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Fish as Indicators of Disturbance in Streams Used for Snorkeling Activities in a Tourist Region

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Abstract A set of metrics that reflect various aspects of population and fish community structure in streams used for snorkeling was evaluated in the tourist region of Bodoquena Plateau, Brazil, with the purpose of biomonitoring the impacts of such activities. Observations were made while snorkeling in two sites (active = with tourism; inactive = without tourism) and along the gradient of daily tourist activity (before, during and after the passage of tourists) in two streams. Five metrics discriminated active from inactive sites: (i) the abundance of *Crenicichla lepidota* and (ii) the incidence of reproductive activity in *Crenicichla lepidota* which were greater in inactive sites, regardless the gradient of daily tourist activity; (iii) the feeding pattern of *Prochilodus lineatus,* which differed among sites and along the gradient of daily tourist activity; (iv) the abundance of *Moenkhausia bonita,* which was higher in the active sites and significantly increased along the gradient of daily tourist activity in one stream but decrease along the gradient in other stream; (v) the abundance of *Hyphessobrycon eques,* which was greater in inactive sites, regardless the gradient of daily tourist activity. With the exception of metric "iv", the metrics were mediated by the reduction in habitat structural complexity due to snorkeling disturbance. The definition of these metrics is relevant because the degradation of ecosystem structural elements is one of the main impacts of recreational activities on aquatic environments. The easy recognition of target species and high water transparency throughout the year ensures the feasibility of these metrics in monitoring programs and may be applied by technicians after quick guides and training.

Keywords Tourism · Biomonitoring · Anthropogenic impacts · Skin diving

Introduction

Tourism based on wildlife is often identified as a sustainable activity (Roe and others 1997). Regardless of the benefits of tourism, there are negative impacts triggering changes in biological systems (Giannecchini 1993), as demonstrated in different taxonomic groups such as mammals (Rode and others 2006), reptiles (Romero and Wikelski 2002), birds (Gill 2007), fish (Medeiros and others 2007) and invertebrates (Hasler and Ott 2008). Disturbances caused by tourist activities may cause changes in individuals, such as physiological and behavioral alterations (Fowler 1999; Müllner and others 2004), in populations (Pearce-Higgins and others 2007; Lindsay and others 2008) and in communities (Sweatman 1996; Hawkins and others 1999).

Indicator species have been used to test environmental conditions for decades. The use of plants and insects to

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assess the air and water quality (Ott 1978; Phillips 1980; Newman and Schreiber 1984; Rosenberg and others 1986) or as indicators of agricultural frontiers (Clements 1920; Shantz 1938; Stoddart and others 1975) can be cited as examples. Recently, there has been a significant increase in the use of vertebrates as indicators of environmental quality (Wren 1986; Jaramillo-Villa and Caramaschi 2008; Lailson-Brito and others 2008), and fish communities have been highlighted in this context (Roset and others 2007; Casatti and others 2009). There are some examples of the use of fish in biomonitoring the impacts of tourism in aquatic environments (Hodgson 1999; Sabino and Andrade 2003); however, metrics are rarely based on tested evidence. Prior to monitoring, it is necessary to establish and standardize metrics that are sensitive to the impacts that must be evaluated and can be distinguished from natural impact variations (Roset and others 2007).

Studies focusing on the effects of recreational activities on fish metrics have found divergent results (Medeiros and others 2007; Claudet and others 2010). The extent of impact, in general, depends on the intensity and nature of the activity being performed (Milazzo and others 2002). This is an important issue in aquatic management, especially in freshwater ecosystems, where studies establishing and standardizing metrics for biomonitoring are incipient. Therefore, we conducted this study with the purpose of testing metrics extracted from the fish community in streams exploited for tourism in Bodoquena Plateau, Central-Western Brazil. We evaluated metrics based on space usage, abundance and behavior of benthic and nektonic species, and we hypothesized that these metrics will enable discrimination of the areas used for touristic activities from those areas where these activities are prohibited. This region was chosen as a model for the present study because it is one of the most popular tourist destinations in Brazil. This is mainly due to the scenic beauty, high biodiversity (Willink and others 2000 cited 52 species in the headwaters of this region) and water transparency (over 40 meters in some places) of this aquatic ecosystem, factors that contribute to the high popularity of snorkeling among tourists. For example, the city of Bonito, in Mato Grosso do Sul state, has 17,856 inhabitants (IBGE 2000) and receives approximately 80,000 tourists per year (Michaels and others 2006). Moreover, there is evidence that this high visitation results in environmental changes, especially impacting fish (e.g., decreases in the occurrence and abundance of target species) (Sabino and Andrade 2003). Thus, the identification of biological metrics that indicate such impacts is a key step in the execution of monitoring programs aimed at the sustainability of tourism.

Material and Methods

Study Area

The study was conducted in Bodoquena Plateau, southwestern Mato Grosso do Sul state, belonging to the Upper Paraguay River basin (Willink and others 2000). This basin is included in the La Plata-Uruguay-Paraguay-Paraná system, the second largest (3.2 million km^2) in South America (Lowe-McConnell 1987). The rivers of the Bodoquena region are distributed over three major drainages that are the Formoso, Mimoso, and Miranda basins.

Two streams were selected as sites for the study: Rio Sucuri (21°15′58.3″S 56°33′30.6″W) and the Córrego Olho D'Água (21°26′15.8″S 56°06′41.0″W), in the municipalities of Bonito and Jardim, respectively. Both have high water transparency (often exceeding 30 m) and high fish diversity (Willink and others 2000), which are important features for attracting snorkeling activities. The marginal areas of Rio Sucuri are dominated by rooted emergent macrophytes (mainly *Gomphrena elegans*) and submerged macrophytes (mainly *Ludwigia peruviana* and *Echinodorus bolivianus*). The main course is 5–20 m wide and 0.6–2 m deep, the substrate is composed mostly of sand, mollusks shell fragments, branches, logs, and rooted submerged macrophytes. The Córrego Olho D'Água has a width varying from 10 to 15 meters and a depth between 0.30 and 1 m (note: there are passages in the Córrego Olho D'Água reaching 3 m depth, but they are downstream of the studied stretch), sandy substrate with plenty of woody debris, and rooted submerged macrophytes. Tourism activities occur daily, starting at around 08:00 AM and ending around 16:00, and the areas receive around 150 visitors each day in groups of nine people. Offering food to fish is not allowed in either stream.

Sampling Design and Hypothesis

As both areas represent fragile ecosystems and because fish are the major attraction for tourists, no fish were caught and, therefore, the sampling protocol was based on underwater observations, using noninvasive and low-impact techniques. These activities were carried out using snorkeling equipment.

In each stream, selected sites ($n = 4$) were 10 m long and 3 m wide (=30 m^2). Two of them were often visited by tourists (named active sites) and two were located in prohibitive access areas (named inactive sites). Structural differences between active and inactive sites exist in the Córrego Olho D'Água but not in the Rio Sucuri. These differences result from the constant passage of tourists in the active area, where low depth promotes gradual removal

Table 1 Structural features of active and inactive sites in Rio Sucuri and Córrego Olho D'Água

Areas	Average depth (cm)	In stream habitat composition (%)
Sucuri		
Active	121	Rocks (4), sand (55), mollusk's shell fragments (16), macrophytes (9), woody debris (4), algae (6), roots (6)
Inactive	110	Rocks (3), gravel (20), sand (18), mollusk's shell fragments (14), clay (17), macrophytes (10), woody debris (5), algae (7), roots (6)
Olho D'Água		
Active	63	Sand (70), macrophytes (14), algae (12), woody debris (4)
Inactive	66	Sand (15), macrophytes (68), algae (3), woody debris (14)

of submerged vegetation and other habitat structures such as small trunks and branches (Table 1). In the Rio Sucuri, active and inactive sites are naturally simplified; therefore, tourist passage does not provoke physical structural alterations. The influence of tourism on physical habitat structure in one but not the other stream represents the variety of contexts occurring in regional streams. Additionally, this condition allows for the testing of the association between touristic activities and structural modification.

The active and inactive sites were selected as close as possible to each other in order to minimize the hydrological variations between areas. In Rio Sucuri, tourists occupy the whole width of the river course, so the active and inactive areas were established along the longitudinal gradient of the stream, separated by the point of entry for tourists. Thus, the two active sites were located downstream from

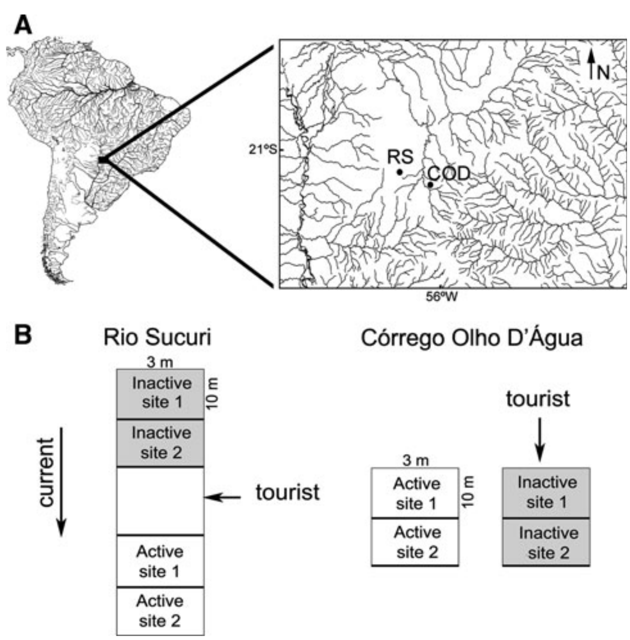

Fig. 1 **a** Location of the study area and streams (RS, Rio Sucuri; COD, Córrego Olho D'Água), **b** schematic layout of the sample sites in both streams

the point of entry for tourists, and inactive sites were established upstream of this place, where tourists have no access (Fig. 1). In the Córrego Olho D'Água, tourists' passage follows a defined path, occupying a longitudinal subaquatic path approximately 5 m wide along the stream, so that a lateral area adjacent to the path is free of such disturbance. Thus, the two active sites and two inactive areas are side by side (Fig. 1).

The selection of metrics was based on conspicuousness and abundance of focal species and ecological and behavioral aspects that are potentially affected by tourism activities conducted in those streams. The selection of metrics occurred independently across areas because some species occur exclusively in one of the streams. We tested five metrics in the Rio Sucuri and ten metrics in the Córrego Olho D'Água, of which three were common to both environments. These metrics correspond to aspects related to the use of space and the abundance and behavior of six species.

Metrics Associated with Space Use

In this investigation, we assumed the classical view of niche concept, as a hyper-volume in the multidimensional space of ecological variables, within which a species can maintain a viable population (Hutchinson 1957). Considering that the presence of tourists may influence some dimensions of a species' niche, niche breadth can be a useful metric for detecting impacts caused by tourist presence. Two conspicuous and abundant species, *Moenkhausia bonita* Benine, Castro and Sabino (2004) (Rio Sucuri and Córrego Olho D'Água) and *Astyanax marionae* Eigenmann 1911 (Córrego Olho D'Água) were selected for testing by niche breadth quantification, as a measure of their distribution in active as opposed to inactive sites.

Niche breadth was calculated using the Levins' index ($B = 1/\Sigma pi^2$), where B is a measure of niche breadth and pi is the measured proportion of fish abundance in relation to species space use (Krebs 1999). We quantified fish position in the water column (bottom, middle, or surface) and fish association to the internal structures of the habitat (woody debris, roots, and macrophytes).

Metrics Associated with Abundance and Behavior

This investigation started from the premise that the abundance and various key behaviors (related to reproduction and feeding) of some species may be affected by tourism activities. The cichlid, *Crenicichla lepidota* Heckel 1840 was one species investigated using this approach. *Crenicichla lepidota* individuals are common both in areas used for tourism and in preserved areas (Sabino and Andrade 2003). This species shows reproduction and biparental care of offspring associated to logs, rocks, and macrophytes. These structures can be removed with the constant passage of tourists, and hence, populations and reproductive activity may decrease in tourist sites. To test this hypothesis, the abundance of *C. lepidota* and the proportion of individuals engaged in reproductive activity was quantified in each site. Reproductive individuals were identified by the color pattern, as *C. lepidota* exhibits a darkened body, reddish belly and red patches at opercle during reproduction (José Sabino and Luciana P. Andrade, unpublished data). This metric was tested at the Rio Sucuri and Córrego Olho D'Água. A second species evaluated using the same approach was the curimatid, *Prochilodus lineatus* (Valenciennes 1837), an illiophagous species whose individuals ingest detritus from the bed (Fugi and others 1996). This is significant considering that changes in substrate composition due to tourist frequentation can affect the abundance and feeding behavior of benthic species with this type of feeding behavior. Therefore, the number of individuals and frequency of feeding were quantified.

Abundance of four other species was quantified: *Moenkhausia bonita* in both streams, *Bryconops melanurus* (Bloch 1794) in Rio Sucuri, *Hyphessobrycon eques* (Steindachner 1882) and *A. marionae* in Córrego Olho D'Água. These species were chosen because they were easily recognized during snorkeling. Moreover, *H. eques* appears to occur preferentially in areas rich in macrophytes, thus removal of these structures caused by the constant passage of tourists could possibly result in the individual's displacement to other areas. Individuals of other species exhibit nektonic behavior and are very abundant in studied streams, being apparently less dependent on the structural components of the habitat.

Sampling Procedures

Data collection was conducted in three field trips during three consecutive months (April, May and June 2008), of two days each, by two observers. Samplings were performed during daytime. The "niche breadth" metrics were sampled in sessions of 10 min, whereas "abundance and behavior" metrics were sampled in sessions of 5 min, except for species whose niche was measured, as is the case of *M. bonita* and *A. marionae*. In such cases, the observations of ten minutes for the measurement of niche served also to quantify their abundances. Samplings of each metric were taken by two observers at the same time in both active and inactive sites, avoiding biases in the data caused by fish movement between areas, which could be influenced by the presence of observers. Observers alternated sites sampled in each of the two sampling days per month. Moreover, the order of sampling the two sites in each condition was also alternated minimizing the differential effects of the order of observation in the data.

Metrics were evaluated under a spatial perspective, comparing the active and inactive sites, and also from a time perspective because there is a circadian variation in the intensity of tourist visitation in both environments. In this case, there were three temporal sampling sessions: before the start of tourist activities (07:00–08:00 AM), during the visitation (09:00–14:00 h), and after tourism activities (16:00–18:00 h). Procedures performed on the first sampling day were repeated on the second day and collected data were combined to produce average data for each month.

Statistical Analysis

Due to the scarcity of a larger number of spatial replicates, we assumed monthly samples as independent measures. Thus, six replicates for each metric were obtained, except for niche breadth of *M. bonita* at Córrego Olho D'Água, which was evaluated after the second month of study, and the niche breadth of *A. marionae*, which was not registered in the last month of study; therefore, these two metrics had a smaller number of replicates ($n = 4$ and $n = 5$, respectively).

Differences between active and inactive sites and along the gradient of daily tourist activity (before, during and after the passage of tourists) were tested separately in each stream. Because active and inactive sites were not isolated and, consequently, movements of fish between sites were possible, sites were designed as dependent samples. We compared the metrics' responses in each time interval between active and inactive sites (site effect) by using Wilcoxon Matched Pairs test in the software Statistica 7.0 (StatSoft Inc. 2004). Additionally, we used Friedman ANOVA complemented by Wilcoxon-Nemenyi-McDonald-Thompson test (Hollander and Wolfe 1999) carried out with an R package (R Development Core Team 2005) to compare the metrics' responses along the gradient of daily tourist activity (before, during and after the passage of tourists) in each site. These nonparametric tests were performed because assumptions to parametric analysis (i.e., normality and homoscedasticity) were violated.

Results

Metrics Associated with Spatial Use

Spatial niche breadth analysis of *M. bonita* in both streams and *A. marionae* in Córrego Olho D'Água indicated no differences between active and inactive sites (Wilcoxon test, $P > 0.14$). Moreover, the species did not differ regarding the use of space along the daily gradient of tourist activity in both active and inactive sites (Friedman ANOVA, $P > 0.37$).

Metrics Associated with Abundance and Behavior

Crenicichla lepidota abundance and the proportion of reproductive individuals in Córrego Olho D'Água differ between sites, with greater values in inactive sites in all periods of the day (Wilcoxon test, $P < 0.04$). There was no effect of the daily gradient of tourist activity in active and inactive sites (Friedman ANOVA, $P > 0.08$, Fig. 2).

The abundance of *P. lineatus* did not differ between active and inactive sites (Wilcoxon test, $P > 0.13$) and remained constant throughout the day (Friedman ANOVA, $P > 0.34$, Fig. 2). However, the feeding frequency of *P. lineatus* increased in active sites throughout the day after tourist activities started ($\chi^2 = 9.33$, $P < 0.01$; post hoc test, $P < 0.05$). This effect was marginally significant in the inactive sites ($\chi^2 = 5.33$, $P = 0.06$). In this case, a higher frequency of feeding behavior was registered after touristic activities in relation to the period before touristic activities (post hoc test, $P = 0.05$). Significant differences between active and inactive sites was found when comparing the feeding frequency after touristic activities started ($Z = 2.2$, $P = 0.03$).

In Rio Sucuri, *C. lepidota* and *B. melanurus* exhibited no differences in their abundances between sites (Wilcoxon test, $P > 0.11$), nor along the gradient of tourist activity (Friedman ANOVA, $P > 0.22$) (Fig. 3). In contrast, the abundance of *M. bonita* differed significantly between sites ($Z = 2.2$, $P = 0.03$), being higher in the active area. In the active sites fish abundance increased significantly after touristic activities when compared to the period before touristic activities ($\chi^2 = 10.33$, $P < 0.01$; post hoc test, $P < 0.01$; Fig. 3). There was no daily differences in the inactive areas ($P = 0.31$, Fig. 3).

The number of individuals of *M. bonita* did not differ between active and inactive sites in the Córrego Olho D'Água (Wilcoxon test, $P > 0.14$) but varied along the gradient of tourist activity, with fish abundance decreasing significantly after touristic activities in both sites ($\chi^2 = 6.5$,

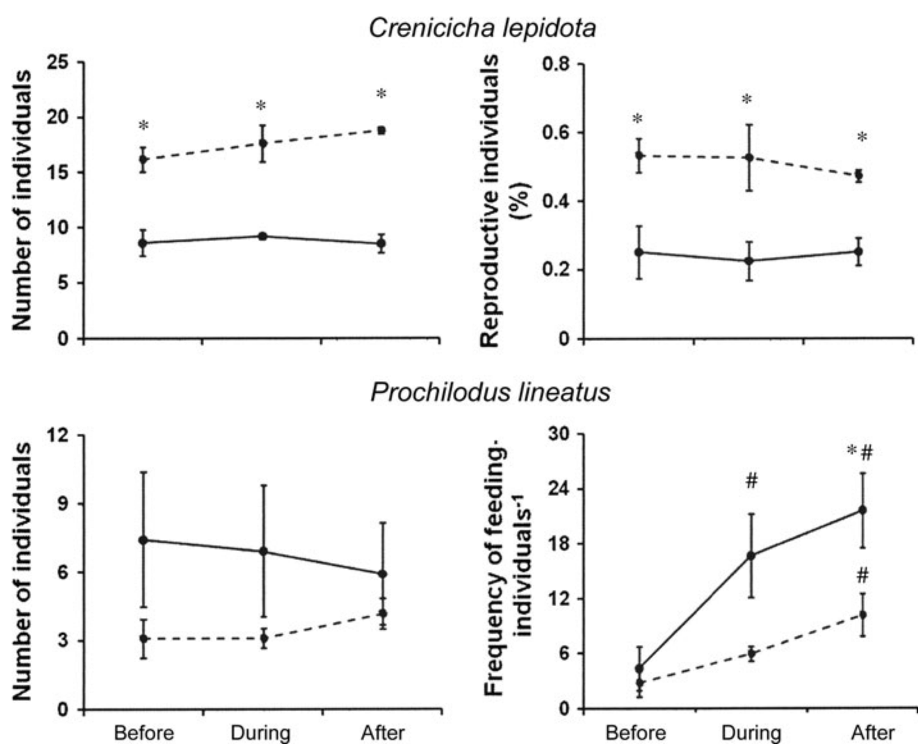

Fig. 2 Mean (±standard error) of *Crenicichla lepidota* abundance, proportion of reproductive *Crenicichla lepidota* individuals, number of *Prochilodus lineatus* individuals, and frequency of feeding per individual of *Prochilodus lineatus* in active (*solid line*) and inactive sites (*dashed line*) in Córrego Olho D'Água. Before, during and after refers to the gradient of tourism activity. * indicates significant difference between sites and # indicates significant difference in relation to period before of the tourist passage

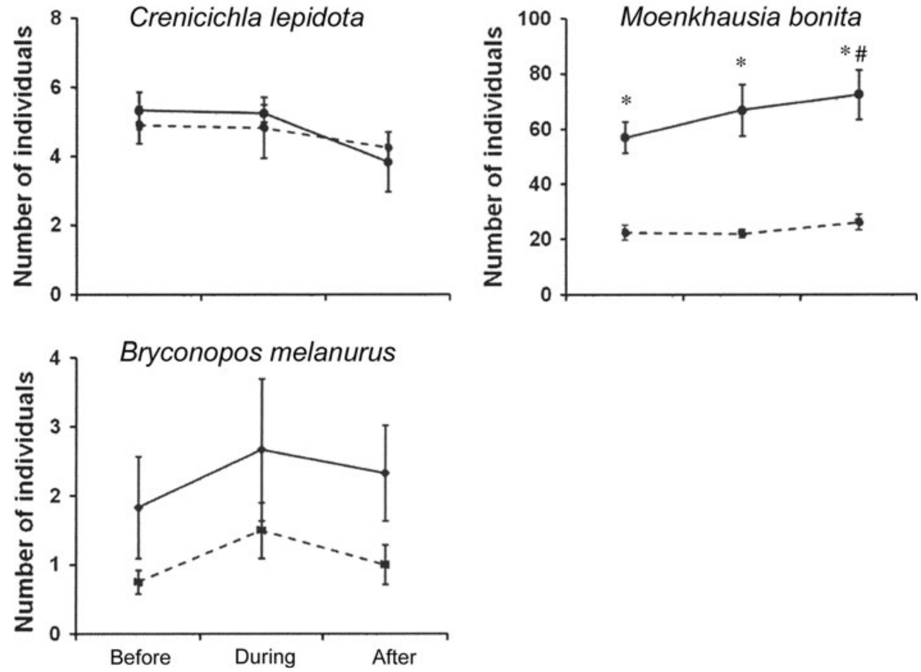

Fig. 3 Mean (±standard error) of *Crenicichla lepidota*, *Moenkhausia bonita*, and *Bryconops melanurus* abundances in active (*solid line*) and inactive sites (*dashed line*) in Rio Sucuri. Before, during and after refers to the gradient of tourist activity. * indicates significant difference between sites and # indicates significant difference in relation to period before of the tourist passage

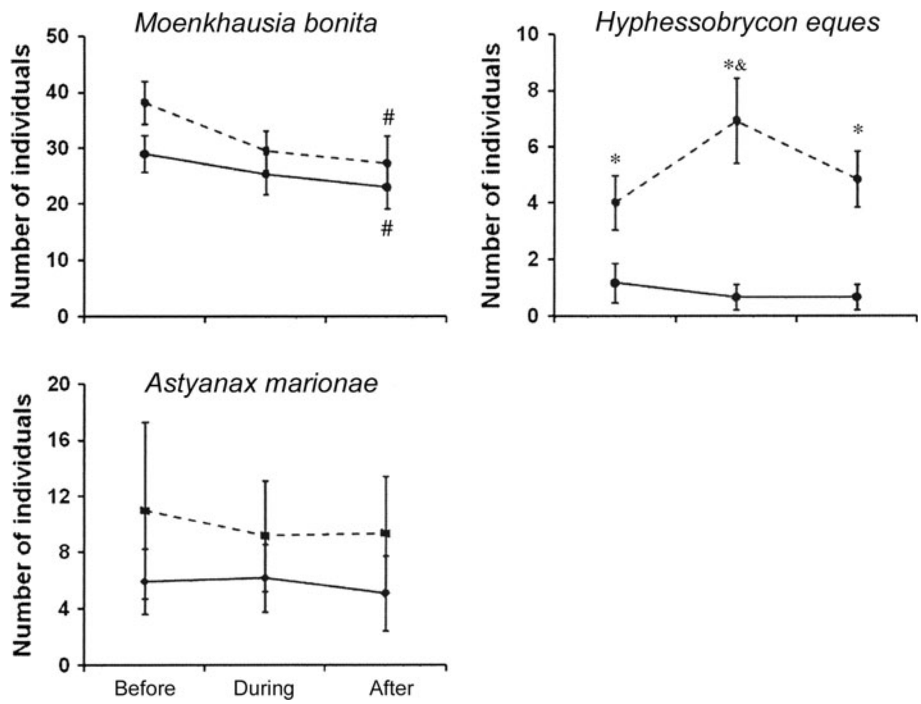

Fig. 4 Mean (±standard error) of *Moenkhausia bonita*, *Hyphessobrycon eques*, and *Astyanax marionae* abundances in active (*solid line*) and inactive sites (*dashed line*) in Córrego Olho D'Água. Before, during and after refers to the gradient of tourism activity. * indicates significant difference between sites, # indicates significant difference in relation to period before of the tourist passage and & indicates significant difference between the period during and before of the tourist passage

$P = 0.04$; post hoc test, $P = 0.03$; Fig. 4). The abundance of *H. eques* was greater in the inactive sites in all periods of the day (Wilcoxon test, $P < 0.04$). In addition, a higher abundance in the inactive sites during the passage of tourists in relation to the previous period was observed ($\chi^2 = 6.9$, $P = 0.03$; post hoc test, $P = 0.02$; Fig. 4). Abundance of *Astyanax marionae* did not differ between sites (Wilcoxon test, $P > 0.40$) or throughout the day (Friedman ANOVA, $P > 0.38$; Fig. 4).

Discussion

According to the general hypothesis of this study, the constant movement of tourists in the active areas would force the displacement of species swimming in the water column, such as *M. bonita* and *A. marionae*. However, changes in patterns of space use were not confirmed by assessing niche breadth. The tourists' passage actually resulted in fish displacement to adjacent areas, but only momentarily; the fish quickly returned once the tourists had passed. Changes in space use by animals in response to direct or indirect human disturbance in tourist areas has been demonstrated for different species (Stalmaster and Newman 1978; Klein and others 1995; Gill 2007). While some species are clearly affected by recreational activities, others show little sensitivity to these momentary disturbances (Cooke 1980; Gill 2007), as seems to be the case of *M. bonita* and *A. marionae* regarding space use.

The assessment of abundance in active and inactive sites showed a species-specific response to disturbance. While some species did not change their abundance pattern due to tourist disturbance (such as *B. melanurus*, *P. lineatus*, and *A. marionae*) others (such as *M. bonita*, *C. lepidota*, and *H. eques*) were responsive to these changes. One of the most important dimension of a species affected by tourism is increase in food supply, which has the potential to change patterns of species abundance (Cole 1994; Ilarri and others 2008). In this context, the higher abundance of *M. bonita* in the active sites of the Rio Sucuri could be due to the sediment suspension caused by contact of tourists with the river bed, which could cause the suspension of previously unavailable food items from the substrate. This interpretation is consistent with the trend of an increase in *M. bonita* abundance after tourist activities started in the Rio Sucuri (see Fig. 3), a pattern not registered in inactive sites. However, there were no differences regarding abundance of *M. bonita* in the Córrego Olho D'Água. In this case, structural differences between active and inactive sites may generate other factors such as risk of predation, competition and food availability, which influence fish habitat use and foraging (Godin 1997; Gill and others 2001; Vehanem 2003). The direct and indirect effects of structural differences in the Córrego Olho D'Água may have interacted with the possible increase in food supply caused by tourist passage, generating different results in relation to those observed in the Rio Sucuri. Although no difference in the abundance of *M. bonita* between sites was observed in the Córrego Olho D'Água, a tendency of reduction in the abundance of this species along time was registered. This effect was similar in both active and inactive sites, suggesting a circadian natural variation in the spatial occupation of this species.

The differences in *C. lepidota* and *H. eques* abundances seem to have causes other than those assigned to *M. bonita*. *Crenicichla lepidota* is a species whose reproductive cycle is associated to macrophytes and woody debris located in the substrate (Sabino and Andrade 2003) and *H. eques* is a typical species of backwater areas and is normally associated with macrophytes (Casatti and others 2003). The lower abundance of these species in the Córrego Olho D'Água active sites is probably due to habitat simplification caused by the removal of structures such as macrophytes and woody debris caused by tourist activities. This effect dependence on structural variability is reinforced by the results obtained in Rio Sucuri, where active and inactive sites showed similar structural complexity and populations of *C. lepidota* with similar size. Active sites of the Córrego Olho D'Água, besides having a lower abundance of *C. lepidota*, also maintained a smaller proportion of individuals engaged in reproductive activity. This is a species whose reproductive behavior follows the pattern of Neotropical cichlids, showing formation of couples, establishment and defense of territory where mating and care for their offspring occur (Barlow 1974; Keenleyside 1991). Individuals spawn in cavities on the bottom, preferentially in trunks and roots associated with macrophytes. Therefore, any changes in habitat that result in the removal of these structures provide a reduction in the availability of breeding sites.

The substrate of the active sites is constantly stirred by the passage of tourists, which may cause the reduction of organic matter deposited on the bottom. In contrast, the absence of disturbance to the substrate in the inactive sites contributes to an accumulation of detritus, which can be even greater due to the abundance of macrophytes present in these areas. Moreover, the higher density of macrophytes banks contribute to the maintenance of higher amounts of detritus because those banks represent natural buffers reducing the influence of water flow on the substrate loading (Pusey and Arthington 2003). These evidences suggests more stable food availability for benthic species in the form of organic matter present on the bottom of Córrego Olho D'Água inactive sites. Thus, increased feeding activity of *P. lineatus* in the active sites may represent a compensatory response to reduced availability of food in these areas. Furthermore, the increase in feeding frequency over time seems to reflect a circadian pattern of their feeding behavior rather than a response to the start of tourist activities because this increase occurred in both areas. This is consistent with the pattern of diurnal feeding of *P. lineatus* evidenced by Fugi and others (1996) in reservoirs.

To conclude, five metrics were sensitive to tourism disturbances in streams of the Bodoquena Plateau. All involve the evaluation of populational attributes that are easily recognized during snorkeling. These characteristics ensure the feasibility of using these metrics in monitoring programs of environmental impacts caused by tourism activities in aquatic environments and may be applied by technicians after quick guides and training. Except for the feeding frequency of *P. lineatus* and abundance of *M. bonita*, which apparently respond to differential food availability, the other sensitive metrics are useful to indicate the indirect effects of tourist activities on fish assemblages through structural habitat modification. The relevance of the recognition of these metrics is reinforced by the fact that degradation of ecosystem structural elements is one of the main impacts of recreational activities in aquatic environments (Uy and others 2005; Hasler and Ott 2008).

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