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Habitat use by *Astyanax taeniatus* (Jenyns, 1842) (Characiformes: Characidae) in a coastal stream from Southeast Brazil

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The habitat use of a stream-dwelling *Astyanax taeniatus* from the State of Rio de Janeiro was investigated. We performed 12 h of underwater observation in a 200 m long stretch in the upper Roncador stream and quantified the following microhabitat descriptors: (i) water velocity, (ii) distance from the stream bank, (iii) substratum, and (iv) water column depth. Microhabitat selectivity was analyzed by comparing the microhabitat used by fish and the microhabitat available in the study site as well as by applying the Ivlev Electivity Index to the microhabitat use data. Differences in the use and availability of the various microhabitats revealed non-stochastic patterns of spatial occupation by *A. taeniatus*, which was selective for two of the four analyzed microhabitats. Our findings indicated that *A. taeniatus* is associated with habitats that have higher depths, low water velocity, and sand and bedrock substratum.

O uso do micro-habitat por *Astyanax taeniatus* de riacho do estado do Rio de Janeiro foi investigado. Realizamos 12 h de observações subaquáticas em um trecho de 200 m do alto rio Roncador e quantificamos os seguintes descritores do micro-habitat: (i) velocidade da água, (ii) distância da margem, (iii) substrato, e (iv) profundidade da coluna d'água. A seletividade do micro-habitat foi analisada pela comparação do micro-habitat usado pelos peixes e o micro-habitat disponível na área de estudo, bem como pelo Índice de Eletividade de Ivlev aplicado aos dados de uso do micro-habitat. As diferenças no uso e disponibilidade dos diferentes descritores do micro-habitat revelaram um padrão não aleatório para a ocupação especial por *A. taeniatus* que foi seletivo para dois dentre quatro descritores analisados. Nossos registros indicaram que *A. taeniatus* está associado à habitats com maior profundidade, baixa velocidade da água e substrato de areia e rocha.

Key words: Snorkeling, Micro-habitat, Rain Forest, Non-stochastic use, Environmental resources.

Introduction

The spatial segregation of individuals due to differences in resource use is an important aspect of population and community structure (Ross, 1986; Arlettaz, 1999). Fish species have specific patterns of habitat use and feeding and reproductive strategies that allow only a few species to occupy the same space (Weatherley, 1963), and therefore, these species segregate in the available space (Roff, 1992).

The different habitats used by stream-dwelling fish can be defined at different scales. The mesohabitat represents large-scale physical units determined by the presence of riffles, runs, and pools (Angermeier & Schlosser, 1989), and the most important differences between these units are related to water velocity and substratum. On a minor scale, the microhabitat represents specific subunits of the mesohabitats with specific physical structural components (Sedell *et al*., 1990). Microhabitats can be recognized in relation to the focal position of the fish (*e.g.*, water velocity, depth) (Inoue & Nunokawa, 2002). Heterogeneous environments provide a greater variety of microhabitats with protected places where fish can shelter themselves from predators and where they can find a wide range of food resources and sites for reproduction (Wootton, 1998).

Studies concerning the use of microhabitats are normally focused on the description of local areas used by fish (Rincón, 1999). The physical habitats and the specific microhabitat used by different species have been studied due to their influence

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on the structure of stream-dwelling fish communities (Rincón & Lobón-Cerviá, 1993; Suen & Su, 2010; Lee & Suen, 2012). Nonetheless, the habitats used by fish are also strongly influenced by the availability of food and resource partitioning (Gray & Stauffer-Jr., 1999; Yamasaki *et al.*, 2006) and the predominance of different environmental characteristics, such as water depth, flow velocity and type of substrate (Wootton, 1998; Mazzoni *et al.*, 2011). Fish behavior and swimming performance can also cause a different spatial distribution among the species in a community (Uieda, 1984; Sabino, 1999).

Characiformes are very active fish and have very pronounced spatial exploratory behavior (Sazima, 1980). *Astyanax* species are prone to using different microhabitat resources (Uieda, 1984; Aranha *et al.*, 1998; Mazzoni *et al.*, 2004; Barreto & Aranha, 2005), but they are more frequently found inhabiting pools and runs with moderate currents and sand and gravel substrata (Fogaça *et al.*, 2003; Rezende *et al.*, 2010). In the present study, we aimed to quantify the used and available resources to address whether *Astyanax taeniatus* (Jenyns, 1842) has a stochastic or selective use of the microhabitats in a rain forest stream in the Mata Atlântica. This species was chosen because it was the most abundant Characiform species in the studied stream and is an excellent model to address issues related to the use of environmental resources (Aranha *et al.*, 1998; Mazzoni *et al.*, 2004).

Material and Methods

Study Area

Fieldwork was conducted at Roncador stream, which is part of the Mato Grosso fluvial system in the Northeast of Rio de Janeiro State (22°53'S 42°39'W). Roncador is a second-order stream and flows for approximately 12 km. Its headwaters are located at 500 m in Serra do Mato Grosso, and it discharges into the Saquarema Lagoon. The study site was chosen because the fish density was sufficiently high to obtain numerous observations of *Astyanax taeniatus* and to minimize the probability of making more than one observation of the same individual. Roncador stream presents heterogeneous physical properties and a wide range of available microhabitats with different characteristics, allowing for the differentiation between stochastic and selective use of the microhabitats.

Data collection and analysis

Data records were obtained for individuals of *Astyanax taeniatus* in a 200 m long stretch of the Mato Grosso stream. Microhabitat surveys were conducted through underwater observation (snorkeling) in two sampling sessions, during the wet and the dry seasons of 2010. Each sampling session lasted for 6 h with sessions of 30 min, totaling 12 h of underwater observation during the entire study.

The surveys were conducted in two stages: (i) quantification of microhabitat resources used by individual fish and (ii) quantification of microhabitat resources available along the study area. Microhabitat use was quantified according to a focal individual approach (*sensu* Altmann, 1974). At the beginning of each diving session, the diver laid calm for 10 min downstream of the site to allow the fish become accustomed to the observer, and then the diver moved from the lower to the upper section of the study site. For each observed fish, resource descriptors (Table 1) and fish size (standard length) were recorded.

Microhabitat availability was quantified along the study site. Fifty transects perpendicular to the water flow were established 5 m apart from each other along 245 m of the study site. At each transect, five microhabitat parameters (Table 1) were recorded in 0.4x0.4 m (0.16 m^2) quadrats. The

Table 1. Microhabitat descriptors and their respective measurements for fish use and environmental availability measurements applied for the microhabitat study of *Astyanax taeniatus* from Roncador stream.

Environmental Descriptors	Description	Use Measurement	Availability Measurement
Distance from the nearest bank (cm)	Distance from the stream bank to a given point in the stream channel Measured with a measuring tape	Distance from the stream bank to the fish focal position	Distance from the stream bank to a place where the quadrats were placed
Water Velocity (m/sec)	Water velocity measured through a fluxometer probe	Water velocity measured at the fish focal position	Water velocity measured where the quadrats were placed
Stream Width (m)	Distance from one to another stream bank. Measured through a measuring tape	Distance from one to another stream bank in the fish focal position	Distance from one to another stream bank where the quadrats were placed
Substratum	Substratum types occurring in the study site: (i) mud – particles < 0.2 cm and subject to suspension; (ii) sand - particles 0.2 cm ≥ 2.5 cm; (iii) gravel - particles 2.5 cm > 5.0 cm; (iv) boulder - particles 5.0 cm > 30 cm; and (v) bedrock - particles > 30 cm	Percentage of each substratum type measured just below the fish focal position	Percentage of each substratum type measured just below the quadrats
Water Column Depth (cm)	Distance from the water surface to the stream bottom	Distance from the water surface to the fish focal position	Distance from the water surface to a place where the quadrats were placed

position of each quadrat was selected among four points along the transect: (1) position on the right shore (10 cm from the bank), (2) position in the first third of the channel, (3) position in the second third of the channel and (4) position on the left shore (10 cm from the bank). The sampled quadrats represented 4% of the total area of the studied stream stretch.

The substrate was classified into five categories according to particle size: mud (particles <0.2 cm and subject to suspension); sand (particles 0.2 cm > 2.5 cm); gravel (particles 2.5 cm > 5.0 cm); boulder (particles 5.0 cm > 30 cm); and bedrock (particles > 30 cm). Water velocity was classified into five categories based on Gorman (1988): very slow (<0.10 m/sec); slow (0.10-0.25 m/sec); moderate (0.25-0.75 m/sec); fast (0.75-1.25 m/sec); and torrential (>1.25 m/sec). The existence of correlations among the predictor variables was tested by performing Pearson correlations between all pairs of variables.

Differences in the frequency of each category within each variable between used and available resources were evaluated using Chi-square tests with the Yates correction when necessary, using a significance value of $p < 0.05$ (Zar, 1999). The Electivity Index (Ei) (Krebs, 1989): Ei = (Ui - Ai)/(Ui+Ai), where Ui = fish proportion using resource i and Ai = available proportion of resource i, was applied to test the preference/avoidance of each microhabitat resource. Ei ranges from -1 to +1, where positive values indicate preference and negative values indicate avoidance of a given resource. Voucher specimens of *A. taeniatus* were placed at the Ichthyological Collection of Museu Nacional, Rio de Janeiro (MNRJ 29949 and MNRJ 29950).

Results

Resources available in the study site were quantified in 200 quadrats, totaling 32 m^2, established within the total sampling area of 400 m^2. The analysis of microhabitat availability revealed that the studied site was quite heterogeneously represented by (i) areas of pools (deep areas with low water velocity, sand, and mud substrata); (ii) areas of runs (moderate water velocity areas without visually apparent surface turbulence, with gravel and bedrock substrata); and (iii) areas of riffles (shallow and high water velocity with high, visually apparent surface turbulence and with boulder and gravel substrata) (Table 2). We observed 50 adult individuals with lengths varying from 3.9 cm to 6.3 cm (average of 5.3 cm). *Astyanax taeniatus* was observed inhabiting the water column, organized in shoals (80% of the observations) and, on average, 9 cm from the riverbank. The individuals were frequently in groups of up to 30 individuals swimming in the water column and spending much of the time foraging in environments with moderate currents. Only adult individuals (> 3.8) were observed in the study site.

Correlation analysis among the predictor variables revealed two cases of significant positive correlations: distance from the nearest stream bank and stream width ($R^2 = 0.185$; $p < 0.005$) and water velocity and sand substrate ($R^2 = 0.191$; $p < 0.005$). We eliminated stream width from further analysis but retained water velocity and sand substrate due to their importance for many aspects of fish life history and microhabitat use.

Table 2. Environmental characterization of the study site at Roncador stream, including maximum, minimum and mean of depth; water velocity and stream width; and percentage values of substratum type: bedrock, boulder (diameter between 5.0 and 30.0 cm), gravel (diameter between 2.5 and 5.0 cm), sand, and mud.

Variable	Mean	Minimum	Maximum
Water column depth (cm)	23.3	2.00	75.00
Water velocity (m/sec)	0.6	0.00	4.25
Channel width (m)	3.3	1.05	6.25
Substratum Type		%	
Bedrock		15	
Boulder		18	
Gravel		15	
Sand		24	
Mud		28	

Differences in the use and availability of the microhabitat descriptors revealed non-stochastic patterns of microhabitat use by *A. taeniatus*. The water column depth varied from 2 to 75 cm along the study site, but individuals of *A. taeniatus* showed significant differences ($\chi^2 = 24.6$; df = 4; $p < 0.001$) in the use of this microhabitat. According to the Ivlev index, individuals showed a preference for depths between 30 and 75 cm and avoidance of depths below 30 cm (Fig. 1a). The water velocity varied from 0 m/sec to 4.0 m/sec, but those between 0.25 m/sec and 0.75 m/sec were the most frequently used without significant differences ($\chi^2 = 2.8$; df = 4; $p>0.25$ - Fig. 1b). Positive values of Ivlev index were expressed only for slow and moderate water velocities. All types of substrata occurred in similar proportions along the study site, but bedrock and sand were significantly the most used ($\chi^2 = 30.6$; df = 4; $p <0.001$) as shown by the Ivlev index (Fig. 1c). The distance from the stream bank (lateral position) varied from 0 to 200 cm and presented the same incidence along the study site. The use of this variable did not show a significant difference ($\chi^2 = 6.8$; df = 4; $p>0.25$), as indicated by a close to zero Ivlev index in all positions (Fig. 1d).

Discussion

The use of habitats by fish can be related to many life-history features, including morphology (Wootton, 1998), reproductive requirements (Munro, 1990) and body size (Davey *et al.*, 2005; Beyer *et al.*, 2007). For the studied species, we recorded a clear case of size selective segregation, as only adult individuals were observed in the upstream area during the study. Following this same pattern, *A. janeiroensis* segregated along a coastal stream in response to reproductive requirements, and only adult (*i.e.*, larger) individuals were found in the upstream stretches of the studied area (Mazzoni *et al.*, 2004). This pattern of distribution explains why we limited our analysis to only adult individuals of *A. taeniatus*, and it assured that our analyses were not biased by the

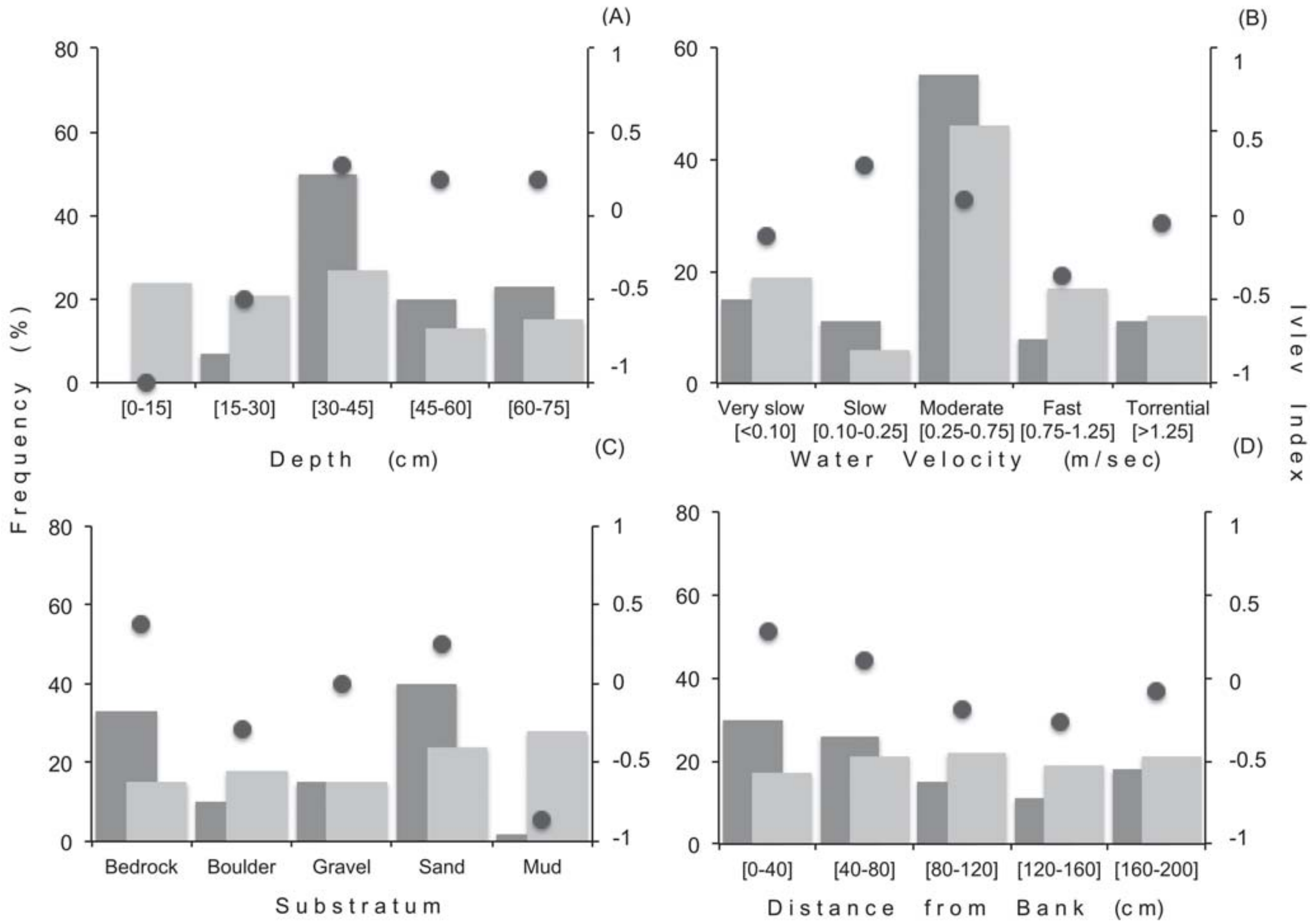

Fig. 1. Availability (light grey bars), use (dark grey bars), and Ivlev Index (black circles) for the four studied microhabitat parameters affecting *Astyanax taeniatus* from Roncador stream: (A) total depth; (B) focal water velocity; (C) substratum; (D) distance from the nearest bank.

specific behaviors of fish of different ages. Nonetheless, the study site contained all the mesohabitats frequently found in many rain forest streams from the Mata Atlântica (Mazzoni *et al*., 2011), including a combination of depths, water velocities and substrata, which represented pools, runs, and riffles, creating conditions suitable for high species diversity (Angermeier & Schlosser, 1989; Ceneviva-Bastos *et al*., 2010).

Depths below 30 cm were avoided by the studied species; this is a typical behavior of mid-water pelagic fish (Costa, 1987; Casatti, 2002; Fogaça *et al*., 2003; Abilhoa *et al*., 2008). Concerning this position in the water column, body shape and fin morphology can influence ecological performance characteristics, such as hydrodynamics, swimming speed, maneuverability and habitat use (Motta, 1988; Gibran, 2007). *Astyanax taeniatus*, as well as many other *Astyanax* species (Uieda, 1984; Abilhoa *et al*., 2008), also selected slow to moderate water velocities with bedrock and sandy bottoms. Ceneviva-Bastos *et al.* (2010) observed two *Astyanax* species associated with sandy bottoms. These patterns of habitat use could be reflecting the feeding tactics frequently described for *Astyanax* species that forage in the water column, feeding on drift items available throughout the year in these coastal streams (Motta, 1988; Motta *et al*., 1995; Casatti & Castro, 2006; Gibran, 2007). *Astyanax* species are highly active with a marked exploratory behavior (Fogaça *et al*., 2003), and this behavior was in agreement with that observed for *A. taeniatus* in the present study, as well as elsewhere (Manna *et al*., 2012). The fish collected drifting food items, mostly terrestrial plant and debris, and are therefore characterized as "drift feeders" (*sensu* Sazima, 1986), corroborating other studies based on *Astyanax* species (Costa, 1987; Casatti, 2002; Abilhoa *et al*., 2008).

Predation, intraspecific competition, and foraging efficiency can influence the selection for deep areas of the water column (Punchard *et al*., 2000), apart from the observation that shoaling behavior appears to be an important foraging strategy (Medeiros *et al*., 2010). This strategy could be an important factor leading to a non-stochastic spatial distribution by *A. taeniatus* in Roncador stream. In addition to this feature, habitat selection was recognized as a hierarchical process in which macro- and microhabitats are selected following decisions related to the reduction of predation risk (Kramer *et al.*, 1997). Avoiding shallow waters has been reported as a strategy related to reduce predation risk and to avoid refuge-poor areas (Liefferinge *et al*., 2005). In fact, the shallow areas of these coastal streams tend to be avoided by small fish species due the presence of ambush predators, such as *H. malabaricus* (Mazzoni & Iglesias-Rios, 2002; Brejão *et al.*, 2013), and aquatic birds that are very abundant in the study area.

The microhabitat parameters selected by *Astyanax taeniatus* cover a set of characteristics that describe areas of runs similar to those occupied by many *Astyanax* species from Mata Atlântica streams (Ceneviva-Bastos *et al.*, 2010; Teresa & Casatti, 2013; Costa, 1987; Casatti, 2002; Fogaça *et al.*, 2003; Abilhoa *et al.*, 2008). Nonetheless, *A. taeniatus* was characterized as a pool indicator in another coastal stream of the same basin (Rezende *et al.*, 2010), corroborating the findings of Romero & Casatti (2012) that discuss the adaptive niche plasticity of *Astyanax* species that allows the species to use a broader array of microhabitats and environmental features. Stream-dwelling fish species can be very plastic and tolerant to environmental changes (Abelha *et al.*, 2001; Luz-Agostinho *et al.*, 2006; Menezes *et al.*, 2007; Manna *et al.*, 2012), and differences in habitat availability could be responsible for different patterns of habitat use by this group of species (Schlosser, 1982).

In summary, *Astyanax taeniatus* presented a non-stochastic habitat use reflecting the preference of runs characterized by deep areas with low to moderate currents and sand or bedrock substrate. Thus, the combination of all these physical parameters and their availability in the studied stream could be an important factor in the maintenance of this species in the Mato Grosso fluvial system. These results could also be used as basic parameters for the understanding of habitat use by other *Astyanax* species because many species of this genus respond similarly to environmental resources.

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