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Article

Occurrence of potential wild hosts of *Echinococcus vogeli* in the forests of southwestern Brazilian Amazonia

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Abstract: The helminth *Echinococcus vogeli* Rausch & Bernstein, 1972 is a causative agent of Neotropical Echinococcosis, a chronic zoonotic disease which is endemic to the Neotropical region. This parasite is transmitted from bush dogs (*Speothos venaticus*) to their prey, which include lowland pacas (*Cuniculus paca*) and agoutis (*Dasyprocta* spp.). In Brazil, most human cases of Neotropical Echinococcosis have been recorded in the Amazonian states of Acre and Pará, although few data are available on the occurrence of the potential definitive or intermediate hosts of *E. vogeli* in the Amazon region. In the present study, we surveyed the forests surrounding 46 human communities located within and around of outside six sustainable-use protected areas in the southwestern Amazon basin of Brazil. The forests were surveyed using camera traps to determine the local presence of potential wild hosts of *E. vogeli*, and the exploitation of these hosts for game meat was evaluated through interviews with 136 subsistence hunters resident in the local communities. We recorded pacas, agoutis, and bush dogs, as well as domestic dogs (*Canis familiaris*), all potential reservoirs of Neotropical Echinococcosis, using the same habitats. We also confirmed the frequent consumption of paca and agouti meat by subsistence hunters and their families in the study communities. Our data contribute to the understanding of the occurrence of *E. vogeli* in Brazilian ecosystems.
Keywords: *Neotropical echinococcosis; subsistence hunting; Brazilian Amazonia; camera trap.*

Ocorrência de potenciais hospedeiros silvestres de *Echinococcus vogeli* nas florestas do sudoeste da Amazônia brasileira

Resumo: O helminto *Echinococcus vogeli* Rausch & Bernstein, 1972 é o agente causador da Equinococose Neotropical, uma doença zoonótica crônica e endêmica da região Neotropical. Este parasito é transmitido entre o cachorro-vinagre (*Speothos venaticus*) e suas presas, como pacas (*Cuniculus paca*) e cutias (*Dasyprocta* spp.). No Brasil, a maioria dos casos humanos de Equinococose Neotropical é registrada nos estados do Acre e Pará, embora existam poucos dados disponíveis sobre a ocorrência de potenciais hospedeiros definitivos e intermediários de *E. vogeli* na Amazônia. No presente estudo, foram investigadas áreas de floresta ao redor de 46 comunidades humanas localizadas no interior e entorno de seis unidades de conservação de uso sustentável no sudoeste da bacia amazônica brasileira e, por meio de armadilhas fotográficas, foram avaliadas as presenças de potenciais hospedeiros silvestres de *E. vogeli.* Adicionalmente, foram avaliados o padrão de consumo da carne dos hospedeiros silvestres por meio de entrevistas com 136 moradores dessas comunidades. Foram registradas pacas, cutias e cachorros-vinagre, bem como cães domésticos (*Canis familiaris*) utilizando os mesmos habitats, todos potenciais reservatórios da

Equinococose Neotropical. Além disto, confirmamos a alto consumo de paca e cutia nas comunidades. Os dados do presente trabalho contribuem para pesquisas em andamento sobre a presença dos potenciais reservatórios de *E. vogeli* em ambientes brasileiros.

Palavras-chave: *equinococose neotropical; caça de subsistência; Amazônia brasileira; armadilha fotográfica.*

Introduction

Infectious diseases with zoonotic potential are a research priority, given their potential impacts on public health, livestock, and wildlife conservation (Cleaveland et al. 2001). Worldwide, zoonotic diseases are the leading cause (61%) of human infections (Cunningham 2005), and 70% of emerging infectious diseases originate from wildlife, in particular mammals (Cleaveland et al. 2001, Thompson et al. 2009, Johnson et al. 2015). Many of the helminths that infect humans are zoonotic pathogens with wild and domestic animal hosts (Carmena & Cardona 2014, Gordon et al. 2016, Otranto & Deplazes 2019). Wild mammals, such as carnivores and rodents, may often host a considerable diversity of zoonotic helminths (Cleaveland et al. 2001, Han et al. 2016).

Echinococcosis is a helminthic zoonotic infection caused by the larval stage of the tapeworms of the genus *Echinococcus* Rudolphi, 1801, which have a worldwide distribution. This zoonotic disease is clinically important and considered the most prevalent of the zoonotic helminthiases, which causes serious human morbidity and death, affecting not only humans, but also livestock and wildlife, with implications for the conservation of wild mammal populations (Jenkins et al. 2005, Thompson et al. 2009, Gordon et al. 2016). Echinococcosis can be transmitted through a variety of domestic, synanthropic, and sylvatic cycles, with wild animals being considered a major source of infection in humans (Carmena & Cardona 2014). In a recent molecular study, Vuitton et al. (2020) validated four *Echinococcus* species of public health interest: *Echinococcus granulosus* (Batsch, 1786) *sensu lato (s.l.),* which causes cystic echinococcosis; *Echinococcus multilocularis* Leuckart, 1863, causing alveolar echinococcosis; and *Echinococcus vogeli* Rausch & Bernstein, 1972 and *Echinococcus oligarthra* Diesing, 1863, which cause neotropical echinococcosis. Only three of these species occur in Brazil (*E. granulosus, E. vogeli* and *E. oligarthra)*, however, only two are prevalent: *Echinococcus granulosus* which is found in southern Brazil and causes cystic echinococcosis, and *Echinococcus vogeli*, which occurs in northern Brazil, and causes neotropical echinococcosis (Siqueira et al. 2013) (Figure 1).

Echinococcus vogeli is endemic to the Neotropical region, where its definitive host is the bush dog (*Speothos venaticus* Lund, 1842), and the principal intermediate host is the lowland paca (*Cuniculus paca* Linnaeus, 1766), which is the preferred prey of bush dog (D'Alessandro et al. 1981, D'Alessandro 1997, D'Alessandro & Rausch 2008). Other wild animals are known to act as hosts of *E. vogeli* in Brazil, including the agouti (*Dasyprocta leporina* Linnaeus, 1758), and the nine-banded armadillo (*Dasypus novemcinctus* Linnaeus, 1758 (Santos et al. 2012, Almeida et al. 2013, Soares et al. 2014). In addition to the natural cycle of the parasite in these animals, *E. vogeli* may circulate in a partially synanthropic cycle, in particular, through the hunting and consumption of the meat of wild paca (an intermediate host of *E. vogeli*), and the introduction of domestic hunting dogs (*Canis familiaris*), which may feed on infected paca tissue (Eckert & Deplazes 2004, D'Alessandro & Rausch 2008).

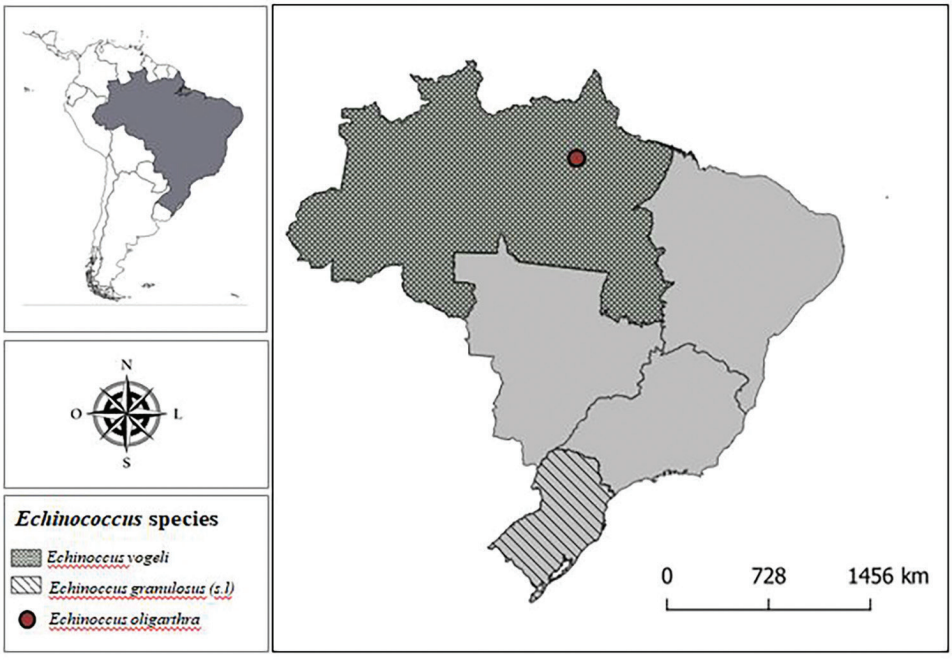

Figure 1. Map of Brazil showing endemic areas for *Echinococcus vogeli* and *Echinococcus granulosus (s.l.).*

The subsistence hunting of wild mammals is common and widespread in the rural and indigenous communities of the Amazon region (Peres & Palacios 2007), which paca and agouti are important game species to rural communities in central-western portion of Brazilian Amazon (Sampaio et al. 2022) and dogs are widely used for hunting (Bittencourt-Oliveira et al. 2018, Guimarães et al. 2019). Humans are considered to be an accidental intermediate host of *E. vogeli* (Rausch & Bernstein 1972) – they are infected through the accidental ingestion of eggs present in the feces of domestic dogs (Eckert & Thompson 2017).

In Brazil, most human cases of neotropical echinococcosis have been reported from the Amazonian states of Acre and Pará (Siqueira et al. 2013). In Acre, infection by *E. vogeli* has also been reported in both the paca (Meneghelli et al. 1992, Almeida et al. 2013, Oliveira 2016) and domestic dogs (Neves et al. 2017), which indicates the occurrence of both sylvatic and domestic cycles in this region. Despite these findings, relatively few data are available on the occurrence of the potential hosts of *E. vogeli*, whether definitive or intermediate, in most areas of Brazilian Amazonia.

In the present study, we used camera traps to survey forests in the vicinity of 46 human villages located within and immediately outside of six sustainable-use protected areas in the southwestern Brazilian Amazon in order to investigate the local occurrence of potential wild hosts of *E. vogeli*, that may maintain the wild cycle of this parasite in the region. Through interviews with 136 local hunters, we also evaluated the frequency of the consumption of the meat of these mammals of the local communities.

Material and Methods

1. *Study area*

The study was carried out in and around six sustainable-use protected areas located in southwestern Brazilian Amazonia in 2018, 2019, and 2020 (Figure 2). Four of these protected areas, the Cazumbá-Iracema Extractive Reserve (CIR), the Riozinho da Liberdade Extractive Reserve (RLR), the Liberdade State Forest (LF), and the Mogno State Forest (MF), hereafter Liberdade Reserves (LR), all protect areas above are located in the Brazilian state of Acre, while the other two – the Arapixi Extractive Reserve (AR) and the Médio Purus Extractive Reserve (MPR) – are located in Amazonas state. The families residing in the local communities live on plots of 300–500 ha, with a mean of four members per household, which are distributed along rivers, streams, and roads. The financial income of these families is derived from cattle ranching and farming (manioc, corn, and rice),

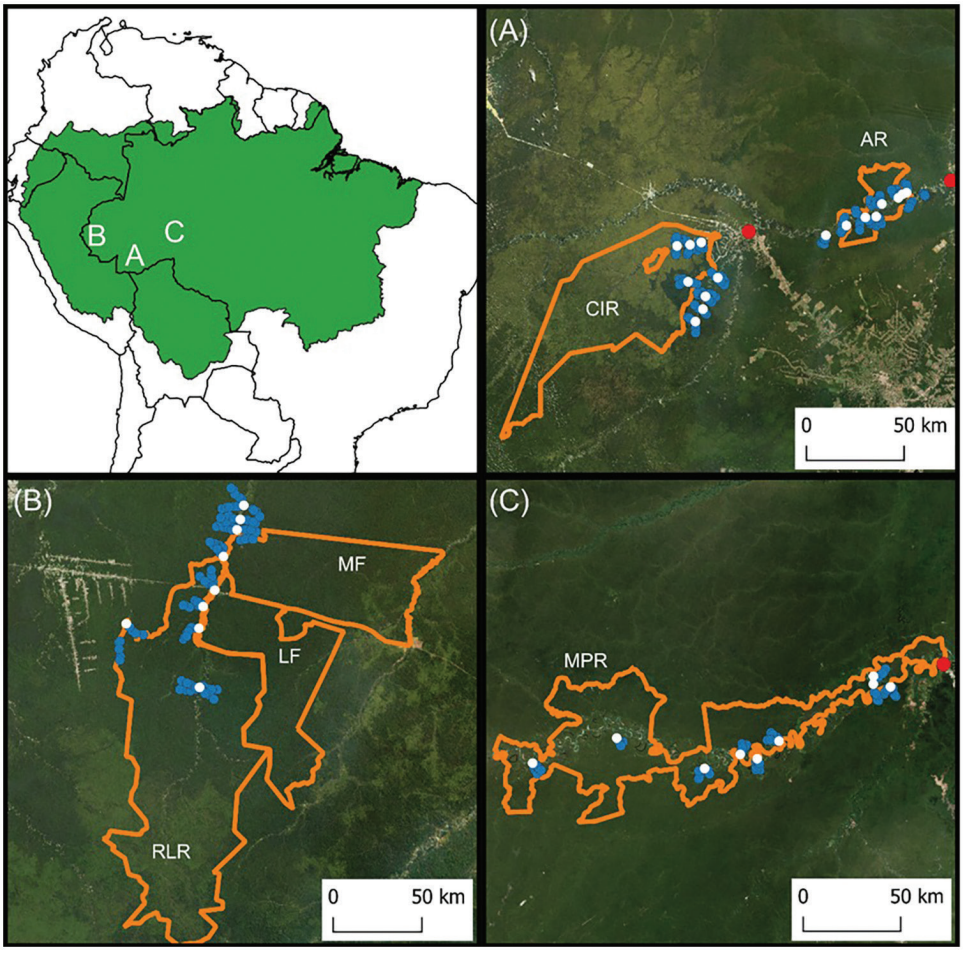

Figure 2. Location of the three study areas (panels A–C) within lowland Amazonia (green portion of the upper left panel), South America. (A) Cazumbá-Iracema Extractive Reserve (CIR) and Arapixi Extractive Reserve (AR); (B) Riozinho da Liberdade Extractive Reserve (RLR), Liberdade State Forest (LF) and Mogno State Forest (MF); and (C) Médio Purus Extractive Reserve (MPR). The maps show the 46 study communities (white dots), 452 camera traps (blue dots), the nearest urban centers (red dots), and the shapes of the protected areas (orange polygons).

as well as rubber tapping and the harvesting of Brazil nut from the forest (Oliveira & Calouro 2020). Subsistence is based on livestock, agricultural produce, forest resources, fishing, and hunting (Tourinho et al. 2013, Souza et al. 2021).

2. *Data collection and analysis*

The study areas were surveyed using unbaited Bushnell® digital camera traps, which are cameras triggered remotely by heat and motion. We used these devices to record the presence of potential wild mammalian reservoirs of polycystic echinococcosis during two distinct phases of sampling. A total of 452 camera traps were installed in the vicinity of 46 human communities in continuous primary *terra firme* forest. The total sampling effort was 21,909 trap-days, with each individual camera being operational for between half a day and 62 days (mean ± SD = 49.3±9 days).

The camera traps were deployed only in areas of primary forest found in the vicinity of each community, being distributed along a logarithmic gradient of distances of between 220 m and 7 km from the nearest community. The traps were affixed to tree trunks approximately 30–45 cm above the ground and programmed to operate continuously for 24 hours per day. Once triggered, each camera took photographs at 10-second intervals until no further movement was detected, with the following information being logged for each photograph: the date, time, season, and species (Srbek-Araujo & Chiarello 2013). The photographs were uploaded to the Camera Base (https://www.atrium-biodiversity.org/tools/camerabase/) and Wild.id (https://github.com/ConservationInternational/Wild.ID) databases for processing.

We calculated the frequency of sightings of each host species based on the number of photographs of a given species obtained by the same camera trap at an interval of at least one hour. These photographs were considered to be independent records of occurrence, following the recapture protocol of Srbek-Araujo & Chiarello (2013). We calculated the Relative Abundance (RA) of each species, where RA = the number of records of the species/the number of trap-days × 100) following Springer et al. (2012) and O'Brien (2010).

After obtaining explicit consent from all the participating communities and informants, we interviewed experienced subsistence hunters, who were willing informants and had been indicated to us based on a community-level snowball approach. A semi-structured questionnaire was applied to determine how often each hunter consumed the meat of the paca and agouti (reservoirs of *E. vogeli*). The study was approved by the Ethics Committee of the University of São Paulo (process number 2296078) and by the Brazilian Federal System of Biodiversity Information and Authorisation (SISBIO), through license number 68985-1.

Results

Based on a total sampling effort of 21,909 trap-days, we obtained 4,334 independent records of potential *E. vogeli* reservoirs (Table 1). We recorded the agouti (Figure 3a) in 44 (96%) of the communities surveyed, with detection distances in relation to the nearest community ranging from 293.6 to 7,316.6 meters (mean±SD = 3,135.4±1,650.5 m). This species was recorded most frequently in the early morning (between 6:27 am and 9:00 am) and around sunset (5:00 pm). We

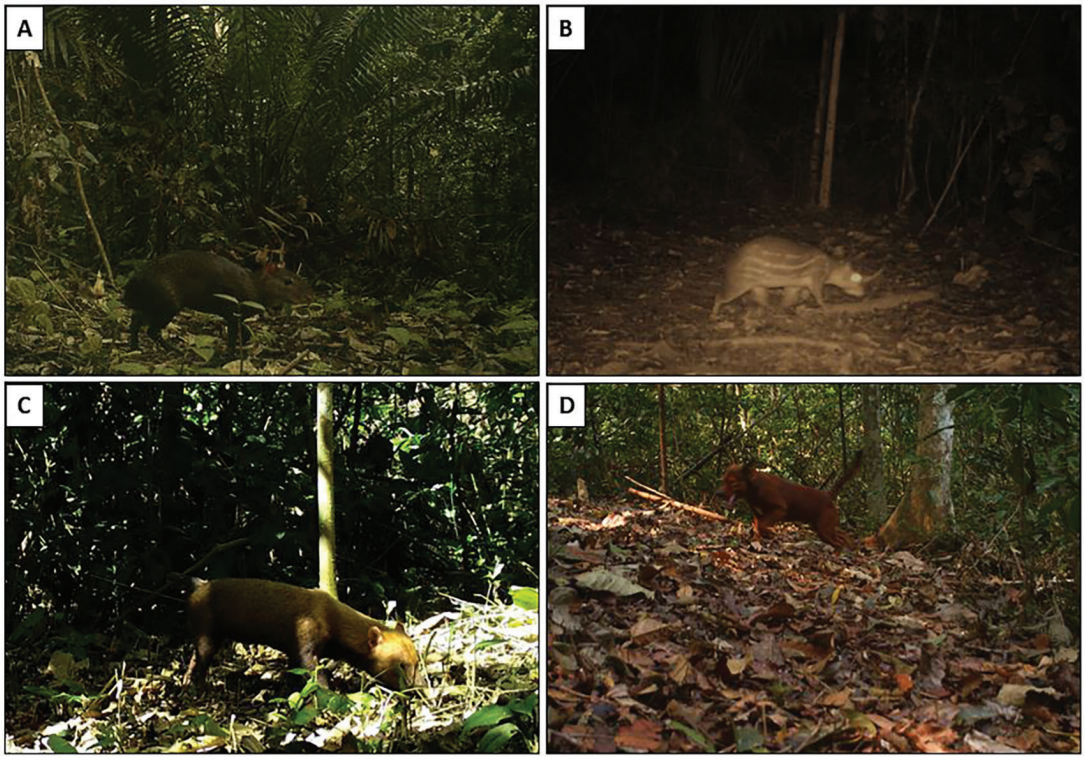

Figure 3. Potential wild and domestic hosts of *Echinococcus vogeli* captured by the camera traps deployed in the study region in the southwestern Amazon basin of Brazil (see Figure 2): (A) *Dasyprocta* ssp., (B) *Cuniculus paca*, (C) *Speothos venaticus*, and (D) *Canis familiaris.*

Table 1. Number of camera trap records (N) and the Relative Abundance (RA) of the four potential wild and domestic hosts of *Echinococcus vogeli* recorded in the communities located in and around the sustainable-use protected areas in the southwestern Brazilian Amazon basin.

Protected area	Domestic dog		Paca		Agouti		Bush dog		
	N	RA (%)	N	RA (%)	N	RA (%)	N	RA (%)	Sampling effort (trap-days)
Arapixi Extractive Reserve	7	0.15	120	2.53	577	12.14	5	0.11	4752
Cazumbá-iracema Extractive Reserve	64	0.96	418	6.27	1002	15.02	11	0.16	6671
Médio Purus Extractive Reserve	16	0.32	254	5.05	626	12.45	1	0.02	5029
Liberdade Reserves	49	0.90	362	6.63	819	15.01	3	0.05	5458
Total	**136**	**0.62**	**1154**	**5.27**	**3024**	**13.80**	**20**	**0.09**	**21909**

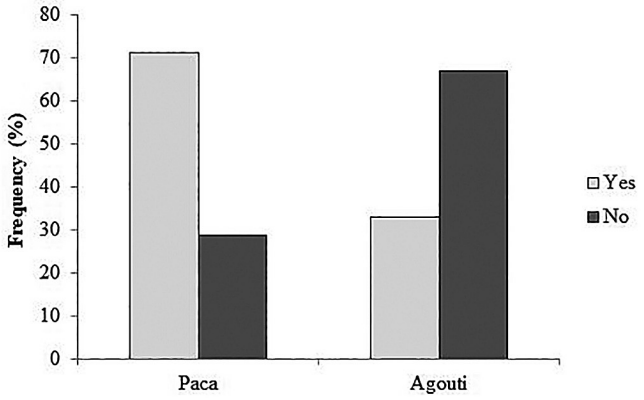

Figure 4. Frequency of the reports of the consumption of paca and agouti meat by the 136 subsistence hunters interviewed in the rural communities surveyed in the southwestern Amazon basin of Brazil (see Figure 2).

recorded the paca (Figure 3b) in 45 (98%) communities, at distances of between 293.6 and 7316.6 meters (mean = 3172.9 ± 1732.1 m), with the highest frequency of records being recorded between 7:00 pm and 11:00 pm.

We recorded the bush dog (Figure 3c) in only nine (20%) communities, where the photographs were obtained in the mid-morning, between 9:23 am and 12:32 pm, at distances of between 495.0 and 5,923.7 meters from the nearest community (mean = 3,538.6±1,683.4 m). Records of this species were more frequent in the communities in which pacas and agoutis were more abundant. Domestic dogs (Figure 3d) were recorded moving along the trails in the forests located in the vicinity of 30 (65%) communities, at distances of between 439.7 and 6,507.4 meters from the local community (mean = 2,509.4±1,604.8 m).

We interviewed 136 subsistence hunters resident in all the different communities of the study region. Most of the interviewees in all the communities indicated that they consume paca (71.3% – n = 96) and agouti (33.1% – n = 45) meat, with the paca being the species reported most often (Figure 4). All residents also reported that domestic dogs are fed with the raw viscera of these animals.

Discussion

The present study investigated the local occurrence of three wild mammals (the agouti, paca, and bush dog) and the domestic dog in the vicinity of 46 rural communities located both within and adjacent to six sustainable-use protected areas in southwestern Brazilian Amazonia. All these species are potentially important hosts of Neotropical echinococcosis, which is caused by *E. vogeli*, and are often found in areas close to human settlements, which are used as communal hunting grounds. Subsistence hunting is the only known route for the establishment of the domestic cycle of *E. vogeli* (Meneghelli et al. 1992, D'Alessandro et al. 2008, Almeida et al. 2013). This occurs through contact with the domestic dogs that accompany the hunts and are often fed raw game meat, which may sometimes be infected with *E. vogeli* (Siqueira et al. 2013, Bittencourt-Oliveira et al. 2018).

The bush dog is a rare species in the wild, and our records are new for its range in the Amazon basin (Michalski 2010, Rocha 2015, Oliveira et al. 2018), and possibly also the occurrence of *E. vogeli* in these areas. Oliveira & Calouro (2019) recently surveyed medium- and large-bodied mammals in the Cazumbá-Iracema Extractive Reserve through both direct observations (e.g. camera trapping, sightings, and the collection of vestiges and osteological material) and indirect records, such as interviews. While these authors reported the presence of the paca, agouti, and bush dog in this protected area, only the paca and agouti were recorded directly, with the bush dog only being reported by the local residents. The results of the present study confirm the findings of Oliveira & Calouro (2019), including the presence of the bush dog, which was recorded by the camera traps.

The first record of *E. vogeli* in a wild canid was from a bush dog captured in late 1969 in the province of Esmeraldas, Ecuador (Rausch and Bernstein 1972), while the second was from the municipality of Anajás, in the Brazilian state of Pará (Soares et al. 2014). Both these reports highlight the importance of the bush dog as a definitive host, which may maintain the natural cycle of the parasite in different regions of northern South America, in particular in the Brazilian Amazon biome.

Domestic dogs may play a crucial role in the transmission of *E. vogeli* eggs to humans, and the present study recorded these animals in all the habitats in which the wild mammals were recorded. Using molecular markers, Neves et al. (2017) identified *E. vogeli* eggs in fecal samples collected from domestic dogs in Sena Madureira (Acre state), which further highlights the potential role of dogs as a source of infection for humans, thereby establishing and maintaining the domestic cycle.

The first report of the presence of *E. vogeli* in pacas in the state of Acre dates to 1989 (Meneghelli et al. 1992), although no records are available for the state of Amazonas. Our findings show that the known hosts of *E. vogeli* are common in the study region, providing the conditions necessary to maintain its parasitic cycle in this region. Reports of infection by *E. vogeli* in agoutis (*Dasyprocta* spp.) are rare overall, with only one record from Brazil, in the state of Pará, in the eastern extreme of the

Amazon region (Soares et al. 1999). There are no other published records of the infection of agouti by *E. vogeli* in the Amazon region.

Most human cases of neotropical echinococcosis recorded in Brazil come from the Amazon region, where the disease is commonly known as "Paca Disease" (D'Alessandro & Rausch 2008, Daipert-Garcia et al. 2019). In the state of Amazonas, six cases of the disease were reported (Guimarães et al. 2005; Siqueira et al. 2013). In the state of Acre, many human cases have been recorded since 1992 (Meneghelli et al. 1992, Daipert-Garcia et al. 2019), which reflects the continuity of the parasitic cycle of the disease in the Amazon region. Three studies estimated the prevalence of infection in Acre based on serum antibody levels. In the first study, Pastore et al. (2003) recorded a frequency of 4% in a group of 1064 individuals from the municipality of Sena Madureira, while Pereira (2016) found a frequency of 25% when analyzing 332 samples collected in the municipalities of Sena Madureira, and Bujarí. Souza (2021) investigated 327 residents of the Cazumbá-Iracema Extractive Reserve, in Sena Madureira, and recorded positive serology in 8.6% of the individuals and hydatid cysts in 10.3%. These studies demonstrated that Neotropical echicoccosis is prevalent within the study area in Acre, where conditions may be favorable for the maintenance of the parasitic cycle.

The present study confirmed the presence of potential hosts of *E. vogeli*, both definitive and intermediate, within the same habitat in the southwestern Brazilian Amazon basin. This probably guarantees the full life cycle of this parasite through the contamination of the environment by bush dog feces infected with *E. vogeli*, which may be transferred to pacas and agoutis when they ingest eggs from contaminated soil (D'Alessandro & Rausch 2008). Both these rodents, in turn, are prey for the bush dog, which thus ensures the completion of the parasite's wild cycle (Lima et al. 2009, 2012, Jorge et al. 2013), with the parasite being introduced into the domestic environment through intense subsistence hunting, as observed throughout the area of the present study.

Conclusions

The confirmation of the presence of potential wild reservoirs of Neotropical echinococcosis (caused by *Echinococcus vogeli*) in the study region, together with the frequent consumption of paca and agouti meat by local hunters and their families, indicate the existence of an environment favorable to the maintenance of both the wild and the domestic cycles of this parasite. These findings extend our understanding of the occurrence of the hosts of *E. vogeli*, which will be fundamental to the development of more systematic research and effective programs for the monitoring and control of this parasitic infection in the Amazon region.

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Associate Editor

Diego Astúa

Author Contributions

Leandro Siqueira de Souza: Collected, analyzed, and interpreted the data and prepared the manuscript.

Ricardo Sampaio: Collected, analyzed, and interpreted the data and prepared the manuscript.

Ana Paula Nascimento Gomes: Contributed to the preparation of the manuscript and revised the text critically.

Ronaldo G. Morato: Contributed to the preparation of the manuscript and revised the text critically.

Adriano G. Chiarello: Contributed to the preparation of the manuscript and revised the text critically.

Leilandio Siqueira De Souza: Contributed to the collection of data.

Francisco Glauco de Araújo Santos: Contributed substantially to the conception and design of the study, and the analysis and interpretation of the data.

Marcio Neves Boia: Contributed substantially to the conception and design of the study, and the analysis and interpretation of the data.

Rosângela Rodrigues e Silva: Contributed substantially to the conception and design of the study, and the analysis and interpretation of the data.

Conflicts of Interest

The authors declare that they have no conflicts of interest related to the publication of this manuscript.

Ethics

The study was approved by the Ethics Committee of the University of São Paulo (process number 2296078) and by the Brazilian Federal System of Biodiversity Information and Authorization (SISBIO), through license number 68985-1.

Data Availability

Supporting data are available at <https://doi.org/10.5281/zenodo.6646839>

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