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Original Article

Associations between morphological attributes and food resources in anurans from the Middle Xingu region, Brazil

Associações entre atributos morfológicos e recursos alimentares em anuros da região do Médio Xingu, Brasil

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Abstract

Considering the hypothesis that there is a relationship between morphology and the choice or feeding habit in anurans, our objective was to identify the food items present in the anurans' diet; verify the existence of a pattern in the diet of the anurans collected; and show the relationship between diet and species morphology. Sampling was carried out using an active search methodology carried out by three people, lasting approximately three hours per unit. For that work, only species that had an abundance equal to or greater than five individuals were considered. We identified dietary patterns in taxonomic groups and tested their significance, in addition to groupings by family, genus and species and the relationship between morphology and diet. 148 individuals were collected, belonging to 41 anuran species, 16 genera and nine families, 44 items were observed, highlighting the Formicidae family and Tadpoles, with shrimp and crab being the least frequently found items. We concluded that there was a relationship between morphology and diet, in addition to the formation of a guild of insectivorous anurans, indicating a greater frequency of Hymenoptera as a food resource, mainly composed of the genus *Rhinella*.

Keywords: food resources, diet, ecomorphology, habitat choice, morphometric measurements.

Resumo

Considerando a hipótese de que existe relação entre a morfologia e a escolha ou habito alimentar em anuros, nosso objetivo foi identificar os itens alimentares presentes na dieta dos anuros; verificar a existência de padrão na dieta anuros coletadas; e mostrar a relação entre dieta e morfologia das espécies. A amostragem foi realizada por meio de metodologia de busca ativa realizada por três pessoas, com duração aproximada de três horas por unidade. Para esse trabalho foram consideradas apenas as espécies que apresentavam abundância igual ou superior a cinco indivíduos. Identificamos padrões alimentares em grupos taxonômicos e testamos sua significância, além de agrupamentos por família, gênero e espécie e a relação entre morfologia e dieta. Foram coletados 148 indivíduos, pertencentes a 41 espécies de anuros, 16 gêneros e nove famílias. Foram observados 44 itens, destacando-se a família Formicidae e os Girinos, sendo o camarão e o caranguejo os itens menos encontrados. Concluímos que houve relação entre morfologia e dieta, além da formação de uma guilda de anuros insetívoros, indicando maior frequência de Hymenoptera como recurso alimentar, composta principalmente pelo gênero *Rhinella*.

Palavras-chave: recursos alimentares, dieta, ecomorfologia, escolha de habitat, medidas morfométricas.

1. Introduction

Anurans have a wide global distribution, occupying almost every continents, and are currently represented by 7,651 described species (Frost, 2023). Of these, 1,188 species occur in Brazil (Segalla et al., 2021), 309 are found in the Brazilian Amazon (Hoogmoed and Galatti, 2017). It has arboreal, semiaquatic and fossorial habits, with diurnal and nocturnal species, with specialized morphology for different reproductive modes and varying both in size and external appearance (Lima et al., 2006; Pough et al., 2008). Around 41% of anuran species are threatened with extinction (IUCN, 2023), which reinforces the need for studies on this group (Verdade et al., 2010).

The Anurans is considered excellent bioindicators, as they can provide information about the conditions of terrestrial and aquatic ecosystems (Cooke, 1981), they are organisms that have an aquatic habit in the larval stage

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and a terrestrial habit in the adult stage (Verdade et al., 2010) and it is sensitive to changes in terrestrial and aquatic ecosystems (Toledo, 2009). Furthermore, the permeable skin makes most anurans dependent on humid areas, thus limiting the group's mobility and dispersal/migration routes, making them even more susceptible to environmental changes than animals with greater mobility and autonomy to migrate, disperse or even escape (Santos et al., 2011).

The factors that influence external morphology are still little known, as well as their ecological interactions and evolution, which makes assertive methods of conserving anurans impossible (Menin et al., 2008). The high adaptive morphological diversity of anurans allows the simultaneous occurrence of several species in the same habitat (Vasconcelos et al., 2011). An example of this is the relationship of these organisms with the food consumed, since eating habits can describe the size of the niche (Wells, 2010), making it possible to infer habitat preferences, their relationships with other species, the inhabited geographic zone and evolutionary trends (Vitt and Caldwell, 2009).

Although there is a wide range of food resources available to anurans (Abbey-Lee, 2012), the diet of these organisms is mainly composed of small invertebrates, vertebrates (Vitt and Caldwell, 2009), and in some cases, they it can even attack other anuran species (Haddad et al., 2008). In fact, variations in diet can mean quite complex patterns, since anurans feeding mechanisms have evolved in response to selective pressures (Caldart et al., 2012). In this way, we can observe species that occur in the same habitat, but with very different diets (Cáceres and Machado, 2013). This may occur in response to historical or recent competition, leading to differentiation between species, or as a consequence of the specialization of some individual (Araújo et al., 2011).

In this context, ecomorphology, understood as the study of the relationships between the morphology and ecological behavior of species since their performance is linked to the pressures exerted by the environments (Cardoso et al., 2015), becomes important to understand the correlation between the shapes of organisms and their respective life habits (Fornel, 2011).

The study of the ecomorphological relationships of anurans is essential for a better understanding of their diversity of forms and habitat occupation (Eterovick et al., 2010; Pezzuti, 2011). Thus, our objectives are: (i) Identify whether there is a pattern in the diet of the frogs collected, testing whether this pattern is consistent between species, genera and families; and (ii) Relate the diet (food items) with the ecomorphological pattern (morphological measurements) of the species.

2. Materials and Methods

2.1. Study area

The study areas were composed of five collection points, comprising the upper and middle Xingu region (Figure 1, Appendix 1). Locality P1, collected in April 2017 and September 2018, has four sampling points, located in the

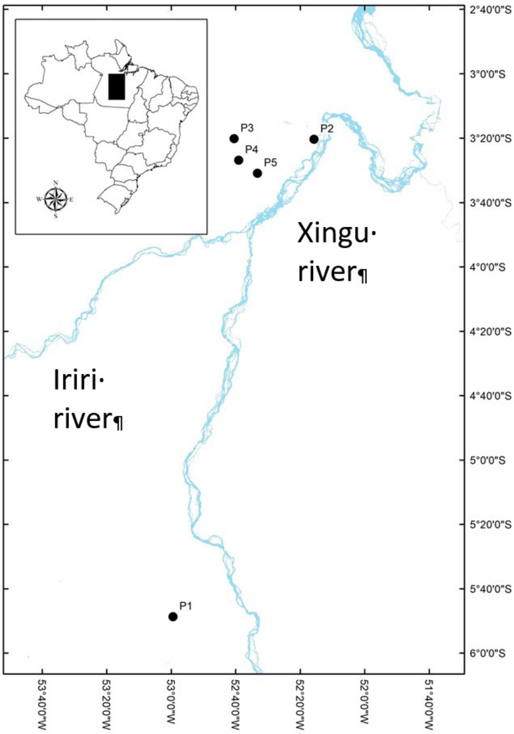

Figure 1. Map with the study collection stations. (P1) Parna Serra do Pardo Sítio; (P2) Module II; (P3) Agrovila Grande esperança; (P4) Fazenda Sayonara; (P5) Sítio Ecológico Raízes do Xingu.

Parque Nacional da Serra do Pardo (Supplementary Material S1). Locality P2, collections carried out in November 2017 and March 2018, has two sampling points, located in "Module II" (forest area used for monitoring fauna, resulting from the constraints of the Belo Monte Hydroelectric Power Plant). The third location is located in Agrovila Grande Esperança at km 50 (3°21'30.6"S and 52°37'58.8"W) pasture area with the presence of a dam the fieldwork was carried out in May and August 2018; the fourth location is located at Fazenda Sayonara (3°23'22.1"S and 52°38'11.5"W) on the 17th indent with a forest fragment and the presence of a stream, 12 km from the municipality of Brasil Novo, sampled in August 2018, and the last location is at Sítio Ecológico Raízes do Xingu (3°37'73.2" S and 52°57'55.9" W), municipality of Brasil Novo, presenting a preserved forest fragment and rugged area, sampled in June 2018 The climate in the region is tropical, with a short dry season between July and November, with an average temperature of 26.2 °C. and rainfall of 1844 mm per year average (INMET, 2019). The predominant vegetation is of the broadleaf type, with a transition zone between the Amazonian and the shrub and herbaceous formations of the Brazilian plateau (Galvão and Simões, 1966; Villas-Boas, 2012).

2.2. Sampling, morphometric measurements and stomach contents

Sampling was carried out using an active search methodology (Heyer et al., 1994) by three people, day and night, with two days of collection and duration of approximately three hours per sampling unit. Individuals were collected with SISBio 58050-2 authorization, euthanized while still in the field, and later identified with specific literature (Lima et al., 2006). All specimens were deposited in the Laboratorio do Grupo de Pesquisas em Comportamento e Ecologia Animal - GPCEA, listed and packed in glass containers with ethyl alcohol (70%).

In the laboratory, the stomachs of the individuals were opened and the stomach contents identified to the lowest possible taxonomic level, following specific literature (Baccaro et al., 2015). For morphological characterization, 32 morphometric measurements were taken (De-Carvalho et al., 2008; Freitas et al., 2008; Silva, 2006) using a digital caliper (–precision 0.05 mm). These measures were selected because they represent characteristics such as efficiency in capturing prey, patterns of spatial distribution and locomotion related to living habits, living habits (terrestrial, arboreal, semi-aquatic) and adaptations to the occupation of environments (De-Carvalho et al., 2008; Freitas et al., 2008) (Figure 2, Supplementary Material S2). For that work, only species that had an abundance equal to or greater than five individuals were considered.

2.3. Analytical treatment of data

The lists of toad species and food items present in the diet of anurans from the middle Xingu region were organized into tables and grouped by family and genus, in the case of frogs and family and order for food items. The frequency of occurrence of items was calculated for each anurans species (item abundance divided by the total abundance of items present in the diet) and for each food item (number of species in which the item was found divided by the total number of species) (Supplementary Material S4).

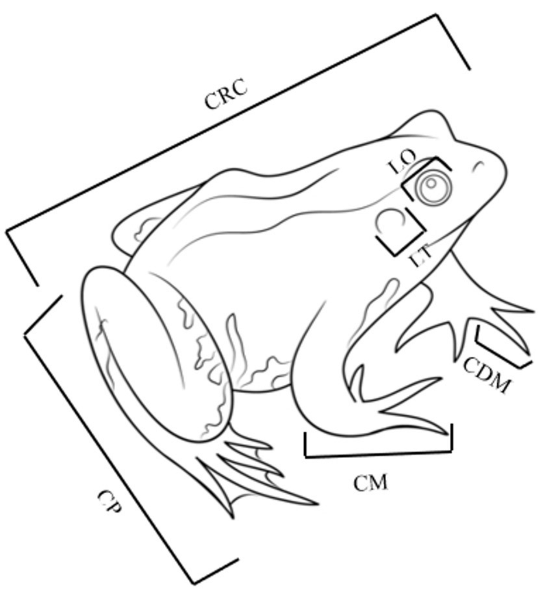

Figure 2. Illustration of morphological measurements performed in frogs. CM: hand length; CP: foot length; CDM: hand finger length; LT: eardrum width; LO: eye width; CRC: rostrum cloacal length.

To identify the existence of a pattern in the diet of the anurans collected, testing whether the pattern is consistent across species, genera and families, we performed a Principal Component Analysis – PCA. For this, we transformed the diet data by the Hellinger procedure, thus equivalent to a composition PCA (Legendre and Gallagher, 2001). The PCA scores (representation of individuals in the multidimensional space), were categorized by family, genus and later species, thus allowing the search for feeding patterns within the three taxonomic levels. As the PCA does not test the significance of the groups, we performed an analysis of Permutational Multivariate Variance – PERMANOVA (Anderson, 2005), grouping the individuals within the three studied taxonomic levels. In this way, we obtained three PCAs; (i) Family, (ii) Genus and (iii) Species, each associated with a PERMANOVA. As the stomach content data was treated as abundance, we used the Bray-Curtis distance as a similarity method. The distance matrix was calculated by the vegdist function, the PERMANOVA with the adonis function, the standardization with the decostand function and the PCA with the *rda* function, all implemented in the vegan package (Oksanen et al., 2020).

To relate the diet (richness of food items) with the ecomorphological pattern (morphological measurements) of the species, we performed a Redundancy Analyse - RDA (Legendre and Legendre, 1988) in which the diet matrix (abundance of items per stomach) was used as a dependent variable and the matrix of morphological measures as a predictor variable. The diet matrix was transformed by the Hellinger procedure, in the same way as in the composition PCA. The morphological matrix was logarithmised, avoiding the influence of outliers. Data standardization was performed using the *decostand* function and the RDA that builds a classification using regularized group covariance matrices avoiding multicollinearity in the data, with the *rda* function, all implemented in the *vegan* package (Oksanen et al., 2020). All analyses were made in the R environment (R Development Core Team, 2017).

3. Results

3.1. Abundance and list of frog species

We were collected 148 individuals, belonging to 41 species of frogs, 16 genera and nine families (**Appendix** 1 – Supplementary Material). Stomach contents were classified into 22 categories, most frequently in the phylum Nematoda, and the orders Hymenoptera, Coleoptera and Isopterae. We observed 44 items (Supplementary Material S3), highlighting Formicidae (Insecta: Hymenoptera) (42.92%) and Rhabdiasidae (Chromadorea: Rhabditida) (29.6%). Tadpoles, shrimp and crab are the least found items (Supplementary Material S3). The species with the most categories of food items found were *Rhinella granulosa* Spix, 1824, *Rhinella proboscidea* e *Rhinella marina*, with greater frequency of Formicidae (Supplementary Material S4).

3.2. Pattern in the diet of anurans

The PCA performed with the diet (Figure 3, Supplementary Material S5) presented 61.36% of explanation in the first two

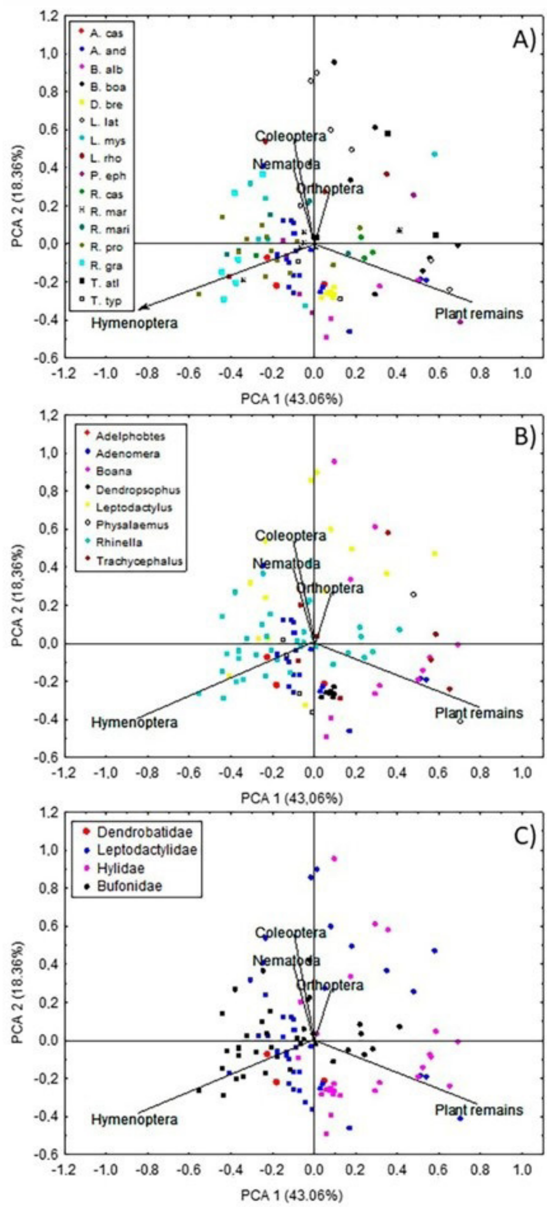

Figure 3. Principal Component Analysis (PCA) with data on the diet of frogs that occur in the Middle Xingu. (A) Relationship between food items in the multidimensional space with scores categorized by species, (B) genus and (C) family of anuran amphibians considered in the study.

axes (Supplementary Material S5). The variables (items) with the greatest relationship were Nematoda, Hymenoptera, Coleoptera and Isoptera. The results indicate which species *Adenomera andreae* and *Rhinella proboscidea* (Figure 3) consuming items like *Solenopsis invicta*, *Paraponera clavata*, *Acromyrmex* sp. and *Atta* sp. *Leptodactylus latrans* has a greater abundance of Scarabaeidae (Gromphas) (Insecta: Coleoptera) in food (Supplementary Material S5).

The species *Dendropsophus brevifrons* and *Leptodactylus mystaceus* showed higher frequency of Formicidae (*Solenopsis invicta* and *Atta* sp.). *Adelphobates castaneoticus* showed higher frequency of Formicidae (*Atta*). *Boana boans* showed higher frequency of Pentatomidae (*Arma*) (Insecta: Hemiptera). *Leptodactylus rhodomystax* showed higher frequency of Dorylaimidae (Enoplea: Dorylaimida) and Curculionidae (*Sitophilus*) (Insecta: Coleoptera). *Physalaemus ephippifer* showed higher frequency of Formicidae (*Solenopsis invicta*). *Rhinella margaritifera* showed higher frequency of Formicidae (*Wasmannia auropunctata*) (Supplementary Material S5).

Rhinella marina showed higher frequency of Rhabdiasidae. *Rhinella proboscidea, Rhinella granulosa, Trachycephalus typhonius* showed higher frequency of Formicidae (*Cephalotes, Ectatomma*, *Monomorium*, *Cephalotes, Wasmannia auropunctata* and *Camponotus*) and Termitidae (Insecta: Isoptera). *Trachycephalus atlas* showed higher frequency of Gryllotalpidae (*Gryllotalpa*) (Insecta: Orthoptera). The variation observed between species (pseudo-$F_{(15,109)}$ = 1.947; R^2 = 0.237; p<0.01), genus (pseudo-$F_{(16,145)}$ = 1.542; R^2 = 0.160; p<0.01) and families (pseudo-$F_{(8,145)}$ = 1.825; R^2 = 0.096; p<0.01) did not show a pattern different from chance.

3.3. Diet and ecomorphological pattern

The result of the RDA presented 42.56% of explanation in the first axis (Figure 4, Supplementary Material S6). The morphological variables with greater relation to the first axis were nostril width, arm width, distance between fore and hind limbs, muzzle length, shoulder width, leg width, feet length and the length of the first, third and fifth toes of the feet (Figure 4). Among the stomach items found, the variable with the greatest relationship to the axis is Hymenoptera, followed by, Coleoptera and Orthoptera (Supplementary Material S6). Individuals with larger body sizes, such as *Boana boans*, *Rhinella marina*, *Leptodactylus latrans* and species of the genus *Trachycephalus* are related to the consumption of Coleoptera and Nematoda. Individuals of smaller body size, such as genus *Adenomera*, *Adelphobates* and *Dendropsophus*, are related to the consumption of Hymenoptera. Individuals who have an intermediate body size such as *Rhinella granulosa*, *Rhinella margaritifera*, *Rhinella proboscidea*, *Rhinella castaneotica*, *Boana albopunctata*, *Leptodactylus mystaceus* and *Leptodactylus rhodomystax* are related to Orthoptera (Figure 4).

4. Discussion

Currently, there is no consensus on the effect of anuran morphology on their diet, with some results showing a correlation between morphology and diet, while others do not (Faye et al., 2012). However, we found that the anuran diet is more linked to the environmental structure, and may be affected more by the variety of foods than by the variety of morphology. We also observed the lack of correlation between the feeding habit of Formicidae and any morphological variable, where some anurans feed on prey larger and smaller than their morphological measurements.

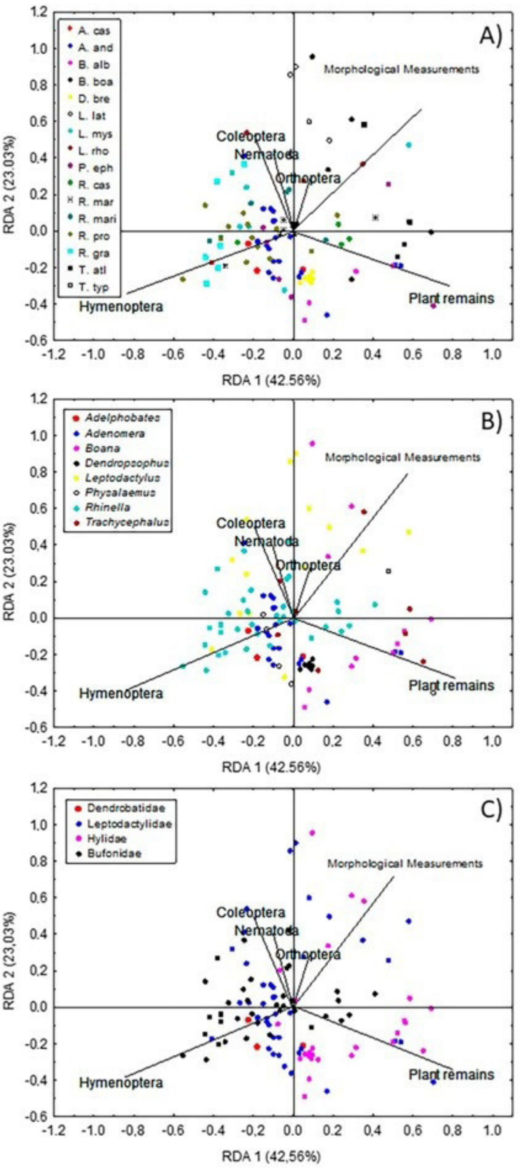

Figure 4. Redundancy Analysis – RDA, relating (A) morphological data and food items in the multidimensional space with the scores are by species; (B) genus and (C) family of anuran amphibians considered in the study.

It is known that the morphometry of anurans is directly related to their life habits (Pinto, 2011), and this was observed in this study, where the highest frequency of Hymenoptera was found in the species *Rhinella proboscidea*, which is small. As well as for the genera *Rhinella* and *Adenomera* and for the Bufonidae family (Amphibia: Anura) ranging from smaller to large specimens. Reinforcing what the literature reports, which describes that members of the Bufonidae family feed mainly on ants (Caldwell, 1996; Ramon et al., 2010; Ceron et al., 2023).

Regarding diet variation for most specimens collected, beyond of the abundance and availability of Isoptera ("Blattodea") and Formicidae (Hymenoptera) in the environment, may be linked to their being an important source of energy and food (Silva, 2013). The predation of Orthoptera and Hemiptera, mainly by the Hylidae family observed in this study may be related to morphological variations and experiences in capturing prey during the development of specimens, which attributes advantages such as better recognition of prey and capture ability (Ferreira et al., 2007; Whitfield and Donnelly, 2006).

The species *Allophryne ruthveni Proceratophrys* aff. *concavitympanum*, *Rhinella marina*, *Scinax fuscomarginatus* and *Scinax ruber* had tadpoles of at least two species in their stomachs, the identification was not possible. Ergo, we cannot say (or rule out) that this is intraspecific predation. This form of predation can occur due to pressures such as variation in food availability, changes in the environment and population increase (Pincheira-Donoso, 2012; Silva, 2013). The consumption of anurans was also recorded by Teixeira and Campião (2018).

The termites and, mainly, ants were evidenced in the diet of 29 anurans species collected, and are one of the main food items ingested (Caldart et al., 2012; Forti et al., 2011; Oliveira et al., 2015). In the study arboreal (3), semi-aquatic (1) and terrestrial (2) species had tadpoles, decapods (Paleomidae (Malacostraca: Decapoda) and Brachyura in the diet. The species *Scinax ruber* displayed both items. Their low numerical representation may be related to their larger size in relation to the other items, which would explain their relevance in the diet. In the work of Downie et al. (2010) was recorded consumption of Decapods by *P. paradoxa* and was considered as an occasional food item. In this study the species *L. knudseni*, *P. hypocondrialis*, *S. ruber* and *T. typhonius* ingested Decapods. A plausible explanation for the variation in prey is the existence of different habitats, providing the capture experience for these species (Caldart et al., 2012).

Eight species consumed mineral material (sediment) and plant remmants (Supplementary Material S4), that could be considered as accidental ingestion, as also noted by Klaion et al. (2011). Species of the genus *Trachycephalus* and some species of *Rhinella* consumed practically the same items, but with small differences (Blattodea and Coleoptera). Our data indicate that among the Leptodactylidae and Bufonidae a guild of terrestrial insectivores (more representative) (Figure 3) so that the coexistence between different species with similar feeding habits can be facilitated by the use of different microhabitats and periods of activity by species (Casatti, 2002).

The generalist consumption of some species in our study may be based on the theory of optimal foraging, which tells us that with the lower availability of prey, individuals tend to adhere to a generalist diet, and the increase in food availability, indicates a selective prey diet (Palmeira, 2017). In this sense, Dendrobatidae are considered active foragers, which feed on small and abundant prey, such as Formicidae and Isoptera as verified in the present study. *Hylidae* and *Leptodactylidae*, on the other hand, consume large prey and in smaller quantities, and are considered stalk foragers (Santana and Juncá, 2007). This method of foraging has been recorded in the genus *Pithecopus* (Lima et al., 2010), but the species *P. hypochondrialis* revealed higher consumption of Formicidae, which may indicate active foraging of this species. We also check this consumption for *Boana faber* and *T. typhonius*. It can be inferred that species that feed mainly on Formicidae and Isoptera are active foragers (Santana and Junca, 2007).

The Bufonidae are considered to have generalist eating habits, which vary according to the availability of prey (Batista et al., 2011). However in this study, the Bufonidae had a diet consisting mainly of ants and beetles. While Hylidae are opportunistic foraging generalists (Campos, 2015; Freitas et al., 2008). The foraging modes of anurans indicate that specialist individuals prefer to feed on ants and mites, and generalist species avoid this type of food (Campos, 2015). Our results showed the preference of the Hylidae for ants, diverging in part works that show Orthoptera and Hemiptera as preference of these (Campos, 2015; Freitas et al., 2008; Silva et al., 2017).

In addition, the Leptodactylids are considered intermediate foraging strategy generalists (active, sit and wait) (Wells, 2010). In our research, the diet of these species was composed of Coleoptera, Hemiptera and Blattodea, corroborating the sit and wait mode described in other works with the family (Camera et al., 2014; Solé and Rödder, 2009; Sugai et al., 2012). On the other hand, the presence of Opiliones and Pseudoscorpiones proposes opportunistic behavior and disproportionate food availability in the environment occupied by this family (Solé and Rödder, 2009).

Given the above, we conclude that the anuran diet is more linked to the environmental structure, rather than the variety of morphology, the most ingested food was Hymenopteras (Formicidae), pointing to a guild of insectivorous anurans, mainly composed of the genus *Rhinella*. Each of the anuran species found revealed a more representative set of prey in the diet, some agreeing with the literature and others partially.

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Appendix 1. Table with the individuals analyzed. The table shows the collection locations, species, number of listings in the collection and date of collection.

Locality	Species	Nº listed	Date
Module II	*Proceratophrys* aff. *concavitympanum*	MOD 001	nov/17
Module II	*Adenomera andreae*	MOD 002	nov/17
Module II	*Rhinella castaneotica*	MOD 003	nov/17
Module II	*Adenomera andreae*	MOD 004	nov/17
Module II	*Rhinella proboscidea*	MOD 005	nov/17
Module II	*Allobates femoralis*	MOD 006	nov/17
Module II	*Rhinella margaritifera*	MOD 007	nov/17
Module II	*Rhinella margaritifera*	MOD 008	nov/17
Module II	*Rhinella castaneotica*	MOD 009	nov/17
Module II	*Rhinella castaneotica*	MOD 010	nov/17
Module II	*Rhinella margaritifera*	MOD 011	nov/17
Module II	*Dendropsophus brevifrons*	MOD 012	nov/17
Module II	*Dendropsophus brevifrons*	MOD 013	nov/17
Module II	*Dendropsophus brevifrons*	MOD 014	nov/17
Module II	*Dendropsophus brevifrons*	MOD 015	nov/17
Module II	*Allobates combriei*	MOD 016	nov/17
Module II	*Dendropsophus brevifrons*	MOD 017	nov/17
Module II	*Adenomera andreae*	MOD 018	nov/17
Module II	*Dendropsophus brevifrons*	MOD 019	nov/17
Module II	*Rhinella margaritifera*	MOD 020	nov/17
Module II	*Dendropsophus brevifrons*	MOD 021	nov/17
Module II	*Dendropsophus brevifrons*	MOD 022	nov/17
Module II	*Adenomera andreae*	MOD 023	nov/17
Module II	*Adenomera andreae*	MOD 024	nov/17
Module II	*Adenomera andreae*	MOD 025	nov/17
Module II	*Boana multifasciata*	MOD 026	nov/17
Module II	*Adelphobates castaneoticus*	MOD 027	mar/18
Module II	*Pristimantis fenestratus*	MOD 028	mar/18
Module II	*Pristimantis fenestratus*	MOD 029	mar/18
Module II	*Adenomera andreae*	MOD 030	mar/18
Module II	*Adenomera andreae*	MOD 031	mar/18
Module II	*Adenomera andreae*	MOD 032	mar/18
Module II	*Physalaemus ephippifer*	MOD 033	mar/18
Module II	*Adenomera andreae*	MOD 034	mar/18
Module II	*Adelphobates castaneoticus*	MOD 035	mar/18
Module II	*Adenomera andreae*	MOD 036	mar/18
Module II	*Rhinella proboscidea*	MOD 037	mar/18
Module II	*Rhinella castaneotica*	MOD 038	mar/18
Module II	*Leptodactylus mystaceus*	MOD 039	mar/18
Module II	*Leptodactylus sp.*	MOD 040	mar/18
Parna Serra do Pardo	*Allobates femoralis*	S.A 001	apr/17
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 002	apr/17
Parna Serra do Pardo	*Leptodactylus mystaceus*	S.A 003	apr/17

Appendix 1. Continued...

Locality	Species	Nº listed	Date
Parna Serra do Pardo	*Leptodactylus mystaceus*	S.A 004	apr/17
Parna Serra do Pardo	*Adenomera andreae*	S.A 005	apr/17
Parna Serra do Pardo	*Adenomera andreae*	S.A 006	apr/17
Parna Serra do Pardo	*Osteocephalus oophagus*	S.A 007	apr/17
Parna Serra do Pardo	*Lithodytes lineatus*	S.A 008	apr/17
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 009	apr/17
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 010	apr/17
Parna Serra do Pardo	*Leptodactylus mystaceus*	S.A 011	apr/17
Parna Serra do Pardo	*Adenomera andreae*	S.A 012	apr/17
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 013	apr/17
Parna Serra do Pardo	*Rhinella margaritifera*	S.A 014	apr/17
Parna Serra do Pardo	*Lithodytes lineatus*	S.A 015	apr/17
Parna Serra do Pardo	*Allophryne ruthveni*	S.A 016	apr/17
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 017	apr/17
Parna Serra do Pardo	*Physalaemus ephippifer*	S.A 018	apr/17
Parna Serra do Pardo	*Leptodactylus mystaceus*	S.A 019	apr/17
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 020	apr/17
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 021	apr/17
Parna Serra do Pardo	*Physalaemus ephippifer*	S.A 022	apr/17
Parna Serra do Pardo	*Physalaemus ephippifer*	S.A 023	apr/17
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 024	apr/17
Parna Serra do Pardo	*Adenomera andreae*	S.A 025	apr/17
Parna Serra do Pardo	*Adelphobates castaneoticus*	S.A 026	apr/17
Parna Serra do Pardo	*Dendropsophus minusculus*	S.A 027	apr/17
Parna Serra do Pardo	*Adenomera andreae*	S.A 028	apr/17
Parna Serra do Pardo	*Rhinella marina*	S.A 029	apr/17
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 030	apr/17
Parna Serra do Pardo	*Leptodactylus rhodomystax*	S.A 031	apr/17
Parna Serra do Pardo	*Rhinella margaritifera*	S.A 032	apr/17
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 033	apr/17
Parna Serra do Pardo	*Leptodactylus rhodomystax*	S.A 034	apr/17
Parna Serra do Pardo	*Leptodactylus rhodomystax*	S.A 035	apr/17
Parna Serra do Pardo	*Trachycephalus atlas*	S.A 036	apr/17
Parna Serra do Pardo	*Trachycephalus typhonius*	S.A 037	apr/17
Parna Serra do Pardo	*Boana multifasciata*	S.A 038	apr/17
Parna Serra do Pardo	*Leptodactylus rhodomystax*	S.A 039	apr/17
Parna Serra do Pardo	*Trachycephalus atlas*	S.A 040	apr/17
Parna Serra do Pardo	*Trachycephalus atlas*	S.A 041	apr/17
Parna Serra do Pardo	*Pristimantis reichlei*	S.A 042	apr/17
Parna Serra do Pardo	*Rhinella marina*	S.A 043	apr/17
Parna Serra do Pardo	*Boana boans*	S.A 044	apr/17
Parna Serra do Pardo	*Boana faber*	S.A 045	apr/17
Parna Serra do Pardo	*Boana faber*	S.A 046	apr/17

Appendix 1. Continued...

Locality	Species	Nº listed	Date
Parna Serra do Pardo	*Rhinella marina*	S.A 047	apr/17
Parna Serra do Pardo	*Boana boans*	S.A 048	apr/17
Parna Serra do Pardo	*Boana boans*	S.A 049	apr/17
Parna Serra do Pardo	*Boana albopunctata*	S.A 050	apr/17
Parna Serra do Pardo	*Boana albopunctata*	S.A 051	apr/17
Parna Serra do Pardo	*Boana albopunctata*	S.A 052	apr/17
Parna Serra do Pardo	*Adenomera andreae*	S.A 053	apr/17
Parna Serra do Pardo	*Boana albopunctata*	S.A 054	apr/17
Parna Serra do Pardo	*Rhaebo guttatus*	S.A 055	apr/17
Parna Serra do Pardo	*Rhaebo guttatus*	S.A 056	apr/17
Parna Serra do Pardo	*Leptodactylus podicipinus*	S.A 057	apr/17
Parna Serra do Pardo	*Boana boans*	S.A 058	apr/17
Parna Serra do Pardo	*Leptodactylus podicipinus*	S.A 059	apr/17
Parna Serra do Pardo	*Rhinella margaritifera*	S.A 060	set/18
Parna Serra do Pardo	*Rhinella marina*	S.A 061	set/18
Parna Serra do Pardo	*Rhinella marina*	S.A 062	set/18
Parna Serra do Pardo	*Rhinella marina*	S.A 063	set/18
Parna Serra do Pardo	*Physalaemus ephippifer*	S.A 064	set/18
Parna Serra do Pardo	*Physalaemus ephippifer*	S.A 065	set/18
Parna Serra do Pardo	*Physallaemus sp.*	S.A 066	set/18
Parna Serra do Pardo	*Physallaemus sp.*	S.A 067	set/18
Parna Serra do Pardo	*Leptodactylus mystaceus*	S.A 068	set/18
Parna Serra do Pardo	*Rhinella proboscidea*	S.A 069	set/18
Parna Serra do Pardo	*Adenomera andreae*	S.A 070	set/18
Parna Serra do Pardo	*Scinax ruber*	S.A 071	set/18
Parna Serra do Pardo	*Scinax ruber*	S.A 072	set/18
Parna Serra do Pardo	*Rhinella margaritifera*	S.A 073	set/18
Sítio Ecológico R. Xingu	*Leptodactylus petersii*	SBN 001	jun/18
Sítio Ecológico R. Xingu	*Rhinella granulosa*	SBN 002	jun/18
Sítio Ecológico R. Xingu	*Rhinella granulosa*	SBN 003	jun/18
Sítio Ecológico R. Xingu	*Rhinella granulosa*	SBN 004	jun/18
Sítio Ecológico R. Xingu	*Boana lanciformis*	SBN 005	jun/18
Sítio Ecológico R. Xingu	*Rhinella granulosa*	SBN 006	jun/18
Sítio Ecológico R. Xingu	*Adenomera andreae*	SBN 007	jun/18
Sítio Ecológico R. Xingu	*Adenomera andreae*	SBN 008	jun/18
Sítio Ecológico R. Xingu	*Boana boans*	SBN 009	jun/18
Sítio Ecológico R. Xingu	*Rhinella granulosa*	SBN 010	jun/18
Sítio Ecológico R. Xingu	*Rhinella granulosa*	SBN 011	jun/18
Sítio Ecológico R. Xingu	*Leptodactylus knudseni*	SBN 012	jun/18
Sítio Ecológico R. Xingu	*Leptodactylus knudseni*	SBN 013	jun/18
Sítio Ecológico R. Xingu	*Rhinella margaritifera*	SBN 014	jun/18
Sítio Ecológico R. Xingu	*Adenomera andreae*	SBN 015	jun/18
Agrovila Grande Esperança	*Trachycephalus typhonius*	SDA 001	may/18

Appendix 1. Continued...

Locality	Species	Nº listed	Date
Agrovila Grande Esperança	*Trachycephalus typhonius*	SDA 002	may/18
Agrovila Grande Esperança	*Trachycephalus typhonius*	SDA 003	may/18
Agrovila Grande Esperança	*Dendropsophus melanargyreus*	SDA 004	may/18
Agrovila Grande Esperança	*Trachycephalus typhonius*	SDA 005	may/18
Agrovila Grande Esperança	*Scinax fuscomarginatus*	SDA 006	may/18
Agrovila Grande Esperança	*Dendropsophus leucophyllatus*	SDA 007	may/18
Agrovila Grande Esperança	*Scinax nebulosus*	SDA 008	aug/18
Agrovila Grande Esperança	*Dendropsophus leucophyllatus*	SDA 009	aug/18
Agrovila Grande Esperança	*Dendropsophus minusculus*	SDA 010	aug/18
Agrovila Grande Esperança	*Pithecopus hypochondrialis*	SDA 011	aug/18
Agrovila Grande Esperança	*Pithecopus hypochondrialis*	SDA 012	aug/18
Fazenda Sayonara	*Boana boans*	SDA 013	aug/18
Fazenda Sayonara	*Boana boans*	SDA 014	aug/18
Fazenda Sayonara	*Leptodactylus latrans*	SDA 015	aug/18
Fazenda Sayonara	*Leptodactylus latrans*	SDA 016	aug/18
Fazenda Sayonara	*Leptodactylus latrans*	SDA 017	aug/18
Fazenda Sayonara	*Leptodactylus latrans*	SDA 018	aug/18
Fazenda Sayonara	*Leptodactylus spixi*	SDA 019	aug/18
Fazenda Sayonara	*Adenomera andreae*	SDA 020	aug/18

Supplementary Material

Supplementary material accompanies this paper.

Supplementary Material S1. Morphological measurements with morphological and ecomorphological patterns among anurans. In parentheses, the abbreviation of each morphometric measure. [1]Siqueira et al. (2006), [3]Souza and Barrella (2009).

Supplementary Material S2. Study specimens, divided by families, genera and species. Only species that had more than five individuals collected were included in the statistical analysis*.

Supplementary Material S3. Categories and stomach items found.

Supplementary Material S4. Classification, specificity, frequency of occurrence and abundance of stomach items found by species.

Supplementary Material S5. Principal Component Analysis (PCA) performed with the anuran diet. The variables presented correspond to those listed in Supplementary Material S3, and the analyzed species are listed in Supplementary Material S2.

Supplementary Material S6. Redundancy Analysis – RDA performed with anuran species that occur in the Middle Xingu, seeking ecomorphological relationships. The abbreviations of the morphological variables correspond, respectively, to those listed in Supplementary Material S1, and diet variables are listed in Supplementary Material S3.

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