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Following food clouds: feeding association between a minute loricariid and a characidiin species in an Atlantic Forest stream, Southeastern Brazil

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Following behavior is a widespread feeding tactic among marine fishes, but remains poorly documented for freshwater fishes. The present study describes such association between two freshwater species: the minute armored catfish *Parotocinclus maculicauda* and the South American darter *Characidium* sp. During underwater observations in an Atlantic Forest stream, we recorded *Characidium* sp. closely following *P. maculicauda* (<5cm), catching the particles dislodged by this catfish's grazing activity. The following behavior displayed by the darter is considered opportunistic and possibly favors the capture of preys associated to the periphyton. This study is one of the few records of nuclear-follower feeding association between freshwater fishes and the first one in Atlantic Forest streams.

O comportamento seguidor é uma tática de forrageio bastante conhecida entre peixes marinhos, mas pouco documentada para peixes de água doce. O presente estudo descreve essa associação alimentar entre duas espécies de riacho: o cascudinho *Parotocinclus maculicauda* e o peixe-canivete *Characidium* sp. Por meio de sessões de observação subaquática, *Characidium* sp. foi registrado seguindo *P. maculicauda* (<5cm), abocanhando partículas deslocadas pela atividade de pastejo do cascudinho. Esse tipo de comportamento do peixe seguidor é considerado oportunista e possivelmente favorece a captura de presas associadas ao perifíton. Trata-se de um dos poucos registros de associação alimentar do tipo nuclear-seguidor entre peixes de água doce e o primeiro para riachos de Mata Atlântica.

Key words: Following behavior, foraging habits, freshwater, Hypoptopomatinae, Crenuchidae.

Introduction

Feeding associations may comprise a large number and a diverse array of organisms and foraging tactics, including the so-called nuclear-follower association. This interspecific interaction is characterized by the presence of a nuclear species that promote some kind of disturbance on the bottom while foraging, and a follower species that feeds on items exposed or flushed out by the former (Fricke, 1975; Sazima, 1986; Strand, 1988).

Records of following behavior are recurrent in marine ecosystems, mainly among coral reef fishes (*e.g.* Strand, 1988; Baird, 1993; Silvano, 2001; Sazima & Grossman, 2005; Sazima *et al*., 2005; 2006a, 2006b). In the Gulf of California, almost half of the resident reef fishes was recorded as follower species (Strand, 1988). Sazima *et al*. (2006b) report that approximately 20% of the reef fish fauna of Fernando de Noronha Archipelago (tropical West Atlantic) engage in a nuclear-follower association and that nearly 50% of the fish species that forage by disturbing the bottom act as nuclear species. Besides fishes, other marine organisms like octopuses, sea stars and even turtles were recorded to behave as nuclear species in this kind of feeding association (*e.g.* Diamant & Shpigel, 1985; Gibran, 2002; Sazima *et al*., 2004).

Among freshwater fishes, however, nuclear-follower association records are scarce, but interactions between two species of cypriniforms from North American streams (Baker & Foster, 1994) and cichlids from an African lake (Stauffer *et al*., 1996) qualify as following associations. In the Neotropics, Sazima (1986) recorded *Astyanax bimaculatus* (Characidae) as a follower species that feeds on insects, crustaceans, plant debris and algae flushed out by the foraging activity of *Corydoras polystictus* (Callichthyidae) in a freshwater pond in the Brazilian Pantanal. Sabino & Sazima (1999) reported a remarkable case of monkeys (*Cebus apella*) followed by schools of the characid fish *Brycon microlepis* (= *hilarii*),

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that readily took the fruits dropped in the water by the monkey's destructive foraging in the riparian forest at Bonito region, Paraguay River drainage.

We describe herein a case of feeding association between two freshwater fishes in an Atlantic Forest stream in Southeastern Brazil, involving the minute suckermouth catfish *Parotocinclus maculicauda* (Siluriformes: Loricariidae) as the nuclear species, and the South American darter *Characidium* sp. (Characiformes: Crenuchidae) as the follower one.

Material and Methods

The study was conducted in rio do Ouro (22°17'15"S, 42°00'37"W), a fourth order tributary of rio São Pedro, Macaé river basin, northern Rio de Janeiro state. The sampled stream stretch is bordered by a second-growth Atlantic Forest and is characterized by clear water with rocks, logs and dead leaves banks scattered over a sand bottom substrate. The studied stream reach was 20m in length, less than one meter deep and 3-10m wide, with water level variations in function of local rainfall and seasonal dynamics.

We performed diurnal direct observations of the association between individuals of *Parotocinclus maculicauda* and *Characidium* sp. while snorkeling, using the sequence sampling method (*cf.* Lehner, 1979). Each monthly session lasted about 40 min and was conducted in February, March, July and September 2005, totaling four sessions and 160 min of sampling. Following interactions were registered *in situ* by means of underwater photographs. Voucher specimens of *P. maculicauda* and *Characidium* sp. were deposited in the Fish Collection of Museu Nacional do Rio de Janeiro (MNRJ 30875, MNRJ 30877, MNRJ 30878, MNRJ 30882). *Characidium* sp. is a new species and will be described elsewhere (P. A. Buckup and R. P. Leitão, in prep.).

Results

Nuclear-follower associations between *Parotocinclus maculicauda* and *Characidium* sp. were recorded in three of the four observation sessions (February, March and July). The association was registered only when both fish species were positioned on a rocky substrate (large rocks up to 1m in diameter) covered by periphyton and a fine sediment layer, in areas of high water flow (current speed up to 50cm/s at the stream bottom). Individuals of the minute catfish *P. maculicauda* were observed grazing singly or in groups on periphytic algae attached to the rocks, making head and body movements over short distances ahead and sideways during foraging [see Buck & Sazima (1995) for examples of such movements in other Loricariidae]. When foraging the catfish occasionally drifted downstream for a short distance displaced by the water flow, but quickly resumed its position. This activity set frequently suspended the sediment deposited on the rock surface, resulting in small clouds of particles drifting away and quickly dispersing by the fast flowing water.

The feeding association was characterized by the presence of a single individual of *Characidium* sp. standing downstream of, and in close proximity (ca. 5cm) with the foraging catfish (Fig. 1). At this position, the darter adopted a sit-and-wait foraging tactic (*sensu* Sazima, 1986) and fed on particles suspended by the grazing activity of the catfish (Fig. 2). The nuclear-follower interaction lasted between a few seconds to about five minutes and each of these events occasionally occurred more than once during the 40 min observation session.

Although we observed a ratio of one individual of *Characidium* sp. to about 15 *P. maculicauda*, feeding association events comprised almost always only one individual of each species. However, we observed a single case of one individual of the darter alternately following two closely positioned catfishes.

Discussion

Parotocinclus maculicauda is a small sized catfish that apparently doesn't produce a high substrate disturbance during its foraging. Nevertheless, this species clearly played the nuclear role in the feeding association herein observed. Although this role isn't strictly performed by bottom disturbing organisms, substrate disturbance is considered a strong predictor of the nuclear role in a nuclear-follower association (Sazima *et al*., 2006b). In the studied stream, a characteristic bottom-dwelling species that stirs up a dense sediment cloud is the bearded cory *Scleromystax barbatus*, Callichthyidae (RPL, pers. obs.); however, no feeding associations involving this species was yet observed in rio do Ouro. Sazima (1986) registered another callichthyid species, *Corydoras polystictus*, being followed by *Astyanax bimaculatus* during its foraging activity in a Pantanal pond. It is possible that differences in microhabitat preferences by *Characidium* sp. and *Scleromystax barbatus* in rio do Ouro may impair the occurrence of a feeding association between these two species.

Dislodging sediment, algae and (possibly) small animals during foraging activities of loricariid catfishes was already observed by Buck & Sazima (1995) in an Atlantic Forest stream, but without any records of following associations such as the observed in the present study. Species of the genus *Characidium* are known to feed predominantly on substrate-dwelling aquatic insect larvae (Godoy, 1975; Costa, 1987; Sabino & Castro, 1990; Castro & Casatti, 1997; Uieda *et al.*, 1997; Aranha *et al.*, 2000; M. P. Albrecht, pers. comm.). Chironomidae (Diptera) larvae were the most abundant item on the diet of *Characidium fasciatum* and *C. gomesi* in Mogi-Guaçu river basin (Godoy, 1975). Besides Chironomidae, Ephemeroptera nymphs and Simuliidae larvae were the most important items on the diet of *C. lanei* and *C. pterostictum* in Cabral stream, Paraná State, Southern Brazil (Aranha *et al*., 2000). Considering the benthic habits and the small size of those insect preys, we believe that the foraging activities of *P. maculicauda* on the fine sediment-periphyton layer over

Fig. 1. An individual of *Characidium* sp. positioned behind a grazing catfish, *Parotocinclus maculicauda*, on a large submerged rock in a fast flowing stretch of the rio do Ouro stream. Photo by R. Leitão.

the rocks could dislodge these items and make them available for *Characidium* sp.

Behavioral studies on *Characidium* species (*e.g.* Sazima, 1986; Sabino & Castro, 1990; Aranha *et al.*, 1998; Sabino & Silva, 2004, Zuanon *et al*., 2006) revealed the use of two main foraging tactics: "sit-and-wait predation" (*sensu* Sazima, 1986), in which the fish stays stationary on the bottom and preys on small invertebrates spotted in the bottom or drifted by the current; and "hunting by speculation" (*sensu* Curio, 1976), in which the fish actively search for preys buried in the upper layer of the substrate. In this sense, we suggest that the following behavior displayed by *Characidium* sp. represents a modified sit-and-wait foraging tactic, capitalizing upon a food supply (previously attached to the substrate) provided by the catfish's feeding activity. The second foraging tactic was not registered to *Characidum* sp. in our observations in rio do Ouro.

Individuals of *P. maculicauda* were observed predominantly in the middle portion of the stream channel, occupying spots with high water flow and hard substrates like rocks, logs, and twigs (RPL, pers. obs.). Besides *Characidium* sp., other *Characidium* species are known to occupy sites with swift water current (Costa, 1987; Sabino & Castro, 1990; Aranha *et al.*, 1998), over gravel and rock bottom (our pers. obs.). A high amount of preys per unit of time may be available under swift water flow (Fausch, 1984); however, the ability of some fishes to locate and catch them is lessened under this condition (Hill & Grossman, 1993), which may be possible in the case of *Characidium* sp. Thus, the feeding association of *Characidium* sp. with *P. maculicauda* would enhance its foraging success.

The feeding association reported herein possibly occurs because the two species occupy similar microhabitats, and forage during the same daytime period. *Characidium* species are diurnal foragers, as most of the Characiformes (Lowe-McConnell, 1987; Sabino & Castro, 1990). On the other hand, the vast majority of catfishes (Siluriformes) are typically nocturnal (Lowe-McConnell, 1987). However, the diurnal habits of the "cascudinhos" of the subfamily Hypoptopomatinae represent one of the exceptions among the catfishes in general and among the Loricariidae in particular (Buck & Sazima, 1995; Schaefer, 2003). In fact, *P. maculicauda* was found more active and in higher abundances during the daylight period, when compared with nocturnal observations in rio do Ouro (RPL, pers. obs.). Finally, we believe that the scarcity of records of this kind of behavioral interaction among freshwater fishes mainly reflects the lack of natural history studies in such environments, rather than its rarity.

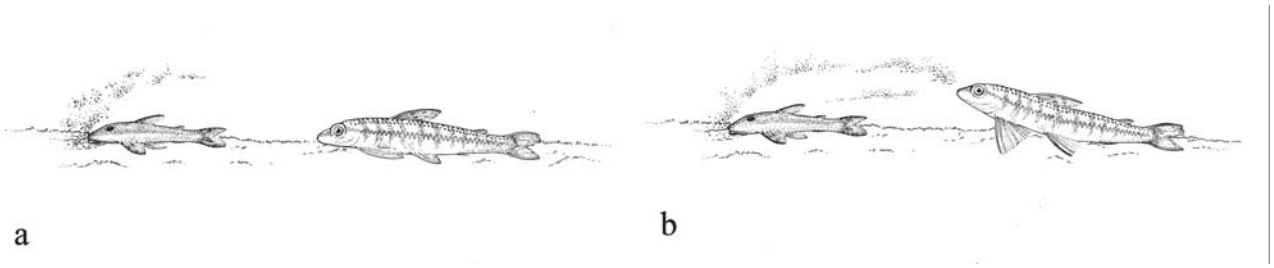

Fig. 2. The grazing activity of *Parotocinclus maculicauda* that dislodges particles, resulting in small clouds (a); and *Characidium* sp. standing downstream of the foraging catfish, adopting a sit-and-wait foraging tactic to feed on the particles (b). Illustration by A. Peixoto.

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