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ECOLOGY

Two records of anurophagy in *Leptodactylus macrosternum* from Cerrado, Brazil, with a review list of cases for the genus *Leptopdactylus* (Anura: Leptodactylidae)

Dos nuevos registros de anurofagia para *Leptodactylus macrosternum* en el Cerrado, Brasil, con una lista de revisión de los casos para el género *Leptodactylus* (Anura: Leptodactylidae)

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ABSTRACT

Anurophagy represents a small percentage of anurans' diet, however, the observation of this behavior is frequent and well-documented. Herein we reported two events of anurophagy of *Leptodactylus macrosternum* preying a newly metamorphosed *Physalaemus nattereri* and an adult *Boana punctata*, both in the municipality of Dois Irmãos do Buriti, Mato Grosso do Sul state, Western Brazil. Additionally, we summarized literature records of anurophagy in *Leptodactylus*. We found 99 records of anurophagy in different stages of development. *Physalaemus nattereri* and *Boana punctata* have never been reported as prey for *Leptodactylus* and this predation might be due to a combination of abundance and the high call activity during the breeding season. Anurophagy in *Leptodactylus* has more records for large-sized species, even in the larvae stage. Anurophagy occurrence in leptodactylids may be related to the size of the predator, habitat, and area diversity since more complex and diverse environments tend to present more anurophagy events.

Keywords: Batracophagy, diet, predation.

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RESUMEN

La anurofagia representa un pequeño porcentaje de la dieta de los anuros, sin embargo, es un comportamiento común y bien documentado. Reportamos aquí dos eventos de anurofagia de *Leptodactylus macrosternum* depredando un juvenil metamorfo de *Physalaemus nattereri* y un adulto de *Boana punctata,* ambos eventos en el municipio de Dois Irmãos do Buriti, estado de Mato Grosso del Sur, Brasil. Adicionalmente, presentamos una revisión de los eventos de anurofagia del género *Leptodactylus*. Encontramos en total 99 registros de diferentes estados de desarrollo. *Physalaemus nattereri* y *Boana punctata* no habían sido reportadas como presas de *Leptodactylus*. Estas depredaciones pueden deberse a una combinación de la abundancia y la alta actividad de canto durante la reproducción. La anurofagia en leptodactílidos ha sido registrada mayormente en especies de gran tamaño, incluyendo en estados larvales. La ocurrencia de la anurofagia puede ser predicha por el tamaño del depredador, el hábitat y la diversidad del área, siendo que ambientes más complejos y de mayor diversidad tienden a presentar más eventos de anurofagia.

Palabras clave. Batracofagia, dieta, depredación.

Anurans play an important role in food webs in different habitats (Duellman and Trueb 1994). In the Neotropical region, they feed mainly on arthropods, and they are predated by fish, mammals, birds, reptiles, and invertebrates (Andrade *et al.* 2012, Aoki and Landgref-Filho 2013, Oliveira *et al.* 2014, Cortés-Gomez *et al.* 2015, Ferreira *et al.* 2017, Folt and Lapinski 2017, Ceron *et al.* 2019, Landgref-Filho *et al.* 2019, Cruz-Sáenz *et al.* 2020). Eventually, anurans can eat other frogs (i.e., anurophagy), and although this behavior represents a small percentage of anurans' diet, these events are well-documented (Toledo *et al.* 2007, Loebmann 2013, Oda *et al.* 2019, Caicedo-Martínez *et al.* 2021). Most anurans are known by their generalist diet, and their prey sizes may be related to the tongue and the mouth shape (Emerson 1985). For those reasons not only, the size is related to anurophagy, but also the skull shape and the habitat, especially in environments with high anuran abundance (Emerson 1985, Scott and Aquino 2005, Measey *et al.* 2015). Among Neotropical anurans, reports on anurophagy events in *Leptodactylus* are frequent (Sanabria *et al.* 2005, Toledo *et al.* 2007, Ávila-López *et al.* 2012, Sierra-Rueda and Acosta-Ortiz 2020). *Leptodactylus macrosternum* Miranda-Ribeiro, 1926, commonly called butter frog, is a large species (48.7–98.9 mm snout-vent length [SVL]) belonging to the *L. latrans* group (Magalhães *et al.* 2020). *Leptodactylus macrosternum* has a wide distribution in South America, from Santa Fé, Argentina, to northern Brazil and the Guiana Shield; also, it has been recorded in Trinidad and Tobago (Magalhães *et al.* 2020, Frost 2021).

Leptodactylus macrosternum reproductive activity occurs mainly during the rainy season (Prado *et al.* 2000, Camurugi *et al.* 2017). It is a generalist species with a foraging strategy between sit-and-wait and active search; its diet includes mainly coleopterans (Schaefer *et al.* 2006, Camurugi *et al.* 2017). Although anurophagy is well known for *Leptodactylus* species, most of the records are solely based on anecdotal observation, with the preyed anurans identified only to the order level (i.e., Anura) (e.g., Gallardo 1964, Maneyro *et al.* 2004, Solé *et al.* 2009, Camurugi *et al.* 2017).

Prey identification is fundamental to understanding trophic interactions (Ceron *et al.* 2020a), the role of anurans as energy and protein sources to other animals (Cortés-Gomes *et al.* 2015), the role of predators as regulators, and the possible drivers of anurophagy (Measey *et al.* 2015). Given the lack of specific records, herein we report two new anurophagy events of *Leptodactylus macrosternum* and provide a list of anurophagy cases for the genus *Leptodactylus*.

Both new records occurred at the edge of a permanent pond at Estância Crioula Farm, located at Dois Irmãos do Buriti municipality, Mato Grosso do Sul state, Western Brazil (20° 32' 07" South, 55° 33' 00" West). All specimens were collected under SISBIO license (SISBIO 49080-5), killed with lidocaine (5 %), fixed in 10 % formalin, preserved in 70 % Ethanol, and housed at Coleção Zoológica da Uni-

versidade Federal de Mato Grosso do Sul (ZUFMS-AMP). Additionally, to recover a list of anurophagy records by *Leptodactylus* species as predators from literature, we used the following keywords: "*Leptodactylus*", "Anurophagy", "Diet", "Predation" and "Cannibalism" in "Google Scholar". As a complement, we checked specialized journals such as Herpetological Review and Herpetology Notes, in the "Natural History" section. We included studies of diet, even with unidentified prey. The size category of species follows Haddad *et al.* (2013), who considered species as small (< 3 cm), medium (3 – 10 cm), and large (> 10 cm). We included reports of predation attempts or regurgitations and exclude those that not occurred in nature (e.g., Regnet and Loebmann 2017). When information about the locality and/or photographs allowed a more precise prey and predator identification, we included it (e.g., Faivovich *et al.* 2005, Heyer 2005, Frost *et al.* 2006, Narvaes and Rodrigues 2009, Duellman *et al.* 2016, Magalhães *et al.* 2020; Gazoni *et al.* 2021). Details about species names originally reported by authors are in Supplementary file 1.

Our first report occurred on 11 Nov 2020, around 20:00h, when we collected a female of *L. macrosternum* (SVL= 77.10 mm, ZUFMS-AMP13951, Fig. 1a) with an anuran leg out of its mouth. After dissection, we identified that the prey was a juvenile of *Physalaemus nattereri* (Steindachner, 1863) (SVL=13.62, ZUFMS-AMP13952, Fig. 1b). That night we recorded at the same pond the species *Boana raniceps* (Cope, 1862) in calling activity and saw individuals of *Leptodactylus podicipinus* (Cope, 1862) and *L. macrosternum*. The second report occurred at the edge of the same pond. This report occurred on 3 Mar 2021, around 20:00h. During that night *Boana punctata* (Schneider, 1799), *B. raniceps*, *Dendropsophus minutus* (Peters, 1872), and *Pithecopus azureus* (Cope, 1862) were calling; *L. macrosternum* and *Leptodactylus podicipinus* (Cope, 1862) were also observed although no calling behavior was recorded in these species. We observed and handled a female of *L. macrosternum* (SVL=79.21mm, ZUFMS-AMP14659, Fig. 1c) with an adult of *Boana punctata* (SVL=35.29 mm, ZUFMS-AMP14649, Fig. 1d) in its mouth. After we stored the *L. macrosternum* in a plastic bag, the *B. punctata* was regurgitated.

We found 66 references reporting events of anurophagy for a total of 99 records (101 including both records described here) (Table 1). Large-size species represent 64.35 % of the total records, Medium-size species, represent the others 35.65 % and we were not able to find anurophagy in Small-size leptodactylids.

The four-eyed frog, *P. nattereri*, has inguinal macroglands that can be used against predators during deimatic display (Lenzi-Mattos *et al.* 2005). This species has already been reported as prey for other species of *Leptodactylus* (Vaz-Silva *et al.* 2003, França *et al.* 2004), however, in two events, with *L. luctator* (Hudson, 1892), the toxin secreted by *P. nattereri* was efficient to avoid predation (Rodrigues and Filho 2004). In the present report, the preyed individual was a juvenile, newly metamorphosed, which may suggest that this is a less-effective defensive method at this life stage such as occur in *Rhinella arenarum* (Hensel, 1867) (Regueira *et al.* 2016). During the night of the second event of anurophagy reported here, many *B. punctata* were exhibiting calling behavior. This species selects different vegetation strata to call and exhibits territorial behavior, moving 100 cm around the calling site (Brunetti *et al.* 2014). The combination of the high abundance and the increase in calling activity and mobility during the breeding season of these species might result in occasional encounters and subsequent predation of *L. macrosternum* upon *B. punctata*. This is the first report of *Leptodactylus* preying on *B. punctata*

Although some large frogs, such as bufonids, are negligible predators of anurans (Measey *et al.* 2015), in leptodactylids the majority of anurophagy events are displayed by large-size frogs (Table 1). In medium size species, *L. macrosternum* represents half of the anurophagy records and it is the largest species of its category (Maximum SVL=9.89cm). Trophic ecology studies are paramount to follow temporal variations and the diversity of interactions (Ceron *et al.* 2020a, 2020b). For that purpose, we need proper identification of both, predator, and prey species. Our literature review on anurophagy by *Leptodactylus* leaps further in the anuran trophic ecology, which includes new records.

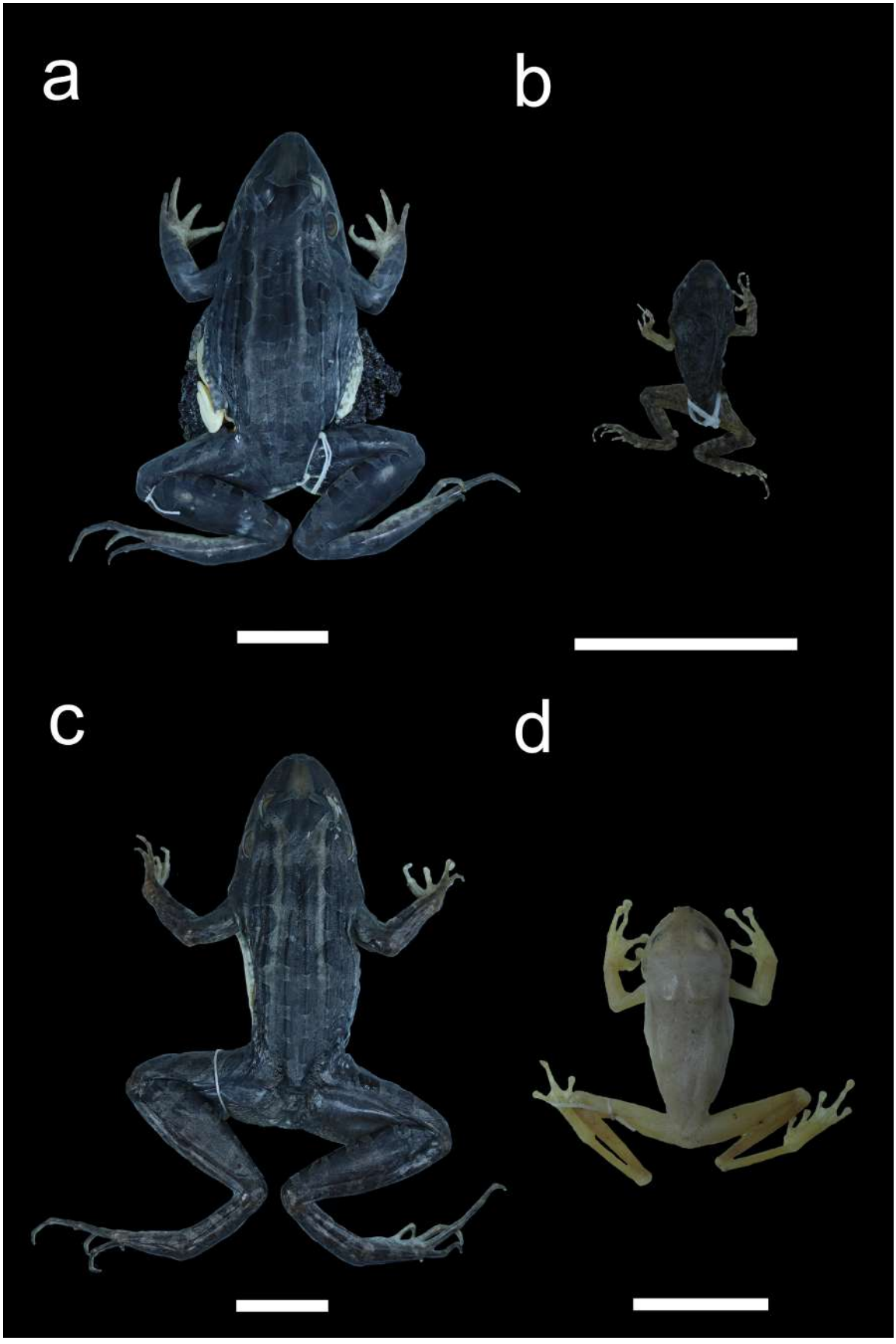

Figure 1. Individuals from the two anurophagy events reported. **a**. *Leptodactylus macrosternum*, **b**. juvenile of *Physalaemus nattereri* preyed on by the specimen "a", **c**. *L. macrosternum*, **d**. *Boana punctata* found inside the mouth of the specimen "c". Scale bar= 20mm.

Table 1. Events of anurophagy of *Leptodactylus* species and their preys. AP = Amapá, BA = Bahia, CE = Ceará, ES = Espírito Santo, GO = Goiás, MG = Minas Gerais, MS = Mato Grosso do Sul, MT = Mato Grosso, PE = Pernambuco, PI = Piauí, PR = Paraná, RJ = Rio de Janeiro, RN = Rio Grande do Norte, RS = Rio Grande do Sul, SC = Santa Catarina, SE = Sergipe, SP = São Paulo.

Predator (% of observations)	Size	Family of Prey	Prey	Locality	Country	Reference
Leptodactylus cunicularius (0.99)	Medium	Leptodactylidae	*Leptodactylus cunicularius* Sazima and Bokermann, 1978	Ouro Preto - MG	Brazil	Pirani *et al.* 2010
Leptodactylus furnarius (0.99)	Medium	Hylidae	*Scinax fuscomarginatus* (Lutz, 1925)	Botucatu - SP	Brazil	Rolim *et al.* 2009
Leptodactylus fuscus (2.97)	Medium	Hylidae	*Boana* sp.	Villavicencio - Meta	Colombia	Sierra-Rueda and Acosta-Ortiz 2020
		Leptodactylidae	*Leptodactylus caatingae* Heyer and Juncá, 2003	Jequié - BA	Brazil	Novaes-e-Fagundes and Zina 2017
		-	Unidentified Anura	southeastern Brazil	Brazil	Araújo *et al.* 2007
Leptodactylus labyrinthicus (14.85)	Large	Hylidae	*Boana albopunctata*	-	-	Toledo *et al.* 2007
			Boana faber (Wied-Neuwied, 1821)	-	-	Toledo *et al.* 2007
			Dendropsophus minutus	Uberlândia - MG	Brazil	França *et al.* 2004
			Dendropsophus minutus	Uberlândia - MG	Brazil	Silva *et al.* 2005
			Scinax cf. *similis*	Uberlândia - MG	Brazil	França *et al.* 2004
			Scinax sp.	Uberlândia - MG	Brazil	França *et al.* 2004
			Trachycephalus typhonius (Linnaeus, 1758)	Corumbá - MS	Brazil	Landgref-Filho *et al.* 2012
		Leptodactylidae	*Leptodactylus labyrinthicus*	Uberlândia - MG	Brazil	França *et al.* 2004

(Continúa)

Predator (% of observations)	Size	Family of Prey	Prey	Locality	Country	Reference
			Leptodactylus labyrinthicus	Uberlândia - MG	Brazil	Silva *et al.* 2005
			Physalaemus cuvieri Fitzinger, 1826	Águas de Santa Bárbara - SP	Brazil	Diaz-Ricaurte and Marques 2021
			Physalaemus cuvieri	Uberlândia - MG	Brazil	Silva *et al.* 2005
			Physalaemus marmoratus (Reinhardt and Lütken, 1862)	Uberlândia - MG	Brazil	Silva *et al.* 2005
			Physalaemus nattereri	Caldas Novas - GO	Brazil	Vaz-Silva *et al.* 2003
			Physalaemus nattereri	Uberlândia - MG	Brazil	França *et al.* 2004
			Pseudopaludicola saltica (Cope, 1887)	Uberlândia - MG	Brazil	França *et al.* 2004
Leptodactylus latrans (13.86)	Large	Bufonidae	*Rhinella crucifer* (Wied-Neuwied, 1821)	Uruçuca - BA	Brazil	Rojas-Padilha *et al.* 2018
			Rhinella ornata (Spix, 1824)	Ubatuba - SP	Brazil	Bovo *et al.* 2014
		Hylidae	*Boana albomarginata* (Spix, 1824)	Anchieta - ES	Brazil	Teixeira and Vrcibradic 2003
			Boana pardalis (Spix, 1824)	Espera Feliz - MG	Brazil	Heitor *et al.* 2012
			Boana raniceps	Capela - SE	Brazil	Ferreira *et al.* 2011
			Scinax fuscovarius (Lutz, 1925)	Vassouras - RJ	Brazil	Bezerra *et al.* 2015
			Scinax x-signatus (Spix, 1824)	São Lourenço da Mata - PE	Brazil	Santos 2009
			Trachycephalus mesophaeus (Hensel, 1867)	Igrapiúma - BA	Brazil	Mendes *et al.* 2012

(Continúa)

Predator (% of observations)	Size	Family of Prey	Prey	Locality	Country	Reference
		Leptodactylidae	*Leptodactylus latrans*	Anchieta - ES	Brazil	Teixeira and Vrcibradic 2003
			Physalaemus crombiei Heyer and Wolf, 1989	Anchieta - ES	Brazil	Teixeira and Vrcibradic 2003
			Physalaemus cuvieri	São Lourenço da Mata - PE	Brazil	Santos 2009
		Ranidae	*Lithobates catesbeianus* (Shaw, 1802)	Vieira - MG	Brazil	Silva and Filho 2009
		-	Unidentified Anura	Ilhéus - BA	Brazil	Solé *et al.* 2009
		-	Unidentified Anura	Anchieta - ES	Brazil	Teixeira and Vrcibradic 2003
Leptodactylus luctator (15.84)	Large	Bufonidae	*Rhinella mirandaribeiroi* (Gallardo, 1965)	Uberlândia - MG	Brazil	França *et al.* 2004
			Rhinella ornata	São Paulo - SP	Brazil	Capela *et al.* 2020
			Rhinella sp.	Uberlândia - MG	Brazil	França *et al.* 2004
			Unidentified Bufonidae	San Juan - Dep. Zonda	Argentina	Sanabria *et al.* 2005
		Hylidae	*Boana faber*	Apiaí - SP	Brazil	Pombal Jr, 2007
			Boana faber	Serra do Japi - SP	Brazil	Haddad and Sazima 1992
			Unidentified Hylidae	Uberlândia - MG	Brazil	França *et al.* 2004
		Leptodactylidae	*Leptodactylus furnarius*	Uberlândia - MG	Brazil	França *et al.* 2004
			Leptodactylus luctator	Unaí - MG	Brazil	Kokubum and Rodrigues 2005

(Continúa)

Predator (% of observations)	Size	Family of Prey	Prey	Locality	Country	Reference
			Physalaemus biligonigerus (Cope, 1861)	Tucumán	Argentina	Gallardo 1964
			Physalaemus centralis Bokermann, 1962	Araguari - MG	Brazil	Heyer and Giaretta 2009
			Physalaemus marmoratus	Paraúna - GO	Brazil	Santos *et al.* 2021
			Physalaemus nattereri	Uberlândia - MG	Brazil	Rodrigues and Filho 2004
		-	Unidentified Anura	Apiaí - SP	Brazil	Pombal Jr 2007
		-	Unidentified Anura	Caçapava do Sul - RS	Brazil	Pazinato *et al.* 2011
		-	Unidentified Anura	Arroyo Espinas - Maldonado	Uruguay	Maneyro *et al.* 2004
Leptodactylus macrosternum (18.81)	Medium	Bufonidae	*Rhinella major* (Müller and Hellmich, 1936)	Santana - AP	Brazil	Sousa *et al.* 2016
		Hylidae	*Boana albomarginata*	Macaíba - RN	Brazil	Baracho *et al.* 2013
			Boana punctata	Aquidauana - MS	Brazil	This study
			Dendropsophus nanus (Boulenger, 1889)	Corguinho - MS	Brazil	Carrillo *et al.* 2019
			Pseudis platensis Gallardo, 1961	Diamante do Norte - PR	Brazil	Oda *et al.* 2016
			Scinax nasicus Cope, 1862	Selvíria - MS	Brazil	Queiroz *et al.* 2019
		Leptodactylidae	*Leptodactylus elenae* Heyer, 1978	Estirão Comprido - MT	Brazil	Moreira and Smaniotto 2017
			Leptodactylus fuscus	Macapá - AP	Brazil	Silva *et al.* 2018
			Leptodactylus fuscus	Acreúna - GO	Brazil	Costa and Trevelin 2020

(Continúa)

Predator (% of observations)	Size	Family of Prey	Prey	Locality	Country	Reference
			Leptodactylus macrosternum	Santana - AP	Brazil	Sousa *et al.* 2016
			Leptodactylus podicipinus	Corumbá - MS	Brazil	Carrillo *et al.* 2019
			Leptodactylus troglodytes	Serra Negra do Norte - RN	Brazil	Sales *et al.* 2015
			Physalaemus nattereri	Aquidauana - MS	Brazil	This study
			Physalaemus centralis	Jardim - MS	Brazil	Costa-Pereira *et al.* 2015
			Physalaemus cuvieri	Selvíria - MS	Brazil	Queiroz *et al.* 2019
		-	Unidentified Anura	Corrientes - Corrientes	Argentina	Dure 1999
		-	Unidentified Anura	Macaíba - RN	Brazil	Camurugi *et al.* 2017
		-	Unidentified Anura	Miranda - MS	Brazil	Piatti and Souza 2011
Leptodactylus melanonotus (2.97)	Medium	Hylidae	*Dendropsophus ebraccatus* (Cope, 1874)	San Luis - Limón	Costa Rica	Hoffmann 2006
			Tlalocohyla smithii (Boulenger, 1902)	Minatitlán - Colima	Mexico	Ávila-Lopez *et al.* 2012
		Ranidae	*Lithobates vaillanti* (Brocchi, 1877)	Barra del Colorado	Costa Rica	Lewis *et al.* 2008
Leptodactylus mystaceus (0.99)	Medium	Bufonidae	*Atelopus hoogmoedi* Lescure, 1974	Laranjal do Jarí - AP	Brazil	Pinto and Costa-Campos 2015
Leptodactylus natalensis (3.96)	Medium	Hylidae	*Dendropsohus* aff. *decipiens*	Guarapari - ES	Brazil	Ferreira *et al.* 2007
			Scinax argyreornatus (Miranda-Ribeiro, 1926)	Guarapari - ES	Brazil	Ferreira *et al.* 2007
		Leptodactylidae	*Physalaemus* sp.	Guarapari - ES	Brazil	Ferreira *et al.* 2007

(Continúa)

Predator (% of observations)	Size	Family of Prey	Prey	Locality	Country	Reference
		-	Unidentified Anura	São Lourenço da Mata - PE	Brazil	Santos *et al.* 2004
Leptodactylus paranaru (0.99)	Large	Hylidae	*Boana bischoffi* (Boulenger, 1887)	Azambuja - SC	Brazil	Peres *et al.* 2017
Leptodactylus payaya (0.99)	Large	Hylidae	*Boana raniceps*	Barbalha - CE	Brazil	Chaves *et al.* 2012
Leptodactylus pentadactylus (1.98)	Large	Bufonidae	*Rhinella margaritifera* (Laurenti, 1768)	Serra do Návio - AP	Brazil	Santana *et al.* 2018
		Hylidae	*Boana rosenbergi* (Boulenger, 1898)	-	-	Kluge 1981
Leptodactylus podicipinus (2.97)	Medium	Bufonidae	*Rhinella diptycha* (Cope, 1862)	Corumbá - MS	Brazil	Ceron *et al.* 2018
			Rhinella major	Macapá - AP	Brazil	Santos *et al.* 2018
			Rhinella mirandaribeiroi	Pontalina - GO	Brazil	Guimarães *et al.* 2004
Leptodactylus rhodonotus (0.99)		Bufonidae	*Rhinella marina*	Mascoitania reserve - Peru	Peru	Thomas *et al.* 2017
Leptodactylus savagei (0.99)	Large	Leptodactylidae	*Engystomops pustulosus* (Cope, 1864)	Norcasia - Caldas	Colombia	González-Duran and Gutiérrez-Cárdenas 2013
Leptodactylus troglodytes (0.99)	Medium	Leptodactylidae	*Leptodactylus troglodytes*	Natal - RN	Brazil	Jorge and Freire 2011
Leptodactylus vastus (8.91)	Large	Bufonidae	*Rhinella mirandaribeiroi*	Parque Nacional de Sete Cidades - PI	Brazil	Cardoso and Sazima 1977
		Hylidae	*Boana albomarginata*	Capela - SE	Brazil	Santana *et al.* 2012
			Boana albopunctata	Parque Nacional de Sete Cidades - PI	Brazil	Cardoso and Sazima 1977
			Boana faber	Capela - SE	Brazil	Neto *et al.* 2015
		Leptodactylidae	*Leptodactylus latrans*	Capela - SE	Brazil	Santana *et al.* 2012

(Continúa)

Predator (% of observations)	Size	Family of Prey	Prey	Locality	Country	Reference
			Leptodactylus natalensis	São Lourenço da Mata - PE	Brazil	Santos 2009
			Leptodactylus vastus	Mata de São João - BA	Brazil	Guimarães *et al.* 2015
			Physalaemus albifrons (Spix, 1824)	Aiuaba - CE	Brazil	Teles *et al.* 2015
			Physalaemus cuvieri	São Lourenço da Mata - PE	Brazil	Santos 2009
Leptodactylus sp. (gr. *latrans*) (5.94)	Large	Bufonidae	*Rhinella crucifer*	-	Brazil and Argentina	Gallardo 1964
			Rhinella sp. (gr. *granulosa*)	-	Brazil and Argentina	Gallardo 1964
		Hylidae	*Boana albomarginata*	-	-	Toledo *et al.* 2007
			Pseudis minuta Günther, 1858	-	Brazil and Argentina	Gallardo 1964
			Scinax squalirostris (Lutz, 1925)	-	Brazil and Argentina	Gallardo 1964
			Boana sp. (gr. *pulchella*)	-	Brazil and Argentina	Gallardo 1964

AUTHOR CONTRIBUTIONS

J.F.C. Carrillo and D. G. Cavalheri designed the research structure and D.G. Cavalheri and V.S. Souza collected and drafted the manuscript. J.F.C. Carrillo and D. J. Santana substantially edited and improved the manuscript.

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CONFLICT OF INTEREST

The authors do not report any potential conflict of interest.

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