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**Article**

# Diet of *Moenkhausia bonita* (Benine, Castro & Sabino 2004) (Characiformes: Characidae) in streams in the basin of rio Formoso, Brazilian Midwest

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***Abstract:*** To characterize the diet composition of *Moenkhausia bonita* and its temporal and ontogenetic variations in streams in the Formoso River basin (MS). The collections were carried out in seven sampling points in two periods throughout the year (dry and rainy). The food items were analyzed according to the volumetric and occurrence frequency methods and the diet was characterized through the Food Index (IAi%). To determine ontogeny, the specimens were divided into five size classes in the dry (D1 to D5) and rainy (R1 to R5) periods. To verify the difference between the species' diet between the size classes and the periods of the year, the Permutational Multivariate Analysis of Variance – PERMANOVA analysis was performed. *Moenkhausia bonita* was classified as an invertivore when it consumed basically both aquatic and terrestrial invertebrates (99.5% of the diet), with higher consumption of aquatic invertebrates. There was a significant difference in the diet of between the dry and rainy periods, and although the species basically consumed the same items in the two studied periods, the proportions were different and there was no difference in the diet between size classes. *M. bonita* diet is based on autochthonous resources regardless of the size class, but that there were different consumption patterns when comparing the different periods of the year. The present study provided the first information on the feeding of *M. bonita* in a lotic environment and diet spectrum in the developmental phases, (ontogeny) and periods of the year, enabling a better understanding of the species, the importance of invertebrates in its diet, and the need for future studies on the biology, autoecology, and behavior of this species.
***Keywords:*** *Feeding; tetra; trophic category; ontogeny.*

# Dieta de *Moenkhausia bonita* (Benine, Castro & Sabino 2004) (Characiformes: Characidae) em riachos da bacia do rio Formoso, Centro-Oeste brasileiro

***Resumo:*** Caracterizar a composição alimentar de *Moenkhausia bonita* e as variações temporais e ontogenéticas na dieta desta espécie em riachos da bacia do rio Formoso (MS). As coletas foram realizadas em sete pontos amostrais em dois períodos do ano (seco e chuvoso). Os itens alimentares foram analisados de acordo com os métodos volumétrico e de frequência de ocorrência e a dieta foi caracterizada através do Índice Alimentar (IAi%). Para determinar a ontogenia, os espécimes foram divididos em cinco classes de tamanho nos períodos seco (D1 a D5) e chuvoso (R1 a R5). Para verificar a diferença entre a dieta da espécie entre as classes de tamanho e os períodos do ano foi realizado a Análise de Variância Multivariada Permutacional – PERMANOVA. *M. bonita* foi classificada como invertívora ao consumir basicamente invertebrados tanto aquáticos quanto terrestres (99,5% da dieta), com consumo maior de invertebrados aquáticos. Houve diferença significativa na dieta entre os períodos seco e chuvoso, apesar da espécie consumir basicamente os mesmos itens nos dois períodos estudados, as proporções foram distintas e não houve diferença na dieta entre as classes de tamanho. A dieta de *M. bonita* é baseada em recursos autóctones independente da classe de tamanho, mas que houve consumo diferente entre os períodos

do ano. O presente estudo forneceu as primeiras informações sobre a alimentação de *M. bonita* em ambiente lótico e seu espectro alimentar nas fases de desenvolvimento(ontogenia)e períodos do ano, possibilitando melhor conhecimento da espécie, a importância dos invertebrados em sua dieta e a necessidade de estudos futuros sobre a biologia, autoecologia e comportamento desta espécie.
***Palavras-chave:*** *alimentação; lambari; categoria trófica; ontogenia.*

## Introduction

The Neotropical region has the most diverse freshwater ichthyofauna in the world, with about 50% of the known fauna (Reis et al. 2016). Brazil is home to great biodiversity of fish (Buckup et al. 2007; Froese et al. 2016). Most of this richness of fish inhabits inland waters, representing about two-thirds of the ichthyofauna that occurs in this region (Nelson et al. 2016).

The state of Mato Grosso do Sul is drained by the Middle Paraguay River and Upper Paraná River basins, where 358 fishes species have been recorded, 257 species of which are recorded in the Paraguay River basin, (Froehlich et al. 2017). The Formoso River basin is a sub-basin of the Miranda River, inserted entirely within the municipality of Bonito, a place that presents tourist trend due to its scenic beauty (Teruya-Júnior 2011). This region is a reference for ecotourism in the country since most of the tourist attractions are linked to water resources (Lelis et al. 2015). Few studies have been conducted on the ichthyofauna in the Formoso River basin, such as the composition and structure of the ichthyofauna in streams comparing conservation gradients (Casatti et al. 2010), the weight-length relationship in stream fishes (Severo-Neto et al. 2018) and studies of the ecological interactions of fishes with habitat characteristics (Nunes et al. 2020).

Eight species of *Moenkhausia* are known in the state of Mato Grosso do Sul (Froehlich et al. 2017). *Moenkhausia bonita* is a small characid species that have been described in the Baía Bonita River, a tributary of the Formoso River (area of this study) (Benine et al. 2004). This species occurs mainly near the water surface, swimming in schools of 10 to 30 individuals (Benine et al. 2004). It is a widely distributed species in the Paraguay River basin but has been recorded in other basins, like La Plata River and Amazon region (Froehlich et al. 2017; Vanegas-Ríos et al. 2019; Fricke et al. 2020). *Moenkhausia bonita* isn't registered on the Red List of endangered species of the Ministry of the Environment (PORTARIA MMA 148/2022) and is classified as Least Concern (LC) according to the International Union for Conservation of Nature (IUCN, 2019).

The differentiation in the diet of a fish species may be due to spatial, temporal, ontogenetic, individual variations, and according to feeding tactics (Abelha et al. 2001). In tropical regions, subject to wide seasonal variations in water level, seasonality is one of the main factors influencing changes in fish diet, since it causes qualitative and quantitative changes in the availability of food items in aquatic ecosystems (Junk et al. 1989; Junk et al. 2021). Seasonal changes in fish diet are especially related to the entry of allochthonous resources into the aquatic environment (Quirino et al. 2017). Ontogenetic variation is an important factor to be verified in the diet of fish, usually accompanied by morphological changes throughout the development of individuals (Hahn et al. 2000; Bozza and Hahn 2010; Alves et al. 2021). Feeding tactics can change as fish grow, due to physical limitations regarding prey and food selectivity (Wainwrigth and Richard, 1995; Arim et al. 2010; Bozza and Hahn 2010; Keppeler et al. 2015; Alves et al. 2021). Dietary ontogenetic changes can reduce intraspecific competition and allow species to successfully establish themselves in environments (Alves et al. 2021). Understanding the relationships between fish fauna and the environment is essential to assist in methods of conservation and environmental restoration (Ferreira & Casatti 2006; Dias et al. 2022). The studies on the trophic ecology of fish are of paramount importance to know both individual and community processes, being important aspects for the conservation of species (Nunn et al. 2012; Tonella et al. 2019). Thus, this study aimed to characterize the diet of *M. bonita* in streams of the Formoso River basin and to verify possible changes in the diet of the species by periods (dry and rainy) and highlight the origin (allochthonous or autochthonous) of the food items most consumed by the species in the respective evaluated periods and to identify ontogenetic diet variations of the species.

## Material and Methods

### 1. *Study area*

The study was carried out in seven points sampled in the streams of the Formoso River basin (MS). The Formoso River basin is located mostly in a limestone region and is situated in the sub-basin of the Miranda River, one of the six sub-basins of the Upper Paraguay basin (Mato Grosso do Sul 2004). The main river names the basin and extends a drainage area of about 136,000 hectares and is within the Serra da Bodoquena (Teruya-Júnior et al. 2009).

The Formoso River basin has an area of 1,334 km², located in the central region of the municipality of Bonito, in the state of Mato Grosso do Sul and is 100 km long (Duarte et al. 2005). The Formoso River is characterized by clear waters, a sandy-clay riverbed, thick litter and dense riparian forest that in some stretches is about 500 m wide from the riverbed (Reys et al. 2005). According to the Köppen classification, the climate of the region is sub-hot tropical, with hot and rainy periods occurring on average between October to April and dry seasons predominating from May to September, with average annual temperatures between 22 °C and 26 °C.

### 2. *Collecting the fish*

The fish were collected at two times of the year (January/rainy and October/dry 2016) in the seven points sampled in the streams of the Formoso River basin (coordinate 21°02'01"S 56°28'31"W), (coordinate 21°06'34"S 56°28'24"W), (coordinate 21°04'22"S 56°28'26"W), (coordinate 21°04'08"S 56°25'59"W), (coordinate 21°06'24"S 56° 33'42"W) (coordinate 21°02'55"S 56°18'10"W) and (coordinate 21°02'14"S 56°18'39"W) (Figure 1). The fish were sampled using seine net (5 mm mesh) and sieves. The specimens were anesthetized with Eugenol (clove oil; 70 mg/L) and then euthanized and fixed in 10% formalin solution and preserved 70% ethanol. Voucher specimens

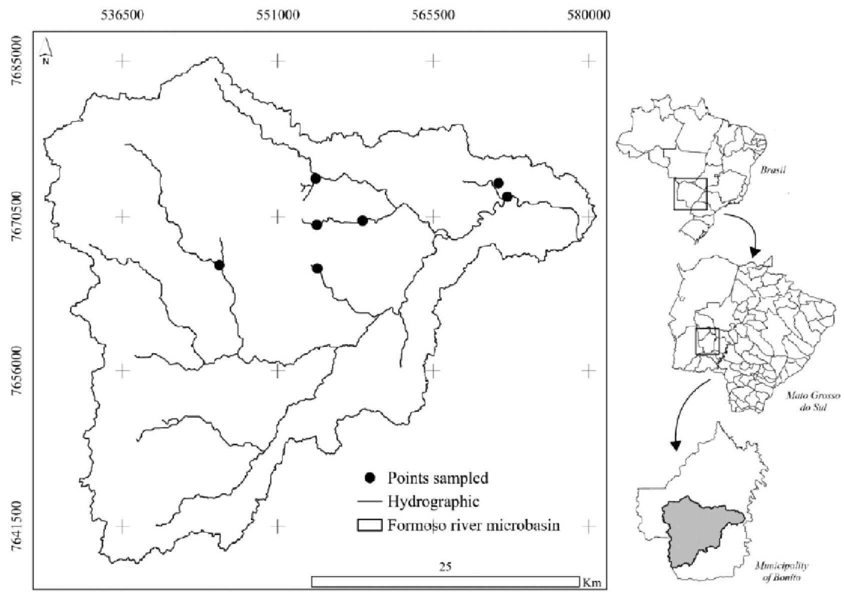


**Figure 1.** Map showing the location of the study area and the seven points sampled in the streams of the Formoso River basin, Mato Grosso do Sul, Brazil.

were deposited in the Zoological Collection (ZUFMS) of Universidade Federal do Mato Grosso do Sul (ZUFMS-PIS06693).

### 3. Diet analysis

In the laboratory, the biometry of the individuals of *M. bonita* were measured standard length (SL-mm), and the total weight (g) were taken. The individuals were dissected and the stomachs were removed. Stomach content was analyzed under a stereomicroscope and the food items were identified to the lowest possible taxonomic level with the support of specialized literature (McCafferty 1981; Mugnai et al. 2010). The items were analyzed according to the frequency of occurrence and volumetric methods (Hyslop, 1980). The volume of the items was obtained by compressing the material with a glass slide on a millimeter plate to a known height (1 mm), and the result was converted to milliliters (1 $mm^3$ = 0.001 ml) (Hellawell & Abel 1971).

### 4. Data analysis

The food items were grouped according to the following food categories: terrestrial invertebrate, aquatic invertebrate, plant, and other (filamentous algae and fish scale) and according to origin of food items (autochthonous, allochthonous and indeterminate). To characterize the diet the Food Index (IAi%) was calculated *Fi* is the relative frequency of occurrence of item *i* (%) and *Vi* is the relative volume of item *i* (total%) (Kawakami & Vazzoler 1980).

To assess ontogenetic variations in diet, individuals were grouped into five size classes (mm) in the dry (D1 to D5) (D1 = 15,3 – 20,3); (D2 = 20,4 – 25,4); (D3 = 25,5 – 30,5); (D4 = 30,6 – 35,6) and (D5 = 35,7 – 40,7) and rainy (R1 to R5) (R1 = 14,6 – 19,6); (R2 = 19,2 – 24,7); (R3 = 24,8 – 29,8); (R4 = 29,9 – 34,9) and (R5 = 35,0 – 40,0) periods. The groups were separated every five millimeters from the smallest individual for each period. To verify whether the diet of *M. bonita* showed differences in relation to size classes and sampling periods, we performed Permutational Multivariate Analysis of Variance – PERMANOVA (Anderson et al. 2008).

## Results

The stomach contents of 240 specimens of *M. bonita* were analyzed during the dry (97) and rainy (143) periods. The diet of *M. bonita* was characterized as invertivorous as it basically consumed both aquatic and terrestrial invertebrates, despite the higher consumption of aquatic invertebrates in both periods (Figure 2). In the diet of *M. bonita*, were identified 30 food items consumed by the species, 27 food items were found in the dry, and 26 in the rainy period (Table 1). The main food items eaten in the dry period were fragments of aquatic insects, Formicidae and larvae, and pupae of Diptera. In the rainy period, the species mainly consumed Formicidae and Aquatic Insect fragments. Resources autochthonous origin were the most consumed in both periods (dry and rainy). The interaction term between period and size classes was not significant. Significant differences were identified in the diet of

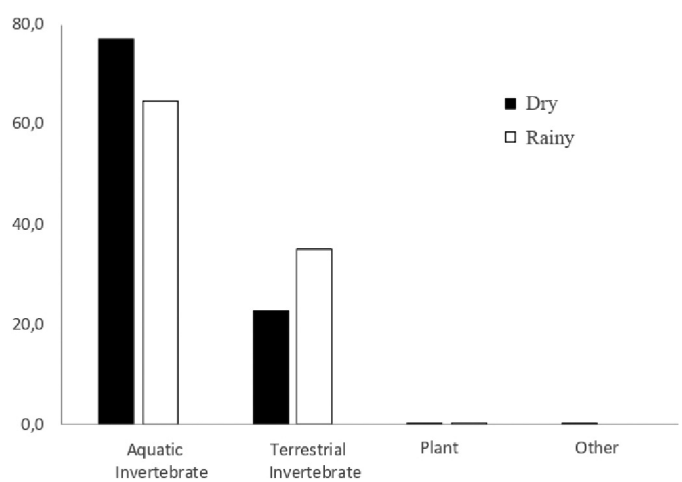


**Figure 2.** Food categories (IAi%) consumed by *Moenkhausia bonita* in the dry and rainy periods in streams of the Formoso River basin, Mato Grosso do Sul, Brazil.

**Table 1.** Frequency of occurrence (FO%), volume frequency (VO%) and Food index (IAi%) of the food items and food categories found in the diet of *Moenkhausia bonita* in the dry and rainy periods in streams of Formoso river basin, Mato Grosso do Sul, Brazil. Origin of food items in parentheses. F = Fragments.

| Food items | Dry | | | Rainy | | |
|---|---|---|---|---|---|---|
| | FO% | VO% | IAi% | FO% | VO% | IAi% |
| Aquatic invertebrates (Autochthonous) | | | | | | |
| Ephemeroptera | 17.5 | 2.1 | 1.4 | 8.2 | 4.8 | 1.2 |
| Trichoptera | 15.4 | 3.8 | 2.2 | 16.5 | 3.4 | 1.7 |
| Trichoptera (pupae) | 4.2 | 2.9 | 0.5 | 4.1 | 0.8 | 0.1 |
| Plecoptera | 6.3 | 0.6 | 0.1 | 1.0 | 0.1 | <0.1 |
| Chironomidae | 37.8 | 3.3 | 4.6 | 22.7 | 2.7 | 1.8 |
| Chironomidae (pupae) | 0.7 | 0.6 | <0.1 | | | |
| Diptera (larvae) | 35.0 | 10.2 | 13.3 | 26.8 | 3.2 | 2.6 |
| Diptera (pupae) | 32.2 | 7.8 | 9.3 | 20.6 | 7.4 | 4.6 |
| Ceratopogonidae | 15.4 | 0.9 | 0.5 | 5.2 | 0.3 | 0.1 |
| Simuliidae | 11.2 | 0.8 | 0.3 | 2.1 | 0.3 | <0.1 |
| Odonata | 7.0 | 0.8 | 0.2 | 7.2 | 1.5 | 0.3 |
| Coleoptera | 6.3 | 1.6 | 0.4 | 8.2 | 3.9 | 1.0 |
| Coleoptera (adult) | 12.6 | 6.0 | 2.8 | 11.3 | 5.2 | 1.8 |
| Hemiptera | 4.9 | 1.9 | 0.3 | 1.0 | 1.2 | <0.1 |
| Megaloptera | | | | 1.0 | 0.8 | <0.1 |
| Insect exuvia | 10.5 | 5.6 | 2.2 | 5.2 | 1.2 | 0.2 |
| Aquatic invertebrates (F) | 39.2 | 21.6 | 31.4 | 36.1 | 21.7 | 23.4 |
| Hydracarina | 1.4 | <0.1 | <0.1 | 2.1 | 0.1 | <0.1 |
| Nematoda | | | | 5.2 | 0.4 | 0.1 |
| Oligochaeta | | | | 2.1 | 2.1 | 0.1 |
| Terrestrial invertebrates (Allochthonous) | | | | | | |
| Formicidae | 44.1 | 12.6 | 20.5 | 64.9 | 30.1 | 58.6 |
| Coleoptera | 21.7 | 6.7 | 5.4 | 14.4 | 5.0 | 2.2 |
| Hemiptera | 3.5 | 1.1 | 0.1 | 1.0 | 0.6 | <0.1 |
| Diptera | 4.2 | 0.6 | 0.1 | 1.0 | 0.3 | <0.1 |
| Terrestrial invertebrates (F) | 16.1 | 5.5 | 3.3 | 3.1 | 1.2 | 0.1 |
| Araneae | 11.2 | 2.5 | 1.0 | 7.2 | 0.9 | 0.2 |
| Plant (Indeterminate) | | | | | | |
| Seeds | 1.4 | 0.1 | <0.1 | | | |
| Plant Fragments | 0.7 | <0.1 | <0.1 | 3.1 | 0.6 | 0.1 |
| Other (Autochthonous) | | | | | | |
| Filamentous Algae | 2.8 | 0.2 | <0.1 | | | |
| Fish scale | 2.8 | 0.1 | <0.1 | | | |

the species between the periods considered (pseudo-F = 5.02; p = 0.02). However, the diet of *M. bonita* did not show ontogenetic variations, which indicates that the species feeds on the same food resources throughout development. The aquatic and terrestrial invertebrates food categories were the most consumed in most size classes (Figure 3). The main food items consumed in the different size classes were aquatic insect fragments, Formicidae, Diptera larvae, and pupae.

## Discussion

We classified *Moenkhausia bonita* as invertivorous in the streams of the Formoso River basin, by consuming basically aquatic and terrestrial insects, with a tendency to consume higher proportions of autochthonous invertebrates. In lake environments, the insects were also the main items consumed by *M. bonita* (Carniatto et al. 2014; Carniatto et al. 2016; Quirino et al. 2018) where Chironomidae pupae were the most consumed item in most lakes. Others species of *Moenkhausia* showed a diet based on terrestrial and aquatic insects, such as *M. dichroura* (Toffoli et al. 2010), *M. sanctafilomenae* (Crippa et al. 2009; Toffoli et al. 2010), and *M. intermedia* (Crippa et al. 2009; Vidotto-Magnoni et al. 2009). Several authors emphasize the importance of the insectivorous diet, considering it as an adaptive advantage since the nutritional value of insects is more relevant than other food items present in the environment (Lowe-Mcconnell 1987, Gandini et al. 2012).

In relation to the periods sampled, although the specimens consumed basically the same items, the proportions were unequal, presenting a significant difference in diet according to the two periods sampled. In both periods aquatic invertebrates (mainly fragments of aquatic insects, larvae, and pupae of Diptera) were more consumed. Larvae and pupae of Diptera have different locomotion and dispersal techniques (Backenbury 2000), which often favors the capture of aquatic forms of this insect group by fish (Quirino et al. 2018). In the rainy season, there was a

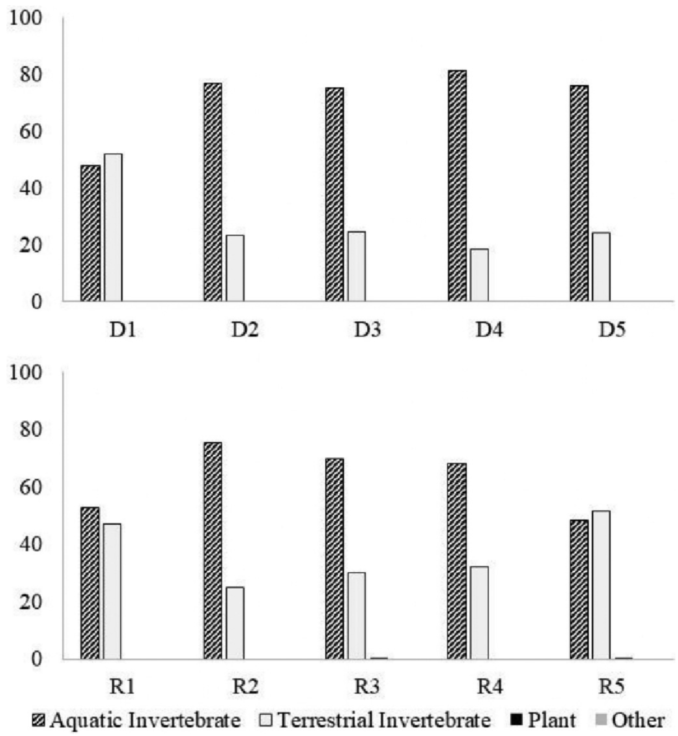


**Figure 3.** Food categories (IAi%) consumed by *Moenkhausia bonita* in different size classes (A) in the dry (D1 to D5) and (B) rainy (R1 to R5) in streams of the Formoso river basin, Mato Grosso do Sul, Brazil.

higher increment of terrestrial invertebrates (mainly Formicidae). Some studies with tetras of the genus *Astyanax* (Borba et al. 2008; Ferreira et al. 2012a) report an expressive consumption by Formicidae. We assume that the ingestion of this item was possible due to its availability and abundance in the sampled sites and periods. The abundance of Formicidae in the diet of fishes species may be related to the action of rain and wind, which would result in the fall of individuals from the riparian vegetation (Toffoli et al. 2010). With the onset of rainfall, there is increase in water velocity, which provides increase in water volume in the terrestrial environment, which contributes to a greater transport of items into the aquatic environment (Payne 1986).

Regarding size variations, there was no difference in diet among size classes, with aquatic invertebrates being the main food category in most classes for both periods, except for Classes D1 and R5 where the consumption of terrestrial invertebrates was slightly higher. In a study on ontogenetic variations in the diet of *Astyanax janeiroensis*, the authors pointed out that the smallest individuals consumed greater proportions of items of animal origin and the larger ones had a diet based on items of plant origin (Mazzoni et al. 2010). In the process of fish development, it is common for larvae and juveniles to include larger prey items in their diet, modifying their diet (Makrakis et al. 2005; Nunn et al. 2007), that is, as the fish increase in size, they consume wider variety of prey items becoming generalists (Winemiller 1989; Sánchez-Hernández et al. 2012; Keppeler et al. 2015). Morphological changes are factors that instigate fish to seek food resources of various sizes and appropriate nutritional proportions for each developmental stage (Winemiller 1989; Ortiz & Arim 2016). Consumption of small food items by smaller fish individuals is generally associated with mouth opening and position and number of teeth (Dala-Corte et al. 2016; Bonato et al. 2017). In the literature, smaller individuals of characids have a diet based on small aquatic organisms such as microcrustaceans and insect larvae, showing ontogenetic variations in their diets (Araújo et al. 2005; Mazzoni et al. 2010; Lampert et al. 2022). Unlike these studies, we did not find ontogenetic differences in the diet of *M. bonita*. The fact that this species does not present a significant difference between the size classes may be due mainly to the greater consumption of aquatic invertebrates in all stages of developmen generally smaller individuals consume this resource, that making necessary, further studies on the biology, ecology, and behavior of this species. Riparian forests have vast importance in regulating energy flow and nutrient cycling (Vannote et al. 1980). The maintenance of aquatic biodiversity is extremely dependent on the ecological functions performed by forests, mainly in providing abundant terrestrial food of animal and plant origin that falls into the water (Barrela & Petrere Junior 2001). Gregory et al. 1991; Bretschko & Waidbcher 2001; Sabino & Deus e Silva 2004, emphasize the influence of the riparian forest even when fish feed on autochthonous items because the primary source of these food resources has an allochthonous origin, considered the base of the trophic chain in streams. The Formoso River basin is a region with high agricultural and cattle ranching exploitation and with this we have been observing the decline of forest areas, reduction of permanent preservation areas, and increase of urban areas and ecotourism (Teruya-Júnior 2011). Riparian forests can act as an effective barrier against sedimentation and provide resources for stream fauna (Ferreira et al. 2012b), besides hindering the carriage of agrochemicals into the water bodies, particularly in streams that pass through basins subjected to intense agricultural and livestock activity (Sweeney et al. 2004, Martinelli & Filoso 2007).

Taking into account that the streams sampled along the Formoso River basin have forested riparian zones in different degrees of preservation, we can infer that the invertivorous diet of *M. bonita* is favored by food resources coming directly and indirectly from these environments. The results found in this first study with the species in a lotic environment reinforce the importance of resources of autochthonous origin in the food composition of the species. Emphasizing the importance of aquatic invertebrates, mainly immature forms of aquatic insects, which were verified in the diet of *M. bonita*. These resources were important for both times and for all size classes.

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## Associate Editor

Rosana Mazzoni

## Author Contributions

Amanda Menegante Caldatto: Substantial contribution to the idea and design of the study, contribution to the analysis and interpretation of data and the writing of the paper.

Anderson Ferreira: Substantial contribution to the idea and design of the study, contribution to data collection, contribution to data analysis and interpretation.

Rosa Maria Dias: Contribution to the analysis and interpretation of data and critical review (adding intellectual content).

## Conflicts of Interest

The authors declare no conflict of interest related to the publication of this manuscript.

## Data Availability

Supporting data are available at https://doi.org/10.48331/scielodata.BGIQSN

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