An Acad Bras Cienc (2025) 97(3): e20240499 DOI 10.1590/0001-3765202520240499
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ANIMAL SCIENCE

Living in big houses: the role of parasitism on anacondas (Boidae: *Eunectes*), with new records, parasites catalog, and assessment perspectives

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Abstract: Anacondas rank among the largest snakes on Earth. Found throughout South America, including urban areas, they are commonly traded globally. However, information on anacondas' parasites and pathogens is scattered, necessitating a comprehensive summary. Using morphological and molecular approaches, we provide new records of the ticks *Amblyomma dissimile* and *A. rotundatum* hosted on ethanol-preserved specimens of *Eunectes murinus* and *E. deschauenseei*. The presence of *A. rotundatum* on *E. deschauenseei* represents the first record to this rare and poorly known species. Our literature review revealed 45 organisms living on anacondas (13 animal species, four protozoans, 10 fungi, 17 bacteria, and one viral lineage), mostly on *E. murinus*. Anacondas rescued in urban areas or kept in zoos provide a fortuitous opportunity for collecting data on parasites and pathogens, useful for measuring the impacts of habitat anthropization, as well as for preventing the spread of diseases disseminated by traded animals. Withal, characterizing anacondas' parasites and pathogens is paramount to establishing appropriate treatment of diseases caused by these agents, and in cases of accidents involving humans.

Key words: *Eunectes deschauenseei*, *Eunectes murinus*, health status, parasites, ticks, *Amblyomma*.

INTRODUCTION

A parasite is an organism that benefits from living on (ectoparasite) or inside (endoparasite) another organism, known as a host. Parasites are essential for biodiversity and community-level ecological dynamics (Poulin et al. 2016, Sures et al. 2017). They could affect their host populations, influencing mortality, fecundity, growth, nutritional status, energetic requirements and behavior (Miura et al. 2006, Preston & Johnson 2010, Magalhães et al. 2020), leading to ecologically-relevant shifts in species-species interactions (Wood et al. 2007, Hatcher et al. 2012). Parasites are also useful bioindicators of environmental impact (Vidal-Martínez et al. 2010), and their characterization provides evidence of the participation of animals in epidemiological chains as reservoirs of some important pathogens (Jongejan & Uilenberg 2004, Davis et al. 2012, Rodrigues et al. 2016). Studies with parasites are essential to assess the implications for wildlife health and environment quality (Davis et al. 2012).

Snakes can host several parasites (Davis et al. 2012), however information on Neotropical snakes' parasites and associated pathogens is scarce (Calle et al. 1994, Moravec & Santos 2009, Pontes et al. 2009, Fiorini et al. 2014, Fonseca et al. 2020). Anacondas (Squamata: Boidae) are emblematic Neotropical snakes comprised by four semiaquatic constricting species: the green anaconda, *Eunectes murinus* (Linnaeus 1758); the yellow anaconda, *E. notaeus* Cope 1862; the dark-spotted anaconda, *E. deschauenseei* Dunn & Conant 1936; and the Beni's anaconda, *E. beniensis* Dirksen 2002. Living in the land-water interface, they prosecute key roles in ecosystems as predators, exerting top-down pressure on prey species populations, increasing the energy flow in cascades trophic, transporting nutrients from the land to water, and performing cleaning service by eating carrion, also preventing the spread of diseases (Miranda 2017). The status of all anaconda species on the Red List is 'least concern' (LC) (Dirksen 2010, Muñoz et al. 2016, Calderón et al. 2021, Waller et al. 2021) and, as for all species in the Boidae family, *Eunectes* is listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) subjecting the international anaconda trade to severe controls. Despite their ecological relevance and renown as largest snakes in the Neotropics, information on parasites and pathogens of anacondas is scattered and a summary of them is still necessary.

As parasite characterization can provide evidence of the participation of anacondas in the epidemiological chain, in this study we analyzed ethanol-preserved anacondas housed in Brazilian herpetological collections to provide new records of ectoparasites hosted on anacondas. In addition, we also provide a literature review summarizing knowledge on anacondas' parasites and pathogens, and discuss perspectives on monitoring their health status. All these results can help improve conservationist and sanitary strategies for these giant snakes.

MATERIALS AND METHODS

Sampling anacondas' parasites

To provide new data on anaconda' parasites, between May and September 2022, we searched for ectoparasites in 398 collected anacondas (*E. murinus* = 333, *E. notaeus* = 21, *E. deschauenseei* = 42, *E. beniensis* = 2) housed in the following scientific collections: Museu Paraense Emílio Goeldi (MPEG), Belém, Pará; Universidade Federal de Mato Grosso (UFMT), Cuiabá, Mato Grosso; Universidade Federal de Mato Grosso do Sul (UFMS), Campo Grande, Mato Grosso do Sul; Universidade Federal da Bahia (UFBA), Salvador, Bahia; Universidade Estadual de Feira de Santana (UEFS), Feira de Santana, Bahia; Universidade Federal do Ceará (UFC), Fortaleza, Ceará; Universidade Estadual de Santa Cruz (UESC), Ilhéus, Bahia; Pontifícia Universidade Católica (PUCRS), Porto Alegre, Rio Grande do Sul; Museu de História Natural Capão da Imbuia (MHNCI), Curitiba, Paraná; Museu Nacional do Rio de Janeiro (MNRJ), Rio de Janeiro; Instituto Butantan (IB), São Paulo; Museu de Zoologia da Universidade de São Paulo (MZUSP), São Paulo.

We found 12 tick individuals on *E. murinus* and *E. deschauenseei*. Ticks were removed from their host and stored in ethanol PA for morphological and molecular identification.

Morphological and molecular identification

After collection, the ticks were preserved in PA ethyl alcohol and sent to the Acarological Collection of Instituto Butantan (IBSP) for identification and study. Specimens were identified at genus and species level using the bibliography (Barros-Battesti et al. 2006, Martins et al. 2010).

Each tick was placed in a separate plastic microtube. The larvae were fully macerated and the adults were cut in half with a sterile needle (1.20*40 - 18G). A half of the adults was kept housed in the IBSP collection (Table I) and the other half was macerated to DNA extraction. The samples were submitted individually

Table I. Anacondas specimens analyzed in Brazilian scientific collections parasitized by ticks. Tick stage: L = larvae. SVL = anaconda snout-ventral length.

Host species	Host code	Tick species	Tick code	Locality and collection date
E. murinus SVL 168,3 cm ♀	MPEG 18511	*Amblyomma* sp. L	IBSP 18699	Av. Perimetral S/N, around the FCAP, Belém, Pará, Brazil. 04.iv.1992
E. murinus SVL 132 cm ♀	MPEG 19002	*A. rotundatum* ♀	IBSP 18700	Ajarani River. 4km E, highway BR-210, Vista Alegre, Roraima, Brazil. 30.vi.1993
		A. rotundatum ♀	IBSP 18701	
E. murinus SVL 202 cm	IBSP 24029	*A. dissimile* ♂	IBSP 18702	Boa Vista, Roraima, Brazil
		A. rotundatum L	IBSP 18703	
E. deschauenseei SVL 171,7 cm ♀	IBSP 15207	*A. rotundatum* ♀	IBSP 18704	Severino farm, Marajó Island, Pará, Brazil
		A. rotundatum ♀	IBSP 18705	
		A. rotundatum ♀	IBSP 18706	
		A. rotundatum ♀	IBSP 18707	
		A. dissimile ♂	IBSP 18708	
E. deschauenseei SVL 153,4 cm ♂	MCP 13032	*A. dissimile* ♀	IBSP 18709	PUCRS's zoo, Porto Alegre, Rio Grande do Sul, Brazil
		A. dissimile ♀	IBSP 18710	

for DNA extraction using the 'DNeasy Blood and Tissue Kit (Qiagen)' according to the manufacturer's protocol. Conventional PCRs targeting a partial fragment of the 16S rRNA gene of the tick were performed using the extracted DNA, Thermo Scientific DreamTaq Green PCR Master Mix (2X), UltraPure™ DNase/RNaseFree Distilled Water, and the primers 16S + 1 (CTGCTCAATGATTTTTTAAATTGCTGTGG) and 16S − 1 (CCGGTCTGAACTCAGATCAAGT), following the thermal conditions by Mangold et al. (1998). All reactions included positive (DNA extracted from *Amblyomma brasiliense*) and negative (DNA-free ultrapure water) controls. Positive samples for the endogenous gene were considered viable, and thus the screening for bacteria of the genus *Rickettsia* was performed by conventional PCR using the primers CS-78 (GCAAGTATCGGTGAGGATGTAAT) and CS-323 (GCTTCCTTAAAATTCAATAAATCAGGAT) which amplify a 401-bp fragment of the *gltA* gene, present in all bacteria of this genus. This reaction was performed following the protocols described by Labruna et al. (2004). All reactions included positive (DNA extracted from cell culture infected with *Rickettsia vini*) and negative (ultrapure water type I) controls.

Reactions yielding amplicons of the expected size were treated with ExoSAP-IT (USB Corporation®, OH) following the manufacturer's instructions (3 µl of ExoSAP with 7.5 µl of the amplified DNA). Sanger sequencing was performed at the "Centro de Pesquisa sobre Genoma Humano e Células Tronco do Instituto de Biociências da USP", São Paulo, SP, Brazil. The sequences obtained were assembled and trimmed with Geneious R11 (Kearse et al. 2012) and then submitted to BLAST analysis (NCBI 1988) to infer the closest similarities with other homologous sequences (Altschul et al. 1990).

Literature review

We reviewed the literature on *Eunectes* parasites, with exhaustive searches of related articles in the Web of Science (WoS) platform using the keywords "((Eunect* OR sucuri* OR anaconda*))" in the title, abstract, and keywords, selecting the research mode "Topic" (TS) until 2022. After that, we used a snowball approach (Flick 2009) to guide us to new literature. We attempted to synthesize the information from the literature review, summarizing the data related to *Eunectes* parasites and pathogens.

RESULTS

New records

Of the 398 specimens of anaconda housed in herpetological collections, we found 12 ticks on five specimens: one specimen of *Amblyomma dissimile* Koch 1844 on *E. murinus* (IBSP 24029) and three on *E. deschauenseei* (IBSP 15207 and MCP 13032); three individuals of *Amblyomma rotundatum* Koch 1844 on *E. murinus* (MPEG 19002 and IBSP 24029) and four on *E. deschauenseei* (IBSP 15207); and one *Amblyomma* sp. on *E. murinus* (MPEG 18511) (Table I, Figure 1).

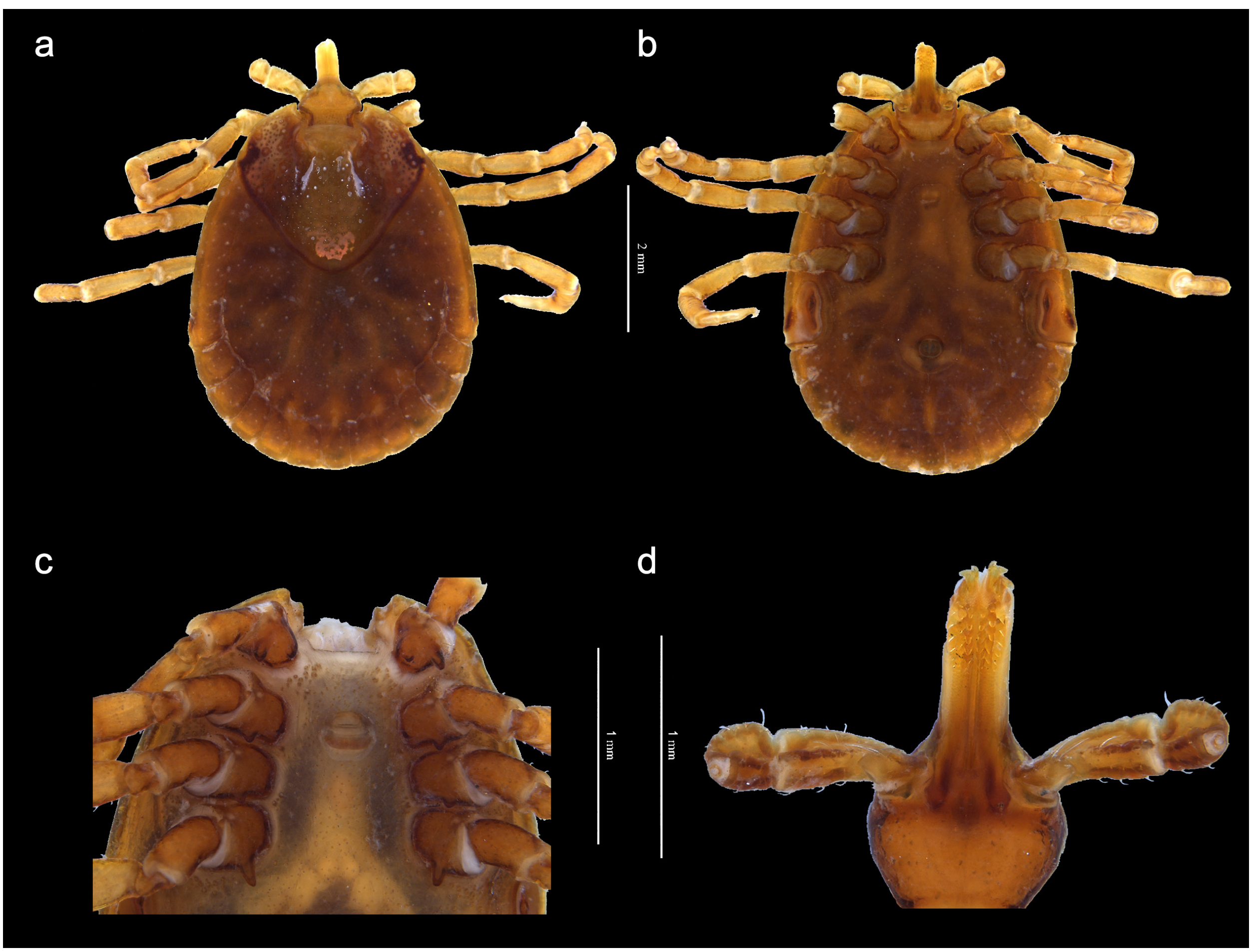

Figure 1. Ticks sampled on anacondas. a) dorsal and b) ventral view of an adult female of *A. rotundatum* (IBSP 18706) sampled from *E. deschauenseei* (IBSP 15207); c) ventral and d) buccal apparatus of an adult female of *A. dissimile* (IBSP 18709) sampled from *E. deschauenseei* (MCP 13032).

Molecular identification

The twelve specimens found in the hosts were processed using the 16S rRNA gene as a target to confirm the taxonomic identification of the species. All sequences obtained were compatible with *A. dissimile* and *A. rotundatum*, and only one *Amblyomma* sp. larvae could not be identified at the species level because the DNA was not amplified. The sequences were homologous among each other, and the GenBank access number for the obtained sequence of *A. rotundatum* is OR251337, and for the *A. dissimile* is OR251338. When compared with the other sequence available in the Genbank database, the sequence for *A. rotundatum* showed 100% with *A. rotundatum* (KY020986.1), and the sequence for *A. dissimile* showed 99,70 % with *A. dissimile* (ON679580.1). The samples were tested for bacteria of the genus *Rickettsia*, and no DNA amplification was detected in any of the specimens.

Literature review

We found 32 papers reporting 45 organisms living on anacondas. Most records were for *E. murinus* (N = 26), followed by *E. notaeus* (N = 6) and *E. deschauenseei* (N = 1). None record was found for *E. beniensis*. Most records were made in zoos or collections (N = 22), and freeliving anacondas were sampled in nine papers. The papers reported 13 animal species, four protozoans, 10 fungi, 17 bacteria, and one viral lineage living on anacondas (Table II).

DISCUSSION

This work provided new records of ticks parasitizing anacondas and the first parasitism by *A. rotundatum* for the enigmatic and poorly studied *E. deschauenseei*. We also provided a catalog of parasites and pathogens on anacondas. Finally, we discuss perspectives on parasite load and health status monitoring for this important ecological actor in the Neotropics and one of the largest snakes on Earth.

Parasitism is often challenging to observe (Preston & Johnson 2010). A long-duration investigation on free-living *E. murinus* was carried out in the Venezuelan Llanos and assessed a broad spectrum of health parameters (Calle et al. 1994, 2001). These pioneer studies provided few data on parasites and pathogens for wild anaconda's populations (Calle et al. 1994). Moreover, the description of worm and virus lineage species from anacondas is notable and highlights the scarcity of parasitological studies on these snakes.

Anacondas are frequently found in cities (Novaes et al. 2016, Camera & Meneses 2022, Camera et al. 2022), and urbanization exhibits relevant ecological roles on host-parasite interactions (Bradley & Altizer 2007), increasing the host's susceptibility to infection by pathogens due chronic stress and immunosuppression (Keesing et al. 2010) caused by changes on habitat quality, animal dispersal capacity, and nutrient availability (Gottdenker et al. 2014). Thus, snakes in urban areas are subject to higher levels of parasitic infection. Recently, an investigation looking for wild vertebrates rescued in urban rainforest fragments in northeastern Brazil highlighted potential pathogens ranging from 7% to 15% for sampled ticks (Fonseca et al. 2020). Withal, parasitological studies are paramount to clarify the epidemiologic role of anacondas in urban areas.

Despite the scarcity of tick parasitism in aquatic snakes due to their terrestrial ecology (Pontes et al. 2009), some reports were made to anacondas (Table II, Figure 2). Ticks are remarkable and represent an important concern to veterinary medicine and public health due hosting pathogens of animals and humans (Fuente 2008, Moura et al. 2012, Ogrzewalska et al.

Table II. Literature records of parasites and pathogens on anacondas.

Class	Family	Species	Host	Site of infection	Locality	Reference
ANIMALIA						
Arachnida	Ixodidae	*Amblyomma argentinae* Neumann 1904	*E. notaeus*	Skin	Argentina	Guglielmone et al. 2001
		Amblyomma dissimile Koch 1844	*E. murinus, E. deschauenseei*	Skin	French Guina; Llanos, Venezuela; Boa Vista, Marajó Island, Santarém, Brazil; Zoo in Manaus, Brazil	Floch & Fauran 1959, Keirans 1972, Calle et al. 1994, Brum & Rickes 2003, Guglielmone & Nava 2010, Rivas 2016, Nascimento et al. 2017, Polo et al. 2020, this study
		Amblyomma rotundatum Koch 1844	*E. murinus, E. deschauenseei*	Skin	Boa Vista, Lauro de Freitas, Marajó Island, Salvador, Vista Alegre, Brazil	Fonseca et al. 2020, this study
Insecta	Tabanidae	*Phaeotabanus nigriflavus* Krober 1930	*E. murinus*	Skin	Manaus, Brazil	Ferreira et al. 2002
		Stenotabanus bequaerti Rafael, Fairchild & Gorayeb 1982	*E. murinus*	Skin	Manaus, Brazil	Ferreira et al. 2002
		Stenotabanus cretatus Fairchild 1961	*E. murinus*	Skin	Manaus, Brazil	Ferreira et al. 2002
		Tabanus occidentalis Linnaeus 1758	*E. murinus*	Skin	Manaus, Brazil	Ferreira et al. 2002
Enoplea	Capillariidae	*Capillaria* sp.	*E. murinus*	Intestines	Zoo in Barranquilla, Colombia	Duran et al. 2020
Secernentea	Dracunculidae	*Dracunculus brasiliensis* Moravec & Santos 2009	*E. murinus*	Mesentery, subcutaneous tissue	Mexiana Island, Pará, Brazil	Moravec & Santos 2009
		Dracunculus sp.	*E. murinus*	Subcutaneous tissue	Llanos, Venezuela; Zoo in Plague, Czech Republic	Moravec 1966, Calle et al. 1994
Cestoda	Proteocephalidae	*Crepidobothrium gerrardii* (Baird 1860)	*E. murinus*	Small intestine	Zoo in Wien, Austria; Zoo in Sapucaia, Brazil	Kutzer & Grünberg 1965, Fortes & Hoffmann 1987
		Crepidobothrium sp.	*E. murinus*	Intestines	Llanos, Venezuela	Calle et al. 1994
Trematoda	Dicrocoeliidae	*Infidum infidum* (Faria 1910) Travassos 1916	*E. murinus, E. notaeus*	Gallbladder	Cuiabá river, Brazil; Argentina	Fernandes & Kohn 2014
	Plagiorchiidae	*Styphlodora condita* Faria 1911	*E. notaeus*	NA	NA	Fernandes & Kohn 2014
	Telorchiidae	*Telorchis clava* (Diesing 1850)	*E. murinus*	Small intestine	Formosa, Argentina	Lunaschi & Drago 2010, Fernandes & Kohn 2014
PROTISTA						

Table II. Continuation.

Archamoebae	Entamoebidae	*Entamoeba invadens* Rodhaim 1934	*E. murinus*	Gastrointestinal mucosa, kidneys, liver	Zoo in Gwangju, South Korea	Park et al. 2019
Conoidasida	Eimeriidae	NA	*E. murinus*	Intestines	Zoo in Barranquilla, Colombia	Duran et al. 2020
Discosea	Acanthamoebidae	*Acanthamoeba hatchetti* Sawyer, Visvesvara & Harke 1977	*E. notaeus*	Intestines	Zoo in Kilkenny City, Ireland	Tuska-Szalay et al. 2022
Aconoidasida	Haemoproteidae	*Haemoproteus* sp.	*E. murinus*	Blood	Llanos, Venezuela	Calle et al. 1994
FUNGI						
Dothideomycetes	Pleosporaceae	*Alternaria* sp.	*E. murinus*	Skin	Zoo in Georgia	Miller et al. 2004
Eurotiomycetes	Aspergillaceae	*Aspergillus* sp.	*E. murinus*	Lungs, skin	Zoo in Georgia; Zoo in São Paulo, Brazil	Miller et al. 2004, Freire et al. 2019
	Trichocomaceae	*Penicillium* sp.	*E. murinus*	Skin	Zoo in São Paulo, Brazil	Freire et al. 2019
	Arthrodermataceae	*Trichophyton* sp.	*E. murinus*	Skin	Zoo in Georgia	Miller et al. 2004
	Onygenaceae	*Ophidiomyces ophiodiicola* Sigler, Hambleton & Paré 2013	*E. murinus, E. notaeus*	Eyes, lungs, skin, spleen	Zoo in Washington, United States of America	Sigler et al. 2013, Anderson et al. 2021
Sordariomycetes	Hypocreaceae	*Acremonium* sp.	*E. murinus*	Skin	Zoo in São Paulo, Brazil	Freire et al. 2019
	Plectosphaerellaceae	*Verticillium* sp.	*E. murinus*	Skin	Zoo in Georgia	Miller et al. 2004
	Microascaceae	*Scopulariopsis* sp.	*E. murinus*	Skin	Zoo in São Paulo, Brazil	Freire et al. 2019
Tremellomycetes	Cryptococcaceae	*Cryptococcus neoformans* Vuill. (1901)	*E. murinus*	Brain, lungs	Zoo in New York, United States of America	McNamara et al. 1994
Mucoromycetes	Mucoraceae	*Mucor* sp.	*E. murinus*	Skin	Zoo in São Paulo, Brazil	Freire et al. 2019
BACTERIA						
Flavobacteriia	Weeksellaceae	*Elizabethkingia meningoseptica* (King 1959)	*E. murinus*	Lungs	Zoo in Georgia	Miller et al. 2004
Chlamydiae	Chlamydiaceae	*Chlamydia pneumonia* Grayston et al. 1989	*E. notaeus*	Choana	Zoo in Australia	Taylor-Brown et al. 2015
Bacilli	Enterococcaceae	*Enterococcus* sp.	*E. murinus*	Mouth	Uberlândia, Brazil	Martins et al. 2019

Table II. Continuation.

Betaproteobacteria	Alcaligenaceae	*Alcaligenes faecalis* Castellani & Chalmers 1919	*E. notaeus*	Muscles, skin	Zoo in Sorocaba, Brazil	Veinert et al. 1983
	Burkholderiaceae	*Burkholderia* sp.	*E. murinus*	Mouth	Zoo in São José do Rio Preto, Brazil	Fonseca et al. 2009
	Xanthomonadaceae	*Stenotrophomonas maltophilia* Palleroni & Bradbury 1993	*E. murinus*	Coelomic cavity, intestines, liver, lungs, skin	Zoo in Georgia	Miller et al. 2004
Gammaproteobacteria	Aeromonadaceae	*Aeromonas hydrophila* (Chester 1901) Stanier 1943	*E. murinus*	Intestines, lungs, mouth, gums, spleen	Zoo in Georgia; Zoo in Sofia, Bulgaria; Zoo in Gwangju, South Korea	Miller et al. 2004, Orozova et al. 2012, Park et al. 2019
	Enterobacteriaceae	*Citrobacter freundii* (Braak 1928) Werkman & Gillen 1932	*E. murinus*	Mouth, skin	Uberlândia, Brazil; Zoo in Salvador, Brazil	Ferreira et al. 2014, Martins et al. 2019
		Enterobacter sp.	*E. murinus*	Mouth, skin	Uberlândia, Brazil; Zoo in Salvador, Brazil	Ferreira et al. 2014, Martins et al. 2019
		Klebsiella pneumonae (Schroeter 1886) Trevisan 1887	*E. murinus*	Skin	Zoo in Salvador, Brazil	Ferreira et al. 2014
		Salmonella sp.	*E. murinus*	Skin	Zoo in Salvador, Brazil	Ferreira et al. 2014
	Morganellaceae	*Morganella morganii* Winslow et al. 1919, Fulton, 1943, Brenner et al. 1978	*E. murinus*	Blood	Zoo in New York, United States of America	McNamara et al. 1994
		Proteus mirabilis Hauser 1885	*E. notaeus*	Muscles, skin	Zoo in Sorocaba, Brazil	Veinert et al. 1983
		Providencia rettgeri Rettger 1904	*E. murinus*	Coelomic cavity, intestine, liver, lungs, and skin	Zoo in Georgia	Miller et al. 2004
	Moraxellaceae	*Acinetobacter* sp.	*E. murinus*	Coelomic cavity, intestine, liver, lungs, and skin	Zoo in Salvador, Brazil	Ferreira et al. 2014
	Pseudomonadaceae	*Pseudomonas aeruginosa* (Schröter 1872) Migula 1900	*E. murinus*	Liver, lungs	Zoo in Salvador, Brazil	Ferreira et al. 2014
Leptospirae	Leptospiraceae	*Leptospira interrogans* (Stimson 1907) Wenyon 1926	*E. murinus*	Blood	Llanos, Venezuela	Calle et al. 2001
VIRUS						
Monjiviricetes	Paramyxoviridae	Anaconda Paramyxovirus (AnaPV)	*E. murinus*	Kidneys, liver, lungs, pancreas, stomach	Zoo in Hong Kong	Woo et al. 2014

2019, Stanley et al. 2020, Eisen & Paddock 2021). This issue became especially problematic at this time due a continued rise and geographical spread of ticks and tick-borne diseases in some regions (Sonenshine 2018, Rosenberg et al. 2018), in addition to the large trade and smuggling of living reptiles around the world (Burridge & Simmons 2003, Stringham et al. 2021) and relocation events (pers. obs.).

In Neotropics, ticks of the genus *Amblyomma* are often reported parasitizing snakes of the families Boidae (Calle et al. 1994, Brum & Rickes 2003, Dantas-Torres et al. 2008, Carrascal et al. 2009, Pontes et al. 2009, Ogrzewalska et al. 2019), Colubridae (Pontes et al. 2009), Dipsadidae (Pontes et al. 2009, Ogrzewalska et al. 2019), Elapidae (Pontes et al. 2009, Ogrzewalska et al. 2019), and Viperidae (Dantas-Torres et al. 2005, Pontes et al. 2009, Ogrzewalska et al. 2019). The anaconda specimen MPEG 18511 is remarkable in our records because it was collected in the urban area of Belém, Pará State, Brazil. For this same Amazonian city, the infestation of *A. dissimile* was reported on *Boa constrictor* Linnaeus 1758 (Ogrzewalska et al. 2019). It highlights the demand for more studies on the snakes inhabiting Brazilian cities and their ecological and epidemiological roles. The presence of *A. dissimile* and *A. rotundatum* hosting on wild and captive *E. deschauenseei* represents the first parasitism report to this rare and poorly known anaconda species and the first step to elucidate traits of its ecology and health.

In the absence of data on the microbiota, hematological and parasitic profiles of the species, it is not possible to measure the health implications of habitat anthropization, as well as for the prevention of diseases disseminated by traded animals worldwide (Fèvre et al. 2006, Travis et al. 2011, Lentz et al. 2016) and during relocations (Viggers et al. 1993, Mathews et al. 2006). It was highlighted that anacondas caught in the wild and exported to Georgia were infected with several fungi species (Miller et al. 2004), and anacondas exported from Japan to Hong Kong were infected with a new virus lineage (Woo et al. 2014), attesting to the importance of monitoring the sanity of anacondas.

Characterizing the microbiota of anacondas is extremely important to establish appropriate therapeutic measures in cases of accidents involving humans (Silva et al. 2009). Directing the treatment and prevention of diseases caused by these agents in anacondas kept in

Figure 2. A wild anaconda (*E. murinus*) recorded in Rondônia State, Brazil, with two ticks on the snout. Photo courtesy of Carlos Tuyama.

captivity or even in eventual epidemics in wild populations is also essential. Anacondas host a wide diversity of dermal fungi and oral bacteria. Fungal snake disease represents an emerging threat to wild snakes (Lorch et al. 2016), and can be lethal to reptiles (Miller et al. 2004). However, fungal diseases are usually secondary to other pathogens or predisposing factors, such as stress and undernutrition (McNamara et al. 1994, Miller et al. 2004, Severo et al. 2010).

By preying on rodents (Miranda et al. 2017, Camera et al. 2019), anacondas can control the spread of pests, but anacondas can also be natural reservoirs of *Leptospira* (Faine et al. 1999, Calle et al. 2001). *Leptospira interrogans* was detected on *Boa constrictor* syntopic with *E. murinus*, in Salvador, Brazil (Rodamilans et al. 2020). Leptospirosis is among the most common zoonosis in the world (Costa et al. 2015) and Brazil has a significant incidence of this disease in humans (Santos et al. 2017). Withal, multiresistant bacterial lineages on *E. murinus* (Ferreira et al. 2014) highlight the importance of health monitoring on wild and captive anacondas. In this study, our tests for pathogens, focusing on *Rickettsia*, were negative. The low number of ticks tested can explain it, and/or the low bacteremia found on these ticks.

The integration of landscape ecology with epidemiology is crucial to better understand the interactions between vectors, hosts, potential reservoirs, and transmission (Ostfeld et al. 2005). Since the parasite load is positively related to urbanization (Davis et al. 2012), the high occurrence of anacondas in urban areas (pers. obs.) represents a fortuitous opportunity for parasites sampling (see Fiorini et al. 2014), as well as to assess their health status and prevent the spread of plague during the relocating individuals. Long-term population-level studies with urban anacondas can elucidate whether parasitism or a combination of parasitism and the possible secondary stress of urbanization affects host fitness in anacondas inhabiting urban environments. Furthermore, collecting parasitological data on these sizeable predator snakes in cities can help us to identify areas with higher parasite loads, determine and predict parasite prevalence, and investigate landscape variables that influence parasite prevalence and transmission.

Acknowledgments

We thank all the curators of the collections for allowing the examination of the specimens: IBSP - Felipe G. Grazziotin, Valdir Germano; MHNCI - Julio C. M. Leite; MNRJ - Manoela W. Cardoso, Paulo Passos, Pedro Pinna; MZUSP - Hussam E. D. Zaher; PUCRS - Carlos A. S. Lucena, Juliano Romanzini; UEFS - Dulcinéia F. Andrade, Ilka B. Biondi; UESC - Antônio J. S. Argôlo; UFBA - Rejane M. L. Silva, Catharina Ma; UFC - Robson W. Ávila; UFMS - Diego J. Santana, Liliana Piatti; UFMT - Felipe F. Curcio. We thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for scholarship (BFC process CNPq 140630/2020-1 and CNPq 200753/2022-3). This work was supported by CNPq (ALCP process 302611/2018-5, PROTAX 441462/2020–0; FCJ process CNPq 402575/2021-0); by Fundação de Amparo à Pesquisa do Estado de São Paulo (FCJ process FAPESP 2019/19853-0 and 2024/01231-0, IPP process FAPESP 2022/11576-0 and RBS process FAPESP 2020/11755-6); and by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. We thank GR de Andrade and MCF do Rosário from the Laboratório de Coleções Zoológicas, Instituto Butantan, for technical contribution.

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How to cite

CAMERA BF, PRUDENTE ALC, PESENATO IP, BASSINI-SILVA R & JACINAVICIUS FC. 2025. Living in big houses: the role of parasitism on anacondas (Boidae: *Eunectes*), with new records, parasites catalog, and assessment perspectives. An Acad Bras Cienc 97: e20240499. DOI 10.1590/0001-3765202520240499.

Manuscript received on May 15, 2024;
accepted for publication on March 29, 2025

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