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Original paper

Diversity and prevalence of intestinal parasites of zoonotic potential in animal hosts from different biomes in the central region of Brazil

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ABSTRACT. The Brazilian state of Mato Grosso comprises the biomes Cerrado, Pantanal, and Amazon rainforest. The animals that make up the biodiversity of these biomes have an ongoing relationship with domestic animals. This study aimed to describe the prevalence and diversity of intestinal parasites in different class of animal hosts, domestic and wild, from the three biomes of Brazil's central region, during 2019. We analyzed animal faecal samples by sedimentation tests and centrifugal flotation in sucrose. The Shannon index test to calculate diversity and equitability, was used. In the 280 samples analyzed, 79.64% was positive. Domestic animals showed positivity of 87% and wild animals of 51%, being mammals the most prevalent, with 81%. *Blastocystis* sp. was the most prevalent protozoan, and *Ascaris* sp. of the helminths. Shannon's indexes were higher for the Pantanal. Overall, pigs, cows, and chickens had high prevalence values and diversity and equitability of enteroparasites. Due to the great diversity of parasites found in pigs, cows and chickens, these animals can play an important role in the transmission and maintenance of the infection to other mammals, including humans.

Keywords: Protozoa, helminths, zoonosis, Pantanal, Cerrado, Amazon

Introduction

The state of Mato Grosso, located in the Midwest region of Brazil, comprises three Brazilian biomes (Cerrado, Pantanal, and Amazon rainforest). The second largest biome in Brazil, the Cerrado, consists of a savanna-like area characterized by a long dry season and acidic soils poor in nutrients [1]. The Pantanal, on the other hand, covers floodplains in the interior of South America subjected to long flooding periods [2].

In this context, Mato Grosso has a great diversity of wild animal species since it coverages different biomes. Currently, the wide variety of animals that make up the biodiversity of these biomes have a continuous relationship with domestic agricultural animals.

With the advancement of extensive cattle raising in different regions of Mato Grosso, humans and their domestic animals have come into contact with wild animal populations. These interactions may facilitate the transmission of enteroparasites, which

results in new parasite-host relationships and new ecological niches in the disease transmission chain [3]. Understanding these new relationships is of great importance in the transmission of zoonotic diseases, as approximately 90% of the parasites described in humans have animal species (domestic and wild) as definitive hosts in their life cycles [4].

Several studies have analyzed faecal samples from domestic and wild animals in Brazil and revealed different prevalence percentages according to the type of animal studied, allowing the observation of a high prevalence of enteroparasites among livestock, such as cattle, pigs, horses, sheep, and birds [5–7]. On the other hand, in wild animals the prevalence rates vary depending on the region studied [8,9].

A lack of information regarding the prevalence of intestinal parasites in rural areas poses a possible threat to the health of wild animal populations as well as humans in close contact with domestic animals due to management practices. Parasitological studies are essential for understanding the life cycle of parasites and transmission mechanisms between wild and domestic animals as well as the involvement of humans as intermediate hosts. This study aimed to describe the prevalence and diversity of intestinal parasites in different class of animal hosts, domestic and wild, from the three biomes of Brazil's central region that make up the state of Mato Grosso to identify the environmental risk to the local fauna and human populations during the year 2019.

Materials and Methods

Study location and sample collections

A cross-sectional study was carried out with non-probabilistic samples, collected from different animal species (domestic and wild) from three different Brazilian biomes in the state of Mato Grosso. The municipalities of the collection sites were selected for convenience, making up the following biomes: Pantanal (Caceres), Cerrado (Tangara da Serra), and Amazon rainforest (Alta Floresta). Data were collected between December 2018 and January 2020.

Samples of domestic and wild animals were collected by active search directly from the environment by waiting and observing the animals and collecting their fresh feces without the need to anesthetize, euthanize or handle the animals.

The Ethics Committee on the Use of Animals at the Mato Grosso State University /CEUA/ UNEMAT no. 009/2016" made it possible to obtain faecal samples from wild birds.

Evaluation of interaction type

According to the type of interaction with humans the analyzed animals were classified as: domestic (are those that live or are raised at home, and that have undergone a continuous and systematic process of domestication, including pets and farm animals) and wilds (are those of free life in their habitat).

We analyzed a total of 280 faecal samples of different domestic and wild animals distributed among mammal and bird species. Considering the hosts' classifications according to their direct interactions with humans, 223 (79.64%) samples were collected from domestic animals and 57 (20.36%) from free wild animals. We only collected samples of domestic animals considered to be of economic interest, pet samples were excluded. Regarding the domestic animals' classification, 173 (77.58%) samples were obtained from mammals and 50 (22.42%) from birds. Of the wild animal samples analyzed, 43 (75.44%) were obtained from mammals and 14 (24.56%) from birds.

Regarding the sample distribution analyzed according to the studied biome, 105 (37.5%) were collected in the Pantanal, 91 (32.5%) in the Amazon rainforest, and 84 (30%) in the Cerrado.

In the distribution of samples analyzed in the Pantanal biome, 83 (79%) were from domestic animals and 22 (21%) from wild animals. Of the 83 samples of domestic animals, 73 (87.95%) corresponded to mammals and 10 (12.05%) to birds. We studied pigs, cows, horses, and chickens in this region. Of the 22 samples of wild animals, 21 (95.45%) corresponded to mammals; capybaras, non-human primates, armadillos, wild boar, tapir, collared peccary, and lowland paca, and only one sample corresponded to an unidentified wild bird.

Regarding the 91 samples analyzed from the Amazon rainforest biome, 82 (90.10%) were obtained from domestic animals and nine (9.90%) from wild animals. Of the domestic animals, 59 (71.95%) were mammals and 23 (28.05%) were birds. Samples of domestic mammals encompassed cows, sheep, goats, pigs, horses, and a donkey. Chickens and geese comprised the poultry studied. Of the nine samples of wild animals analyzed, eight (88.89%) were obtained from mammals, all of them non-human primates, and only one sample was obtained from a wild macaw.

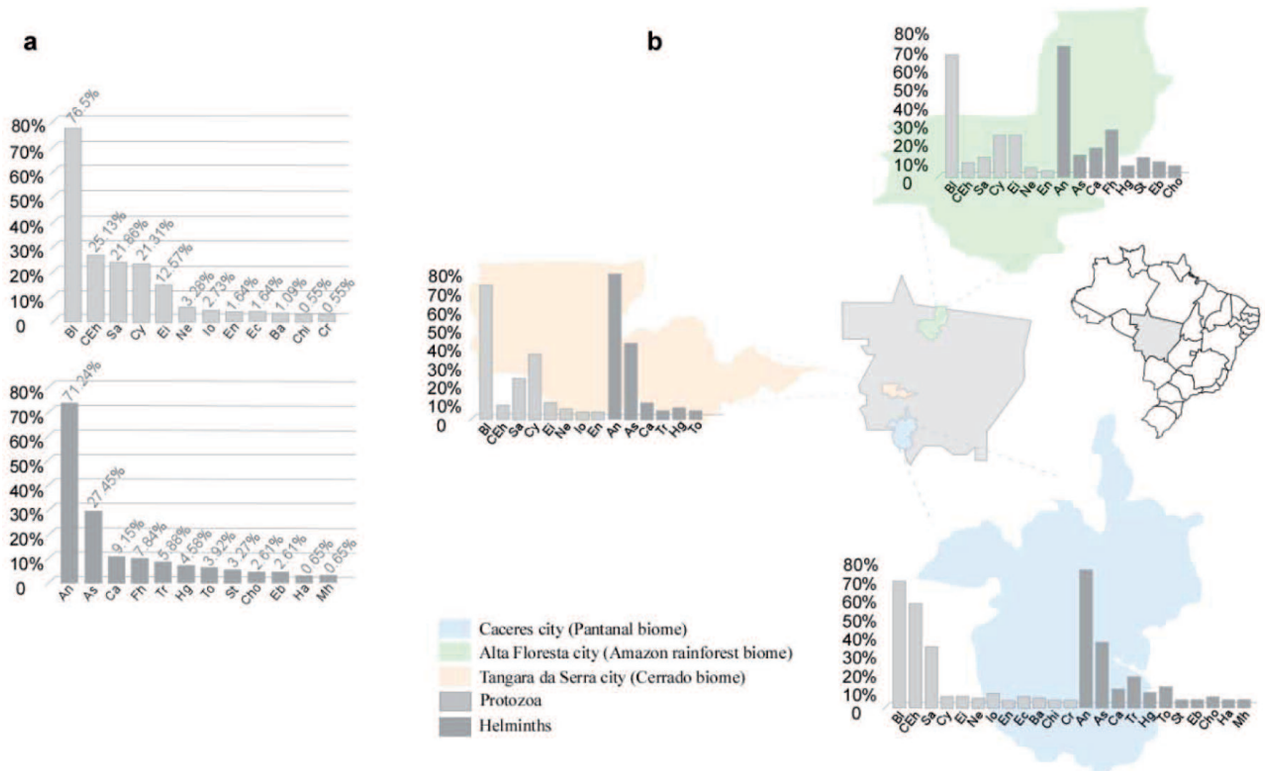

Figure 1. Prevalence of enteroparasitic infections. a – General prevalence of parasites found; b – Distribution of prevalence by biome
Explanations: Bl – *Blastocystis* sp.; Ba – *Balantidium* sp.; CEh – *Entamoeba histolytica Complex*; Cy – *Cystoisospora* sp.; An – *Ancylostomatidae*; Ei – *Eimeria* sp.; Eb – *Enterobius* sp.; As – *Ascaris* sp.; Fh – *Fasciola hepatica*; Ca – *Capillaria* sp.; Chi – *Chilomastix* sp.; Sa – *Sarcocystis* sp.; To – *Toxocara* sp.; Tr – *Trichuris* sp.; Hg – *Heterakis gallinarum*; Cho – *Choanotaenea* sp.; Io – *Iodamoeba* sp.; Ec – *Entamoeba coli*; St – *Strongyloides* sp.; Ha – *Haemonchus* sp.; Ne – *Neospora* sp.; En – *Endolimax nana*; Cr – *Cryptosporidium* sp.; Mh - *Macracanthorhynchus hirudinaceus*

Finally, of the 84 samples analyzed in the Cerrado, 58 (69.05%) were obtained from domestic animals and 26 (30.95%) from wild animals. Of the domestic animals, 41 (70.69%) were obtained from mammals and 17 (29.31%) from birds. Samples of domestic mammals included cows, horses, and pigs. The poultry analyzed were chickens and helmeted guineafowl. Of the 26 samples of wild animals in this region, 14 (53.85%) were obtained from mammals, all capybaras, and 12 (46.15%) were obtained from wild birds of an unidentified species

Laboratory procedures

The collected faeces were sent to the Laboratory of Parasitic Biology at the Mato Grosso State University. Each stool sample was submitted to the following parasitological techniques: spontaneous sedimentation according to Hoffmann et al. [10] and centrifugal flotation in sucrose [11]. The microscope slides obtained for each of the parasitological techniques were examined using light microscopy. We considered the samples positive when at least one stage of the life cycle of a parasite (egg, larva, trophozoite, cyst, or oocyst) was detected.

Statistical analyses

The data were entered into an Excel spreadsheet and transferred to Stata version 13.1 (Stata Corp; College Station, USA). Descriptive statistics was used by calculating the prevalence percentages. The Chi-square test was used to assess whether there was a significant difference between the animal species (domestic and wild) of the studied biomes. $P < 0.05$ was considered statistically significant. Shannon's diversity index was used to calculate the diversity, abundance, and equitability of parasite species present in the different animal hosts of the three biomes.

Results

The results about distribution and parasitic

Table 1. Distribution and parasitic positivity of samples obtained from different animal hosts in the Pantanal, Amazon rainforest and Cerrado biomes

Biome	N animal host	Positive	Bl	CEh	Sa	Io	Ec	Cy	Ei	Ne	Ba	Chi	Cr	En	An	As	Tr	To	Ca	Hg	Cho	Eb	Ha	Mh	St	Fh
PANTANAL	40 pigs	**34**	19	21	18	3	0	2	0	0	0	0	0	0	21	13	2	0	1	0	0	0	0	0	0	0
	23 cows	**22**	14	13	0	0	2	0	2	0	1	1	0	0	2	1	0	1	0	0	0	1	0	0	0	0
	10 horses	**9**	3	0	0	0	0	0	0	0	0	0	0	0	9	0	1	1	0	0	0	0	1	0	0	0
	10 chickens	**9**	4	1	0	0	0	0	0	1	0	0	0	1	3	2	3	2	2	3	2	0	0	0	1	0
	10 capybaras	**5**	3	0	2	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
	5 non-human primates	**3**	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2 armadillos	**2**	2	1	1	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
	1 wild boar	**1**	1	1	1	0	0	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
	1 tapir	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1 collared peccary	**1**	1	1	0	1	0	1	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	1	0	0
	1 lowland paca	**1**	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1 wild bird	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	105 Total	**87**	**49**	**39**	**22**	**4**	**3**	**3**	**3**	**2**	**2**	**1**	**1**	**1**	**38**	**18**	**8**	**5**	**4**	**3**	**2**	**1**	**1**	**1**	**1**	**0**
AMAZON rainforest	7 pigs	**7**	4	1	3	0	0	1	5	0	0	0	0	0	3	4	0	0	3	0	0	0	0	0	1	0
	21 cows	**12**	7	0	0	0	0	1	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	1	5
	2 horses	**2**	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	10 goats	**8**	3	0	0	0	0	0	2	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
	18 sheep	**18**	16	3	0	0	0	3	8	1	0	0	0	0	12	0	0	0	0	0	0	1	0	0	2	7
	1 donkey	**1**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15 chickens	**14**	8	0	3	0	0	10	1	1	0	0	0	0	1	1	0	0	4	2	2	2	0	0	0	0
	8 geese	**8**	8	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8 non-human primates	**5**	0	0	0	0	0	0	0	0	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0	0
	1 wild macaw	**1**	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	91 Total	**76**	**49**	**4**	**6**	**0**	**0**	**16**	**16**	**2**	**0**	**0**	**0**	**1**	**34**	**5**	**0**	**0**	**7**	**2**	**2**	**3**	**0**	**0**	**4**	**12**

Table 1. Distribution and parasitic positivity of samples obtained from different animal hosts in the Pantanal, Amazon rainforest and Cerrado biomes

Biome	N animal host	Positive	Bl	CEh	Sa	Io	Ec	Cy	Ei	Ne	Ba	Chi	Cr	En	An	As	Tr	To	Ca	Hg	Cho	Eb	Ha	Mh	St	Fh
CERRADO	11 pigs	**11**	10	0	11	0	0	11	4	1	0	0	0	0	8	11	0	0	2	0	0	0	0	0	0	0
	16 cows	**15**	10	1	0	0	0	2	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0
	14 horses	**14**	10	0	0	0	0	0	0	0	0	0	0	0	14	0	0	1	0	0	0	0	0	0	0	0
	10 chickens	**4**	3	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0
	7 helmeted guineafowl	**6**	5	0	1	0	0	6	0	1	0	0	0	0	0	6	0	0	1	1	0	0	0	0	0	0
	14 capybaras	**9**	3	2	0	1	0	1	0	0	0	0	0	1	6	0	1	0	0	0	0	0	0	0	0	0
	12 wild birds	**1**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	84 Total	**60**	**42**	**3**	**12**	**1**	**0**	**20**	**4**	**2**	**0**	**0**	**0**	**1**	**37**	**19**	**1**	**1**	**3**	**2**	**0**	**0**	**0**	**0**	**0**	**0**

Explanations: Bl – *Blastocystis* sp.; Ba – *Balantidium* sp.; CEh – *Entamoeba histolytica* Complex; Cy – *Cystoisospora* sp.; An – Ancylostomatidae; Ei – *Eimeria* sp.; Eb – *Enterobius* sp.; As – *Ascaris* sp.; Fh – *Fasciola hepatica*; Ca – *Capillaria* sp.; Chi – *Chilomastix* sp.; Sa – *Sarcocystis* sp.; To – *Toxocara* sp.; Tr – *Trichuris* sp.; Hg – *Heterakis gallinarum*; Cho – *Choanotaenia* sp.; Io – *Iodamoeba* sp.; Ec – *Entamoeba coli*; St – *Strongyloides* sp.; Ha – *Haemonchus* sp.; Ne – *Neospora* sp.; En – *Endolimax nana*; Cr – *Cryptosporidium* sp.; Mh – *Macracanthorhynchus hirudinaceus*

positivity of samples obtained from different animal hosts in the Pantanal, Amazon rainforest and Cerrado biomes are pointed in Table 1.

Overall enteroparasite prevalence

The overall prevalence of intestinal parasite infection in the 280 samples analyzed was 79.64%. We found protozoan infections in 183 (82.06%) positive samples, with the greatest prevalence in *Blastocystis* sp. (76.50%) followed by *Entamoeba histolytica* complex (23.13%) and *Sarcocystis* sp. The prevalence of all species of protozoa are shown in the Figure 1.

Helminths appeared in 153 (68.61%) positive samples. Ancylostomatidae were the most prevalent (71.24%), followed by *Ascaris* sp. (27.45%), *Capillaria* sp. (9.15%), *Fasciola hepatica* (7.84%) and *Trichuris* sp. (5.88%). The prevalence of all species of helminths are shown in the Figure 1.

Enteroparasite distribution according to the type of interaction between animal hosts and humans

According to the type of interaction between hosts and humans, 87% of domestic animals (194/223) tested positive for enteroparasites. In the distribution of positive samples according to the type of enteroparasite, we observed that 83% (161/194) were parasitized by protozoa and 70% (135/194) by helminths. *Blastocystis* sp. were the most prevalent protozoan among domestic animals (78.26%), followed by *E. histolytica* complex (24.84%) and *Cystoisospora* sp. (22.98%). Ancylostomatidae were the most prevalent helminths (69.63%), followed by *Ascaris* sp. (29.63%), *Capillaria* sp. (9.63%) and *F. hepatica* (8.89%).

We found 51% prevalence of intestinal parasite infection in wild animals (29/57). Among the positive samples, 76% (22/29) were parasitized by protozoa and 62.07% (18/29) by helminths. The most prevalent protozoan was *Blastocystis* sp. (63.64%) followed by *E. histolytica* complex (27.27%) and *Sarcocystis* sp. (18.18%). Ancylostomatidae were the most prevalent helminths (83.33%), followed by *Trichuris* sp. (16.67%), *Ascaris* sp. (11.11%), *Capillaria* sp., *Toxocara* sp., and *M. hirudinaceus* at 5.56%.

Enteroparasite species distribution according to host class

Among the positive samples for enteroparasites, we observed a prevalence of 81% (180/223) in samples of host species belonging to the mammal class. Of the positive mammals, 80.56% (145/180) were parasitized by protozoa and 70.56% (127/180) by helminths. The most prevalent protozoan was *Blastocystis* sp. (75.86%), followed by *E. histolytica* complex (31.03%) and *Sarcocystis* sp. (25.52%). On the other hand, the most prevalent helminths in mammals were Ancylostomatidae (81.89%), followed by *Ascaris* sp. (24.41%), *F. hepatica* (9.45%) and *Capillaria* sp. (5.51%).

In the positive samples for enteroparasites, we observed prevalence of 19% (43/223) in samples of host species belonging to birds. Of the positive birds, 86.05% (37/43) were parasitized by protozoa and 60.47% (26/43) by helminths. The most prevalent protozoan was *Blastocystis* sp. (81.08%), followed by *Cystoisospora* sp. (45.95%) and *Sarcocystis* sp. (10.81%). Ancylostomatidae (19.23%), *Choanotaenia* sp. (15.38%) and *Trichuris* sp. (11.54%), *Toxocara* sp. and *Enterobius* sp. at 7.69%, and finally *Strongyloides* sp. (3.85%), were the most prevalent helmints.

Enteroparasite infection prevalence according to the studied biome

Among the positive samples from the three studied biomes, the Pantanal showed an enteroparasite infection prevalence of 39.01% (87/223), followed by the Amazon rainforest at 34.08% (76/223), and the Cerrado at 26.91% (60/223). After applying the Chi-square test, we observed no significant difference between the prevalence of the three biomes.

The prevalence of intestinal protozoa infection in the Pantanal, Amazon rainforest, and Cerrado was 83.91%, 81.58%, and 80%, respectively. Regarding infection by helminth species, the prevalence found in these three biomes was 62.07%, 65.79%, and 81.67%, respectively.

Among protozoa, *Blastocystis* sp. was the most prevalent species in the three biomes, while in helminths this was the Ancylostomatidae. Figure 1 shows the distribution of all enteroparasite species found in the studied biomes.

Diversity and equitability of enteroparasite species

A total of 24 enteroparasite species were found in the three studied biomes. In the Pantanal, infected hosts represented 95.83% of the species found (23/24). In the Amazon rainforest and Cerrado, infected hosts represented 63.5% (15/24) and 58.34% (14/24) of the species found, respectively (Figure 1).

Table 2. Shannon's diversity and equitability index of enteroparasites found among the different animal hosts and biomes analyzed

Host-human interaction	Biome/Host	Shannon-Weiner	Equitability
	Pantanal		
Domestic animals (livestock)	Pigs	1.8526	0.8431
	Cows	1.6783	0.8098
	Horses	1.4255	0.7956
	Chickens	2.3797	0.9576
Wild animals	Capybaras	1.2771	0.9211
	Non-human primates	1.0986	1
	Armadillos	1.9061	0.9795
	Wild boar	1.9459	1
	Collared peccary	2.0794	1
	Diversity Biome	2.3143	0.7381
	Amazônia		
Domestic animals (livestock)	Pigs	2.0578	0.9365
	Cows	1.3747	0.8541
	Horses	1.0986	1
	Goats	1.0608	0.9656
	Sheep	1.8492	0.8416
	Chickens	1.8559	0.8446
	Geeses	0.3488	0.5032
Wild animals	Non-human primates	0.4505	0.6501
	Wild macaw	0.6931	1
	Diversity Biome	2.1483	0.7933
	Cerrado		
Domestic animals (livestock)			
	Pigs	1.8927	0.9192
	Cows	1.0825	0.7808
	Horses	0.9514	0.6863
	Chickens	1.0114	0.9206
	Helmeted guineafowls	1.6374	0.8414
Wild animals	Capybaras	1.6792	0.8629
	Diversity Biome	1.9487	0.7384

Species diversity, reflected in Shannon's diversity and equitability index, was high in all biomes. However, the Pantanal recorded the highest rates of diversity and equitability (H = 2.3143; E = 0.7381). In the three biomes, protozoa had a higher Shannon index and high equitable distribution compared to helminths (Table 2).

In the Pantanal, all animal groups studied showed high values of diversity. When separating the animals studied according to direct interactions with humans, we observed that among domestic animals, chickens showed greater diversity and equitability (H = 2.3797; E = 0.9576), followed by pigs (H = 1.8526; E = 0.8431), and cows (H = 1.6783; E = 0.8098). Amid the three species of wild animals, the collared peccary showed the highest diversity and equitability value (H = 2.0794; E = 1), followed by the wild boar (H = 1.9459; E = 1), and the armadillos (H = 1.9061; E = 0.9795) (Table 2).

In the Amazon rainforest, among domestic animals, pigs showed greater diversity and equitability (H = 2.0578; E = 0.9365), followed by chickens (H = 1.8559; E = 0.8446), and sheep (H = 1.8492; E = 0.8416). Only two categories of wild animals were studied; macaws (H = 0.6931; E = 1) and non-human primates (H = 0.4505; E = 0.6501).

Finally, in the Cerrado, among domestic animals, pigs (H = 1.8927; E = 0.9192) and helmeted guineafowl (H = 1.6374; E = 0.8414) had the highest values. In this biome, only capybaras were studied as wild animals (H = 1.6792; E = 0.8629).

Coinfection prevalence

When analyzing the positive samples according to the number of species found, we observed that simple infections had a prevalence of 35.43% (79/223); the remaining 64.57% (144/223) corresponded to the prevalence of mixed infections.

Regarding the coinfection of enteroparasites according to host-human interactions, the prevalence of mixed infections among samples of domestic animals was 69.59% (135/194). Dual infections with associations between *Blastocystis* sp. and Ancylostomatidae were the most common among domestic animals for 23 samples, followed by the association between *Blastocystis* sp. and *E. histolytica* complex in 10 samples. Amongst domestic animals, associations with higher numbers of enteroparasites, quintuple and six-fold infections, were found in pigs, sheep, and chickens.

Regarding the positive samples of wild animals, the prevalence of mixed infections was 37.93% (11/29). Dual infections with associations between *Blastocystis* sp. and Ancylostomatidae, and *E. histolytica* complex and Ancylostomatidae, were the most common among wild animals. For wild animals, associations with higher numbers of enteroparasites, six-fold, seven-fold, and eight-fold infections, were identified among armadillos, wild boar, and collared peccary, respectively.

Discussion

The overall prevalence of enteroparasites detected in this study was 79.64%. When observing the positivity of enteroparasites according to the animal host-human interactions, our results identified a prevalence of 87% in samples from domestic animals and 51% from wild animals.

In domestic animals, sheep and geese showed the highest percentages (100%), followed by horses (96%), pigs (90%), cows (82%), goats (80%), and chickens (78%). In studies conducted in different countries, domestic animals have been described with high prevalence percentages. These studies also highlight the high infection percentage among sheep, pigs, and cows [12,13]. A study conducted in India revealed a high parasite prevalence in chickens [14]. In Brazil, previously published data also revealed high prevalence values in these animals in the regions of Paraiba, Rio de Janeiro, and Sao Paulo [5–7].

The high prevalence observed in farm animals can be attributed to inadequate management practices that contaminate the environment favoring intestinal parasite transmission and reinfection [12]. Our results suggest that livestock may play an important zoonotic role in the transmission of enteroparasites, such as Ancylostomatidae, *Ascaris* sp., *Blastocystis* sp., *E. histolytica* complex, and *Sarcocystis* sp., which were found to have high prevalence in almost all hosts analyzed, and can cause gastrointestinal diseases in humans as well as damage animal health. For example, intense infestations of *Trichuris* sp. and *Ascaris* sp. usually cause malnutrition, growth retardation, bloody diarrhea in pigs and sheep [15–17]. In humans, these helminths can cause iron deficiency resulting in anemia, growth retardation in children, and other physical and mental health problems [18]. Ancylostomatidae can interfere with animal reproduction and survival [19]; in humans, these species are pathological agents of *larva migrans*, which produce skin, eye, and some organ disorders [20].

The pathogenic potential of *Blastocystis* sp. in humans remains uncertain, although many carriers exhibit mild intestinal discomfort, including acute or chronic diarrhea, abdominal pain, flatulence, vomiting, constipation, and irritable bowel syndrome [21], while in animals, as in cattle, the high prevalence of *Blastocystis* sp. infection can lead to death [22]. On the other hand, invasive amoebic infection by *E. histolytica* complex is the third major parasitic disease responsible for human morbidity and mortality, affecting more than 50 million people worldwide, resulting in 100,000 deaths annually [23]. Regarding animals, a recent study reported diarrhea in non-human primates infected by *E. histolytica* complex [24]. Sarcocystosis is an infection produced by *Sarcocystis* sp., which causes abdominal pain, distension, nausea, vomiting, loss of appetite, and, in dramatic cases, diarrhea and difficulty breathing [25]. This parasite has, as intermediate hosts, several herbivorous animals, including cows, sheep, and pigs [25].

Therefore, raising livestock without proper management and necessary hygienic care can represent a risk factor for illness in humans associated with intestinal parasites transmitted by

the feces of these animals. Farmers need to be properly educated regarding the risks of zoonoses and the importance of regular parasitological analyses in the herd to avoid the transmission cycle.

For domestic animals, it is important to understand the role played by birds in transmitting enteroparasites. Our results reveal that helmeted guineafowl and chickens have a high prevalence of pathogenic parasites for humans, such as *Blastocystis* sp., *Cystoisospora* sp., *Sarcocystis* sp., *Ascaris* sp., *Trichuris* sp., *Toxocara* sp., and *Capillaria* sp. Therefore, we consider that these birds, due to their habit of free breeding, play an important role in transmitting and disseminating parasites to other domestic animals and humans.

For wild animals, mammals (capybaras, non-human primates, armadillos, wild boar, tapir, collared peccary, and lowland paca) showed prevalence rates ranging from 14% to 62%. On the other hand, wild birds showed low prevalence. Unlike poultry, wild birds have less contact with other animals, as they have different habitats and eating habits, which can hinder the enteroparasitic transmission cycle for these animals. Studies conducted on wild animals from the Ivory Coast and Chile have reported lower prevalence than that identified in our study [26,27]. However, other studies conducted in other regions of Brazil have prevalence rates ranging from 39% to 88% [8,9]. The variability in prevalence observed between these studies and our results can be attributed to several factors, including differences in the sampling region, eating habits of the studied populations, habitats, and number of samples.

The overlapping of areas containing wild animals and domestic animals in this study points to the risk of parasite exchange between species. In fact, enteroparasites, such as *Blastocystis* sp., *E. histolytica* complex, *Sarcocystis* sp., Ancylostomatidae, *Ascaris* sp., and *Trichuris* sp., were identified in faecal samples of non-human primates; capybaras, armadillos, wild boar, and collared peccary, collected from areas near rural properties. Our results highlight the need for further investigation and implementation of measures to control enteroparasitic infections of rural areas near forests as domestic animals, due to the high prevalence observed, maintain infections in domestic environments and, thus, may be responsible for transmitting various parasites to wild animals living in close proximity, as well as to humans, meaning that the risk of animal diseases and zoonoses is high in these areas.

When analyzing the three biomes, we observed similarities in the prevalence and type of gastrointestinal parasites identified. Although prevalence differed slightly for each biome, we found no statistically significant difference between them. The prevalence similarity found in the three studied biomes can be explained due to the temperature and humidity conditions, management practices in rural properties, and sanitary programs controlling infectious agents being virtually the same across the three municipalities to which they belong.

Species diversity was high for all biomes, as 24 parasite species were found in total; 12 protozoa and 12 helminths. For the different biomes, 23 species belonged to the Pantanal, 15 to the Amazon rainforest, and 14 to the Cerrado.

Shannon's diversity and equitability analysis recorded higher rates in the Pantanal, but this biome also had a greater number of samples analyzed. In all biomes, we found considerable species diversity and an equitable distribution of intestinal parasites among pigs, cows, and chickens. In wild animals, the collared peccary, capybara, wild boar, and armadillo showed the greatest diversity and equitability of enteroparasites. As we analyzed different species of wild animals among the three biomes, a comparison between them cannot be made.

Intestinal protozoan infection rates (82.06%) were higher than those of helminths (68.61%). The most prevalent protozoa in this study were *Blastocystis* sp. (76.50%) and *E. histolytica* complex (23.13%). The most commonly identified helminths were Ancylostomatidae (71.24%) and *Ascaris* sp. (27.45%). However, most parasite species identified in this study have zoonotic potential and worldwide distribution [13,14,22].

The clinical impact of zoonotic intestinal parasite infections is greater in developing countries, where inadequate sanitation, poor hygiene, and environmental contamination are more prevalent. Given these circumstances, it is unsurprising that infections of more than one species of intestinal protozoa and/or helminths at the same time are often found and, in fact, single infections rarely occur [28]. Overall, our results showed that coinfection with more than one enteroparasite occurred more frequently than single infections in most domestic and wild animal hosts of the three analyzed biomes. Host infection by a species of parasite may alter host susceptibility to

other parasitic species [29]; the presence of high levels of enteroparasitic contamination in the environment may increase coinfection probability. The role of simultaneous infection by multiple parasites in host health is generally understudied, but coinfections have been associated with greater negative health effects [30]. As coinfection was more prevalent in our results, this is an important focus for future investigations.

This is the first study, to our knowledge, in Brazil that compares the enteroparasitic fauna of domestic and wild animals (mammals and birds) from different biomes in the central region of the country, enabling a complete picture of the epidemiological flow of diseases caused by these parasites. Previous studies have reported the prevalence in specific animal groups and/or different regions [5–9]. From the results of this study, it was found that routine epidemiological surveillance, effective veterinary care, and enhanced educational campaigns on parasitic zoonoses of domestic livestock are essential measures to minimize environmental contamination. By reducing environmental contamination, we can ensure good animal productivity, prevent the transmission of parasites to wild animals, and reduce public health risks associated with animal husbandry in the biomes of central Brazil and other areas with similar climatic conditions.

In conclusion, in this study we found a high prevalence of enteroparasites in domestic and wild animals of the three biomes that make up the state of Mato Grosso, with domestic animals being the most prevalent. Regarding to the class, we found that mammals have a higher prevalence of enteroparasites when compared to birds. The diversity analysis revealed the presence of 24 parasite species, with *Blastocystis* sp. and *E. histolytica complex* as the most prevalent protozoa, and Ancylostomatidae and *Ascaris* sp. as the most prevalent helminths. The Shannon index revealed greater diversity and equitability of enteroparasites in the Pantanal biome, followed by the Amazon rainforest and finally the Cerrado. Due to the great diversity of parasites found in pigs, cows and chickens, these animals may be playing an important role in the transmission and maintenance of enteroparasites to other mammals, including humans.

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