Short Communication

Indirect evidence of following association between golden dorados (*Salminus brasiliensis*) and green anacondas (*Eunectes murinus*) in a clearwater river of Midwest Brazil

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Abstract: On four occasions, the golden dorado (*Salminus brasiliensis*) was recorded following the green anaconda (*Eunectes murinus*) in a clearwater river of Midwest Brazil. These observations were considered as an indirect evidence of a following association known as "nuclear-follower feeding association", a condition in which the follower approach the nuclear when it somehow disturbs the substrate and form sediment clouds while foraging, taking the opportunity to feed during this situation. However, no direct observations of golden dorados getting some benefit from the activity of the green anacondas to feed were made. Nevertheless, as there is a varied list of vertebrates considered as nuclear species in the clearwater rivers of Midwest Brazil, it is to be expected that future observations may provide unusual information about nuclear-follower feeding association between fish and snakes in the Neotropics.
Keywords: Bryconidae; Boidae; foraging behaviour; opportunistic interaction; Bodoquena Plateau.

Evidência indireta de associação de seguidor entre dourado (*Salminus brasiliensis*) e sucuri-verde (*Eunectes murinus*) em um rio de águas claras do Centro-Oeste do Brasil

Resumo: Em quatro ocasiões, o dourado (*Salminus brasiliensis*) foi registrado seguindo a sucuri-verde (*Eunectes murinus*) em um rio de águas claras do Centro-Oeste do Brasil. Essas interações foram consideradas como uma evidência indireta de uma associação de seguidor conhecida como "associação de alimentação nuclear-seguidor", uma condição na qual o seguidor se aproxima da espécie nuclear quando esta de alguma forma perturba o substrato e/ou forma nuvens de sedimentos enquanto forrageia, aproveitando a oportunidade para se alimentar durante essa situação. No entanto, observações diretas de dourados obtendo algum benefício da atividade das sucuris para se alimentar não foram feitas. No entanto, como há uma lista variada de vertebrados considerados como espécies nucleares nos rios de águas claras do Centro-Oeste do Brasil, é de se esperar que observações futuras possam fornecer informações incomuns sobre associações do tipo "nuclear-seguidor" entre peixes e serpentes na região Neotropical.
Palavras-chave: Bryconidae; Boidae; comportamento de forrageamento; interação oportunista; Planalto da Bodoquena.

Introduction

A large number of fish and even other animals that feed on benthic preys usually through substrate speculation can attract opportunistic species. This type of interaction is known as "following association", "nuclear-follower feeding association" or "following behaviour", and consists of an aquatic animal [or even more than one individual; named as "nuclear(s)"] that excavate or otherwise disturb the substrate while foraging, and one or more opportunistic species [named as "follower(s)"] that capitalize on the small animals and other food types displaced by the foraging activity of the nuclear (Strand 1988, Lukoschek & McCormick 2000, Somaweera & Somaweera, 2021).

This association is well-documented in marine environments, especially for reef dwellers (see Strand 1988 and Sazima et al. 2007 for overviews). However, an increasing number of records of this type of interaction has been reported from freshwater habitats in the Neotropical region (e.g., Sazima 1986, Baker & Foster 1994, Leitão et al. 2007, Teresa & Carvalho 2008, Garrone-Neto & Sazima 2009, Garrone-Neto & Carvalho 2011, Teresa et al. 2014, Sabino et al. 2016,

Souza et al. 2019). Nevertheless, no records on the following association between snakes and fish are available in the literature, which constitutes an opportunity to bring up questions of this nature. Thus, in this study we present indirect evidence of a following association between the golden dorado *Salminus brasiliensis* (Cuvier 1816) and the green anaconda *Eunectes murinus* (Linnaeus 1758), and discuss the possible motivations for this type of interspecific interaction and its convergence with observations made for other species.

Material and Methods

The underwater observations were performed in the Olho d'Água River, a clearwater river located in the Bodoquena Plateau, in Midwest Brazil (around 21º26'18''S, 56º26'43''W) (Figure 1). The Olho d'Água River is part of the Paraguay River watershed, and it is directly influenced by the karstic geomorphology of the Bodoquena Plateau, which makes the water naturally highly alkaline and with a very low turbidity (the horizontal water transparency is usually higher than 30 m) (Teresa et al. 2011).

Records were made opportunistically while snorkeling, during a long-term monitoring of the ichthyofauna in the Olho d'Água River. As soon as observed, the following associations were recorded in videos for further analysis. We used the combination of the "ad libitum" and "sequence" sampling rules (Altmann 1974, Martin & Bateson 2007) to describe the interactions, in which the number and size of the nuclear and the follower species, the duration of each behavioural event, the depth and the type of substrate were verified. Size estimates (total length – TL, cm) for *S. brasiliensis* and *E. murinus* were calibrated against objects of known size. Animals were identified *in situ* during the underwater observations, following Marques et al. (2005) and Britski et al. (2007).

Results and Discussion

On four occasions (August 2006, June 2018, November 2019, and June 2021), the golden dorado (*Salminus brasiliensis*) was recorded following the green anaconda (*Eunectes murinus*). Observations were made during daylight, between 09:00 am and 10:30 am, around two meters depth in conditions of full transparency of water.
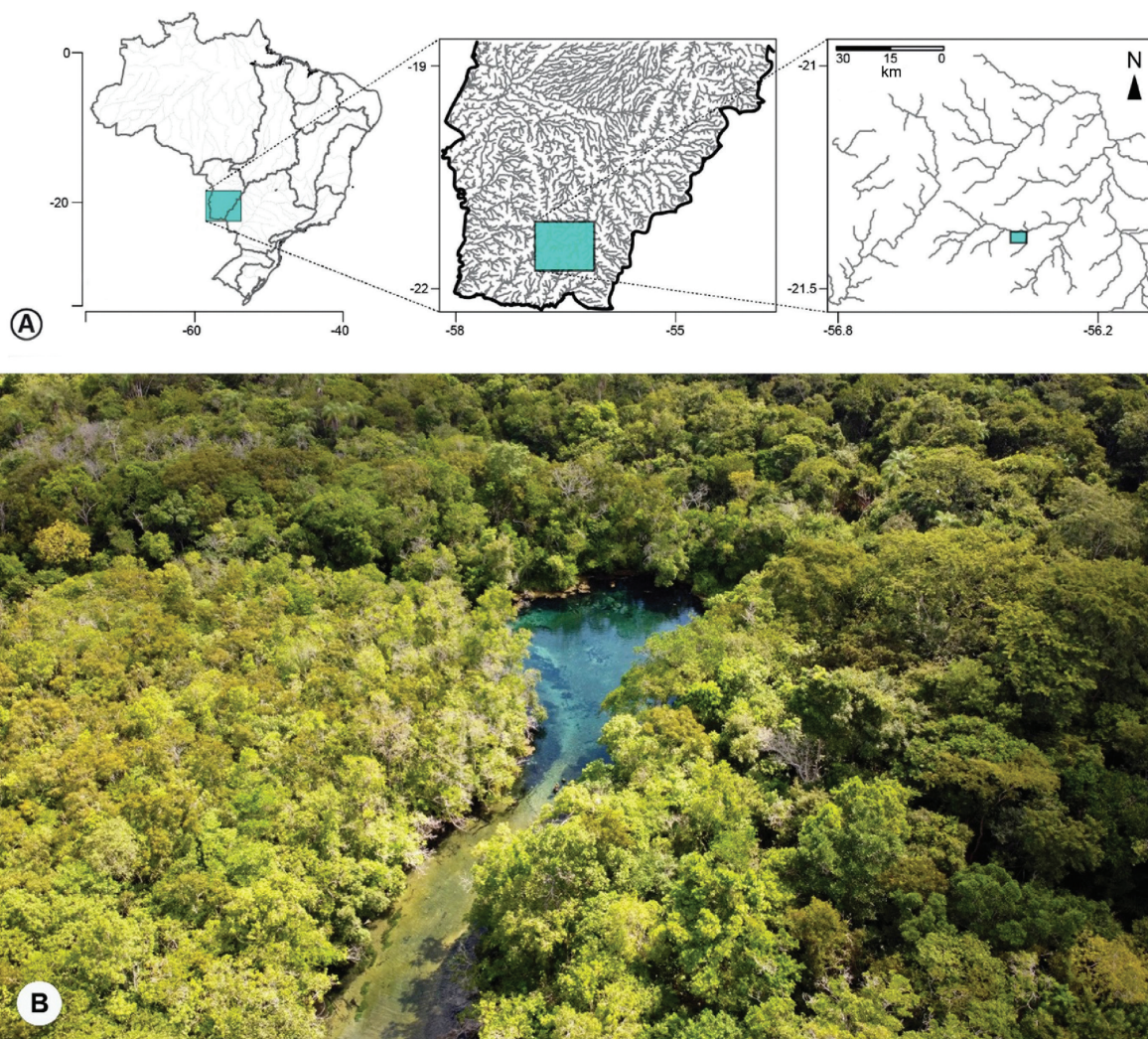

Figure 1. A. Olho d'Água River located in the upper Paraguay River basin, Midwest Brazil. B. Clear water allows observation of the underwater habitats, even in drone photographs.

The interactions were observed when adult and solitary individuals of *S. brasiliensis* (TL ~70 cm) approached to the individuals of *E. murinus* (TL ~400 cm) from the tail. Snakes were moving slowly close to the bottom, composed by sandy substrate, some presence of mud, macrophytes and trunks. Golden dorados remained close to the green anacondas' tails, following the snakes from the posterior region, immediately behind or on one side, never moving forward and approaches the snake's head (Figure 2 and Supplementary Material – Video 1). While moving, some individuals of another species of fish, the piraputanga (*Brycon hilarii*), were observed around or just in front of the green anacondas. Individuals of golden dorados continued to follow the green anacondas, displaying a non-aggressive position in relation to the piraputangas (i.e., a slow swimming, with the dorsal and pectoral fins not arched) (Figure 3). In addition, other fish were also recorded approaching the green anacondas, although in a more temporary way than the piraputangas: tetras (*Astyanax lacustris*), curimbatas (*Prochilodus lineatus*) and piranhas (*Serrasalmus maculatus*) (Supplementary Material – Video 2). No agonistic interactions between *B. hilarii*, *A. lacustris*, *P. lineatus*, and *S. maculatus* and *E. murinus* were observed as well. Observations lasted more than 10 minutes, when the observers stopped following the interactions.

Figure 2. An individual of golden dorado (*Salminus brasiliensis*; TL ~70 cm) following a green anaconda (*Eunectes murinus*; TL ~350 cm) in the Olho d'Água River, Bodoquena Plateau, Midwest Brazil.
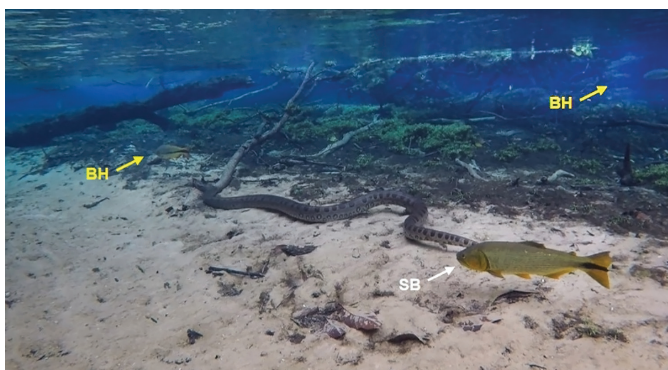

Figure 3. Individual of piraputanga (indication in yellow) (*Brycon hilarii*; TL ~40 cm) positioned close to the head of a green anaconda (*Eunectes murinus*; TL ~350 cm). An adult and solitary individual of the golden dorado (indication in white) (*Salminus brasiliensis*; TL ~70 cm) is following the snake, displaying a non-aggressive position in relation to the piraputanga (e.g., pectoral, and dorsal fins not arched).

Although it was not possible to record the golden dorados benefiting from the feeding activity of the green anacondas, most of the observed facts are consistent with following association (sensu Strand 1988), especially in relation to the disturbance in the substrate caused by the movement of the snakes (Supplementary Material – Video 3). Thus, we assume that *S. brasiliensis* can follow *E. murinus* to opportunistically prey mainly on individuals of *B. hilarii* and, eventually, on other species such as tetras (*A. lacustris*), curimbatas (*P. lineatus*) and piranhas (*S. maculatus*).

The fish from the order Characiformes, especially the piraputanga (*B. hilarii*), are in the list of prey of adult individuals of the golden dorado (*S. brasiliensis*) (Bessa et al. 2011). In the streams of the Bodoquena Plateau, Midwest Brazil, adult individuals of *S. brasiliensis* usually attacks individuals of *B. hilarii* in the darker periods of the day, such as the early morning and the dusk (J. Sabino, pers. obs.). This hunting strategy is probably related to the high transparency of the water that is observed in the region, but at the same time makes hinders the stealth action of a visually oriented predator such as *S. brasiliensis*. Thus, when associating with *E. murinus*, *S. brasiliensis* may appear less aggressive to *B. hilarii*, taking the opportunity to prey on this species in a moment of distraction promoted by the movement or the feeding activity of the snake. Besides a possible predation on *B. hilarii*, another possibility is that the movement of *E. murinus* over sandy substrate with mud could dislodge some prey, which could be attacked by *S. brasiliensis*. A similar behaviour occurs when nuclear fish (e.g., *Megaleporinus* and *Prochilodus*) dig into the sand bed and displace small organisms. In this situation, smaller predators such as the cichlids *Crenicichla lepidota* and *C. vitatta* take advantage of the situation to feed on small characins and benthic invertebrates (Teresa et al. 2014, Sabino et al. 2016). To our knowledge, though transient, this is the first documented evidence on the occurrence of this interaction between freshwater fish and aquatic snakes.

Given the absence of photos and videos of green anacondas (*E. murinus*) capturing prey and golden dorados (*S. brasiliensis*) taking advantage of this fact to feed on organisms attracted by the formation of sediment clouds (notably fishes of the order Characiformes), it is not possible to categorically guarantee that the following association occurs between these two species. However, the anecdotal observations presented herein represent rare and uncommon records between two species of South American aquatic predators. With the increase of tourist activities in wild environments, the interaction between scientists and other people through citizen science and with the increase in the offer of less complex tools for the registration of underwater fauna, it is expected that interactions such as following associations start to be registered more frequently. This may help confirm of the hypothesis on the interaction between golden dorados and green anacondas, expanding the knowledge about this type of behaviour in freshwater environments as well as between species from different taxonomic groups.

In addition to following association, the interaction between fish and other organisms can occur for the purpose of cleaning symbiosis, in which the "cleaner" removes ectoparasites and other material from the "host". Although this behaviour could be an alternative to what is being suggested in this study, we don't believe this can be possible. Green anacondas and golden dorados are top predators in the underwater environment that feed mainly on live and medium to large-sized prey in relation to its body. Thus, golden dorados feeding on ectoparasites,

mucus or other material does not seem to be feasible. Additionally, a golden dorado searching for protection or chasing an anaconda for predation are also discarded.

Due to the increasing number of records of following associations in the clearwater rivers of the Bodoquena Plateau, Midwest Brazil, including interactions between fishes (Sabino et al. 2016, Souza et al. 2019) and other organisms such as monkeys (*Sapajus apella*), tapirs (*Tapirus terrestris*) and giant otters (*Pteronura brasiliensis*) (Sabino & Sazima 1999, Costa-Pereira 2012), new discoveries like what we are suggesting for golden dorados (*S. brasiliensis*) and green anacondas (*E. murinus*) are possible. One of the main predictors for the occurrence of this type of interaction is the presence of a nuclear species that strongly disturb (directly or indirectly) the substrate while foraging, which attracts a greater variety of followers (Krajewski 2009). In freshwater environments with a predominance of unconsolidated substrate such as sand and mud and with deposit of organic matter, a higher suspension of particles is expected to occur during the feeding activity of nuclear species and, consequently, a greater number of followers must be observed (Teresa et al. 2011, 2014). In streams and rivers of the Neotropical region, especially in the area where our observations were performed, followers are usually represented by benthivorous fishes that form large groups while following the nuclear (Sabino et al. 2016). The golden dorado is a carnivorous fish with a tendency to piscivory that can reach up to 1 meter in length (Moraes Filho & Schubart 1955, Britski et al. 2007). Therefore, we assume that the golden dorado follows the green anaconda in order to catch some fish that eventually escapes from an attempt of predation by the snake or prey on smaller fish that are attracted by a situation in which the snake causes a large disturbance in the substrate. Thus, although transitory, these circumstances may support the idea obtained from the indirect evidence of golden dorados following green anacondas to opportunistically obtain food. As there is a varied list of vertebrates considered as nuclear species in the clearwater rivers of Midwest Brazil, it is to be expected that future observations may provide new information about ecological interactions such as following association between fish and snakes in the Neotropics.

Acknowledgments

Associate Editor

Carlos Joly

Author Contributions

Jose Sabino: conceived the research.
Domingos Garrone-Neto: conceived the research.
Fernando Maydana: collected and analyzed data.

All authors contributed with ideias, data and information to the text. All authors reviewed and approved the text.

Conflicts of Interest

The authors declare no conflicts of interest.

Ethics

We declare that the procedures used in this study have no conflict with the Brazilian laws regarding the use of vertebrates in scientific research. In addition, this study was performed in compliance with the guidelines for field research inside protected areas in the Mato Grosso do Sul State.

Data Availability

Supporting data are available at:
Video 1: <figshare.com/articles/media/SUCURI1following_ association_between_dorado_and_anaconda_mpg/20416020>. DOI: 10.6084/m9.figshare.20416020.
Video 2: <figshare.com/articles/media/SUCURI2following_ association_between_dorado_and_anaconda_mov/20422161>. DOI: 10.6084/m9.figshare.20422161.

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