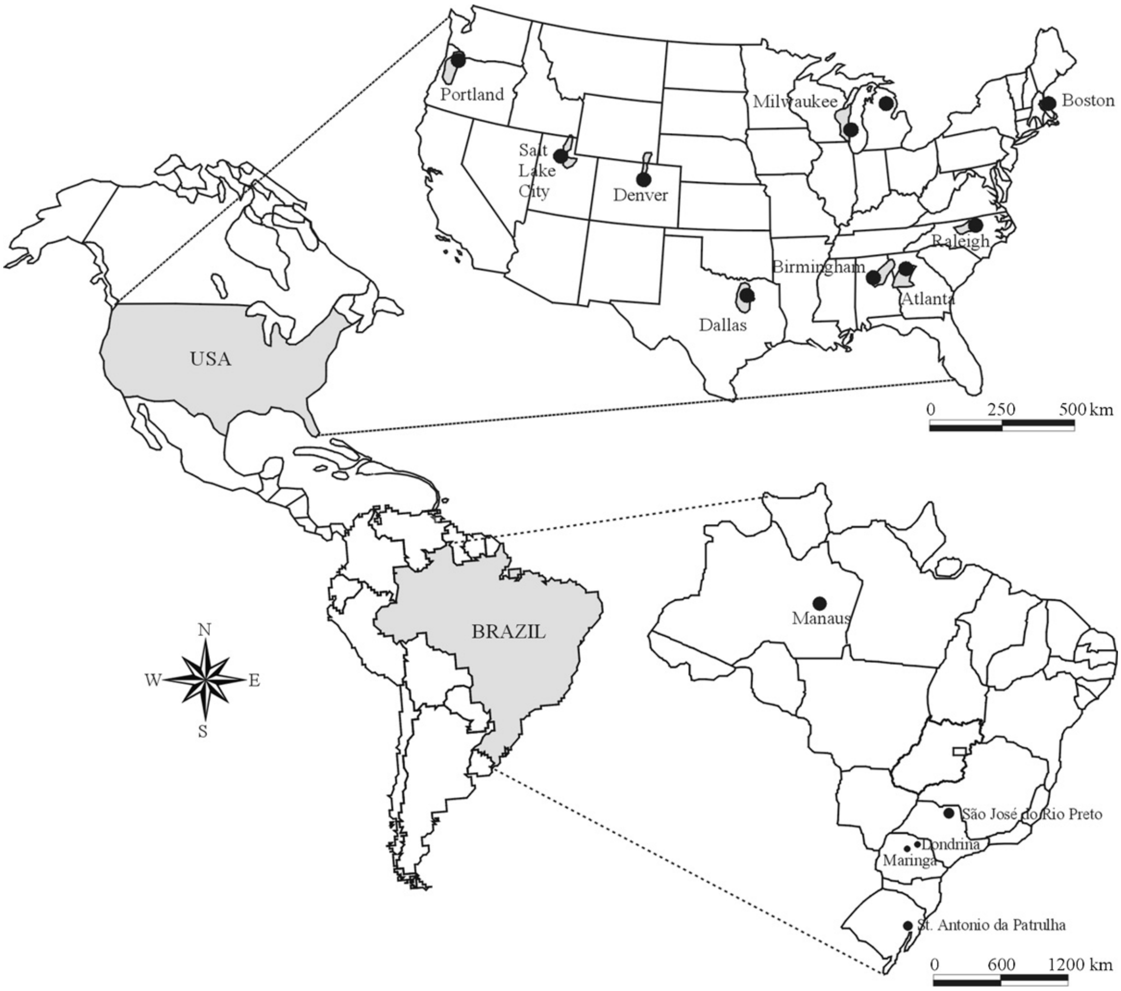

Fig. 1. Location of the 10 USA metropolitan areas and four Brazilian states included in the study.

can adapt to their environment (Lamouroux et al., 2002), environment variables influence the behavior of individual fish (Helfman et al., 2009) and biological trait of species are well documented enabling comparison of communities with different species compositions (Dolédec et al., 1999).

The expectation of convergence in community traits from independent systems having similar environmental features suggests the existence of key, repeated mechanisms underlying community organization (Lamouroux et al., 2002). Poff (1997) noted that understanding the patterns of distribution and abundance of lotic species requires testing theoretical predictions about relationships between functional attributes of species (species traits) and their environments. Ibañez et al. (2009) in a comparative study of freshwater fish assemblages from headwater streams in four continents (Europe, North America, Africa and South America) observed that independent of phylogenetic and historical constraints, fish assemblage richness and trophic structure converged along the stream continua to a substantial degree. In addition, the utility of a life-history approach is a better understand of patterns and processes by which fish communities vary along environmental gradients (Pool et al., 2010). In our study, the aim was describe functional faunal assemblages occurring in streams with high influence of urbanization in USA and Brazil. Thus, the main study question is whether similar biological traits of fish assemblages are found between streams with high influence of urbanization in USA and Brazil.

2. Materials and methods

2.1. Data collection

We compiled data on freshwater fishes from highly urbanized streams from United States of American (46 sites) and Brazil (10 sites) locations. The USA data were available from the National Water Quality Assessment (NAWQA) Program: Effects of Urbanization and Stream Ecosystem (EUSE) for 10 metropolitan areas. Data for Brazil were obtained from the Research Nucleus in Limnology, Ichthyology and Aquaculture (NUPELIA) Project: Identification of Bioindicators in Urban Aquatic Ecosystems, as well as from scientific literature and dissertations encompassing four Brazilian states (Fig. 1).

Sites with a high influence of urbanization in the USA were selected using the multimetric index of the urban index (MIUI), which combines land use, infrastructure, population and socioeconomic variables to derive a value between 0 and 100 (McMahon and Cuffney, 2000; Tate et al., 2005). Sites with MIUI values higher than 70 were retained for further analyses. Sites in Brazil were chosen using the watershed land cover percentage quantified by overlaying watershed boundaries and urban limits in high resolution satellite images (Quickbird – Pancromatic) using Spring 4.3.2 software (Camara et al., 1996) available at www.dpi.inpe.br/spring/. Sites with an urban percentage higher than 70% were retained for further analysis.

Table 1
Functional description of the fish species analyzed in this study.

Functional class	Sub-functional class	Description
Morphology[a]	Maximum length (Lt_{max})	The maximum length of the fish, from the tip of the snout to the tip of the longer lobe of the caudal fin.
Behavior[a,e]	Benthic	Species that exploit the bottom of the stream.
	Non-benthic	Species that exploit the water column.
Trophic guild[a,b]	Herbivorous	Species that feed predominantly on plants and algae.
	Detritivorous	Species that feed predominantly on detritus.
	Omnivorous	Species that feed on animal and vegetable matter.
	Invertivorous	Species that feed predominantly on aquatic and terrestrial invertebrates.
	Piscivorous	Species that feed predominantly on fishes.
Reproductive guild[a,c]	External fertilization – parental care	Species with short or lateral migration. Exhibit well-developed parental care, with nest building or transportation of eggs attached to the body being common.
	External fertilization – no parental care	Species with short or lateral migration, high production of gametes, and external fertilization and development of eggs.
	Internal fertilization – internal development	Species that fertilize eggs internally, with development taking place inside the maternal body.
	Internal fertilization – external development	Species that fertilize eggs internally, with development taking place outside the maternal body.
	Migratory	Species that require long migrations to spawn, fertilize eggs externally and do not guard the eggs.
Tolerance[a,d]	Tolerant	Tolerant species to chemical alterations and oxygen depletion.
	Sensitive	Sensitive species to chemical alterations and oxygen depletion.
Origin[a]	Native	Species with origin in the same country.
	Non-native	Species living outside their native distributional range.

[a] www.fishbase.org; www.natureserve.org.
[b] Matzen and Berge (2008), Gomiero et al. (2007), Ferreira (2007), Pinto and Araújo (2007), Pompeu and Godinho (2006), Oliveira and Bennemann (2005), Kennen et al. (2005), Bastos and Abilhoa (2004), Bozzetti and Schulz (2004), Tabit and Johnson (2002), Hahn et al. (1997).
[c] Matzen and Berge (2008), Ferreira (2007), Pompeu and Godinho (2006), Casatti (2005), Suzuki et al. (2005), Nunes et al. (2004), Vazzoler (1996).
[d] Matzen and Berge (2008), Pinto and Araújo (2007), Pompeu and Godinho (2006), Kennen et al. (2005), Bozzetti and Schulz (2004), Tabit and Johnson (2002).
[e] Matzen and Berge (2008), Pinto and Araújo (2007), Ferreira and Casatti (2006), Bozzetti and Schulz (2004).

2.2. Fish data and functional traits

Species composition was calculated as the relative abundance of all species at each site sampled and categorized into ordinal data to standardize the data for different effort. Kwak and Peterson (2007) recommend use of ordinal data over quantitative measures when species abundance estimates are believed to be poor due to factors such as sampling difficulties, minimizing the influence of sampling bias.

The categories utilized were: category (0) for species with relative abundance <1%, category (1) for species between 1% and 10%, category (2) for species between 10% and 50% and category (3) for species with relative abundance >50%.

We searched the scientific literature and electronic databases to provide a comprehensive functional description of the fish species analyzed in this study. We collated data for 17 relevant functional traits. Trait values were represented by ordinal data based on the relative abundance category, except for the maximum total body length, which was categorized as category (1) $Lt_{max} < 10$ cm, (2) $10 < Lt_{max} \leq 40$ cm, or (3) $Lt_{max} > 40$ cm (Table 1).

2.3. Data analysis

We used cluster analysis to examine the relationships among species composition across all sites sampled. A correlation matrix of 56 sites combined from all species was constructed using Pearson coefficients. Pearson correlation coefficients were used as measures of similarity, and clusters were determined by complete linkage. The results of the cluster analysis were used to produce a dendrogram from which clusters of similar species composition could be identified.

Patterns in functional traits of the fish assemblages among the sites were examined using nonmetric multidimensional scaling (NMS) (McCune and Grace, 2002; McCune and Mefford, 1999). NMS is an ordination method that is well-suited to data that are nonnormal or are on arbitrary, discontinuous, or otherwise questionable scales (McCune and Grace, 2002). Because of this, the technique is increasingly used in community ecology (Kennen et al., 2005; Potapova et al., 2005; Walters et al., 2005). The distance measure used was Sorensen, and all NMS procedures (Kruskal, 1964a,b) were performing using PC-ORD software (McCune and Mefford, 1999). The data were transformed (log + 1), and forty runs and 400 iterations were made. Stress was evaluated using a Monte Carlo test ($p < 0.05$) based on 40 randomized runs and indicated that the three-dimensional solution was the best solution and could not have occurred by chance alone. Higher dimensions did not contribute to improving the model. Spatial variation related to USA and Brazilian sites was tested by one-way analysis of variance (ANOVA). Assumptions of normality (Shapiro–Wilk test) and homoskedasticity (Levene test) were verified. A Spearman rank correlation matrix was established among the NMS scores and the descriptor variables to observe relationships between sites in the functional traits of the fish assemblages. The NMS analysis allowed us to determine which functional traits accounted for the majority of the variability in the distribution of fish species in ordination space.

3. Results

Cluster analysis of the 56 sites indicated highly dissimilar taxonomic composition between Brazil and USA sites (Fig. 2). The 46 urban stream sites in the USA included 96 species in 44 genera and 15 families; the 10 sites in Brazil supported 78 species in 53 genera and 15 families. The most common families in the USA were Cyprinidae, Centrarchidae, Catostomidae, Ictaluridae, Percidae and Poeciliidae; in Brazil the most common families were Poeciliidae, Loricariidae, Characidae, Cichlidae, Erythrinidae and Gymnotidae. Only the family Poecillidae was common in both nations. A few species dominated the fauna in each country. *Lepomis cyanellus*, *Lepomis macrochirus* and *Catostomus commersonii* occurred at frequencies of 54%, 48% and 37% at the USA sites, respectively, and *Poecilia reticulata*, *Rhamdia quelen*, and *Gymnotus carapo* occurred at 90%, 70% and 60% at the Brazilian sites, respectively. Species with relative abundance higher than 50%, meaning that one species comprised over half of the individuals collected at a site, occurred in 48%

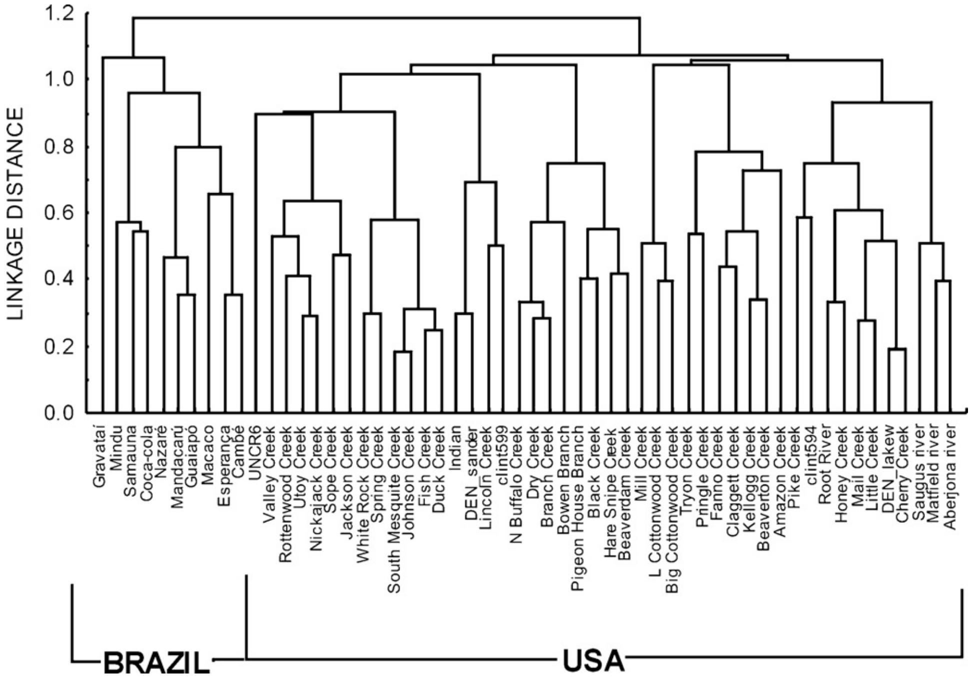

Fig. 2. Cluster analysis of qualitative similarity among fish assemblages from 10 sampling sites of Brazilian streams and 46 USA streams, using Pearson correlation coefficients, and clusters were determined by complete linkage.

of USA sites and 90% of Brazilian sites. In the USA, 13 species and in Brazil two species had relative abundances higher than 50%. *Cottus perplexus* was the most frequent dominant species (13%) in the USA, but restricted in Portland, and *Poecilia reticulata* was the most frequent dominant species in Brazil (80%).

The ordination analysis (NMS) found no differences in the biological and ecological traits between fish assemblages from North and South American urban streams (Fig. 3). The NMS identified three primary gradients that together accounted for 74% of the variance in the analytical data set. The second and third axes accounted for a significant, but small, proportion of variance (10% and 15%, respectively) and were not considered for further analysis. The first axis accounted for 49% of the fish functional trait variation and did not separate the fish assemblages between the USA and Brazil (ANOVA, $F = 0.80$, $p = 0.374$, Fig. 3).

The correlations between the first axis and functional traits identified a positive between omnivorous species with external fertilization and no parental care and occupation of the benthic and non-benthic position in the water column (Table 2). Non-native and tolerant species also were positively correlated with this first axis.

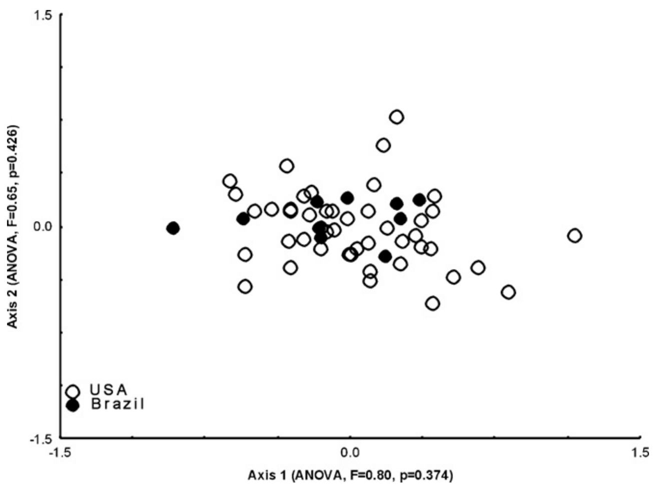

Fig. 3. NMS plot showing functional similarities between the sampling sites of Brazilian and USA urban streams.

4. Discussion

The steady growth of urbanization world-wide strongly influences biological communities, creating homogeneous habitats and increasing the frequency of "urban-adaptable species" (McKinney, 2006), which may share similar functional characteristics independently of their taxonomic affinities. Consistent with such a relationship, we found that the distinct fish assemblages of the USA and Brazil revealed no significant differences in the functional characteristics considered. Urban fish assemblages were dominated

Table 2
Spearman rank correlations of fish traits with nonmetric multidimensional scaling (NMS) axis scores. Significant correlations ($p < 0.05$) are in bold.

	Variable	Axis 1
Morphology	Length maximum	0.292
Trophic guild	Herbivorous	−0.005
	Detritivorous	0.115
	Invertivorous	0.121
	Piscivorous	0.184
	Omnivorous	**0.683**
Reproductive guild	External fertilization – parental care	**0.337**
	External fertilization – none parental care	**0.615**
	Internal fertilization – internal development	−0.093
	Internal fertilization – external development[a]	–
	Migratory	0.185
Behavior	Benthic	**0.512**
	Non-benthic	**0.389**
Tolerance	Tolerant	**0.746**
	Sensible	0.102
Origin	Native	0.044
	Non-native	**0.834**

[a] No species showed this characteristic.

by benthic omnivores with external fertilization, and frequently included tolerant and non-native species. A few species were common almost everywhere within each region, and in most collections over half of their individuals were due to just one species.

The functional traits characteristic of fish assemblages observed in this study agree with previous studies conducted in urban streams in Brazil (Alexandre et al., 2010; Casatti et al., 2009; Cunico et al., 2006; Silva, 1995) and the USA (Onorato et al., 2000; Walters et al., 2005; Wang et al., 2000). Thus, trophic composition seems to be a good indicator of changes in water quality and alterations in habitat complexity that commonly are influenced by urban development. The dominance of omnivorous species may indicate a reduction in food sources for trophic specialists, making fishes with this more general diet and more successful in relation to others that are more specialized (Araújo, 1998). Although the presence of species with generalist trophic characteristics is common in natural environments (Abelha et al., 2001), dominance by omnivorous species is typical of degraded environments (Karr, 1981), in which variation in the availability of resources favors species that are more flexible in their diet.

Physical and chemical alterations of streams in urban landscapes may also influence the reproduction and recruitment of fish species. Early developmental stages including eggs and larvae are particularly sensitive to contaminants and alterations in habitat. Disturbed habitats favor the establishment of species with high production of gametes; thus species with external fertilization and high fertility may represent an effective strategy in such habitats. For example, at degraded and physically variable sites of a river system tributary to the Orinoco in Venezuela, Winemiller (1989) observed the high adaptive capacity and rapid colonization by opportunistic species that were characterized by external fertilization, rapid gonadal development and batch spawning. Although internal fertilization may also contribute to greater reproductive success in degraded areas by reducing predation, the occurrence of species with internal fertilization was significant only in Brazilian urban streams and was due to a particular species, *P. reticulata*, which inhabits urban environments mainly because of their tolerance to pollution (Cunico et al., 2006; Lemes and Garutti, 2002). The family Poeciliidae also occurred in USA urban streams but was less frequent, possibly because its normal range is tropical environments with temperatures above 18 °C (Winemiller et al., 2008) and so is unlikely to survive northern winters at most USA sites.

Alterations to stream hydrology, greater delivery of sediments and associated effects on the structural diversity of the aquatic ecosystem are further characteristics of urban streams (Paul and Meyer, 2008) that might be expected to influence the functional traits of fish assemblages. A number of studies have reported declines in the occurrence of benthic species of fishes and reduction in habitat complexity due to the accumulation of fine sediments (Casatti et al., 2009; Wood and Armitage, 1997; Taylor and Roff, 1986). However we observed benthic and non-benthic association with NMS Axis 1, indicating no clear selection for either, probably because high current velocities, channelization and frequent peak flows produce more coarse sediments than fine, especially in intense urbanized areas with minimal soil erosion what, presumably, favor the presence of benthic species. In addition, frequent and abrupt fluctuations in stream flow characteristic of urban environments may displace pelagic species downstream, causing them to become them less abundant or to be restricted only to the remaining pools.

The altered conditions of urban streams may be important in facilitating colonization by non-native species (Boët et al., 1999; McKinney, 2006; Paul and Meyer, 2008). Boët et al. (1999) reported the introduction of 19 non-native species and the disappearance of seven of the 27 native species of fish from the river Seine resulting from the urbanization of Paris. In addition the aquarium trade has been responsible for frequent introductions of species to urban environments. Non-native ornamental species of the genera *Poecilia* and *Xiphophorus* are commonly found in urban aquatic environments in South America (Cunico et al., 2009), as well as the genus *Carassius* in North America, presumably introduced by deliberate release by aquarists seeking to humanely dispose of unwanted pets (Agostinho et al., 2007; Courtenay and Stauffer, 1990). Obviously, assemblages in USA and Brazil include native narrow endemic species that may respond differently to urbanization and with broad tolerances that might be as well as invasive introduced species. However, the analysis of individual species was beyond the scope of the present study.

5. Conclusion

Our results indicate that biological traits of fish assemblages are similar between streams with high influence of urbanization in USA and Brazil, and in opposition to Brown et al. (2009), suggest that urbanization may affect the functional composition of fish assemblages similarly in different zoogeographic areas with different taxonomic history of fish assemblages.

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