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Diet of the yellow striped poison frog, *Dendrobates truncatus* (Cope, 1861) (Anura: Dendrobatidae) from the Middle Magdalena river valley, Colombia

Mateo Marín-Martínez[1,*], Maria Silvana Cárdenas-Ortega[1], Jorge Mario Herrera-Lopera[1], and Julián Andrés Rojas-Morales[2]

Abstract. This study describes the diet of *Dendrobates truncatus* (Cope, 1861) based on stomach contents of 25 individuals from four localities in the middle Magdalena River valley, department of Caldas, Colombia. A total of 824 prey items were identified and grouped into 21 categories. Formicids (Hymenoptera) were among the most abundant prey, representing 83.4% of the items, followed by Acari (10.7%) and Coleoptera (2.4%). In terms of volume, formicids (83%) and mites (7.1%) were the most dominant taxa. Among formicids, the genus *Solenopsis* was the most important prey item, since it was found in 61% of the contents. The correlation analyses for prey abundance, volume, and richness did not show any type of relation between the latter variables and morphological measurements of the frogs. Our results show that *D. truncatus* is similar to other frogs of the family Dendrobatidae by displaying an ant-based specialized diet.

Key words. Specialized diet, food choice, Ant-specialist, poison dart-frog, central Andes

Introduction

In general terms, anurans are known to be generalist predators that feed on a wide variety of prey (Solé and Rödder, 2009; Gómez-Hoyos et al., 2014, Gutiérrez-Cárdenas et al., 2015; Solé et al., 2017), and this indirectly reflects the availability of prey in the environment (Duellman and Trueb, 1994; Vitt and Caldwell, 2014). However, in some particular cases, several species have shown to be selective in their food choices, where the intake of certain types of prey depends on diverse factors, allowing these frogs species a certain degree of specialization (Toft, 1980; Simon and Toft, 1991; Vitt and Caldwell, 2014). Many factors influence the diet of amphibians, including temporal variations in food abundance, the presence or absence of competition, foraging strategies and body size (Toft, 1980; 1995; Simon and Toft, 1991). In the case of body size, as individuals became larger, the kind of prey that they select may change, ingesting increasingly larger prey items as well as a broader spectrum of prey size (Duellman and Trueb, 1994; Parmelee, 1999; Vitt and Caldwell, 2014). In amphibians, information regarding their diets can be useful to answer key biological questions in many disciplines, such as ecology, evolution, and conservation (Bury, 2006; Anderson, 2012, 2017), since the study of diets allows to infer population fluxes and the impact of habitat disturbance on populations. Furthermore, this knowledge is important for the protection and effective management of threatened and endangered species (Parmelee, 1999; Bury, 2006; Solé and Rödder, 2009).

Dendrobates truncatus (Cope, 1861) is a poison dart frog species, endemic to Colombia, that is distributed in humid forests, sub-Andean forests, and dry forests of the lowlands of the Magdalena River valley and the Caribbean region, between 0 and 1800 m (Corredor-Londoño and Uribe-Tovar, 2008; Gualdrón-Duarte et al., 2016; Acosta-Galvis, 2018). The diet of this species, even among different populations, consists mainly of ants of the subfamily Myrmicinae and mites (Erazo-Londoño et al., 2016; Posso-Peláez et al., 2017). Its dietary composition has been found significantly related with seasonal changes (Posso-Peláez et al., 2017).

[1] Grupo de Ecología y Diversidad de Anfibios y Reptiles, Universidad de Caldas, Manizales, Caldas, Colombia.
[2] Facultad de Ciencias Básicas, Corporación Universitaria Santa Rosa de Cabal (UNISARC), Campus Universitario "El Jazmín" Km 4 Vía Santa Rosa de Cabal, Risaralda, 661028, Colombia.
[*] Corresponding author e-mail: mateo2805@hotmail.com

This study aimed to examine the dietary composition of *D. truncatus* in four populations from the middle Magdalena River valley, as well as to assess the relation of the diet with body size.

Materials and methods

The data was obtained from independent studies carried out in the municipalities of Norcasia, Victoria, Samaná, and La Dorada from the department of Caldas, in areas influenced by the Hydroelectric Power Plant Miel I, between 250 and 700 m of altitude (Fig. 1). Stomach contents were taken from: (a) specimens deposited at the Museo de Historia Natural de la Universidad de Caldas (MHN-UCa) and (b) a field study conducted from 2015-2017 in the areas influenced by the dams of the Manso and Guarinó Rivers that supply the hydroelectric plant. For the field-collected specimens, their stomach contents were obtained from a gastric lavage (see Solé et al., 2005 for a protocol description), while for the collection individuals, the contents were extracted through a ventral dissection (intestines and stomach were used). The following variables were recorded for each individual using a calliper: Snout-vent length (SVL), mandibular width (MW), mandibular height (MH), and mandibular length (ML). The prey items from the stomach contents were identified to the lowest possible taxonomic level. Likewise, prey counts and volume measurements were also recorded, for which only complete prey items were considered and their volume was calculated by the ellipsoid formula (Magnusson et al., 2003).

We compared the relative ratio of each prey item using the index of relative importance (IRI) (Pinkas et al., 1971; Solé and Rödder, 2009). For this, we only considered prey for which it was possible to calculate their volume. The trophic niche amplitude was also assessed, based on Levin's standardized Index (1968), according to the absolute frequency (pi) of each prey taxon.

$$B - \frac{1}{\sum_{i=1}^{n} Pi^2}$$

We standardized a scale ranging from zero to one, where zero corresponds to specialist species and

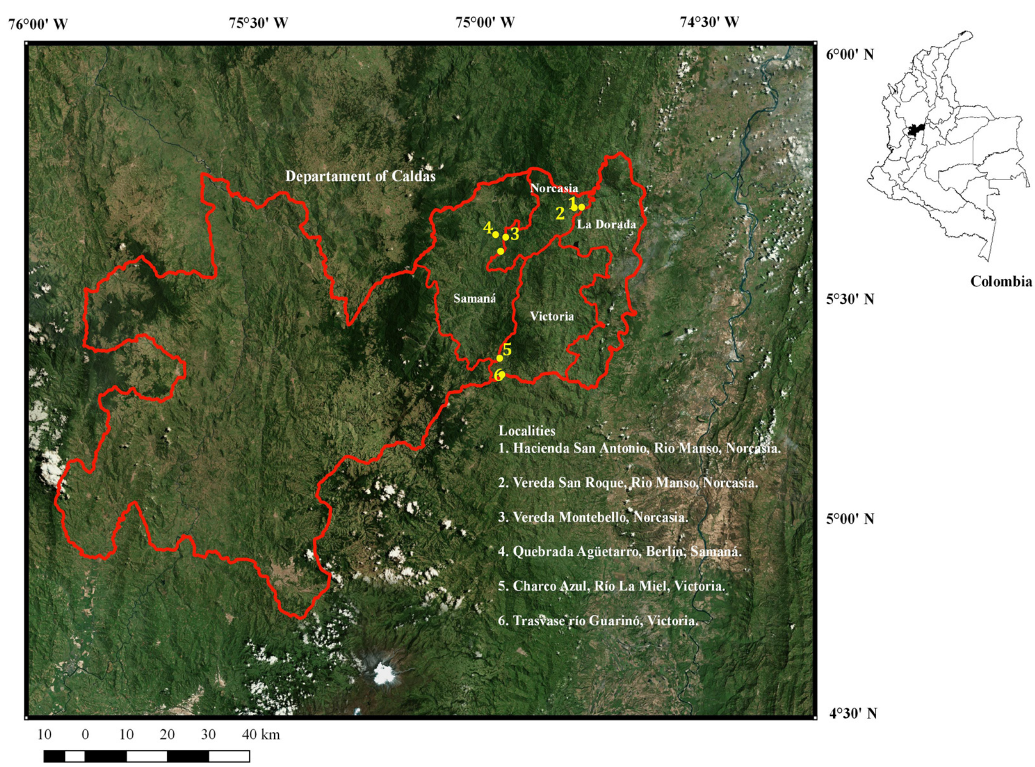

Figure 1. Study sites in the department of Caldas.

one to generalist species, using Levin's standardized Index formula to calculate (B) and the number of prey categories (n).

$$Ba = \frac{B-1}{n-1}$$

In order to determine that the richness values of the prey items were indeed representative, we generated species accumulation curves using the accumulated trophic novelties versus the number of stomach contents assessed. Spearman's correlation was used to study the relation among morphological variables and prey volume, abundance, and richness. These analyses were performed after assessing a normal distribution of the data. All analysis were performed using R project 3.6.1.

Table 1. Morphological traits in mm for individuals of *D. truncatus.* Snout-vent length (SVL); Mandibular width (MW); Mandibular height (MH), and Mandibular length (ML).

Municipality	SVL	MW	MH	ML
Norcasia	25.3	7.3	2.5	5.9
Norcasia	24.4	7.5	2.7	6.1
Norcasia	24.9	8	2.7	6
Norcasia	23.6	7.1	2.1	5.5
Norcasia	21.2	6.2	1.5	4
Norcasia	24.6	7.3	2.6	6.4
La Dorada	24.8	7.2	2.2	6.2
La Dorada	25.9	7	2	5.8
Samaná	25.5	7.1	2.2	5.3
Samaná	23.6	6.9	2.7	5.8
Samaná	21.4	6.4	2.1	5
Victoria	29.5	8.2	3.2	6.6
Victoria	29	7.8	2.4	5.9
Victoria	29.8	8	2.9	5.9
Victoria	30	8.3	3.1	6.5
Victoria	26.2	7.8	3	5.5
Victoria	27	7.8	3.1	5.7
Victoria	26.8	7.8	2.3	6.1
Victoria	24.6	7.6	2.8	5.8
Victoria	24.2	6.5	3	5.6
Victoria	29.5	8.1	3.2	6
Victoria	26.11	8.1	2.8	5.1
Victoria	19.2	-	-	-
Victoria	27.7	7.4	3	5.9
Victoria	26.5	8	2.4	5.8

Results

We captured and analysed 25 individuals of *D. truncatus* (SVL $\overline{x}$ = 25.6 ± 2.7 mm; MW $\overline{x}$ = 7.4 ± 0.5 mm; Table 1); eight individuals through dissection, and 17 by gastric lavages. Of the individuals analysed, 92% showed at least one type of prey in their stomach contents (Abundance $\overline{x}$ = 63.5 ± 67; Volume $\overline{x}$ = 14 ± 20.8 mm^3; Richness $\overline{x}$ = 5 ± 4 prey items). In total, 1522 prey items were extracted, of which 824 were complete and could be classified into 21 prey categories (Table 2). Formicids were the most abundant taxa, spanning 83.4% of the counts, followed by Acari (10.7%) and Coleoptera (2.4%). In terms of volume, formicids (83%) and mites (7.1%) were the dominant taxa. According to the relative importance index (IRI), Formicidae (IRI = 151.2), Acari (IRI = 8.5), and Coleoptera (IRI = 3.4) were again found to be the most important (see Table 2). Among formicids, we identified seven subfamilies and 15 genera. The most representative genera were *Solenopsis* (n = 397, vol = 93.2 mm^3; IRI = 56.3) and *Crematogaster* (n= 85, vol = 96.3 mm^3; IRI= 12.6; Table 3). We found values close to zero for the trophic niche index (0.02 including all prey items, and 0.1 using only the family Formicidae). The abundance-based estimator (Chao1) showed a representative percentage of prey items between 69% and 99%, indicating that prey richness is indeed representative (Fig. 2). The correlation analyses for prey abundance, volume, and richness did not show any type of relation between the latter variables and the morphological measurements of the individuals (p-value > 0.05).

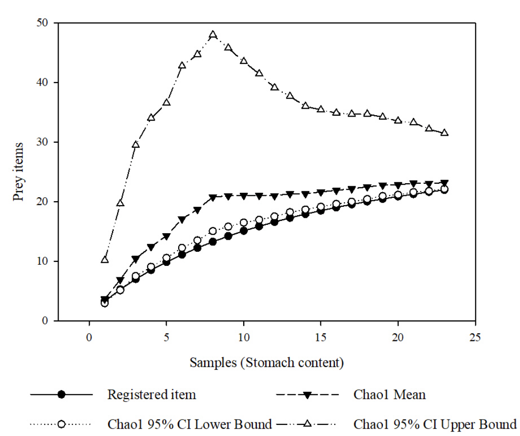

Figure 2. Species accumulation curve for trophic novelties versus the number of stomach contents assessed, in the diet of *Dendrobates truncatus* in Caldas, Colombia.

Table 2. Diet composition and prey choice of *Dendrobates truncatus* in the Magdalena valley in Caldas, Colombia. N: number of prey; %N: percentage of number of prey; % V: percentage of volume of prey; % F: percentage of frequency of each prey item; IRI: relative importance index; UI: Unidentificated

Prey items	N (Completes)	%N	V (mm^3)	%V	F	%F	IRI
Class Arachnida	**90**	**10.92**	**23.15**	**7.2**	**12**	**0.52**	**9.45**
Order Acari	**88**	**10.68**	**22.84**	**7.1**	**11.00**	**0.48**	**8.50**
Order Araneae	**2**	**0.24**	**0.31**	**0.1**	**1**	**0.04**	**0.01**
Family Pholcidae	1	0.12	0.26	0.1	1.00	0.04	0.01
Family Salticidae	1	0.12	0.05	0.0	1.00	0.04	0.01
Order Pseudoscorpionida (Incomplete)	-	-		-	-	-	-
Class Diplopoda	**3**	**0.36**	**1.11**	**0.3**	**3**	**0.13**	**0.09**
Order Polydesmida	**3**	**0.36**	**1.11**	**0.3**	**3.00**	**0.13**	**0.09**
Class Entognatha	**1**	**0.12**	**0.06**	**0.0**	**1.00**	**0.04**	**0.01**
Order Collembola	**1**	**0.12**	**0.06**	**0.0**	**1.00**	**0.04**	**0.01**
Class Insecta	**725**	**87.99**	**314.55**	**97.7**	**21**		
Order Coleoptera	**20**	**2.43**	**15.05**	**4.7**	**11.00**	**0.48**	**3.40**
Family Bostrichidae	2	0.24	0.19	0.1	1.00	0.04	0.01
Family Chrysomellidae	5	0.61	3.40	1.1	3.00	0.13	0.22
Family Curculionidae	2	0.24	7.59	2.4	2.00	0.09	0.23
Family Scarabaeidae	2	0.24	0.25	0.1	2.00	0.09	0.03
Family Staphylinidae	4	0.49	3.17	1.0	2.00	0.09	0.13
Coleopteran larvae	2	0.24	0.25	0.1	3.00	0.13	0.04
UI coleopterans	3	0.36	0.19	0.1	3.00	0.13	0.06
Order Diptera	**8**	**0.97**	**3**	**0.9**	**6.00**	**0.26**	**0.50**
Dipteran larvae	6	0.73	1.84	0.6	5.00	0.22	0.28
UI dipterans	2	0.24	1.16	0.4	2.00	0.09	0.05
Order Hemiptera	**3**	**0.36**	**2.36**	**0.7**	**2.00**	**0.09**	**0.10**
Hemipteran nymphae	1	0.12	0.27	0.1	1.00	0.04	0.01
UI hemipterans	2	0.24	2.09	0.6	1.00	0.04	0.04
Order Hymenoptera (non-Formicidae)	**1**	**0.12**	**0.06**	**0.0**	**1.00**	**0.04**	**0.01**
Order Hymenoptera (Formicidae)	**687**	**83.37**	**267.38**	**83.0**	**21.00**	**0.91**	**151.92**
Order Socoptera	**4**	**0.49**	**6.30**	**2.0**	**3.00**	**0.13**	**0.32**
Class Malacostraca	2	0.24	0.96	0.3	2	0.09	0.05
Order Isopoda	**2**	**0.24**	**0.96**	**0.3**	**2.00**	**0.09**	**0.05**
PHYLLUM MOLLUSCA	**4**	**0.49**	**2.62**	**0.8**	**4**	**0.17**	**0.23**
Class Gastropoda	**4**	**0.49**	**2.62**	**0.8**	**4**	**0.17**	**0.23**
Order Pulmonata	**4**	**0.49**	**2.62**	**0.8**	**4.00**	**0.17**	**0.23**
UI insects	1	0.12	0.06	0.0	1	0.04	0.01
Totals	**824**	**100**	**322.11**	**100**	**23**		

Discussion

Taking into account prey types and ratios, as well as the trophic niche amplitude index values, we analysed and found that *D. truncatus* is an actively foraging species with a specialist diet, as has also been shown for species of the family Dendrobatidae such as: *D. auratus* (*Ba*= 0,03), *Epidodebates bilinguis* and *Ranitomeya virolynensis* both with Ba = 0,04 (Donnelly,

Table 3. Diet composition and prey choice of *D. truncatus* for the family Formicidae: N: number of prey; %N: percentage of number of prey; % V: percentage of volume of prey; % F: percentage of frequency of each prey item; IRI: relative importance index. UI: Unidentificated.

Prey items Order Hymenoptera	N	%N	V (mm^3)	%V	F	%F	IRI
Subfamily Cerapachyinae	**3**	**0.4**	**1.8**	**0.7**	**3**	**0.13**	**5.59**
Genus *Acanthostichus*	3	0.4	1.8	0.7	3	0.13	0.15
Subfamily Dolichoderinae	**3**	**0.4**	**0.8**	**0.3**	**1**	**0.04**	**1.22**
UI Dolichoderinae	3	0.4	0.8	0.3	1	0.04	0.03
Subfamily Ecitoninae	**1**	**0.1**	**1.1**	**0.4**	**1**	**0.04**	**0.90**
Genus *Neivamyrmex*	1	0.1	1.1	0.4	1	0.04	0.02
Subfamily Formicinae	**1**	**0.1**	**0.3**	**0.1**	**1**	**0.04**	**0.40**
UI Formicinae	1	0.1	0.3	0.1	1	0.04	0.01
Subfamily Leptanilloidinae	**1**	**0.1**	**0.1**	**0.1**	**1**	**0.04**	**0.32**
Genus *Leptanilloides*	1	0.1	0.1	0.0	1	0.04	0.01
Subfamily Myrmicinae	**677**	**98.5**	**263.8**	**98.5**	**52**	**2.26**	**3034.48**
Genus *Acanthognathus*	19	2.8	7.6	2.8	8	0.35	1.95
Genus *Adelomyrmex*	35	5.1	15.6	5.8	2	0.09	0.95
Genus *Atta*	1	0.1	0.0	0.0	1	0.04	0.01
Genus *Cephalotes*	7	1.0	1.8	0.7	3	0.13	0.22
Genus *Crematogaster*	85	12.4	96.3	35.9	6	0.26	12.60
Genus *Hylomyrma*	7	1.0	0.6	0.2	1	0.04	0.05
Genus *Leptothorax*	74	10.8	24.2	9.0	4	0.17	3.44
Genus *Pogonomyrmex*	1	0.1	0.5	0.2	1	0.04	0.01
Genus *Rogeria*	2	0.3	2.5	0.9	1	0.04	0.05
Genus *Solepnosis*	397	57.8	93.2	34.8	14	0.61	56.35
Genus *Stegomyrmex*	36	5.2	14.1	5.3	5	0.22	2.28
UI Myrmicinae	13	1.9	6.9	2.6	6	0.26	1.16
Subfamily Ponerinae	**1**	**0.1**	**0.1**	**0.0**	**1**	**0.04**	**0.28**
Genus *Prionopelta*	1	0.1	0.1	0.0	1	0.04	0.01
Total	**687**	**100**	**267.9**	**100**	**23**		

1991; Biavati et al., 2004; Gómez-Hoyos et al., 2014; Herrera-Lopera et al., 2016). The diet of *D. truncatus* is composed mainly of ants and mites, which are an abundant resource in the Neotropics, are mostly found in leaf litter and form big colonies, so it is easy to catch many individuals (Toft, 1981; Davidson et al., 2003; Fernández, 2003). Several studies have also shown that the high intake of this type of prey explains the origin of the alkaloids sequestered in the skin of poisonous frogs (Daly et al., 1999; Saporito et al., 2009). Unlike other anurans, the diet specialization of *D. truncatus* enables it to find its food resource even in disturbed areas (pers. obs.), allowing these species to be found in open forests, since ants and mites are highly abundant even at these sites (Fernández, 2003; Fernandez and Sendoya, 2004).

In general, ant-specialist frogs have small bodies and thin mandibles, they actively forage in order to feed, and a great number of prey can be found in their stomachs (Toft, 1980, 1981). In this study, *D. truncatus* individuals displayed an average body size of 25.6 mm, a mandibular width of 7.4 mm, and an average of 63 prey items in their stomach contents. The intake of different types of prey is common among dendrobatids that specialize on ants (Simon and toft, 1991; Biavati et al., 2004; Gómez-Hoyos et al., 2014). This could be due to natural changes that occur in prey populations, or to the need for a nutritional balance (Donelly, 1991; Clark 1982). Overall, we found 11 orders of arthropods in the diet of *D. truncatus*, and some of these represented over 10% in abundance. Mites were an important prey item in the diet of *D. truncatus*, and our results agree with those found by Simon and Toft (1991), as these authors mention that mites represent between 1 and 10% of the diet of the majority of ant-specialist species. In fact, the authors suggest that mites can be the dietary equivalent of ants (Simon and Toft, 1991).

Dendrobates truncatus consume a high proportion of ants of the genus *Solenopsis*. These results agree with studies conducted by Posso-Peláez et al. (2017), which report that the subfamily Myrmicinae, especially the genera *Pheidole* and *Solenopsis*, are an essential food resource for the species. Ants of this subfamily are present in a wide variety of habitats; some are tree-borne, others inhabit the soil and leaf litter, while other species are associated with plants, fungi, and other ants (Fernández, 2003). In particular, *Solenopsis* is one of the most commonly found genera in soil-borne ant communities (Fernández, 2003; Fernandez and Sendoya, 2004). Their nests can be found in leaf litter, dead wood, epiphytes, or plant cavities (Fernández, 2003; Delsine et al., 2012). Worker ants forage from deep in the soil to high up in the forest canopy and, due to their high richness and abundance; these are considered ecologically very important in the Neotropics (Fernández, 2003; Delsine et al., 2012), mainly because several of these species have become important invasive plagues (Nagrare et al., 2009).

Finally, we did not find any correlation between the morphology of the individuals and the prey variables assessed. These results indicate that an increase in body size does not imply a corresponding increase in the number and volume of consumed prey. These ontogenic changes in prey size are usually associated with modifications in prey types with age, which seem to be more common in species with generalist diets (Simon and Toft, 1991; Parmelee, 1999). However, some frogs display ontogenic changes in the types of prey consumed, independently of changes in prey size (Donnelly, 1991; Lima and Moreira, 1993). For this reason, we suggest that other factors that could influence the diet composition, such as sex or age, should be considered in future research on the diet of *D. truncatus*. In this manner, the ecology and life history aspects of this species could be better understood in order to achieve an adequate management and protection of its wild populations.

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