

Notes on diet composition and reproduction of *Chiasmocleis hudsoni* (Anura: Microhylidae: Gastrophryninae) from eastern Brazilian Amazonia

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Abstract. *Chiasmocleis hudsoni* is a small fossorial anuran widely distributed in the Amazon basin. Due to its fossorial habit and explosive breeding pattern, individuals are rarely found, and data on the natural history of this species are scarce. Here we provide data on the diet composition and reproductive aspects of *C. hudsoni* from eastern Brazilian Amazonia. We found 20 prey categories within eight orders in the stomachs of 106 specimens of *C. hudsoni*. The index of relative importance showed that Formicidae (48.3%) was the most represented prey category in the diet. Oocytes ranged from 202 to 297 per female ($n = 4$, mean = 250, SD = 67.2), with a diameter varying from 0.9 to 1.3 mm ($n = 4$, mean = 1.1 mm, SD = 0.1 mm). Similar to other *Chiasmocleis* species, mites were a large fraction of the diet of *C. hudsoni* in eastern Amazonia, which differs from most leaf-litter dwelling anurans that do not prey on large amounts of mites. The explosive breeding pattern found in Microhylidae frogs is likely to be observed in *C. hudsoni* and the size fecundity relationship may be related to the process of sexual size dimorphism observed.

Key words: natural history, oocytes, myrmecophagy, acariphagy, size-fecundity.

Introduction

Studies on natural history are especially relevant to understanding interactions between individuals and their environment and are important for the establishment of conservation policies (Wells 2007). Basic data on natural history of many anurans are still poorly known and limited for some species even the most basic biological data such as diet and reproductive biology are lacking (Bland et al. 2017).

The family Microhylidae represents one of the four most species-rich anuran clades with 688 recognized nominal species (Frost 2020). *Chiasmocleis* Méhely, 1904 is considered the most diversified genus, comprising 36 species widely distributed through South America to the north and east of the Andes (Frost 2020). Due to their various levels of fossoriality and their low representativeness in anuran communities, detailed information regarding the natural history of *Chiasmocleis* species is poorly known (Haddad & Hödl 1997, Cordioli et al. 2019, Da Silva et al. 2019).

Chiasmocleis hudsoni (Parker 1940) is a small Gastrophryninae frog widely distributed in Venezuela, Guyana, Colombia, Suriname and French Guiana (Peloso et al. 2014). In Brazil it has been reported in some regions of the Amazon basin (Costa-Campos et al. 2019, Frost 2020). This species is an explosive breeder with a nocturnal, terrestrial and fossorial lifestyle that inhabits streamside ponds in primary forests (Lima et al. 2006, Rodrigues et al. 2008). Here, we provide much needed data on the diet composition and on some reproductive aspects of *C. hudsoni* from eastern Brazilian Amazonia.

Materials and methods

We conducted fieldwork at Cancão Municipal Natural Park (CMNP), east of the Amapari River, 2.5 km NW of the village of Ped-

ra Preta (0.9027° N, 52.0049° W; datum WGS84), in the municipality of Serra do Navio, state of Amapá, north Brazil. Climate of this area is Equatorial according to the Köppen-Geiger classification with mean annual precipitation about 2,850 mm in the period of monsoon between February and May, when the monthly rainfall is approximately 400 mm (Alvares et al. 2013). The area of CMNP covers approximately 370 ha of primary forests, including *terra-firme* rainforest and flooded forest (Silva e Silva & Costa-Campos 2018).

Specimens were collected during nocturnal surveys conducted monthly between February to March 2018 in temporary isolated ponds in the forest, using “visual encounter surveys” and “auditory search” (Heyer et al. 1994), under permit SISBIO number 48102-2 issued by the Brazilian Ministry of Environment (MMA-ICMBio). Specimens were killed with topical application of 2% Lidocaine to the abdomen, a fast-acting and effective means of euthanasia (Leary et al. 2013). Direct extraction of stomach content rather than non-lethal techniques (e. g. stomach-flushing) was justified because specimens were also part of research on helminth parasites, which requires euthanasia. The 106 voucher specimens were fixed in 10% formalin, stored in 70% ethanol and deposited in the Herpetological Collection of Universidade Federal do Amapá (CECC 1419, 1420, 1449, 1450, 1452-1463, 1480-1484, 1527-1529, 1854-1866, 1872, 1873, 1875-1880, 1882-1888, 2020, 2063-2079, 2092-2099, 2126-2135, 2142-2155, 2259-2262).

After sacrificing the specimens and prior to fixing them, we removed the stomachs through a small abdominal incision and extracted their contents. The items found in the stomach contents were analyzed and identified to the taxonomic category of order, following the identification keys of Rafael et al. (2012), except for Formicidae (ants), which were classified to the genus level. Subfamilies and genera of Formicidae were identified following Baccaro et al. (2015).

The maximum length and width of all prey items of each category were measured and had their volume calculated using the ellipsoid formula (Colli et al. 1992). We determined the percentages of number, volume and frequency of occurrence of each prey category and calculated an index of relative importance (IRI) (Pinkas et al. 1971). To calculate the trophic niche breadth, we used the Levin's index (Pianka 1986). Niche breadth values from 0.0 to 0.50 are interpreted as specialist habit, and values from 0.51 to 1.0 denote a generalist diet (Hurlbert 1978).

We measured each specimen's snout-to-vent length (SVL) with a Mitutoyo digital caliper to the nearest 0.01 mm. We determined the sex of individuals by dissection and direct observation of gonads and through the presence of secondary sexual characters in males (dermal spines). We obtained mature ovarian eggs of gravid females caught in the field. We dissected females and removed their ovaries to record the number of oocytes and measure their mean diameter with an ocular micrometer in a Zeiss stereomicroscope (Z Series Modular Zoom stereo microscope with Standard HWF10X/23 mm eyepieces).

We applied a simple linear regression to verify the possible relationship between SVL with the volume of the largest prey for each individual, and SVL with the number and mean diameter of the oocytes observed in each female. Also, we performed an Analysis of Variance (ANOVA) to test for differences in Snout-Vent Length (SVL) among sexes. Statistical tests were performed using R software 4.0.3 (R Development Core Team 2015).

Results

We analyzed 106 individuals of *C. hudsoni* (98 males and 8 females). Eighteen individuals (16.9%) had empty stomachs. We found 20 prey items from 8 orders (Acari, Isopoda, Coleoptera, Hymenoptera, Hemiptera, Diptera, Collembola and Isoptera). The IRI showed that Formicidae (IRI: 48.3) was the most represented prey category in the diet of *C. hudsoni*, followed by Acari (IRI: 21.3) and Isoptera (IRI: 21.1). In terms of prey volume, the highest values were from Isoptera (V: 47.9%) and Formicidae (V: 27.1%) (Table 1). Formicidae was represented by 5 subfamilies and 12 genera, the most representative were *Wasmannia* (IRI: 12.6), *Solenopsis* (IRI: 8.7) and *Pheidole* (IRI: 6.6) (Table 1). We did not find significant positive correlation between SVL of *C. hudsoni* and volume of the largest prey ($r_s = 0.2724$; $p = 0.0352$). The niche breadth was 0.17.

Chiasmocleis hudsoni were observed in temporary isolated ponds in the forest during the peak of rainy season (February to March 2018) with two sympatric frogs, *Leptodactylus mystaceus* and *L. petersii*. Male *C. hudsoni* were observed calling after heavy rain within the leaf litter around temporary ponds, in decomposing tree branches and covered by a layer of leaf litter. Amplectant pairs, clutches or tadpoles were not found during sampling. All oocytes were obtained from the abdominal cavity of females and referring as clutch size the number of oocytes per female.

Females were larger in SVL and have a mean SVL about 3.11 mm larger than males ($F_{(1,102)} = 53.82$, $p < 0.00001$). The mean clutch size per female was 250 ± 67.2 (range 202–297, $n = 4$). Mean diameter of oocytes ($n = 30$ per female) was 1.1 ± 0.1 mm (range 0.9–1.3 mm). The number of oocytes per female was significantly associated with SVL ($r_s = 0.54$, $p = 0.006$). However, there was no significant correlation between SVL and oocyte diameter ($r_s = 0.15$, $p = 0.09$).

Discussion

Our population of *C. hudsoni* is primarily myrmecophilous, consuming mainly ants and mites. In another population of *C. hudsoni* from central Amazonia, the frogs showed the same preferences (Da Silva et al. 2019). Other *Chiasmocleis* species, from Amazonia and Atlantic rainforest, are also re-

Table 1. Prey categories of *Chiasmocleis hudsoni* at Cancão Municipal Natural Park, municipality of Serra do Navio, Amapá, north Brazil. N = number of prey items; N (%) = relative abundance; F = frequency of occurrence; F (%) = relative frequency; V = volume of prey items; V (%) = relative volume; IRI = Index of Relative Importance.

Prey categories	N	N (%)	F	F (%)	V	V (%)	IRI
Acari	60	24.8	32	33.3	9.3	5.9	21.3
Collembola	3	1.2	3	3.1	0.6	0.4	1.6
Coleoptera	5	2.1	5	5.2	4.1	2.6	3.3
Coleoptera larvae	1	0.4	1	1.0	0.1	0.05	0.5
Isopoda	1	0.4	1	1.0	8.8	5.6	2.4
Hymenoptera							
Formicidae							
Myrmicinae							
<i>Apterostigma</i> sp.	18	7.4	3	3.1	11.6	7.4	6.0
<i>Carebara</i> sp.	2	0.8	1	1.0	1.0	0.7	0.8
<i>Crematogaster</i> sp.	9	3.7	3	3.1	7.6	4.8	3.9
<i>Cyphomyrmex</i> sp.	16	6.6	1	1.0	6.5	4.1	3.9
<i>Pheidole</i> sp.	23	9.5	8	8.3	3	1.9	6.6
<i>Solenopsis</i> sp.	23	9.5	7	7.3	14.9	9.4	8.7
<i>Strumigenys</i> sp.	1	0.4	1	1.0	0.4	0.3	0.6
<i>Wasmannia</i> sp.	42	17.4	15	15.6	7.4	4.7	12.6
Ponerinae							
<i>Hypoponera</i> sp.	5	2.1	5	5.2	4.4	2.8	3.3
Dolichoderinae							
<i>Tapinoma melanoccephalum</i>	1	0.4	1	1.0	0.4	0.2	0.6
Dorylinae							
<i>Nomamyrmex</i> sp.	1	0.4	1	1.04	1.4	0.9	0.8
Formicinae							
<i>Paratrechina</i> sp.	1	0.4	1	1.0	0.4	0.2	0.6
Hemiptera	1	0.4	1	1.0	0.2	0.1	0.5
Diptera (larvae)	2	0.8	2	2.1	0.3	0.2	1.0
Isoptera	27	11.2	4	4.2	75.7	47.9	21.1
Total	242	100	96	100	158	100	100

ported as strictly myrmecophilous and acariphagous (Simon & Toft 1991, Van Sluys et al. 2006, Araújo et al. 2009, Lopes et al. 2017, Da Silva et al. 2019, Diaz-Perez et al. 2020). While living buried most of the time, *Chiasmocleis* species usually fed on semi-fossorial soil abundant organisms which aggregate in colonies, such as epigeal ants, mites and termites (Hölldobler & Wilson 1990, Fowler 1993). These invertebrates are amongst the most abundant in tropical forests, maintaining large numbers of individuals on the soil and leaf litter.

Termites were an important item in the diet of *C. hudsoni* and high representative in terms of volume. Intake of termites may be advantageous from both nutritional and energetic point of view, due to their high levels of carbohydrates and less sclerotised material (Forti et al. 2011). Anurans exploiting termites may be related to high energetic gain during periods of reproduction which demands higher energy expenditure. It has also been reported in the diets *C. hudsoni* and *C. shudikarensis* from central Amazonia (Da Silva et al. 2019), *C. mehelyi* (Diaz-Perez et al. 2020), *C. albopunctata* (Araújo et al. 2009) and other microhylid species such as *Dermatonotus muelleri* (Carrillo et al. 2020), *Elachistocleis bicolor* (Berzategui et al. 2007) and *E. ovalis* (Solé et al. 2002).

The nests of termites and ants are often patchy distributed in the soil (Levings & Franks 1982, Lofgren & Vander

Meer 1986, Torres et al. 2020) suggesting that *C. hudsoni* actively search on these preys. In addition, *C. hudsoni* consumed mainly on *Solenopsis* and *Pheidole* ants which are known aggregate in enormous colonies that hold large populations above and underneath the soil (Lofgren & Vander Meer 1986, Hölldobler & Wilson 1990). This pattern of diet is generally classified as “ant specialist”, usually assigned to species such as Microhylidae frogs that consume high amounts of ants and other chitinous slow-moving arthropods (Toft 1980, 1981). However, a very few studies estimate resource availability data to support a selective behavior on *Chiasmocleis* and other microhylid species (e. g. Diaz-Perez et al. 2020).

Microhylid frogs are small fossorial and narrow-headed frogs, leading to a limitation and a tendency to consume small and abundant leaf-litter prey. This was also observed in small species from generalist guilds studied in the same region, which demonstrated a tendency toward consuming ants and mites in high proportions (Sanches et al. 2019, Corrêa et al. 2020), supporting that small ground-dwelling frogs capitalize on ants and mites due to their abundance on the leaf litter of tropical forests and due to their limitation in consuming larger preys that are more pleasant to ingest (Simon & Toft 1991).

Despite resource availability was not investigated in *C. hudsoni*, descriptions of ants in refined taxonomic scales demonstrated differences between our population of *C. hudsoni* and that of central Amazon with regards to myrmecophagy. Da Silva et al. (2019) reported ants of the genus *Crematogaster* and *Pheidole* as the most important ants in the diet of *C. hudsoni* from central Amazon, whereas *C. hudsoni* from our population consumed mainly on *Wasmannia* and *Solenopsis* ants. This difference of ants consumed in distinct areas point out a non-selective behavior among types of ants, and possibly is an artifact of distinct ant assemblage between regions. Also, *Chiasmocleis* frogs seem to lack an alkaloid sequestering system, a premise for selective behavior on potential alkaloid-containing ants observed in Dendrobatids and Bufonids (Mebs et al. 2010). In sum, we suggest that the feeding behavior of *C. hudsoni* needs further investigation before major statements, addressing food resource availability to accurately test if ant-eating is due to resource availability and morphological constraints related to the fossorial habits and small size of the species.

As observed in other studies on reproductive aspects of frogs, we describe here the number of eggs based on the counting of mature eggs from the abdominal cavity of females, it substantially represents a coarse approximation of what would be the actual number of eggs deposited. The number of oocytes counted for *C. hudsoni* is somewhat similar to the number of deposited eggs reported for *C. lacrimae* (245 eggs; Cordioli et al. 2019) and *C. leucosticta* (202 eggs, Haddad & Hödl 1997; 212 oocytes, Lopes et al. 2017), but quite different from the number of eggs deposited by a population of *C. hudsoni* at central Amazonia (351 eggs, Rodrigues et al. 2008). Anurans from tropical forests can lay eggs in several reproductive events, which display a variation in the number of oocytes produced over the course of a reproductive season (Haddad & Prado 2005, Crump 2015). This is particular evident in explosive breeders that breed

many times during the rainy season over short periods (Prado et al. 2005).

Our analyses showed that female SVL was positively correlated with clutch size. Female anuran fecundity appears to be related to a process of selection of larger females that could generate sharp sexual size dimorphism (Shine 1979), as seems to be the case for *C. hudsoni* since we found significant differences between males and females SVL. On the other hand, the evolution of burrowing behavior and its role on sexual dimorphism in fossorial anurans have been discussed recently, with reference to Leptodactylinae frogs (Ponssa & Barrionuevo 2012, Ponssa & Medina 2016). As well as Leptodactylinae frogs, some Microhylidae species also construct subterranean chambers to deposit their eggs and develop early larval stages (Nomura et al. 2009). Consequently, the burrowing behavior may be linked to the reduction in male morphometry because in anurans, chambers to deposit foam nests are often constructed by males. However, this question is still to be investigated in Microhylidae species since sexual dimorphism has been reported (Van Sluys et al. 2006, Diaz-Perez et al. 2020, Nascimento et al. 2020).

Natural history studies are unarguably a solid basis for hypothesis-driven studies from different research fields. It may be an important means by which we gather data on biological aspects of rare and hard to detect species in the field, given that these species are often understudied in long-term ecological research. In addition, natural history studies compile fundamental information to design and conduct long-term ecological research to provide a scientific basis for the conservation of populations and species (Hampton & Wheeler 2012). *Chiasmocleis* species were poorly studied for a long time, probably due to the typical explosive breeding pattern of some species leading to an irregular calling activity through the seasons along with the semi-fossorial habits of these frogs, making them hard to detect.

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