Biotemas, 32 (1): 65-76, março de 2019
ISSNe 2175-7925
http://dx.doi.org/10.5007/2175-7925.2019v32n1p65

Analysis of the use of microhabitats, spatial distribution and diet of *Gymnorhamphichthys rondoni* (Miranda-Ribeiro, 1920) (Rhamphichthyidae) in low-order streams in western Amazon

Lucena Rocha Virgilio [1]*
Rodrigo Sousa Gomes [2]
Monik da Silveira Suçuarana [2]
Lisandro J. S. Vieira [2]

[1] Universidade Federal do Acre, Campus Floresta
Estrada do Canela Fina, CEP 69980-000, Cruzeiro do Sul – AC, Brazil
[2] Programa de Pós-graduação em Ecologia e Manejo de Recursos Naturais
Universidade Federal do Acre, BR-364, km 4, CEP 69915-900, Rio Branco – AC, Brazil
* Autor para correspondência
lurubita@gmail.com

Submetido em 24/04/2018
Aceito para publicação em 14/11/2018

Resumo

Análise do uso de microhabitat, distribuição espacial e dieta de *Gymnorhamphichthys rondoni* (Miranda-Ribeiro, 1920) (Rhamphichthyidae) em riachos de baixa ordem, Amazônia Ocidental. O hábito alimentar, psamófilo e a morfologia de *Gymnorhamphichthys rondoni*, o tornam uma espécie altamente especializada, com importante papel em sistemas de riachos. Nesse sentido, o objetivo do presente estudo foi analisar o uso de microhabitats, composição da dieta, estratégias alimentares, amplitude de nicho e distribuição espacial da espécie de *G. rondoni*, em riachos de cabeceira. Em cada um dos três riachos selecionados (P1, P2 e P3), localizados na Fazenda Experimental Catuaba, Acre, foram amostrados três pontos compostos por substrato de areia, três compostos por substrato de matéria orgânica e três compostos por argila, durante os períodos de seca, vazante e cheia. Os resultados mostraram que a população de *G. rondoni* aumentou ao longo do gradiente longitudinal, principalmente, durante o período de seca (376 indivíduos), no qual os indivíduos ocuparam substratos compostos por areia e apresentaram dieta baseada, principalmente, por presas bentônicas, como larvas de Diptera e Coleoptera. Assim, a preferência pelo consumo de larvas autóctone por *G. rondoni* e a sua morfologia especializada podem estar associadas à sua relação com os microhabitats de areia. Assim o presente estudo sugere que a perda desses microhabitats pode influenciar negativamente a população de *G. rondoni*.

Palavras-chave: Alimentação; Ambientes lóticos; Amplitude de nicho; Especialização; Psamofilia

Abstract

The feeding habit, psammophilous behavior and the morphology of *Gymnorhamphichthys rondoni* make it a highly specialized species with an important role in stream ecosystems. Accordingly, the aim of the present

Este periódico está licenciado conforme Creative Commons Atribuição 4.0 Internacional.

study was to analyze the use of microhabitats, diet composition, feeding strategies, niche breadth and spatial distribution of *G. rondoni* species in headwater streams. In each of the three selected streams (P1, P2 and P3), located on the Catuaba Experimental Farm (Acre, Brazil), we collected three samples of organic matter substrate and three of clay during drought, ebb and flood periods. The results showed that the population of *G. rondoni* increased along the longitudinal gradient, mainly during drought (376 individuals), in which the individuals occupied substrates composed of sand and showed a diet based mainly on benthic prey such as larvae of Diptera and Coleoptera. Thus, the preference for feeding on autochthonous larvae by *G. rondoni* and their specialized morphology may be due to their relationship with sand microhabitats. Thus, the loss of these microhabitats may negatively influence the population of *G. rondoni*.

Key words: Feeding; Lotic environments; Niche breadth; Psammophily; Specialization

Introduction

The Amazon basin, with its diversity of aquatic habitats, is formed by a network of small waterways (JUNK, 1983). These streams are relatively fragile systems with low autochthonous production, which makes them dependent on riparian vegetation to maintain their biotic integrity (BARRELLA et al., 2000; HENRY; FISCHER, 2003). These freshwater ecosystems provide an abundance of goods and services, maintain water quality, store water during flood periods, and sustain flows during dry periods (NAIMAN; DECAMPS, 1997). This promotes soil infiltration and maintains the necessary conditions for many forms of life (JUNK; PIEDADE, 2005).

The distribution pattern of aquatic organisms in streams is a result of interactions between habit, physical conditions of the habitat (substrate, flow, turbulence) and food availability (MERRIT; CUMMINS, 1984; RESH; ROSENBERG, 1986). In fish communities inhabiting stream environments, different individuals use different types of habitats (HERDER; FREYHOF, 2006; LEAL et al., 2011).

The substrate is a complex aspect of the physical environment (ALLAN; CASTILLO, 2007) and may influence the existence of the fish fauna. For example, habitats composed of sand are often found in Amazon streams and harbor a group of specialized fish in these environments, such as *Stauroglanis gouldingi* (Siluriformes: Trichomycteridae), *Mastiglanis asopos* (Siluriformes: Heptapteridae), *Imparfinis pristos* (Siluriformes: Heptapteridae) and *Gymnorhamphichthys rondoni* (Gymnotiformes: Rhamphichthyidae), which use sand microhabitats to forage and which are known as psammophilic species, i.e., associated with a sand substrate (ZUANON et al., 2006). South America has the highest diversity of freshwater psammophilic fish species, which inhabit sandy areas and have several adaptations to this environment (SCHAEFER et al., 2005; CARVALHO et al., 2014).

Among these psammophilic species, we highlight the genus *Gymnorhamphichthys* (Gymnotiformes: Rhamphichthyidae). Species of this family have a highly developed electrosensitive system (LOWE-MCCONNELL, 1987; MATTHEWS, 1998), which allows these species to recognize the environment, search for food and regulate intra- and interspecific relationships (LISSMANN, 1961; LISSMANN; SCHWASSMANN, 1965; BULLOCK, 1969).

The genus *Gymnorhamphichthys* has a sand-burying habit, a behavior linked to the combination of morphological characteristics, such as knife-like body shape, elongated head, tapered face and electrical organs that allow a specific lifestyle, including prey capture and defense against predators (RAMOS, 2010; CARVALHO et al., 2011). This indicates a high degree of food specialization and association with habitat (SCHWASSMANN, 1976).

The study of feeding aspects of a population, besides providing an interesting field for discussion of theoretical aspects (SCHOENER, 1974), it provides basic knowledge of species biology, understanding of trophic organization of ecosystems and quantitative knowledge of biological mechanisms of interactions between species and their environments (HERRÁN, 1988).

Studies regarding the diet of *G. rondoni* indicate predominance of consumption of benthic autochthonous invertebrates where foraging on larvae occurs through active search in substrates (BREJÃO et al., 2013). The diet composed of benthic invertebrates make the Gymnotiformes that inhabit Amazon streams essential components of the ichthyofauna, because they consume detritivorous arthropods, being an important element in the food chain (GIORA et al., 2014). Detritivorous invertebrates convert organic matter in components assimilated by other species in the aquatic food chain, and thus, the high consumption of these larvae by *G. Rondoni*, according to Soares et al. (2017), include this species in the food chain of detritivores. Moreover, according to Soares et al. (2017) the strong bond with recycled organic matter highlights the importance of these electric fishes for stream environments, since a great part of Amazon fishes are known for feeding mainly on allochthonous items (MENDONÇA et al., 2012; GONÇALVES et al., 2013; NIMET et al., 2015).

Therefore, the feeding habits, psammophilous behavior and the morphology of *G. rondoni*, make it a highly specialized species with an important role in stream ecosystems. According to Odum (1966) and Roughgarden (1974), specialized species are more successful than generalists when there are plenty of resources, which are renewable. This holds true in preserved areas; however, specialists become vulnerable when resources are no longer maintained. Thus, information about the diet and psammophilous habit of *G. rondoni* is an important tool to understand the ecology of streams and the importance of the conservation of these aquatic environments.

Accordingly, we aimed to evaluate the use of microhabitats (e.g., sand, clay and organic matter substrates) and food resources by individuals of *G. rondoni*, as well as its longitudinal distribution in headwater streams, in three hydrological periods. Specifically, we evaluated the following for *G. rondoni*: (I) spatial distribution along a longitudinal gradient in headwater streams; (II) association with the type of substrate; (III) diet habit and composition; (IV) breadth of trophic niche; and (V) feeding strategies.

Material and Methods

Study area

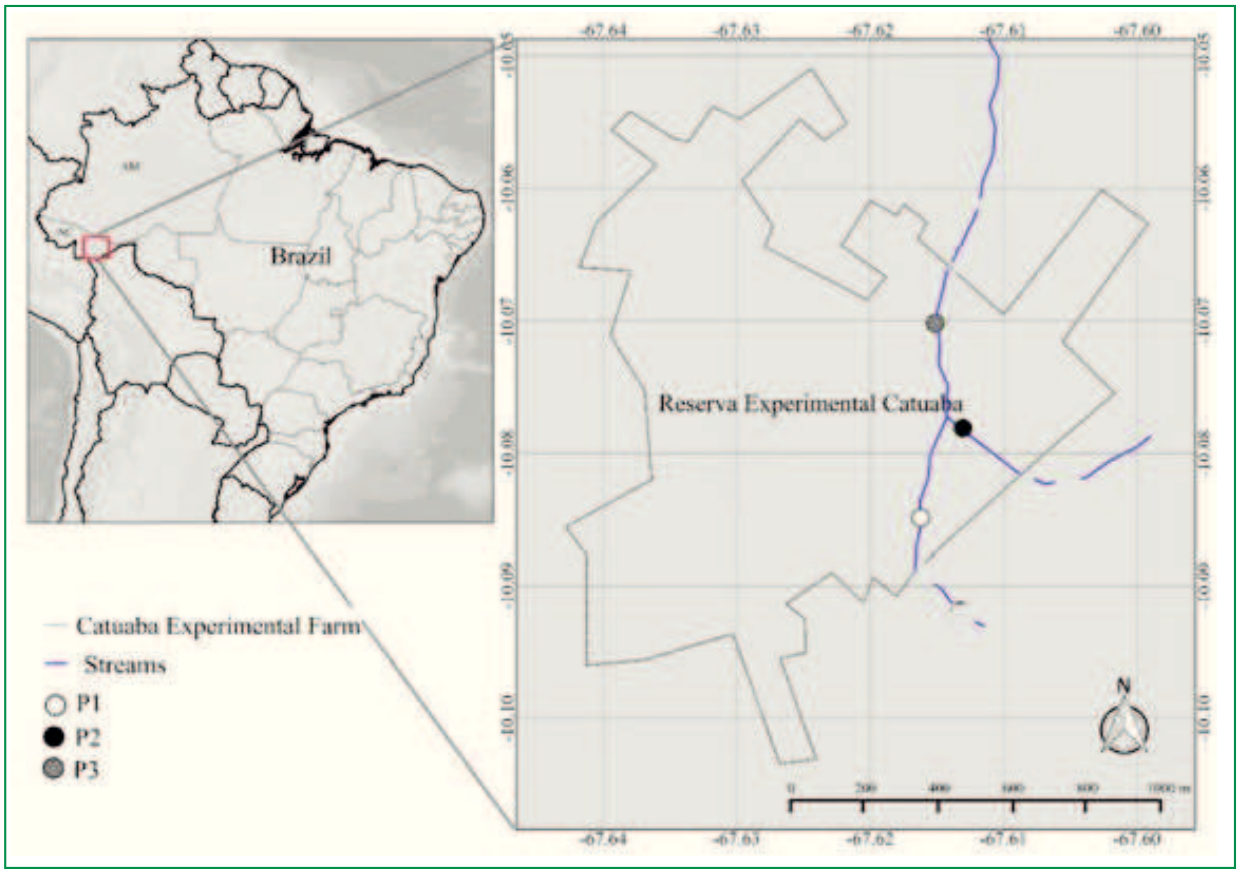
The study was performed on the Catuaba Experimental Farm located in the municipality of Senador Guiomard (10º04'39.6"S; 67º36'48.3"W), Acre State, in the southwestern region of the Brazilian Amazon. The Catuaba farm belongs to the Federal University of Acre (UFAC), with an area of approximately 1500 ha, covered by dense ombrophylous forest with patches of open ombrophylous forest with bamboo (SOUZA et al., 2008) (Figure 1). In this region, deforestation driven by livestock production has taken over a great part of the native vegetation, and thus the landscape is composed of a mosaic of pasture areas surrounding forest fragments (Figure 1).

Sampling was performed in three headwater streams, along three microhabitats (selected from physical characteristic of substrates), where all had dense riparian forest with bamboo patches. We selected two points in first-order streams (P1 and P2) and one in a second-order stream (P3) (Figure 1). At each of these points (P1, P2 and P3), we established 100-m long plots, and each of these plots was subdivided according to the characteristics of the bottom substrate, distributed as follows: (I) three stretches of approximately 12 m composed of sandy bottom and some plant material; (II) three stretches of approximately 10 m with large amounts of trunks and accumulation of plant material; and (III) three stretches of approximately 11 m with substrate composed of clay, trunks and branches. The bottom substrates of each microhabitat were selected through underwater observations performed using a snorkel mask. Field work for stream sampling was carried out at quarterly intervals, during August and November 2009 and February 2010, covering drought, ebb and flood periods, respectively.

Sampling

We sampled *G. rondoni* individuals (Permit ICMBio Nº 11185-1 de 27/10/2007) using two sieves measuring 0.8 m x 0.6 m (55 cm diameter, 0.35 mm mesh), carried by two people for two hours along a

FIGURE 1: Geographical location of study area in the Catuaba Experimental Farm (FEC), municipality of Senador Guiomard, Acre, highlighting the three low-order streams used for sampling. P1 – first-order stream, P2 – first-order stream and P3 – second-order stream.



100-m stretch upstream, during the morning (6:00 to 8:00 am) and evening (7:00 to 9:00 pm). We sampled substrates composed of sand, clay, trunks and other plant material. In the laboratory, the collected fish were identified, measured, weighed and subjected to ventral incision to remove the stomach, which was preserved in 4% formalin for later analysis. The specimens were collected and deposited in the Ichthyological Collection of the Federal University of Acre (*Gymnorhamphichthys rondoni*: MUFAC-IC702-01 a MUFAC-IC702-196).

Diet

We analyzed a total of 270 stomachs of *G. rondoni*, 90 of them during drought with 30 at each point (P1, P2 and P3), 69 during ebb, with 20 at P1, 19 at P2 and 30 at P3, and 53 during flooding, with 11 at P1, 12 at P2 and 30 at P3.

The analysis of the stomach content consisted of identification, counting and estimation of each food item. Larger items were examined with an electronic magnifier on a millimeter-ruled Petri dish. The identification of food items was carried out according to specialized literature (MERRITT; CUMMINS, 1984; MUGNAI et al., 2010) to the lowest possible taxon. Items such as algae were examined in a Sedgewick Rafter counting chamber with 1-ml capacity, and later identified using specialized literature (BICUDO, 2004; ARAÚJO; BICUDO, 2006). The contribution of each item belonging to the species' diet was estimated using the following metrics: (i) the frequency of prey occurrence (%FO), which is the proportion of fish whose stomach had a specific prey; (ii) the numerical percentage of prey (%N), which lists the total number of a prey; (iii) measures of food item volume, estimated in each stomach by the points method (HYNES, 1950). In the last method, food items

are examined on a millimeter-ruled support, where one square millimeter equals one unit. The volume of each item is given by their occupied area. After estimating the area occupied by all items, the volume of each item is converted to a percentage relative to the sum of volumes of all items found in the stomach.

Data analysis

We used aanalysis of variance (two-way ANOVA) to determine the significant difference in the spatial distribution of individuals at the sampling points between seasonal periods and microhabitats, using fish abundance values to assess which points influenced the differences. Significant differences were summarized using the post-hoc Tukey test. The possible associations between individuals of *G. rondoni* and sampling sites (P1, P2 and P3) and their microhabitats (sand, clay and organic matter substrates) were determined by the chi-square test (X^2) using Yates's correction when needed. ANOVA and chi-square test were performed using R software, version 2.11.1 (R DEVELOPMENT CORE TEAM, 2010).

We evaluated the importance of each prey in the diet using the prey-specific index of relative importance (PSIRI%) (BROWN et al., 2012), according to the equation: %PSIRI = %FO (%PNi + %PVi)/2, where %FO is the percent frequency of occurrence (the number of stomachs containing prey i divided by the total number of stomachs, n), and %PNi and %PVi are the prey-specific abundances per number or volume, respectively. Prey-specific abundance was calculated with the equation %PAi = ∑n j=1 %Aij ni -1, where %Aij is the abundance (per number %PNi or volume %PVi) of prey i in stomach sample j and ni is the number of stomachs containing prey i. -PSIRI% is a modification of the index of relative importance (IRI) (PINKAS et al., 1971).

We estimated the trophic niche breadth using Levins' index, given by the formula: BA = 1/ΣPj², where BA is Levins' index, Pj is the proportion of the diet consisting of prey j. BA ranges from 1 (specialist feeder) to n (generalist feeder), where n is the total number of prey consumed.

We used a PERMANOVA (permutational multivariate analysis of variance) to determine differences between sampling areas, substrate and hydrological cycles from volume data (Vi) of food items consumed by the species, using the Bray-Curtis similarity measure. We also used a Monte Carlo permutation test (N = 999) of the similarity matrix to test for significance ($P \leq 0.05$). PERMANOVA analysis was performed using the function *adonis* in the *vegan* package (OKSANEN et al., 2015).

We assessed the feeding strategy using graphical analysis as proposed by Amundsen et al. (1996). This procedure, adapted from Costello's (1990) graphical method, provides information about prey importance and the predator's feeding strategy by evaluating a two-dimensional plot of prey-specific abundance (%Pi) against %FO, with %Pi = (Σ prey i volume/Σ volume of all prey in the stomachs containing prey i) × 100.

Results

We collected 500 individuals of *G. rondoni* during the hydrological cycle, where the greatest number of individuals was collected in the drought period (376 individuals) and the smallest during flooding (55 individuals) (Table 1). We found a significant difference in abundance of individuals between periods of the hydrological cycle (ANOVA-F = 16.9; $P = 0.0001$), which occurred mainly between the drought and flood periods (Tukey-$P = 0.001$) and between drought and ebb periods (Tukey-$P = 0.002$).

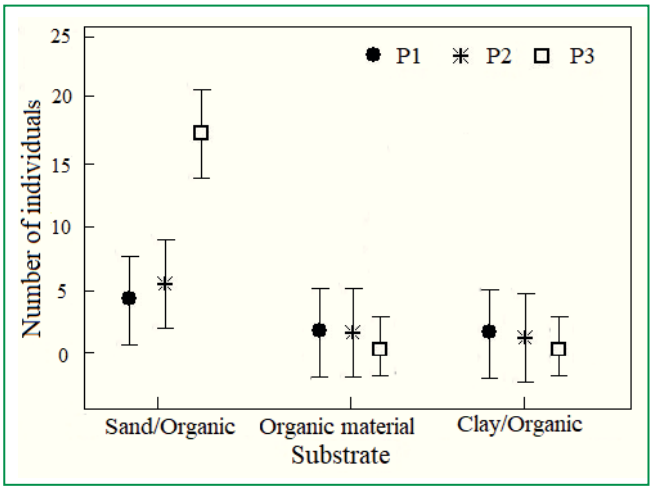
The point with the greatest number of individuals collected was the one second-order stream with 249 individuals in total, while the lowest abundance occurred at the points in the first-order streams P1 and P2, where we collected 130 and 121 individuals, respectively (Table 1). We found a significant difference in individuals' distribution between sampling points (ANOVA-F = 12.7, $P = 0.0001$), which occurred between points P1 and P3 ($P < 0.001$) and points P2 and P3 ($P < 0.001$).

TABLE 1: Number of individuals of *G. rondoni* sampled at points P1 and P2 (first-order streams), and P3 (second-order stream) in the hydrological cycle.

Period	Stream	Individuals	Mean	SD	Size (mm)
Drought	P1	99	33	40.7	20 a 130
	P2	90	30	43.4	
	P3	187	62.3	31.7	
Ebb	P1	20	6.6	7.3	150 a 225
	P2	19	6.3	9.2	
	P3	30	10	15.5	
Flood	P1	11	3.6	5.5	167 a 218
	P2	12	4	6.1	
	P3	32	10.6	16.7	

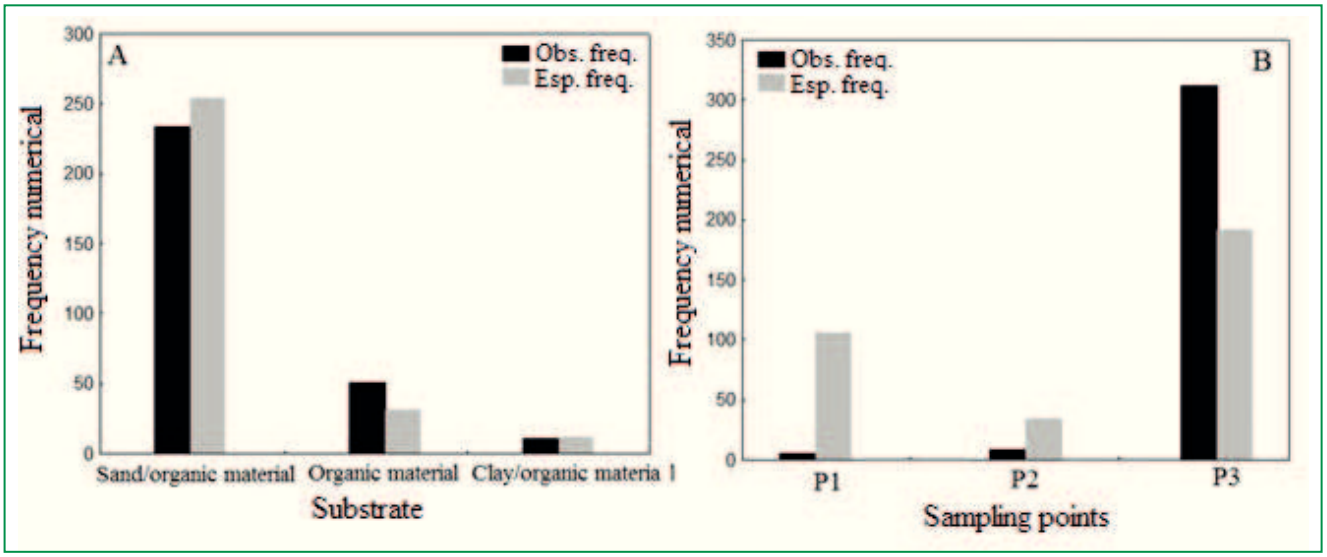
The substrate that presented the greatest abundance was the one composed of sand, with a total of 370 individuals in all collections, and the one with less abundance was the substrate composed of clay and organic matter, with only 65 individuals in total. We found a significant difference between the abundance of individuals in the different types of substrates (ANOVA-F = 15.7, $P = 0.00005$), where the difference occurred between sandy substrate and mix of organic matter and clay ($P < 0.01$) (Figure 2).

FIGURE 2: Difference in distribution of *G. rondoni* according to substrate type: sand, organic matter and clay substrate and sampling points P1 and P2 (first-order streams), P3 (second-order stream) in western Amazon – Brazil.



We found a strong association between *G. rondoni* and microhabitats with sand and organic matter substrates ($X^2 = 15.49$; DF = 2; $P = 0.0004$) (Figure 2) in P3 ($X^2 = 445.68$, df = 2, $P < 0.001$), where the observed frequency was greater than expected by chance (Figure 3).

FIGURE 3: Expected and observed frequency of *G. rondoni* in (A) sandy, organic matter and clayey bottom and sampling points (B) P1 and P2 – first-order streams; P3- second-order stream. Obs. freq.- observed frequency and Esp. freq.- expected frequency in low-order streams in western Amazon – Brazil.



Diet description

The most consumed group in the *G. rondoni* diet, during the three periods of the hydrological cycle, was Diptera larvae, on which the point P1 showed the greatest PISIRI% value during drought (59.9%), P3 during ebb (58.8%) and P2 during flood (60.9%) (Table 2). Coleoptera larvae was the second category of preys most consumed by individuals of *G. rondoni* with the greatest PISIRI% value during drought (20.2% in P1 and 23.3% in P3) (Table 2).

The point P3, during the drought, showed the lowest niche amplitude (BAP1 = 1.33), followed by the points P1 (BAP2 = 2.22) and P2 (BAP3 = 2.33). While during the ebb, the niche amplitude was low in the three collection points (BAP1 = 1.44, BAP3 = 1.46 and BAP3 = 1.4,). During the flood, P3 (BA = 1.77) also presented the lowest niche amplitude in comparison to the other environments (BAP1 = 2.33 and BAP2 = 2.75).

We found no significant variations in the consumption of food items of *G. rondoni* between the three hydrological periods (Pseudo-F = 1.3794, P = 0.201) and sampling points (Pseudo-F = 1.3794, P = 0.201).

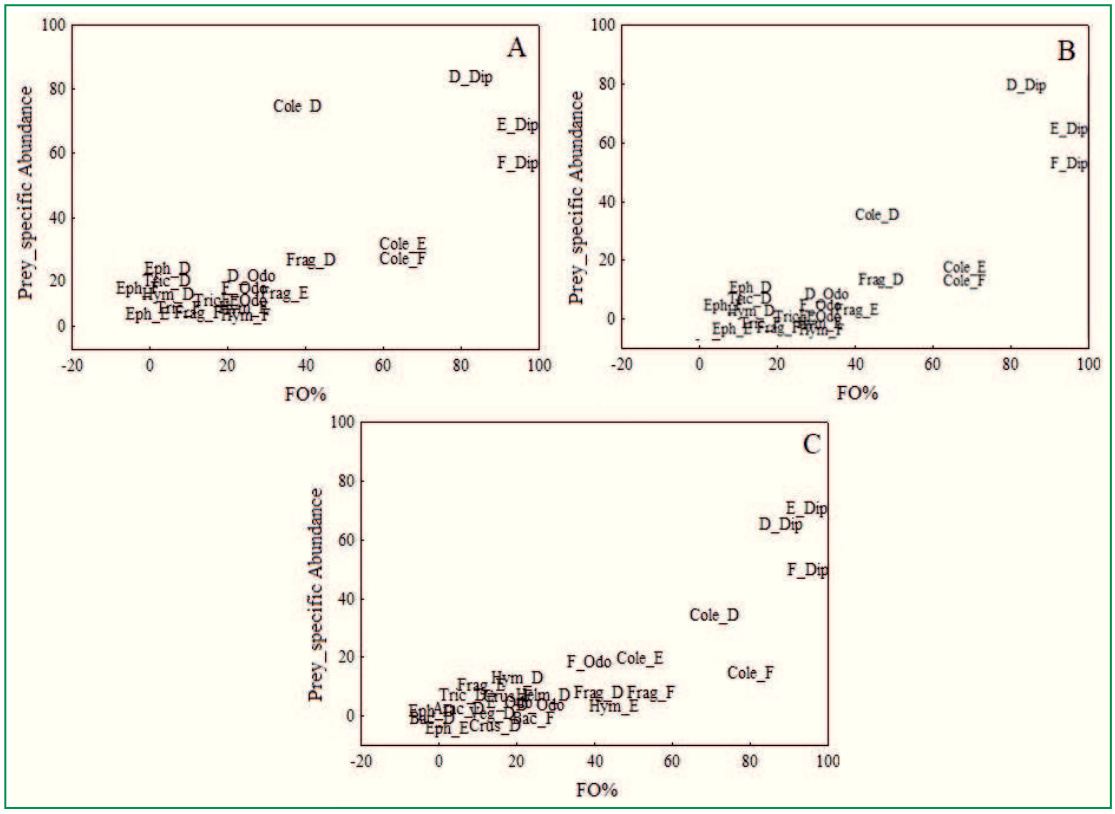
TABLE 2: Percentage of prey-specific index of relative importance (%PSIRI), percent frequency of occurrence (%FO), prey-specific abundances by number and volume (%PN and %PV), relative volume (V%) and numerical percentage of prey (%N) of food items in *G. rondoni* diet, during the periods of the hydrological cycle at the sampling points P1 and P2 – first-order streams and P3 – second-order stream, in western Amazon – Brazil.

Period	Food Items	P1						P2						P3					
		FO%	N%	V%	PN%	PV%	PISIRI%	FO%	N%	V%	PN%	PV%	PISIRI%	FO%	N%	V%	PN%	PV%	PISIRI%
Drought	Diptera larvae/Chir/Cera	80.0	69.3	50.6	86.7	63.2	59.9	80.0	47.9	36.7	59.9	45.8	42.3	86.7	56.3	43.8	65.0	50.6	50.1
	Coleoptera larvae	43.3	17.4	23.0	40.1	53.0	20.2	53.3	12.0	16.7	15.0	20.8	9.6	73.3	24.8	21.8	33.9	29.8	23.3
	Odonata larvae	26.7	3.4	5.1	12.7	19.0	4.2	26.7	2.3	3.7	0.0	0.0	1.0	30.0	2.0	3.8	6.7	12.8	2.9
	Tricoptera larvae	6.7	1.0	0.3	14.5	4.3	0.6	6.7	0.7	0.2	0.0	0.0	0.0	10.0	1.0	0.6	10.0	5.9	0.8
	Ephemeroptera larvae	6.7	1.0	2.3	14.5	34.8	1.6	6.7	0.7	1.7	0.0	0.0	0.1	3.3	0.3	0.3	7.5	8.7	0.3
	Hymenoptera larvae	6.7	0.7	5.9	10.9	88.8	3.3	6.7	0.5	4.3	0.0	0.1	0.2	20.0	2.5	8.5	12.5	42.7	5.5
	Fragments of insects	43.3	7.2	12.9	16.7	29.7	10.1	43.3	5.0	9.3	0.1	0.1	3.9	43.3	3.1	8.0	7.2	18.4	5.6
	Crustaceans	0.0	0.0	0.0	0.0	0.0	0.0	16.7	1.7	2.2	0.0	0.0	0.4	16.7	0.8	0.7	4.5	4.3	0.7
	Arachnids	0.0	0.0	0.0	0.0	0.0	0.0	10.0	1.2	0.1	0.0	0.0	0.1	13.3	0.9	0.9	6.6	6.8	0.9
	Helminth	0.0	0.0	0.0	0.0	0.0	0.0	50.0	25.9	17.8	0.3	0.2	13.6	36.7	6.9	8.8	18.8	23.9	7.8
	Vegetables	0.0	0.0	0.0	0.0	0.0	0.0	20.0	1.2	3.6	0.0	0.0	0.6	16.7	0.9	2.1	5.3	12.6	1.5
	Bacillariophyceae	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.5	3.3	0.0	0.0	0.1	3.3	0.1	0.1	3.8	1.9	0.1
	Chlorophyceae	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.2	0.3	0.0	0.0	0.0	6.7	0.3	0.5	3.8	8.0	0.4
	Other algae	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.3	0.2	0.0	0.0	0.0	3.3	0.1	0.0	3.8	1.0	0.1
Ebb	Diptera larvae	100.0	68.7	45.0	68.7	45.0	56.9	100.0	56.9	48.6	56.9	48.6	52.8	100.0	70.6	47.1	70.6	47.1	58.8
	Coleoptera larvae	66.7	15.2	27.2	15.2	27.2	14.1	63.2	22.4	20.7	22.4	20.7	13.6	55.0	19.2	24.3	19.2	24.3	12.0
	Odonata larvae	26.7	4.7	6.8	4.7	6.8	1.5	47.4	5.6	9.6	5.6	9.6	3.6	20.0	1.5	1.4	1.5	1.4	0.3
	Tricoptera larvae	13.3	1.9	0.4	1.9	0.4	0.2	15.8	2.0	0.5	2.0	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	Ephemeroptera larvae	6.7	1.9	3.3	1.9	3.3	0.2	15.8	2.0	3.6	2.0	3.6	0.4	10.0	0.6	5.2	0.6	5.2	0.3
	Hymenoptera larvae	16.7	0.9	9.1	0.9	9.1	0.8	5.3	0.3	4.2	0.3	4.2	0.1	55.0	5.8	18.4	5.8	18.4	6.7
	Fragments of insects	36.7	6.6	8.1	6.6	8.1	2.7	31.6	4.9	9.3	4.9	9.3	2.2	15.0	2.0	3.5	2.0	3.5	0.4
	Crustaceans	0.0	0.0	0.0	0.0	0.0	0.0	15.8	1.3	2.3	1.3	2.3	0.3	5.0	0.3	0.0	0.3	0.0	0.0
	Arachnids	0.0	0.0	0.0	0.0	0.0	0.0	15.8	3.3	0.2	3.3	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	Vegetables	0.0	0.0	0.0	0.0	0.0	0.0	15.8	1.0	0.5	1.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Chlorophyceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Flood	Diptera larvae	100.0	56.9	56.5	56.9	56.5	56.7	80.0	69.3	52.4	86.7	65.5	60.9	100.0	50.2	51.1	50.2	51.1	50.7
	Coleoptera larvae	66.7	21.2	23.5	21.2	23.5	14.9	53.3	17.4	23.8	21.7	29.8	13.7	83.3	18.2	21.8	18.2	21.8	16.7
	Odonata larvae	25.0	4.6	4.5	4.6	4.5	1.1	30.0	3.4	5.3	4.2	6.6	1.6	25.0	4.4	3.5	4.4	3.5	1.0
	Tricoptera larvae	16.7	2.9	0.4	2.9	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.1	2.5	0.1	0.0
	Ephemeroptera larvae	8.3	2.4	0.2	2.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	8.3	2.1	0.0	2.1	0.0	0.1
	Hymenoptera larvae	25.0	3.4	4.6	3.4	4.6	1.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	2.4	2.7	2.4	2.7	0.4
	Fragments of insects	116.7	7.3	10.0	7.3	10.0	10.1	46.7	7.2	13.4	9.1	16.7	6.0	50.0	7.1	11.3	7.1	11.3	4.6
	Crustaceans	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	2.3	0.1	2.3	0.1	0.2
	Arachnids	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	2.3	0.7	2.3	0.7	0.1
	Helminth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	2.1	0.0	2.1	0.0	0.1
	Vegetables	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	6.4	8.7	6.4	8.7	0.6
	Bacillariophyceae	0.0	0.0	0.0	0.0	0.0	0.0	23.3	1.7	5.2	2.1	6.5	1.0	25.0	0.0	0.0	0.0	0.0	0.0
	Chlorophyceae	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.7	4.8	0.9	6.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	Other algae	8.3	0.7	0.3	0.7	0.3	0.0	3.3	0.2	0.4	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The Amundsen diagram showed a generalist strategy in the diet of individuals of *G. rondoni* (Figure 4). However, larvae of Diptera and Coleoptera were the most frequent items and showed the greatest prey-specific abundance in all periods of the hydrological cycle.

FIGURA 4: Costello Graphic Method (COSTELLO, 1990), adapted by Amundsen et al. (1996), showing the diet of *G. rondoni* (A-P1, B-P2 C-P3) during the hydrological cycle at sampling points in low-order streams in western Amazon – Brazil. Dip – Diptera; Cole – Coleoptera; Egss; Nema- Nematodes; Trico – Trichoptera; Hemy – Hymenoptera; Efe – Ephemeroptera; Odo – Odonata; Crus – Crustaceo; Aca – Acari; Arac – Arachnid. D: drought; E: Ebb and F: flood.



Discussion

The population of *G. rondoni* increased along the longitudinal gradient mainly during drought. The present study demonstrated that the individuals occupied microhabitats composed of sandbanks and showed a diet based mainly on benthic prey. Although they consumed a variety of food items, which indicates a generalist food habit, their diet was composed of dominant food items (i.e., items consumed by most or all individuals within a population in large quantities) such as larvae of Diptera and Coleoptera. We found no difference in the composition of prey consumed by individuals along the longitudinal gradient during different periods of the hydrological cycle. However, the diet of *G. rondoni* showed a low range of trophic niches in the three seasonal periods.

The association of *G. rondoni* with sandbanks, as seen in the present study, is well corroborated and documented in the literature (SCHWASSMANN, 1976; FERRARIS, 2003; ZUANON et al., 2006), which indicated that this species uses this microhabitat as shelter during the day, and a foraging place at night. However, the present study suggests that in addition to sand habitats, this species can be found foraging and shifting to other types of microhabitats at night. As suggested by the present study, where some individuals were captured in places that had substrates composed of clay and organic matter in the nocturnal period. According to Brejão et al. (2013), groups formed by species of gymnotiformes are associated with substrates of small streams, and find shelter and food in this type of microhabit.

The increase in *G. rondoni* population along the longitudinal gradient may be associated with physical and chemical characteristics of the environment, where according to Araújo-Lima et al. (1999), first-order streams show less flow and depth and relatively smaller area compared to second-order streams, influencing microhabitats and consequently the occurrence of *G. rondoni* individuals. Another important point is the addition of new habitats and ecological niches along the longitudinal gradient, which may result in a greater number of species occurrences (RAHEL; HUBERT, 1991; MATTHEWS, 1998). Thus, the reason for larger areas containing a greater number of species would be related to the greater environmental heterogeneity contained in these aquatic systems (LOWE-MCCONNELL, 1987).

In addition to spatial variation, the distribution of the *G. rondoni* population was also influenced by the variation of seasonal periods, where we found a small number of individuals sampled during the flood period, which might have been related to the increase in water level and flow and decreased water transparency. A very similar finding was reported by Espírito-Santo et al. (2009), who after local rains observed a decrease in fish samples, which was attributed to increased flow, turbulence, water turbidity and changes in the substrate.

The present study showed that individuals of *G. rondoni* had predominantly nektobenthic habits, which, according to Zuanon et al. (2006), concerns species with nocturnal activities that capture prey near the substrate. The search for prey on substrates is characteristic of species of the order Gymnotiformes (ADITE; WINEMILLER, 1997; LUZ-AGOSTINHO et al., 2006; GIORA et al., 2012; TESK et al., 2014; SOARES et al., 2017). Moreover, in some species of the family Rhamphichthyidae, for example, the genera Rhamphichthys and Gymnorhamphichthys can be found foraging in sandy substrates in small streams (ZUANON et al., 2006; BREJÃO et al., 2013). According to Schwassmann (1976), electrolocation capability helps species of *Gymnorhamphichthys* to locate prey, and the elongated snout allows the substrate to be turned to capture invertebrate larvae.

The present study showed that along the longitudinal gradient and hydrological cycle, the main items consumed by *G. rondoni* species were benthic insect larvae, mainly Diptera and Coleoptera. According to Lunardon-Branco and Branco (2003), Diptera larvae show sufficient biomass throughout the year on the substrate, due to their long lifespan, which might have influenced their high consumption by the individuals collected. The consumption of Diptera larvae, mainly Chironomidae and Ceratopogonidae, by *G. rondoni* is well evidenced in studies by Zuanon et al. (2006), Carvalho (2008), Virgilio et al. (2009), Tesk et al. (2014)

and Soares et al. (2017). Therefore, we conclude that *G. rondoni* has a food preference for these invertebrate larvae.

However, other food items besides benthic larvae were found in the diet of *G. rondoni* individuals, such as allochthonous items such as insect fragments, Hymenopterans, and other items such as arachnids and crustaceans. Similar results were found for other species of Gymnotiformes (PERETTI; ANDRIAN, 1999; GIORA et al., 2012; FERRIZ; IWASZKIW, 2014), which consumed prey of various nektobenthic and allochthonous origins. Also, remains of plants and algae were consumed at lower abundance and frequency. According to Adite and Winemiller (1997), Gymnotiformes do not apparently exhibit morphological specialization for detritivory and herbivory (for example, extension of the digestive tract). Thus, the present study suggests that these items may have been ingested accidentally during the search for more nutritive prey. The same was observed in the diet of *Gymnotus coropinae* and *G. rondoni* by Soares et al. (2017), who found debris and plant remains in the stomachs of these species. Another alternative hypothesis may be the indirect ingestion of plant remains and algae through the consumption of Diptera larvae. Diptera larvae such as Chironomidae and Ceratopogonidae, according to Butakka et al. (2014), can be found in all environments, including sandy substrates, mainly of organic debris such as plant fragments and algae. Thus, when eating the dipterans, the individuals of *G. rondoni* could be consuming these items incorporated in the larvae.

Although some species of *G. rondoni* were found in other substrates and showed a generalist food strategy, we found a low niche breadth in their diet. This might have been influenced by the predominant consumption of Diptera and Coleoptera larvae. Also, as suggested by Zuanon et al. (2006) and Soares et al. (2017), low niche breadth may be related to the more specialized morphology of *G. rondoni* and preference for foraging on sand substrates. This restricts the consumption of food items to these environments.

Therefore, we expect that our findings will complement other research regarding the ecology of stream fishes and will generate a better understanding of the importance of these habitats to the ecosystem. For example, we know that the loss of the ciliary vegetation causes the sediments to disappear, modifying the characteristics of the substrates, such as loss of porosity and stability of the sand substrate, interrupting the movement of water and oxygen in these systems (RABENI; SMALE, 1995), which may lead to the disappearance of psammophilic species such as *G. rondoni*. Thus, through the knowledge of the ecological importance of *G. rondoni* in these stream ecosystems, we can uncover valuable tools to understand some trophic interactions and associations between organisms and their habitat, providing diverse information that helps in the development of future studies and conservation measures.

Acknowledgments

We thank the project Casadinho (Federal University of Acre, UFAC) for logistic support. The Graduate Program in Ecology and Natural Resource Management (UFAC) for the assistance and the Laboratory of Aquatic Environments Ecology of Federal University of Acre for the materials provision.

References

ADITE, A.; WINEMILLER, K. O. Trophic ecology and ecomorphology of fish assemblages in coastal lakes of Benin, West Africa. **Écoscience**, Québec, v. 4, n. 1, p. 6-23, 1997.

ALLAN, J. D.; CASTILLO, M. M. **Stream ecology:** structure and function of running waters. Berlin: Springer Science & Business Media, 2007. 436 p.

AMUNDSEN, P. A.; GABLER, H. M.; STALDVIK, F. J. A new approach to graphical analysis of feeding strategy from stomach contents data – modification of the Costello (1990) method. **Journal of Fish Biology**, Malden, v. 48, n. 4, p. 607-614, 1996.

ARAÚJO, A.; BICUDO, C. E. M. Criptógamos do Parque Estadual das Fontes do Ipiranga, São Paulo, SP. Algas, 22: Zygnemaphyceae (gêneros *Actinotaenium*, *Cosmarium* e *Heimansia*). **Hoehnea**, São Paulo v. 33, p. 219-237, 2006.

ARAÚJO-LIMA, C. A. R. M.; JIMÉNEZ, L. F.; OLIVEIRA, R. S.; ETEROVICK, P. C.; MENDOZA, U.; JEROZOLIMNKI, A. Relação entre o número de espécies de peixes, complexidade do hábitat e ordem do riacho nas cabeceiras de um tributário do rio Urubu, Amazônia Central. **Acta Limnologica Brasiliensia**, Rio Claro, v. 11, n. 2, p. 127-135, 1999.

BARRELLA, W.; PETRERE JR., M.; SMITH, W. S.; MONTAG, L. F. A. As relações entre as matas ciliares, os rios e os peixes.

In: RODRIGUES, R. R.; FILHO, H. F. L. (Ed.). **Matas ciliares:** conservação e recuperação. São Paulo: EDUSP, 2000. p. 187-207.

BICUDO, C. E. Cryptogams of the "Parque Estadual das Fontes do Ipiranga", São Paulo, SP. Algae, 18: Chlorophyceae (Volvocales). **Brazilian Journal of Botany**, São Paulo, v. 27, n. 1, p. 85-102, 2004.

BREJÃO, G. L.; GERHARD, P.; ZUANON, J. Functional trophic composition of the ichthyofauna of forest streams in eastern Brazilian Amazon. **Neotropical Ichthyology**, Maringá, v. 11, n. 2, p. 361-73, 2013.

BROWN, S. C.; BIZZARRO, J. J.; CAILLIET, G. M.; EBERT, D. A. Breaking with tradition: redefining measures for diet description with a case study of the Aleutian skate *Bathyraja aleutica* (Gilbert 1896). **Environmental Biology of Fishes**, New York, v. 95, n. 1, p. 3-20, 2012.

BULLOCK, T. H. Species differences in effect of electroreceptor input on electric organ pacemakers and other aspects of behavior in electric fish. **Brain Behavior and Evolution**, Basel, v. 2, n. 2, p. 85-118, 1969.

BUTAKKA, C. M. M.; GRZYBKOWSKA, M.; PINHA, G. D.; TAKEDA, A. M. Habitats and trophic relationships of Chironomidae insect larvae from the Sepotuba River basin, Pantanal of Mato Grosso, Brazil. **Brazilian Journal of Biology**, São Carlos, v. 74, n. 2, p. 395-407, 2014.

CARVALHO, L. N. **História natural de peixes de igarapés amazônicos:** utilizando a abordagem do Conceito do Rio Contínuo. 2008. 156 f. Tese (Doutorado em Biologia Tropical e Recursos Naturais) – Instituto Nacional de Pesquisas da Amazônia/ Universidade Federal do Amazonas, Manaus. 2008.

CARVALHO, M. S.; ZUANON, J.; FERREIRA, E. J. Diving in the sand: the natural history of *Pygidianops amphioxus* (Siluriformes: Trichomycteridae), a miniature catfish of Central Amazonian streams in Brazil. **Environmental Biology of Fishes**, New York, v. 97, n. 1, p. 59-68, 2014.

CARVALHO, T. P.; RAMOS, C. S.; ALBERT, J. S. A new species of *Gymnorhamphichthys* (Gymnotiformes: Rhamphichthyidae) from the Paraná-Paraguay basin. **Copeia**, Lawrence, v. 2011, n. 3, p. 400-406, 2011.

COSTELLO, M. J. Predator feeding strategy and prey importance: a new graphical analysis. **Journal of Fish Biology**, Malden, v. 36, n. 2, p. 261-263, 1990.

ESPÍRITO-SANTO, H. M. V.; MAGNUSSON, W. E.; ZUANON, J.; MENDONÇA, F. P.; LANDEIRO, V. L. Seasonal variation in the composition of fish assemblages in small Amazonian forest streams: evidence for predictable changes. **Freshwater Biology**, London, v. 54, n. 3, p. 536-548, 2009.

FERRARIS, C. J. Family Rhamphichthyidae. In: REIS, R. E.; KULLANDER, S. O.; FERRARIS, C. J. (Org.). **Check list of the freshwater fishes of South and Central America.** Porto Alegre: EDIPUCRS, 2003. p. 492-493.

FERRIZ, R. A.; IWASZKIW, J. M. Alimentación de *Gymnotus omarorum* (Gymnotiformes: Gymnotidae) en Laguna Blanca (Parque Nacional Río Pilcomayo), Formosa, Argentina. **Revista del Museo Argentino de Ciencias Naturales**, Buenos Aires, v. 16, n. 2, p. 115-122, 2014.

GIORA, J.; TARASCONI, H. M.; FIALHO, C. B. Reproduction and feeding habits of the highly seasonal *Brachyhypopomus bombilla* (Gymnotiformes: Hypopomidae) from southern Brazil with evidence for a dormancy period. **Environmental Biology of Fishes**, New York, v. 94, n. 4, p. 649-662, 2012.

GIORA, J.; TARASCONI, H. M.; FIALHO, C. B. Reproduction and feeding of the electric fish *Brachyhypopomus gauderio* (Gymnotiformes: Hypopomidae) and the discussion of a life history pattern for gymnotiforms from high latitudes. **PLoS One**, Cambridge, v. 9, n. 9, p. e106515, 2014.

GONÇALVES, A. F. G.; PRUDENTE, B. D. S.; CARVALHO FILHO, F. D. S.; MONTAG, L. F. D. A. Feeding ecology of Dash-dot Tetra *Hemigrammus belottii* (Steindachner 1882) (Characiformes: Characidae) in the streams of the Urucu River basin, central Amazonia, Brazil. **Biota Neotropica**, Campinas, v. 13, n. 3, p. 141-147, 2013.

HENRY, J. C.; FISHER, S. G. Spatial segregation of periphyton communities in a desert stream: causes and consequences for N cycling. **Journal of the North American Benthological Society**, Lawrence, v. 22, n. 4, p. 511-527, 2003.

HERDER, F.; FREYHOF, J. Resource partitioning in a tropical stream fish assemblage. **Journal of Fish Biology**, Malden, v. 69, n. 2, p. 571-589, 2006.

HERRÁN, R. A. Análisis de contenidos estomacales en peces. Revisión bibliográfica de los objetivos y la metodología. **Informes Técnicos del Instituto Español de Oceanografía**, Madrid, v. 1, n. 63, p. 3-74, 1988.

HYNES, H. B. N. The food of fresh-water sticklebacks (*Gasterosteus aculeatus* and *Pygosteus pungitius*), with a review of methods used in studies of the food of fishes. **Journal of Animal Ecology**, London, v. 19, n. 1, p. 36-58, 1950.

JUNK, W. J. Aquatic habitats in Amazonia. **The Environmentalist**, New York, v. 3, n.1, p. 24-34, 1983.

JUNK, W. J.; PIEDADE, M. T. F. The Amazon river basin. In: FRASER, L. H.; KEDDY, P. A. (Ed.). **The world's largest wetlands:** ecology and conservation. Boston: Cambridge University Press, 2005. p. 63-117.

LEAL, C. G.; JUNQUEIRA, N. T.; POMPEU, P. S. Morphology and habitat use by fishes of the Rio das Velhas basin in southeastern Brazil. **Environmental Biology of Fishes**, New York, v. 90, n. 2, p. 143-157, 2011.

LISSMANN, H. W. Ecological studies on gymnotids. In: CHAGAS, C.; PAES DE CARVALHO, A. (Ed.). **Bioelectrogenesis.** Amsterdam: Elsevier, 1961. p. 215-226.

LISSMANN, H. W.; SCHWASSMANN, H. O. Activity rhythm of an electric fish, *Gymnorhamphichthys hypostomus* Ellis. **Zeitschrift fur Vergleichende Physiologie**, Berlin, v. 51, n. 3, p. 153-171, 1965.

LOWE-MCCONNELL, R. H. **Ecological studies in tropical fish communities.** London: Cambridge University Press, 1987. 382 p.

LUNARDON-BRANCO, M. J.; BRANCO, J. O. Alimentação natural de *Etropus crossotus* Jordan & Gilbert (Teleostei, Pleuronectiformes, Paralichthyidae), na Armação do Itapocoroy, Penha, Santa Catarina, Brasil. **Revista Brasileira de Zoologia**, Curitiba, v. 20, n. 4, p. 631-635, 2003.

LUZ-AGOSTINHO, K. D.; BINI, L. M.; FUGI, R.; AGOSTINHO, A. A.; JÚLIO JR, H. F. Food spectrum and trophic structure of the ichthyofauna of Corumbá reservoir, Paraná river Basin, Brazil. **Neotropical Ichthyology**, Maringá, v. 4, n. 1, p. 61-68, 2006.

MATTHEWS, W. J. **Patterns in freshwater fish ecology.** New York: Chapman & Hall, 1998. 756 p.

MENDONÇA, M. B.; DE ASSIS MONTAG, L. F.; RAIOL, R. D. O.; WOSIACKI, W. B. Feeding ecology of two sympatric species of the genus *Jupiaba* (Characiformes: Characidae) in streams in the Urucu River Basin, AM, Brazil. **Uakari**, Tefé, v. 8, n. 1, p. 59-67, 2012.

MERRITT, R. W.; CUMMINS, K. W. **An introduction to the aquatic insects of North America.** Kendall: Hunt Publishing Company, 1984. 862 p.

MUGNAI, R.; NESSIMIAN, J. L.; BAPTISTA, D. F. **Manual de identificação de macroinvertebrados aquáticos do Estado do Rio de Janeiro.** Rio de Janeiro: Technical Books, 2010. 174 p.

NAIMAN, R. J.; DECAMPS, H. The ecology of interfaces: riparian zones. **Annual Review of Ecology and Systematics**, Palo Alto, v. 28, n. 1, p. 621-658, 1997.

NIMET, J.; DELARIVA, R. L.;WOLFF, L. L.; SILVA, J. C. D. (2015). Trophic structure of fish fauna along the longitudinal gradient of a first-order rural stream. **Acta Limnologica Brasiliensia**, Rio Claro, v. 27, n. 4, p. 381-393, 2015.

ODUM, E. P. The strategy of ecosystem development. **Science**, New York, v. 164, n. 3877, p. 262-270, 1966.

OKSANEN, J.; BLANCHET, F. G.; KINDT, R.; LEGENDRE, P.; MINCHIN, P. R.; O'HARA, R. B.; WAGNER, H. **Vegan:** Community Ecology Package. R package version 2.3-0. 2015. *Google Scholar*.

PERETTI, D.; ANDRIAN, I. D. F. Feeding of *Eigenmannia trilineata* (Pisces, Sternopygidae) (Lopez & Castello, 1966), in the upper Paraná River floodplain, Brazil. **Brazilian Archives of Biology and Technology**, Curitiba, v. 42, n. 1, p. 0-0, 1999.

PINKAS, L.; OLIPHANT, M. S.; IIVERSON, I. L. K. Food habits of albacore, bluefin tuna, and bonito in California waters. **California Department of Fish and Game Fish Bulletin**, Oakland, v. 152, n. 1, p. 1-105, 1971.

R DEVELOPMENT CORE TEAM. **The Nlme:** linear and nonlinear mixed effects models. 2011. R Package Version 3.1.

RABENI, C. F.; SMALE, M. A. Effects of siltation on stream fishes and the potential mitigating role of the buffering riparian zone. **Hydrobiologia**, Brussels, v. 303, n. 1, p. 211-219, 1995.

RAHEL, F. J.; HUBERT, W. A. Fish assemblages and habitat gradients in a Rocky Mountain-Great Plains stream: biotic zonation and additive patterns of community change. **Transactions of the American Fisheries Society**, Oxford, v. 120, n. 3, p. 319-332, 1991.

RAMOS, C. D. S. **Revisão taxonômica de *Gymnorhamphichthys* (Gymnotiformes, Rhamphichthyidae) com descrição de duas novas espécies.** 2010. 84 f. Dissertação (Mestrado em Zoologia) – Museu Paraense Emílio Goeldi, Universidade Federal do Pará, Belém. 2010.

RESH, V. H.; ROSENBERG, D. M. **The ecology of aquatic insects.** 1. ed. New York: Praeger Publishers, 1986. 625 p.

ROUGHGARDEN, J. Niche width: biogeographic patterns among *Anolis* lizard populations. **The American Naturalist**, Chicago, v. 108, n. 962, p. 429-442, 1974.

SCHAEFER, S. A.; PROVENZANO, F.; DE PINNA, M. C. C.; BASKIN, J. N. New and noteworthy Venezuelan *Glanapteryginae* catfishes (Siluriformes, Trichomycteridae), with discussion of their biogeography and psammophily. **American Museum Novitates**, New York, v. 3496, v. 1, p. 1-27, 2005.

SCHOENER, T. W. Resource partitioning in ecological communities. **Science**, New York, v. 185, n. 4145, p. 27-39, 1974.

SCHWASSMANN, H. O. Ecology and taxonomic status of different geographic populations of *Gymnorhamphichtys hypostomus* Ellis (Pisces, Cypriniformes, Gymnotoidei). **Biotropica**, Malden, v. 8, n. 1, p. 25-40, 1976.

SOARES, B. E.; ROSA, D. C.; SILVA, N.; ALBRECHT, M. P.; CARAMASCHI, É. P. Resource use by two electric fishes (Gymnotiformes) of the National Forest Saracá-Taquera, Oriximiná, Pará. **Neotropical Ichthyology**, Maringá, v. 15, n. 2, 2017.

SOUZA, V. M. D.; SOUZA, M. B. D.; MORATO, E. F. Effect of the forest succession on the anurans (Amphibia: Anura) of the Reserve Catuaba and its periphery, Acre, southwestern Amazonia. **Revista Brasileira de Zoologia**, Curitiba, v. 25, n. 1, p. 49-57, 2008.

TESK, A.; DE MATOS, L. S.; PARISOTTO, D. C.; CABECEIRA, F. G.; CARVALHO, L. N. Dieta do peixe elétrico *Gymnorhamphichthys petiti* Géry & Vu-Tân-Tuê, 1964 (Rhamphichthyidae), em riachos da bacia do Rio Teles Pires, Amazônia Meridional. **Bioscience Journal**, Uberlândia, v. 30, n. 5, p. 1573-1577, 2014.

VIRGILIO, L. R.; GOMES, R. S.; VIEIRA, L. J. S.; SUÇUARANA, M. S.; BRITO, C. H. Hábito larvívoro em *Gymnorhamphichthys rondoni* (Miranda-Ribeiro, 1920) (Gymnotiformes: Rhamphichthyidae) em um fragmento Florestal no leste do Acre. In: CONGRESSO DE ECOLOGIA DO BRASIL, IX, 2009, São Lourenço. **Anais...** São Lourenço: SBE, 2009. Disponível em: <http://www.seb-ecologia.org.br/2009/resumos_ixceb/718.pdf>.

ZUANON, J.; BOCKMANN, F. A.; SAZIMA, I. A remarkable sand-dwelling fish assemblage from central Amazonia, with comments on the evolution of psammophily in South American freshwater fishes. **Neotropical Ichthyology**, Maringá, v. 4, n. 1, p. 107-118, 2006.