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ORIGINAL ARTICLE / ARTÍCULO ORIGINAL

DIVERSITY OF METAZOAN ENDOPARASITES ASSOCIATED WITH LIZARDS (SQUAMATA, LACERTILIA) IN THREE PROTECTED AREAS AND THEIR SURROUNDING ZONES IN NORTHEASTERN BRAZIL

DIVERSIDAD DE ENDOPARÁSITOS METAZOARIOS ASOCIADOS A LAGARTIJAS (SQUAMATA, LACERTILIA) EN TRES UNIDADES DE CONSERVACIÓN Y ÁREAS ALEDAÑAS EN EL NORDESTE DE BRASIL

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ABSTRACT

The Neotropical region harbors a rich reptile biodiversity, especially lizards. However, research on parasite richness in Brazilian lizards still has many gaps. Parasites play a crucial role in ecosystems, and accurate studies are necessary to describe their richness and species composition. Habitat fragmentation caused by human activities threatens biodiversity, including parasites. In this context, protected areas play a fundamental role in biodiversity conservation. We aim to describe the diversity of metazoan endoparasites (helminths and pentastomids) in lizards within three protected areas in Northeast Brazil: Aiuaba Ecological Station (Caatinga), Sete Cidades National Park (Cerrado), and Ubajara National Park (Highland marsh and Caatinga), including surrounding areas. We collected 690 lizards representing 23 species. We recorded 34 parasite taxa, including nematodes (28), trematodes (2), cestodes (2), acanthocephalans (1), and pentastomids (1). Among them, we recorded parasites commonly associated with lizards, such as *Strongyluris oscari*, and rare parasites, such as *Brevimulticaecum* sp. and *Typhlonema* sp. We also observed the presence of trematodes exclusively in highland marsh areas. This study contributes to understanding lizard parasitism in the Neotropical region, presenting 21 new infection records. Additionally, it suggests that trematodes may be related to environmental humidity, emphasizing the importance of faunal surveys for parasite diversity.

Keywords: faunal survey – Helminths – Pentastomida

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RESUMEN

La región Neotropical alberga una rica biodiversidad de reptiles, especialmente lagartijas. Sin embargo, la investigación sobre la riqueza de parásitos en lagartijas brasileñas todavía tiene muchas lagunas. Los parásitos desempeñan un papel crucial en los ecosistemas, y son necesarios estudios precisos para describir su riqueza y composición de especies. La fragmentación del hábitat causada por actividades humanas amenaza la biodiversidad, incluidos los parásitos. En este contexto, las áreas protegidas desempeñan un papel fundamental en la conservación de la biodiversidad. Nuestro objetivo es describir la diversidad de endoparásitos metazoarios (helmintos y pentastomátidos) en lagartijas dentro de tres áreas protegidas en el noreste de Brasil: la Estación Ecológica de Aiuaba (Caatinga), el Parque Nacional de Sete Cidades (Cerrado) y el Parque Nacional de Ubajara (Brejo de altitud y Caatinga), incluidas las áreas circundantes. Recolectamos 690 lagartijas representando 23 especies. Registramos 34 taxones de parásitos, incluyendo nematodos (28), trematodos (2), cestodos (2), acantocéfalos (1) y pentastomátidos (1). Entre ellos, registramos parásitos comúnmente asociados con lagartijas, como *Strongyluris oscari*, y parásitos raros, como *Brevimulticaecum* sp. y *Typhlonema* sp. También observamos la presencia de trematodos exclusivamente en áreas de brejo de altitud. Este estudio contribuye a comprender el parasitismo en lagartijas en la región Neotropical, presentando 21 nuevos registros de infección. Además, sugiere que los trematodos pueden estar relacionados con la humedad ambiental, enfatizando la importancia de los estudios faunísticos para la diversidad de parásitos.

Palabras clave: Helmintos– levantamiento faunístico – Pentastomida

INTRODUCTION

The Neotropical region is one of the most biodiverse on the planet, with Brazil being a biodiversity hotspot whiting ecosystems supporting a vast array of plant and animal species, many of which are endemic (Myers *et al.*, 2000; Zachos & Habel, 2011; Antonelli, 2022). It harbors the third-largest richness of reptile species globally, and the Northeast region is the second richest in the country, hosting 413 species and subspecies, including 137 lizard species (Squamata, Lacertilia) (Guedes *et al.*, 2023). However, only 56 lizard species in the region (approximately 40%) have been investigated in parasitological studies (Lacerda *et al.*, 2023).

Considering that parasites are important components of ecosystems and exhibit great diversity (Poulin & Morand, 2000), taxonomic studies, geographic distribution analyses, and host interaction investigations are crucial (Poulin & Mouillot, 2003; Bozick & Real, 2015). To better explore this diversity, accurate identifications are essential to avoid underestimating parasite richness (Poulin, 2019). Thus, with the application of modern microscopy techniques, faunal surveys contribute to redescriptions and the discovery of new species (Macedo *et al.*, 2023). However, there is an estimated 75,000 to 300,000 species of helminths parasitizing vertebrates, and up to 33% of these may be at risk of extinction (Dobson *et al.*, 2008; Carlson *et al.*, 2017).

Among the primary threats to biodiversity are human activities, with habitat fragmentation caused by agricultural practices affecting organisms from microorganisms to large vertebrates (Ellis *et al.*, 2010; Christian, 2023). This fragmentation can lead to both immediate species loss and subsequent extinctions, impacting species distribution patterns and community composition due to environmental changes (Krauss *et al.*, 2010). For parasitic helminths, these disturbances can influence the structure and composition of communities, with factors such as abundance, prevalence, and intensity susceptible to interference (Cardoso *et al.*, 2016; Carlson *et al.*, 2017; Portela *et al.*, 2020).

In this context, protected areas play a crucial role in species preservation, serving as biodiversity refuges (Llorente-Culebras *et al.*, 2021; Li *et al.*, 2022). These areas can act as repositories of taxonomic, genetic, and functional diversity for the surrounding areas. Therefore, investigating the biodiversity associated with conservation areas and their surroundings can provide valuable insights into local biodiversity. In Brazil, fully protected areas are a primary means of biodiversity conservation, including national parks, ecological stations, natural monuments, and wildlife refuges. In the Northeastern region, there are 26 fully protected areas covering different types of native vegetation, such as Caatinga, Cerrado, and Highland marshes.

Considering this, studies conducted in protected areas and their surroundings, encompassing faunal surveys, including parasitological assessments, are valuable, as they can unveil rich biodiversity. These studies are also significant for reinforcing the importance of protected areas in safeguarding native species and their ecological relationships. The objective of this study was to describe the richness of metazoan endoparasite species (helminths and Pentastomida) associated with lizards in three protected areas and their surrounding zones in Brazilian northeast.

MATERIAL AND METHODS

Study areas

Field sampling comprised three protected areas (PAs) in northeastern Brazil and their surroundings (Fig. 1). The Aiuaba Ecological Station (AES), covering an area of 11,746.60 ha, is situated in the southern part of the state of Ceará in the municipality of Aiuaba (6°36' to 6°44' S - 40°07' to 40°19' W). This area features a hot-semiarid tropical climate, an average annual rainfall of 568.4 mm, and an average temperature ranging from 24 to 26°C. The predominant vegetation in the ecological station is caatinga stricto sensu, with its interior well-preserved, encompassing 81% of its total area covered by conserved vegetation (Araújo *et al.*, 2017).

The Sete Cidades National Park (SCNP, 4°06'58.8"S 41°43'41.8"W), located in the state of Piauí, between the municipalities of Piracuruca and Brasileira, in a Cerrado stricto sensu area, covers approximately 6,221 ha. It experiences a tropical semi humid dry climate, with an average annual precipitation ranging from 1,300 mm to 1,500 mm and an annual average temperature of 28.8°C, with minimums of 23.2°C and maximums of 36.0°C according National Institute of Meteorology (Castro & Costa, 2007; INMET, 2024).

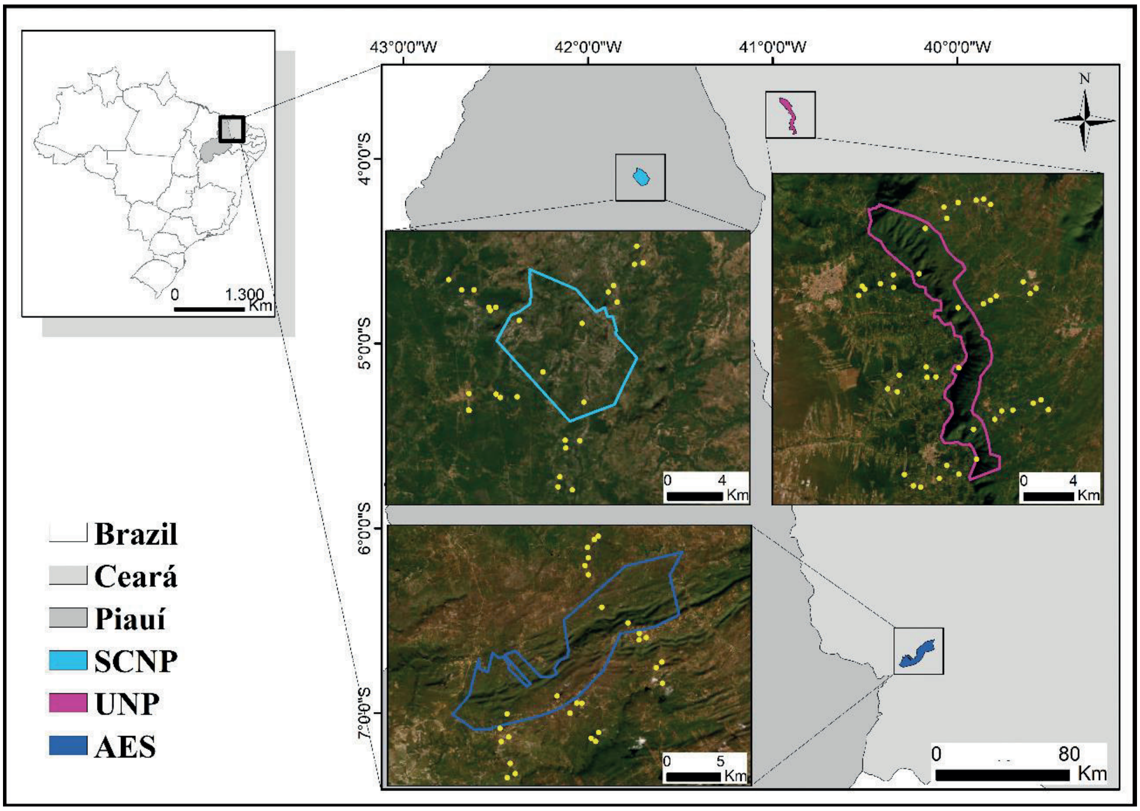

Figure 1. Schematic map illustrating protected areas with highlighted sample points in yellow. Legend: SCNP: Sete Cidades National Park, UNP: Ubajara National Park, and AES: Aiuaba Ecological Station.

Ubajara National Park (UNP, 3°50'31.2"S 40°54'00.5"W), also in the state of Ceará, is in an area that encompasses zones of caatinga stricto sensu and relictual moist forest zones, also known as highland marsh. The park covers 6,288 ha and is situated in the northwest portion of the state of Ceará in the Ibiapaba Plateau, spanning three municipalities: Frecheirinha, Tianguá, and Ubajara. The annual rainfall reaches 1,483.5 mm, with average temperatures ranging between 24 and 26°C.

Sample design and host collection

Lizard sampling were conducted from 2018 to 2020, covering both dry and rainy seasons, except in 2020 when collections were exclusively performed during the rainy period. During the expeditions, visual encounter surveys were carried out, exploring all possible microhabitats used by lizards (Bernarde, 2012). Hosts were manually collected during daytime from 8:00 to 17:00. The total sample effort in hours amounted to 1,110 h, calculated by summing the number of hours in the field multiplied by the number of researchers conducting searches on each expedition. The distribution of sampling points followed the methodology of Brasileiro *et al.* (2023). The lizards were euthanized following the ethical procedures of the Federal Council of Veterinary Medicine – CFMV (2013) with lidocaine hydrochloride 60 mg/kg, preserved in 70% ethanol, and subsequently cataloged in the Herpetological Collection of the Federal University of Ceará.

Collection and Processing of Parasites

After necropsy with a longitudinal anteroposterior ventral incision, the hosts had their coelomic cavity, lungs, stomach, intestines, and accessory organs of the digestive system examined for parasites. When hosts were necropsied fresh and parasites were found, they were fixed in boiling 70% ethanol and preserved in the same solution for subsequent analyses. Due to the number of collected hosts, some could not be necropsied immediately after collection and were fixed as described earlier. In these cases, necropsies were subsequently conducted, and the parasites were stored in 70% ethanol.

The nematodes, acanthocephalans, and Pentastomida collected were clarified using a lactic acid solution (Andrade, 2000). Platyhelminths were colored using the carmine technique (Amato & Amato, 2010), diaphanized with eugenol oil, and mounted on temporary slides for taxonomic identification. Identification was based on the observation, counting, and morphometry of taxonomic characters according to relevant literature (Araújo & Gandra, 1941; Lucker, 1943; Rêgo & Ibáñez, 1965; Rego, 1983; Vicente *et al.*, 1993; Almeida *et al.*, 2008; Anderson *et al.*, 2009; Bursey *et al.*, 2010; Fernades & Kohn, 2014; Pereira *et al.*, 2017; Vieira *et al.*, 2020; De Sousa *et al.*, 2022). Parasitological descriptors of mean abundance, infection range, and infection intensity followed by standard error, and prevalence in percentage was calculated according to Bush *et al.* (1997). After identification, all parasites were deposited in the Parasitological Collection of the Federal University of Ceará

Ethics aspects: All procedures used in this work follow the ethical standards of the relevant national and institutional guides on the care and use of laboratory animals. Collection permit Instituto Chico Mendes de Conservação da Biodiversidade - ICMBio (process n° 68 031–1 and n° 72 762) and the Ethics Committee on Animal Use of the Federal University of Ceará (CEUA-UFC) (#CEUA 6314010321).

RESULTS

A total of 690 hosts were collected, distributed across 23 lizard species, with 237 at Aiuaba Ecological Station (AES, 10 spp.), 239 at Sete Cidades National P\ark (SCNP, 14 spp.), and 214 at Ubajara National Park (UNP, 18 spp.). Among these, parasitic infections were documented in 20 species, except for *Copeoglossum nigropunctatum* Spix, 1825, *Colobosaura modesta* Reinhardt and Lütken, 1862, and *Vanzosaura multiscutata* Amaral, 1933. Regarding hosts, the largest sample size was for *Ameivula pyrrhogularis* Silva and Avila-Pires, 2013 (AES: 67, SCNP: 60, and UNP: 36), and *Tropidurus hispidus* Spix, 1825 (AES: 67, SCNP: 49, and UNP: 66), which are also the species with the highest recorded parasitic richness (Table 1).

The total abundance of parasite individuals was 21,289.00. Specific-level identification was not possible in some cases due to the difficulty in visualizing important morphological characters or due to the ontogenetic developmental stage. In these cases, a more conservative approach was adopted, and a higher taxonomic level was recorded. Therefore, the richness of recorded parasite taxa in this study was 34 taxonomic groups (24 at the specific level, seven at the genus level, two at the family level, and one at the phylum level), with 11 for AES, 24 for SCNP, and 25 for UNP (Table 1).

From the records made in this study, 21 are new infection records for the host species. Sete Cidades National Park (SCNP) had the highest number of new records (13), followed by Ubajara National Park (UNP) with seven and Aiuaba Ecological Station (AES) with one (Table 1). For Ameivula pyrrhogularis, six new records were documented, five in SCNP (*Brevimulticaecum* sp., *Capillaria freitaslenti* Araujo & Gandra, 1941, *Cruzia lauroi* Vieira *et al.*, 2020, *Falcaustra* sp., *Spinicauda*

spinicauda Olfers, 1819 and one in UNP (*Pharyngodon travassosi* Pereira, 1935), making it the host species with the highest number of new records. In the UNP, a single individual of *Typhlonema* sp. infecting *Norops fuscoauratus* d'Orbigny, 1837, was recorded. This was also the only area where the trematodes *Mesocoelium monas* Rudolphi, 1819, and *Paradistomum parvissimum* Travassos, 1918, were registered, occurring only at collection points within the protected area and infecting *Coleodactylus meridionalis* Boulenger, 1888, *Norops fuscoauratus*, *Enyalius bibronii*, *Tropidurus hispidus*, and *Tropidurus semitaeniatus* Spix, 1825.

Table 1. Helminths and Pentastomida associated with lizards (Squamata, Lacertilia) in Aiuaba Ecological Station, Sete Cidades National Park, Ubajara National Park and their surroundings, including the number of examined hosts (N) and parasite taxa, along with total abundance (A), mean abundance (MA) ± standard error (SE), infection range (IR), prevalence in percentage (P%), mean infection intensity (MII) ± standard error (SE), and the life cycle of the parasite, whether monoxenous (M) or heteroxenous (H). New parasitism records are indicated with "*".

Host species	N	Parasite taxon	A	MA ± SE	AP	P%	MII ±SE	Life cycle
Aiuaba Ecological Station								
Ameivula pyrrhogularis Silva & Avila-Pires, 2013	67							
		Acanthocephala						
		Unidentified Cystacanth	2	–	2	1.49	–	M
		Cestoda						
		Oochoristica travassosi Rêgo & Ibáñez, 1965	1	–	1	1.59	–	H
		Nematoda						
		Pharyngodon cesarpintoi Pereira, 1935	693	10.34±3.65	1–165	38.80	26.65±8.55	M
		Strongyluris oscari Travassos, 1923	21	–	1–20	2.99	–	M
Gymnodactylus geckoides Spix, 1825	15							
		Nematoda						
		Parapharyngodon largitor Alho & Rodrigues, 1963	23	1.53±0.49	1–5	53.33	2.87±0.58	M
Hemidactylus agrius Vanzolini, 1978	1	Not parasitized						
Hemidactylus brasilianus Amaral, 1935	17							
		Nematoda						
		Parapharyngodon alvarengai Freitas, 1957	1	–	1	0.06	–	M
		Skrjabinellazia galliardi Chabaud, 1973*	1	–	1	0.06	–	H
		Spauligodon oxkutzcabiensis Chitwood, 1938	94	–	22–72	11.76	–	M
Lygodactylus klugei Smith, Martin & Swain, 1977	8							
		Nematoda						
		Spauligodon oxkutzcabiensis	1	–	1	16,77	–	M

(Continued Table 1)

(Continued Table 1)

Phyllopezus pollicaris Spix, 1825	13							
		Nematoda						
		Pharyngodon cesarpintoi	24	–	24	7,69	–	M
		Spauligodon oxkutzcabiensis	259	19.92±7.47	5–96	69.23	28.78±9.44	M
Tropidurus hispidus Spix, 1825	74							
		Acanthocephala						
		Unidentified cystacanth	3	–	3	1.35	–	H
		Cestoda						
		Oochoristica travassosi	3	0.04±0.02	1	4.05	1±0	H
		Nematoda						
		Ascarididae	1	–	1	1.35	–	M
		Cosmocercidae	1	–	1	1.35	–	M
		Parapharyngodon largitor	97	1.31±0.31	1–15	37.84	3.46±0.62	M
		Pharyngodon cesarpintoi	9	–	1–8	2.70	–	M
		Physaloptera lutzi Cristofaro, Guimarães & Rodrigues, 1976	207	2.78±0.51	1–16	56.76	4.92±0.75	H
		Skrjabinellazia galliardi	3	–	3	1.35	–	H
		Strongyluris oscari	55	0.74±0.30	1–15	16.21	4.48±1.48	M
Tropidurus jaguaribanus Passos, Lima & Borges-Nojosa, 2011	15							
		Acanthocephala						
		Unidentified cystacanth	1	–	1	6.67	–	H
		Nematoda						
		Parapharyngodon largitor	38	2.53±1.62	5–23	20	12.67±5.36	M
		Physaloptera lutzi	35	2.33±1.91	1–29	33.33	7±5.50	H
		Strongyluris oscari	78	5.2±2.30	2–29	40	13±4.10	M
Vanzosaura multiscutata Amaral, 1933	4	Not parasitized						

Sete Cidades National Park

Host species	N	Parasite taxon	A	AM ± EP	AP	P%	IM±EP	Life cycle
Ameiva ameiva Linnaeus, 1758	5							
		Nematoda						
		Capillaria freitaslenti Araujo & Gandra, 1941	18	–	18	20	–	M
		Spinicauda spinicauda Olfers, 1819*	3	–	3	20	–	M
		Parapharyngodon sceleratus Travassos, 1923*	1	–	1	20	–	M
Ameivula pyrrhogularis	60							
		Acanthocephala						
		Unidentified cystacanth	28	0.46±0.29	1–16	8.20	5.6±2.91	H

(Continued Table 1)

(Continued Table 1)

		Cestoda						
		Oochoristica vanzolinni Rêgo & Rodrigues, 1965	7	–	7	1.64	–	H
		Nematoda						
		Brevimulticaecum sp.*	1	–	1	1.64	–	H
		*Capillaria freitaslenti**	36	0.59±0.34	1–18	8.19	7.2–3.22	M
		Cruzia lauroi Vieira *et al.* 2020	5	–	5	1.64	–	H
		Falcaustra sp.*	5	–	5	1.64	–	H
		Pharyngodon travassosi Pereira, 1935*	311	5.09±2.64	1–132	11.47	44.43–17.77	M
		Piratuba sp.	4	–	1–3	3.28	–	
		*Spinicauda spinicauda**	3	–	3	1.64	–	M
Brasilisincus heathi Schmidt & Inger, 1951	7							
		Nematoda						
		Oswaldocruzia sp.	2	–	2	14.28	–	M
		Parapharyngodon sceleratus *	1	–	1	14.28	–	M
		Strongyloides sp.*	10	–	10	14.28	–	M
		Strongyluris oscari *	1	–	1	14.28	–	M
Colobosaura modesta Reinhardt & Lütken, 1862	1	Not parasitized						
Hemidactylus agrius	43							
		Acanthocephala						
		Unidentified cystacanth	3	0.07±0.04	1	6.98	1±0	H
		Nematoda						
		Parapharyngodon largitor	16	0.37±0.16	1–5	13.95	2.67±0.56	M
		Physaloptera lutzi	1	–	1	2.33	–	H
		*Strongyluris oscari**	1	–	1	2.33	–	M
		Pentastomida						
		Raillietiela mottae Almeida & Lopes, 2008	1	–	1	2.33	–	H
Hemidactylus mabouia Moreau de Jonnès, 1818	1							
		Acanthocephala						
		Unidentified cystacanth	1	–	1	100	–	
Iguana iguana Linnaeus, 1758	1							
		Nematoda						
		Alaeuris vogelsangi Lent & Freitas, 1948	19	–	19	100	–	M
Micrablepharus maximiliani Reinhardt & Lütken, 1862	14							
		Acanthocephala						
		Unidentified cystacanth	2	–	2	7.14	–	H
		Nematoda						
		Physalopteroides venancioi Lent, Freitas & Proença, 1946 *	2	–	2	7.14	–	H

(Continued Table 1)

(Continued Table 1)

		*Skrjabinodon campia*oae De Sousa, Silva De Oliveira, Morais, Da Silva Pinheiro & Ávila*	6	0.07±0.07	2	21.42	2±2	M
Phyllopezus pollicaris	7							
		Nematoda						
		Parapharyngodon largitor	7	1±0.69	1–5	42.86	2.33±0.69	M
		Spauligodon oxkutzcabiensis	44	6.29±5.17	2–37	42.86	14.67±5.17	M
Polychrus acutirostris Spix, 1825	1	Not parasitized						
Tropidurus hispidus	49							
		Acanthocephala						
		Unidentified cystacanth	2	–	1	4.08	–	H
		Cestoda						
		Oochoristica travassosi	2	–	2	2.04	–	H
		Nematoda						
		Falcaustra sp.	7	–	2–5	4.08	–	H
		Parapharyngodon alvarengai	26	–	7–19	4.08	–	M
		Parapharyngodon largitor	18	0.37±0.12	1–3	18.37	2±0.24	M
		Parapharyngodon sceleratus	34	0.70±0.40	3–18	10.20	6.08±2.85	M
		Physaloptera lutzi	90	1.84±1.56	1–56	20.41	9±5.27	H
		Piratuba sp.	5	–	5	2.04	–	H
		Strongyloides sp.	3	–	1–2	4.08	–	M
		Strongyluris oscari	70	1.42±0.44	1–13	30.61	4.67±1.05	M
Tropidurus semitaeniatus Spix, 1825	48							
		Acanthocephala						
		Unidentified cystacanth	5	–	1–4	4.17	–	H
		Nematoda						
		*Capillaria freitaslenti**	7	–	3–4	4.17	–	M
		Parapharyngodon alvarengai	41	0.85±0.46	2–18	10.41	8.2±2.97	M
		Parapharyngodon largitor	15	0.31±0.13	2–4	10.42	3±0.32	M
		Parapharyngodon sceleratus	2	–	2	2.08	–	M
		Physaloptera lutzi	2	–	2	2.08	–	H
		Physaloptera retusa Rudolphi, 1819	1	–	1	2.08	–	H
		Rhabdias sp.	6	–	6	2.08	–	H
		Strongyluris oscari	22	0.46±0.15	1–4	20.83	2.2±0.4	M
Ubajara National Park								
Host species	**N**	**Parasite taxon**	**A**	**AM ± EP**	**AP**	**P%**	**IM±EP**	**Life cycle**
Ameiva ameiva	5							
		Nematoda						
		Cosmocercidae	27	–	27	20	–	M
		Pharyngodon cesarpintoi	22	–	22	20	–	M
		Pharyngodon travassosi	3	–	3	20	–	M
		Physaloptera lutzi	1	–	1	20	–	H
		Physaloptera retusa	5	–	4–5	20	–	H
		Skrjabinellazia galliardi	1	–	1	20	–	H

(Continued Table 1)

(Continued Table 1)

Ameivula pyrrhogularis	36							
		Cestoda						
		Oochoristica travassosi	1	–	1	2.78	–	H
		Nematoda						
		Pharyngodon cesarpintoi	50	1.38±0.92	9–31	8.33	16.67±7.17	H
		*Pharyngodon travassosi**	1	–	1	2.78	–	H
Brasilisincus heathi	17							
		Acanthocephala						
		Unidentified cystacanth	14	–	3–11	11.76	–	H
		Cestoda						
		Oochoristica vanzolinni	6	–	6	5.88	–	H
		Nematoda						
		Strongyluris oscari	2	–	2	5.88	–	M
Coleodactylus meridionalis Boulenger, 1888	16							
		Acanthocephala						
		Unidentified cystacanth	2	–	1	12.5	–	H
		Trematoda						
		Mesocoelium monas Rudolphi, 1819	8	0.50±0.38	1–6	18.75	2.67±1.67	H
		Cestoda						
		Oochoristica vanzolinni	3	–	3	6.25	–	H
Copeoglossum arajara Rebouças-Spieker, 1981	4							
		Nematoda						
		Rhabdias sp.	1	–	1	25	–	H
		Physaloptera Lutzi	1	–	1	25	–	
Copeoglossum nigropunctatum Spix, 1825	1	Not parasitized						
Enyalius bibronii Boulenger, 1885	6							
		Acanthocephala						
		Unidentified cystacanth *	1	–	1	16.64	–	H
		Trematoda						
		Mesocoelium monas	145	–	145	16.64	–	H
		Nematoda						
		Physaloptera sp. *	1	–	1	16.64	–	H
Hemidactylus agrius	18							
		Acanthocephala						
		Unidentified cystacanth	1	–	1	5.56	–	H
		Nematoda						
		Parapharyngodon alvarengai	1	–	1	5.56	–	M
		Parapharyngodon largitor	2	–	2	11.11	–	M
		Skrjabinellazia galliardi	9	–	1–7	16.67		H
Hemidactylus mabouia	8							
		Nematoda						
		Parapharyngodon largitor	3	–	3	25	–	M

(Continued Table 1)

(Continued Table 1)

		Physaloptera sp.	1	–	1	12.50	–	
Iguana iguana	2							
		Nematoda						
		Alaeuris vogelsangi	2756	–	2756	50	–	M
		*Capillaria freitaslenti**	1	–	1	50	–	M
		Cosmocercidae	18	–	18	50	–	M
		Ozolaimus cirratus Linstow, 1906	1935	–	1935	50	–	M
Lygodactylus klugei	1	Not parasitized						--
Micrablepharus maximiliani	4	Not parasitized						
Norops fuscoauratus d'Orbigny, 1837	12							
		Trematoda						
		Mesocoelium monas	13	–	1–12	18.18	–	H
		Nematoda						
		Cosmocercidae	2	–	2	9.09	–	M
		Rhabdias sp.	1	–	1	9.09	–	H
		Typhlonema sp.*	1	–	1	9.09	–	M
Phyllopezus pollicaris	1							
		Nematoda						
		Spauligodon oxkutzcabiensis	6	–	6	100	–	
Polychrus acutirostris	2							
		Nematoda						
		Gynaecometra bahienses Araujo, 1978	13005	–	13005	50	–	M
Salvator merianae Duméril & Bibron, 1839	2							
		Nematoda						
		Cruzia lauroi	46	–	46	50	–	H
		Diaphanocephalus galeatus Rudolphi, 1819	128	–	17–111	100	–	M
		Physaloptera retusa	4	–	4	50	–	H
Tropidurus hispidus	66							
		Acanthocephala						
		Unidentified cystacanth	14	0.21±0.15	1–10	4.55	4.67±2.73	H
		Trematoda						
		Mesocoelium monas	1	–	1	1.52	–	H
		Paradistomum parvissimum Travassos, 1918	5	–	5	1.51	–	H
		Cestoda						
		Oochoristica travassosi	2	–	2	1.52	–	H
		Nematoda						
		Oswaldocruzia sp.	24	0.36±0.16	1–9	15.15	2.04±0.78	M
		Parapharyngodon largitor	138	2.09±0.53	1–27	39.39	5.30±1.10	M

(Continued Table 1)

(Continued Table 1)

		Physaloptera lutzi	175	2.65±0.81	1–40	39.39	6.73±1.79	H
		Rhabdias sp.	5	0.07±0.05	1–3	4.54	1.67±0.67	H
		Spauligodon oxkutzcabiensis	15	–	15	1.52	–	M
		Strongyluris oscari	41	0.62±0.30	1–17	15.15	4.1–1.67	M
Tropidurus semitaeniatus	38							
		Acanthocephala						
		Unidentified cystacanth	3	0.16±0.10	1	2.63	–	H
		Trematoda						
		Mesocoelium monas	1	–	1	2.63	–	H
		Nematoda						
		Parapharyngodon alvarengai	2	–	2	5.26	–	M
		Parapharyngodon largitor	6	–	6	2.63	–	M
		Physaloptera lutzi	1	–	1	2.63	–	H
		*Physalopteroides venancioi**	9	–	2–9	5.26		H
		Skrjabinellazia galliardi	2	–	2	2.61	–	H
		Strongyluris oscari	75	1.97±1.23	1–43	21.05	9.36±4.37	M

DISCUSSION

In this study, 34 taxa of parasites were recorded, including Nematoda, Cestoda, Acanthocephala, and Pentastomida, infecting 20 species of lizards (Squamata, Lacertilia) with 21 new infection records. Aiuaba Ecological Station (AES) is one of the three protected areas studied, where most studies on lizard parasites have been conducted, thus, most of the records from this study had already been reported previously (see Brasileiro & Carvalho, 2023; Lacerda *et al.,* 2023). Among the three protected areas, Sete Cidades National Park (SCNP) is the least represented in the literature regarding studies on lizard parasites. Similarly, Ubajara National Park (UNP) is also underrepresented, with *Norops fuscoauratus* and *Tropidurus hispidus* being investigated for parasites in previous studies (Santos-Mesquita *et al.*, 2020; Brasileiro & Carvalho, 2023). As Protected areas represent the local fauna (Zachos & Habel, 2011), the low number of studies in these areas, coupled with the species of hosts not yet investigated for parasites, contributed to the increasing number of new parasitic records in SCNP and UNP compared to AES. The AES has been the focus of numerous studies on herpetological fauna and their parasites by research groups from nearby universities such as the Regional University of Cariri (URCA) and the Federal University of Cariri (UFCA). In comparison, SCNP and UNP have been relatively less explored by researchers studying parasites of reptiles and amphibians. However, with the rise in research centered on conservation units, the trend is for biodiversity records in these areas to increase as well, underscoring the importance of these regions for biodiversity protection.

With a total of 690 analyzed lizards distributed among 23 host species, the richness of parasites found can be explained by the richness of the hosts, their ecological aspects and also by the sample size, since the sampling effort is related to the richness of the species sampled (Guegan *et al.* 2007; Poulin, 2019). Hosts with more recorded parasite species, such as *T. hispidus*, exhibit generalist feeding habits and are well-distributed in the sampling locations (Kolodiuk *et al.*, 2009). The combination of these factors contributes to contact with different parasite species (Leung & Koprivnikar, 2019).

For the species *Colobosaura modesta*, *Copeoglossum nigropunctatum*, and *Vanzosaura multiscutata*, we did not record any parasitic infections in this study. Representatives of the family Gymnophthalmidae are characterized by fossorial and semifossorial habits, and for this reason, they are expected to be parasitized by helminths with heteroxenous life cycles, as discussed by Teixeira *et al.* (2018). For the family Scincidae, whose representatives exhibit intermediate foraging behavior, a rich parasitic fauna is expected, including both monoxenous and heteroxenous species (Cooper, 1995; Rocha *et al.*, 2003). In addition, in previous studies that included *C. nigropunctatum* and *V. multiscutata*, parasites such as *Physaloptera retusa* Rudolphi, 1819, and Cosmocercidae, *Parapharyngodon alvarengai* Freitas, 1957, *Pharyngodon cesarpintoi* Pereira, 1939, *Physaloptera lutzi* Cristofaro, Guimarães & Rodrigues, 1976, *Spauligodon oxkutzcabiensis* Chitwood, 1938, and *Skrjabinodon campiaoae* De Sousa, Silva De Oliveira, Morais, Da Silva Pinheiro & Ávila, 2022, respectively, were recorded (Araujo-Filho *et al.*, 2020; Teixeira *et al.*, 2020; Sousa *et al.*, 2022). The parasites found in the cited studies are commonly associated with lizards (Ávila & Silva, 2010; Lacerda *et al.*, 2023). For *C. modesta*, no records of parasitism were found up to the writing of this work. Therefore, we assume that low sample size may have contributed to this result.

Sete Cidades National Park (SCNP) had the highest number of new parasitism records. For the state of Piauí, where the park is located, only the species *Iguana iguana* Linnaeus, 1758, *T. hispidus*, *T. semitaeniatus*, and *Phyllopezus pollicaris* Spix, 1825, had been investigated for parasites in previous studies (Ávila *et al.*, 2012; Otávio *et al.*, 2018; Brasileiro & Carvalho, 2023). Most of the species analyzed in SCNP had already been the subject of parasitism studies in other locations in the country; however, the associated species were different (Ávila & Silva, 2010; Lacerda *et al.*, 2023). This park is located in a Cerrado stricto sensu area, and this ecoregion is considered an important biodiversity hotspot in Brazil (Zachos & Habel, 2011). Given this, as a rich biodiversity environment, the Cerrado can also harbor a great diversity of parasite species. Additionally, as understudied species are included in research, new data are obtained, and parasites not yet recorded for host species can be discovered.

The species with the highest number of new records was *A. pyrrhogularis*, the majority of which were parasites with a heteroxenous life cycle. Many parasites with this type of life cycle use arthropods as intermediate hosts (Anderson, 2000) and lizards of the genus *Ameivula* spp. has a diverse diet, including mainly arthropods and insect larvae, with active foraging habits (Mesquita & Colli, 2003ab). In an environment rich in biodiversity, ecological connections can become more complex, allowing for numerous interactions. This complexity may lead to more parasite species utilizing a variety of species as intermediate hosts, thereby increasing their success in reaching their final hosts (Poulin, 2014). This richness may have contributed to the number of new records in this study area, given that arthropods are part of the diet of several lizard species. Additionally, *A. pyrrhogularis* had been included in previous research, however, the growing number of new infection records highlights significant gaps in our comprehension of lizard parasitism.

It was also recorded for *A. pyrrhogularis,* a specimen of the genus *Brevimulticaecum* Mozgovoi, 1951, constituting the first record for lizards. Nematodes of the genus *Brevimulticaecum* spp. are more commonly associated, in their adult forms, with freshwater fish and crocodilians. However, records of larval forms have been made in amphibians and a species of snake (Moravec *et al.*, 1994; Anderson, 2000). Studies suggest that the larval forms in amphibians may play a role in the life cycle, aiming for final infection in crocodilians (González & Hamann, 2013). The infection in *A. pyrrhogularis* may have occurred through the ingestion of a larval form, as this lizard species has a broad diet, including both adult and larval arthropods, and the diet may be directly related to the parasitic fauna (Silva *et al.*, 2019). It has been documented that parasites of this genus can cause intestinal lesions in definitive hosts (Cardoso *et al.*, 2013). With the record of *Brevimulticaecum* sp. in the sampled locality, a more detailed examination of the biodiversity that may be involved in the life cycle of this parasite becomes important.

The records of Trematoda (*Mesocoelium monas* and *Paradistomum parvissimum*) were made only in the Ubajara National Park (UNP). Among the three protected areas, UNP has the highest average annual precipitation and the lowest average temperature (1,436.32 mm and 22–26 °C). Environmental conditions may be related to the prevalence of certain groups of parasites (Dybing *et al.*, 2013). Given this and knowing that trematodes have a heteroxenous life cycle, the presence of parasites with this life cycle in more humid environments may be related to the higher survival of their infective larval forms or eggs (Stromberg, 1997; Dybing *et al.*, 2013; Bolek *et al.,* 2019). Additionally, their intermediate hosts, commonly arthropods or small mollusks, are also present in more humid environments (Dronen *et al.*, 2012). Supporting this idea, the literature shows that the presence of reptile-parasitic trematodes is associated with more humid environments, such as the coast, wet forests, collection points near water bodies, or aquatic animals (see checklist collection points in Lacerda *et al.*, 2023). The presence of these parasites only in preserved areas (collection sites within protected areas) may be a sign of how human activities affect biodiversity. As observed by Brasileiro & Carvalho (2023), agriculture affects the richness and abundance of parasites with heteroxenous life cycles, including trematodes.

Another parasite found in Ubajara National Park (UNP) was a specimen of the genus *Typhlonema* Kreis, 1938. This is a genus whose males seem to be unknown except for *Typhlonema salomonis* Kreis, 1938 (Lucker, 1943). They are typically parasites of lizards, and identification is performed through females, with one of the main characteristics being the highly muscular vulva in a prebulbar position and the anus at the end of the body, along with eggs having thick shells (Vicente *et al.*, 1993; Anderson, 2000). In previous studies, they have been recorded parasitizing the intestine of lizards in Brazil, but this is the first record for *Norops fuscoauratus* (Ávila & Silva, 2010).

This study contributes to the understanding of parasitism in lizards in the Neotropical region, presenting 21 new infection records and suggesting that the presence of trematodes may be related to environmental humidity. Thus, the importance of faunal surveys for parasite diversity and investigating land use effects on parasite communities should be emphasized. However, it is important to note the limitations of the study, such as underrepresentation of some species due to the method of collection. For example, Gymnophthalmidae would be better represented if pitfall traps were included in our field collections. Nevertheless, these limitations did not strongly affect our objectives for this work, which are to describe the metazoan endoparasites of lizards in protected areas and their surroundings.

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