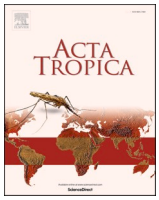
Acta Tropica 268 (2025) 107701

Contents lists available at ScienceDirect

Acta Tropica

journal homepage: www.elsevier.com/locate/actatropica



Risk factors for wildlife-transmitted diseases in communities engaged in wildlife consumption– A case study on neotropical echinococcosis

María Fernanda Menajovsky [a], Adrià San José [b], Marcela Alvares Oliveira [c,d], Joao Campos-Silva [e,f], Pedro Pérez Peña [g], José Eduard Hernández-Guevara [h], Jhon Bosmediano [i], Joe Saldaña [d,j], Fernando Del Moral Sachetti [d,k], Graciela Meza-Sanchez [l], Xavier Rodó [b,m], Pedro Mayor [a,d,m,n,*]

[a] Departament de Sanitat i Anatomia Animals, Facultat de Veterinària, Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain
[b] Climate and Health Group, CANU, ISGlobal, 08003 Barcelona, Spain
[c] Programa de Pós-graduação em Conservação e Uso de Recursos Naturais, Departamento de Ciências Biológicas, Universidade Federal de Rondônia, Porto Velho, Rondônia, Brazil
[d] ComFauna, Comunidad de Manejo de Fauna Silvestre en la Amazonía y en Latinoamérica, Iquitos, Peru
[e] Instituto Nacional de Pesquisas da Amazônia, Manaus, Amazonas, Brazil
[f] Instituto Juruá, Manaus, Amazona, Brazil
[g] Instituto de Investigaciones de la Amazonia Peruana, Iquitos, Perú
[h] Departamento de Ciencia Animal, Universidad Nacional Agraria de la Selva, Tingo María, Perú
[i] Departamento de Ecologia, Universidad Cientifica del Perú, Iquitos, Perú
[j] Servicio Nacional de Áreas Naturales Protegidas por El Estado –SERNANP, Dirección de Gestión de las Áreas Naturales Protegidas, Lima, Perú
[k] Proyecto Juco, Centro de Ciencias Naturales, Ambientales y Antropológicas, Universidad Maimónides, Buenos Aires, Argentina
[l] Facultad de Medicina Humana, Universidad Nacional de la Amazonía Peruana, Peru
[m] Institució Catalana de Recerca i Estudis Avançats (ICREA), 08010 Barcelona, Spain
[n] Museo de Culturas Indígenas Amazónicas, Iquitos, Peru

ARTICLE INFO

Keywords:
Neotropical echinococcosis
Echinococcus vogeli
Wild meat
Dogs
Amazon
Behaviours

ABSTRACT

Neotropical echinococcosis (NE) is a neglected zoonotic disease in tropical Latin America caused by *Echinococcus vogeli*. This study analyzed behavioral factors influencing NE transmission across 52 settlements, including rural and urban sites (285 respondents) within its distribution range. Of the surveyed communities, cysts in pacas associated with *E. vogeli* were reported in 86.5 % of Amazonian rural communities, 75.0 % of Amazonian cities, and 75.0 % of non-Amazonian rural areas. However, only 43.7 % of respondents in Amazonian rural communities and 23.1 % in non-Amazonian rural communities perceived these lesions as dangerous. Discarded livers were often fed to dogs, particularly in Amazonian rural (62.0 %) and non-Amazonian rural (43.6 %) communities, perpetuating the parasite's cycle. Routine dog deworming was also infrequent in rural areas (13.1 % in Amazonian rural and 38.5 % in non-Amazonian rural communities) in comparison to Amazonian cities (72.7 %). Additionally, limited access to healthcare in rural regions likely delays diagnoses, worsening disease outcomes. Human activities, such as handling wild meat and feeding infected organs to dogs, are key to disease transmission. High-risk practices for *E. vogeli* transmission are significantly more frequent in rural communities. Preventive strategies should focus on wildlife handling and domestic animal sanitation to reduce NE and other zoonotic diseases related to the wild meat chain, especially in rural areas.

* Corresponding author at: Department of Animal Health and Anatomy, Autonomous University of Barcelona, 08193 Bellaterra, Spain.
E-mail addresses: mariafernanda.menajovsky@uab.cat (M.F. Menajovsky), adria.sanjose@isglobal.org (A. San José), marcela.mugrabe@gmail.com (M.A. Oliveira), jvpiedade@gmail.com (J. Campos-Silva), pperez@iiap.gob.pe (P.P. Peña), jose.hernandez@unas.edu.pe (J.E. Hernández-Guevara), jhon_bos@hotmail.com (J. Bosmediano), jsaldana@sernanp.gob.pe (J. Saldaña), jfdelmoral@gmail.com (F. Del Moral Sachetti), graciela.meza@unapiquitos.edu.pe (G. Meza-Sanchez), xavier.rodo@isglobal.org (X. Rodó), pedrogines.mayor@uab.cat (P. Mayor).

https://doi.org/10.1016/j.actatropica.2025.107701
Received 1 February 2025; Received in revised form 9 June 2025; Accepted 15 June 2025
Available online 21 June 2025

1. Introduction

The transmission of zoonotic diseases from wildlife depends importantly on human contact with wildlife reservoirs, especially through activities related to the obtention, handling and consumption of wild meat, which pose significant risks for both bloodborne and foodborne pathogens (Wolfe et al., 2005; Van Vliet., 2022). Despite the evident risks, information on diseases associated with wild meat handling and consumption remains largely deficient. Neotropical echinococcosis (NE) is a clear example of a zoonotic disease linked to wild meat practices (San-Jose et al., 2023). NE is caused by the accidental ingestion of *Echinococcus vogeli* tapeworm eggs through contaminated food or water (D'Alessandro and Rausch, 2008). Although being responsible for 29 % of deaths among infected humans (D'Alessandro, 2010), NE is a neglected and underreported disease in Latin America, creating a misleading perception of a low prevalence in the region (San-Jose et al., 2023).

Echinococcus vogeli is a cestode well adapted to neotropical humid forests, where stable ecosystems and humidity support the parasite's development and egg life cycle (San-Jose et al., 2023). *Echinococcus vogeli* has an indirect life cycle that depends on wild rodents, mainly pacas *(Cuniculus paca)* and agoutis *(Dasyprocta* spp.*),* as primary intermediate hosts, which develop cysts mainly in the liver and occasionally in the lungs (D'Alessandro and Rausch, 2008; Mayor et al., 2015). The bush dog (*Speothos venaticus*) and the domestic dog, the definitive hosts, can become infected by consuming the infected organs of the intermediate hosts and developing adult tapeworms in their small intestine (D'Alessandro and Rausch, 2008). The cycle closes when the definitive host excretes eggs into the environment that can be consumed by intermediate hosts (Fig. 1).

In the Amazon, pacas are one of the most frequently hunted species and are key for the diet and cultural practices of rural and urban populations (El Bizri et al., 2020; Mayor et al., 2022). Typically, hunters discard the viscera of medium-sized animals, such as pacas, in sites close to the houses where rural inhabitants process wild meat. When these viscera are consumed by domestic dogs, a pathway is created for the parasite to enter and remain within rural communities (San-Jose *et al.*, 2023). In this case, humans can contract the disease by ingesting food or water contaminated with feces from infected domestic dogs, a risk that is particularly common in rural areas with poor hygiene and sanitation practices (Mayor et al., 2015) and can act as intermediate hosts developing cysts in their organs (D'Alessandro and Rausch, 2008; Eckert and Deplazes, 2004; D'Alessandro, 2010).

To our knowledge, only around 200 human cases have been reported in 12 countries in Latin America (D'Alessandro, 2010; San-Jose et al., 2023), and there is no precise map of their presence (Rodrigues-Morales et al., 2015), so its geographical distribution range partially depends on the coexistence of hosts competent to transmit the parasite (das Neves et al., 2017; San-Jose et al., 2023). In addition, human practices related to subsistence hunting and handling of wild meat may be key to facilitating or hindering the transmission of this disease (D'Alessandro and Rausch, 2008; Knapp et al., 2009; Mayor et al., 2015).

Local ecological knowledge (LEK) includes the knowledge and practices of local people regarding ecological relationships that are obtained through extensive personal empirical observations and interactions with local ecosystems (Charnley et al., 2007). Although LEK-based methods have mainly been used to collect information on habitats, extractive uses of biodiversity, human-wildlife conflicts, ecology and species behavior (Joa et al., 2018), they may also be essential to improve knowledge about diseases that affect wildlife. In this study, we use structured surveys to better understand human behaviors that facilitate or hinder *E. vogeli,* and new geographic insights about the main risks of NE transmission.

2. Material and methods

2.1. Study area

A net-working group was established with fellow researchers developing activities at sites within the territorial range of *E. vogeli* reported by D'Alessandro and Rausch (2008), and included 57 sites, located in Argentina, Bolivia, Brazil and Peru (Suppl Table 1). These sampling sites were divided according to their classification either rural community or city, and, in addition, rural communities were classified according to geographic location within or outside the Amazon region. All the cities surveyed were located within the Amazon.

2.2. Structured surveys

Since the study took advantage of the presence of active research teams in the surveyed area, a structured questionnaire and survey administration guide were agreed upon for all groups, which were used to train the study's 11 interviewers. Participant inclusion criteria included age (>18 years) and frequent hunting or handling wild animals. In each community, we located the first person who met both inclusion criteria and implemented the snowball sampling method to facilitate the identification of other suitable participants. Since hunting and consumption of wild meat is a sensitive and often criminalized activity, we reduced personal questions to ensure a safe environment for participants. All interviews were conducted in person in the interviewees' households. To ensure clarity, the questions were translated and adapted to the primary language spoken in each community

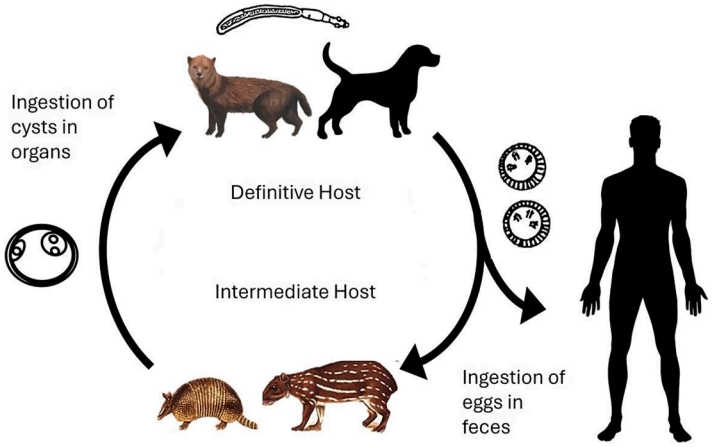


Fig. 1. Epidemiological cycle of *E. vogeli*. This parasite follows an indirect lifecycle, involving intermediate hosts (primarily *C. paca* or *Dasyprocta* spp., and occasionally humans) and definitive hosts (domestic dog and *S. venaticus*). Adapted from San-Jose et al. (2023).

(Portuguese for Brazil, Spanish for Argentina, Bolivia and Peru).

Structured surveys were conducted to 285 residents across the studied communities. This included 213 (74.7 %) participants from rural Amazon communities, 33 (11.6 %) from Amazon cities, 39 (13.7 %) from non-Amazon rural communities. The participants had a sex ratio of 6.9 % women and 93.1 % men, and a proportion of 43.2 % Indigenous and 56.2 % non-Indigenous people.

The questions focused on: a) the observation of cysts in pacas compatible with NE, presenting photographs of NE cysts from other studies (Fig. 2), b) their perception of the danger of these lesions to human health, c) behaviors, such as handling of viscera and consumption, that could facilitate or hinder the transmission of the parasite, d) presence and potential role of dogs in disease transmission, and e) the perception of ease in accessing health centers, categorized in (easy, mid, difficult and very difficult) (See questions in Annex 2). Access to health centers does not affect the risks of transmission but it is essential for NE diagnosis and treatment. Anonymous datasets are available in Supplemental Materials.

2.3. Statistical analysis

A chi-square test was used to assess differences in response percentages based on participants' locations, especially between rural communities and cities, and also between communities within and outside the Amazon region. Pairwise comparisons were then conducted between these groups, with the Holms's adjustment applied to account for multiple testing.

To examine how rurality and location affected affirmative responses across community types, we fit a Generalized Linear Model (GLM) using a binomial family and logit link. The response was the proportion of affirmative responses within each community type. Later on, we used an ANOVA analysis of deviance to assess the contribution of each factor by comparing changes in deviance. Chi-square tests from this analysis were used to assess the significance of each term.

All data analyses were performed using R 4.2.2 (R team, 2023), and we considered a Type I error probability of 0.05 for hypothesis testing.

3. Results

The observation of cysts in intermediate hosts offered valuable information into the geographical distribution of NE. Fig. 3 illustrates the habitat suitability of the paca (adapted from San-José et al., 2023), overlaid with the reported extent of NE based on the performed community interviews. A community was classified as having NE presence if at least one respondent reported observing liver lesions compatible with NE in pacas.

Tables 1 and 2 show the responses of the surveyed population categorized by location. Liver lesions compatible with NE in pacas were reported by 53 % of survey respondents, Amazon location was a significant factor influencing this reporting ($P = 0.05$).

Based on the report of at least one person in each community, NE was observed in 86.5 % (32/37) of Amazonian rural communities, 75.0 % (6/8) of Amazonian cities, and 75.0 % (9/12) of non-Amazonian rural communities. Fig. 3 shows the geographical distribution of NE considering the identification of the disease through surveys.

Of all respondents, 24.9 % considered these lesions frequent, the Amazon region was a significant factor, with people more frequently considering the lesions to be common there ($P = 0.0005$), and especially in Amazonian rural areas (29.6 %) in comparison with non-Amazon rural communities (5.1 %) ($P = 0.0079$). Additionally, in Amazonian rural communities, respondents reported the observation of lesions in 3.28 (±3.98) pacas annually, compared with 1.80 (±5.49) in non-Amazonian rural areas, and 1.44 (±1.63) pacas with lesions in Amazonian cities. The percentages of pacas observed with lesions were 13.6 % (±15.1), 13.0 % (±15.4), and 11.9 % (±19.9) pacas, respectively.

Overall, 43.9 % of respondents considered these lesions to be dangerous to human health. However, this perception varied significantly across study sites. In Amazonian rural communities, 43.7 % of respondents perceived these lesions as dangerous, compared to 69.7 % in Amazonian cities and 23.1 % in non-Amazonian rural communities. Both rurality ($P = 0.005$) and Amazon location ($P = 0.004$) were important factors influencing this response.

Regardless of the respondent's origin, 92.6 % of respondents reported that when they observe lesions compatible with NE in livers, they usually discard the affected organ, while a smaller proportion bury (3.3

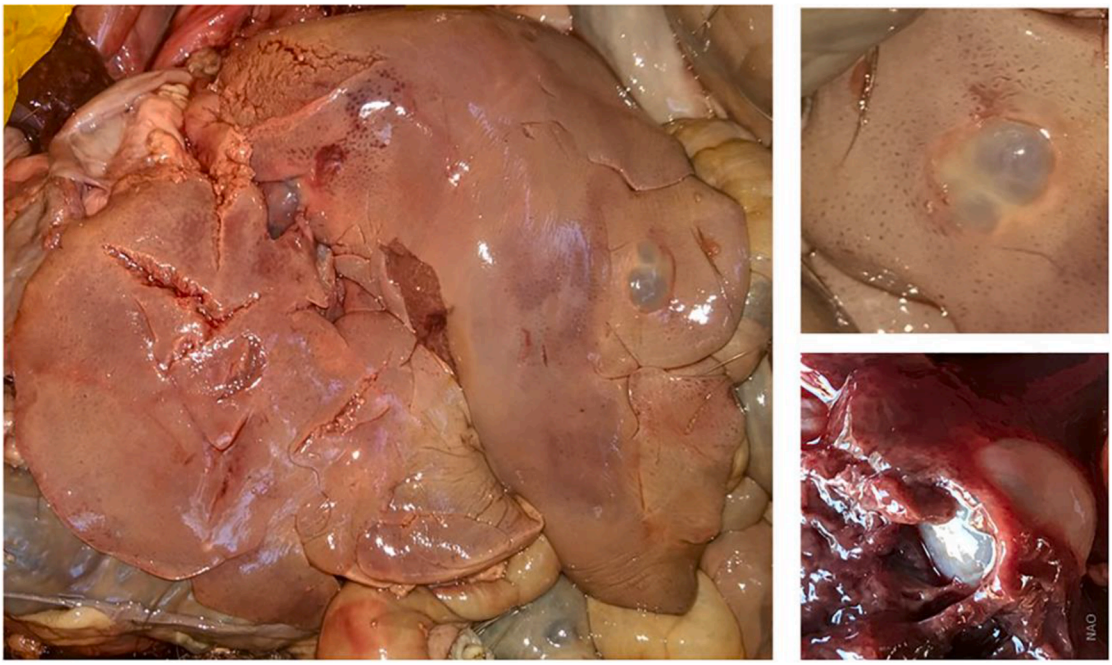


Fig. 2. Photographs of hydatid cysts present in *Cuniculus paca* shown to the 285 surveyed participants. The liver lesions correspond to *E. vogeli* cysts, confirmed through histopathological diagnosis.

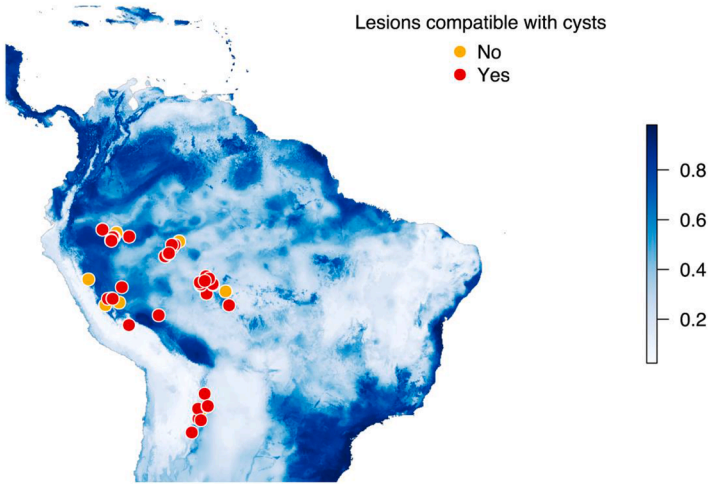


Fig. 3. Survey locations categorized based on weather at least a participant reported observing liver lesions compatible with NE in pacas. In the background, a *Cuniculus paca* habitat suitability map, adapted from (San-José et al., 2023).

Table 1
Responses to statements based on key survey questions categorized by location. 'a' or 'b' values in rows with different superscript letters are significantly different ($P < 0.05$).

Statements	Total respondents	Amazonian rural communities	Amazonian Cities	Non-Amazonian rural communities	p-value	X-squared	df
	$n = 285$	$n = 213$	$n = 33$	$n = 39$			
Statement 1: Reported seeing lesions in pacas	53 % (151)	56.8 % (121)	45.5 % (15)	38.5 % (15)	0.0706	5.3028	2
Statement 2: Consider the lesions are frequent	24.9 % (71)	29.6 % (63) [a]	18.2 % (6) [ab]	5.1 % (2) [b]	0.0033	11.438	2
Statement 3: Owning dogs	62.4 % (178)	53.5 % (114) [a]	75.8 % (25) [b]	94.9 % (37) [c]	0.0014	26.963	2
Statement 4: Confirmed that dogs habitually eat discarded viscera	53.3 % (152)	62.0 % (132) [a]	9.1 % (3) [b]	43.6 % (17)[c]	4.514e-08	33.827	2
Statement 5: Do not deworm their dogs	62.5 % (178)	86.9 % (185) [a]	27.3 % (9) [b]	61.5 % (24) [c]	3.398e-14	62.026	2
Statement 6: Present difficulties accessing the local Health Center	38.9 % (111)	44.1 % (94) [a]	15.2 % (5) [b]	30.8 % (12) [ab]	0.0034	11.363	2
Statement 7: Perceive these lesions as a danger to human health	43.9 % (125)	43.7 % (93) [a]	69.7 % (23) [b]	23.1 % (9) [c]	0.0004	15.791	2

Table 2
Details of the full model using GLM and ANOVA to verify the influence of location and rurality on key survey questions on the presence of Neotropical echinococcosis.

	GLM						ANOVA					
	RegionNoAmaz vs. RegionAmaz			Cities vs. Rural			Region			Rurality		
Statements	Estimate	z-value	Pr(>|z|)	Estimate	z-value	Pr(>|z|)	Df	Deviance	Pr(>Chi)	Df	Deviance	Pr(>Chi)
Statement 1: Reported seeing lesions in pacas	−0.7440	−2.084	0.0372 *	−0.4563	−1.214 +	0.2249	1	3.8342	0.05 *	1	1.4806	0.2237
Statement 2: Consider the lesions are frequent	−2.0503	−2.766	0.00568 **	−0.6366	−1.338	0.18079	1	12.2438	0.0005 ***	1	1.9813	0.1593
Statement 3: Owning dogs	2.7767	3.758	0.000171 ***	0.9984	2.328	0.019900 *	1	26.5633	2.55e-07 ***	1	6.0759	0.0137 *
Statement 4: Confirmed that dogs habitually eat discarded viscera	−0.7462	−2.117	0.03423 *	−2.7909	−4.489	7.16e-06 ***	1	1.720	0.1896	1	35.627	2.389e-09 ***
Statement 5: Do not deworm their dogs	−1.4181	−3.668	0.000244 ***	−2.8690	−6.515	7.25e-11 ***	1	5.116	0.0237 *	1	49.317	2.178e-12 ***
Statement 6: Present difficulties accessing the local Health Center	−0.5751	−1.540	0.12350	−1.4869	−2.946	0.0032 **	1	1.3048	0.2533	1	11.1909	0.0008 ***
Statement 7: Perceive these lesions as a danger to human health	−0.9491	−2.347	0.01893 *	1.0878	2.698	0.007 **	1	8.4176	0.004 **	1	7.8972	0.005 **

%), consume (2.5 %), or incinerate them (1.7 %).

Fig. 4 shows how they discard the livers that are not normally consumed. In Amazonian rural communities, livers were mainly discarded in forests (28.2 %), rivers (17.4 %) or given to dogs (13.2 %). In Amazonian cities, they were typically given to dogs (31.25 %) or thrown in the trash (21.9 %). In non-Amazonian rural areas, most affected livers were discarded in the forest (61.5 %) or given to dogs (20.5 %).

Furthermore, 62.4 % of all people surveyed reported owning dogs, significantly higher in non-Amazonian rural communities (94.9 %) than in rural Amazonian communities (53.5 %) ($P < 0.0001$). Of the

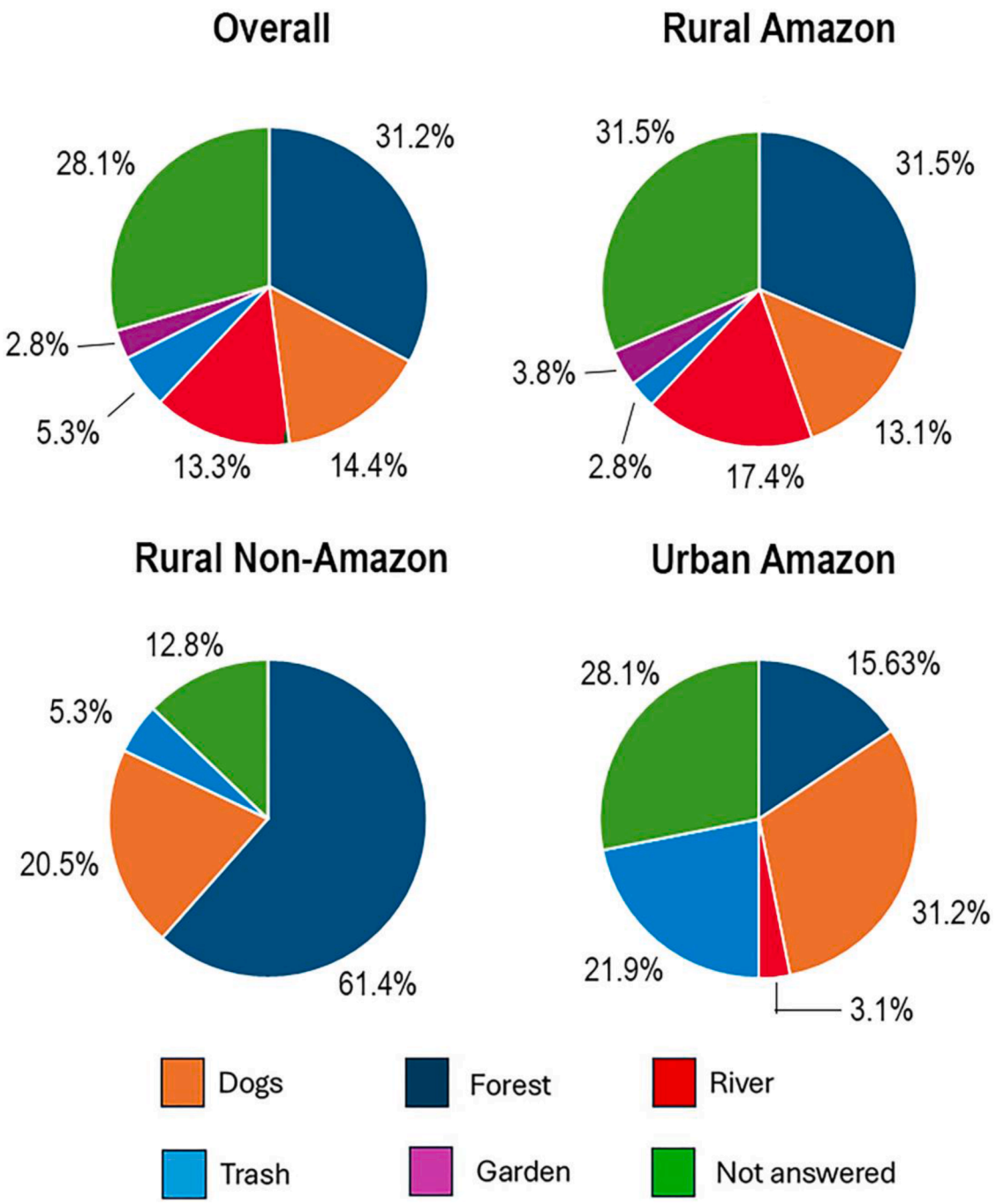


Fig. 4. Detail of the disposal location of the people surveyed when discarding unconsumed livers: general overview and by location-specific responses.

respondents, 53.3 % reported that dogs generally consume discarded viscera, with or without lesions. This practice was significantly more frequent in rural communities overall (Amazon (62.0 %) and non-Amazon (43.6 %)) compared to Amazonian cities (9.1 %; $P < 0.0001$ and $P = 0.005$, respectively). Additionally, only 37.5 % of respondents reported that they routinely dewormed their dogs, a practice especially uncommon in rural areas (Amazonian (13.1 %) and non-Amazonian (38.5 %; $P = 0.0006$)) compared to Amazonian cities (72.7 %; $P < 0.0001$ and $P = 0.0075$, respectively). Fig. 5 illustrates and summarizes the ease of NE transmission across natural barriers, based on questions previously mentioned, grouped by respondents' geographic regions.

For 38.9 % of the overall population surveyed, accessing health centers was a challenge ("difficult" or "very difficult"), and rurality was a significant factor influencing access to health centers ($P = 0.008$; Fig. 6). In Amazonian rural communities, 44.1 % reported "difficult" or "very difficult" accessing health services, significantly different compared to 15.2 % in Amazon cities ($P = 0.05$).

4. Discussion

Neotropical echinococcosis (NE) is a neglected tropical disease most common in communities that rely on wild meat as their primary source of animal protein (San-Jose et al., 2023). However, NE is severely underreported, and its full distribution remains largely unknown (Rodrigues-Morales et al., 2015). In this study, we aimed to understand the individual and cumulated risk behaviors that either promote or hinder the transmission of *E. vogeli* and assess the magnitude of risk across different types of human settlement within the distribution range

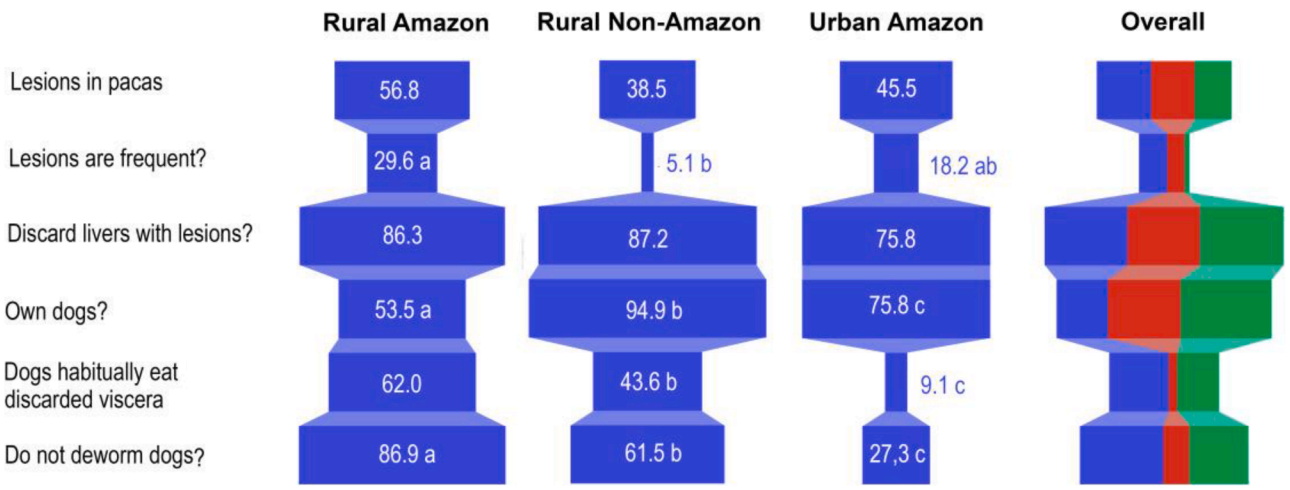


Fig. 5. Funnel plots illustrating the ease of NE transmission across various natural barriers. Wider funnels indicate greater ease of transmission, while narrower funnels highlight bottlenecks that typically prevent spread. The results are categorized by respondents' geographic locations, with Chi-square analysis results integrated to show statistical significance. 'a', 'b' and 'c' values in the same rows indicate significant differences ($p < 0.05$, see Table 1 for further details) ($n = 285$).

of NE.

E. vogeli cysts has been widely reported in pacas, domestic dogs, and bush dogs in rural South American communities, and particularly in the Amazon (Mayor et al., 2015; Bosmediano et al., 2023; Bittencourt-Oliveira et al., 2018; das Neves et al., 2017; Soares et al., 2014; Santos et al., 2012; D'Alessandro and Rausch, 2008), where subsistence activities like hunting create close interactions between humans and parasite hosts (San-Jose et al., 2023). However, human cases of NE have also been reported in other regions of Central and South America (WHO, 2001; D'Alessandro and Rausch, 2008). Notably, bush dogs and pacas inhabit a broad range of regions, from southern Mexico to tropical areas of Peru, Bolivia, Paraguay, Argentina, and Brazil (Rodrigues-Morales et al., 2015), and the presence of this parasite has been documented in domestic dogs, and bush dogs in non-Amazon regions (Vizcaychipi et al., 2013). Our findings align with this and show a greater frequency of observation of *E. vogeli* cysts in pacas from Amazonian rural communities, although cysts are also present less frequently beyond the rural Amazon region. The presence of *E. vogeli* cysts in pacas evidences the risk of transmission of the parasite.

This health risk is not directly related to the consumption of wild meat but is related to the consumption of wild meat offal; thus, wild meat trade chains become potential routes of transmission of the parasite, whenever the viscera, particularly the liver and lungs, are mobilized. In the Amazon, wild mammals are widely sold and consumed in urban areas (El Bizri et al., 2020; Mayor et al., 2022), and *E. vogeli* has already been detected in pacas in Amazonian urban markets (Tantaleán et al., 2012). Thus, as some respondents reported, urban regions are not excluded from the risk of transmission of the disease.

The main human behaviors identified in our study as drivers of disease transmission are related to the handling of paca viscera, and, in general, all prey hunted, and the handling of dogs, including their access to discarded viscera and deworming. When the lesion is observed in intermediate hosts, the human behavior that most effectively interrupts the parasite transmission cycle is the incineration of the viscera with lesions (Pandey et al., 2020). However, this behavior has been reported as a very rare behavior in our study population. Furthermore, in all communities, the routine behavior of most participants with the viscera, whether or not they observe lesions, is usually to feed them to animals or discard them in the forest. These discarding methods do not block the life cycle of the parasite, but, on the contrary, increase the risk of transmission to other potential hosts and allow recirculation of the parasite in areas closer to human communities. This scenario highlights the need for alternative management of viscera to mitigate transmission.

The introduction of domestic animals into rural communities has likely contributed significantly to the spread of zoonotic disease linked to wild meat practices, and particularly NE. Unlike pets in urban settings, domestic animals in rural communities are not confined indoors; they drink from rivers, roam freely in forests, and hunt wild animals (Winders and Menkin-Smith, 2023; Romig and Wassermann, 2024; Cook and Karesh, 2011; Guzman et al., 2024). As carnivores, cats and dogs often prey animals that serve as intermediate hosts for parasites, especially those with complex life cycles, and where they often act as definitive hosts (Han et al., 2021). Therefore, these animals play a pivotal role in the dissemination of parasites in sylvatic environments, harboring nematodes or other parasites in their guts and shedding eggs into the environment through their feces (Winders and Menkin-Smith, 2023; Romig and Wassermann, 2024). This interaction between domestic and wild cycles creates opportunities for spill-back, where parasites move from domestic to wild hosts, or vice versa, especially in regions lacking effective control programs (Romig and Wassermann, 2024).

In rural communities, dogs are usually fed using discarded organs and are also rarely treated with effective anti-parasitic medications, contributing to a high risk of parasite transmission due to environmental contamination. The concomitance of these two widespread practices in rural areas increases the risk of dissemination of *E. vogeli*, and other zoonoses linked to wild meat practices, since humans, and particularly children, can become infected through contact with feces from infected dogs (Mayor et al., 2015; Varcasia et al., 2011; Traversa et al., 2014).

Zoonotic transmission is an eco-epidemiological process in which a pathogen must overcome a series of natural barriers to effectively infect a new host species. Traditionally regarded as a singular event, it is increasingly conceived as a complex multilevel process. Lloyd-Smith et al. (2017) and Plowright et al. (2017) proposed a framework that breaks down zoonotic transmission into distinct subprocesses, each occurring within specific spatial and temporal windows necessary for an effective cross-species transmission. For each pathogen and geographical context, certain subprocesses will act as facilitators while others act as bottlenecks. In this study, we used LEK to break down the transmission of *E. vogeli* into different subprocesses, and illustrated our findings using funnel plots, inspired by Lloyd-Smith's and Plowright's work.

The rural Amazon has a high percentage (34.6 %) of population in poverty, and faces significant barriers to healthcare access, exacerbating health risks in these remote areas (PAHO, 2009; Badanta et al., 2020). Medical facilities are often distant, leaving many communities without timely care. The COVID-19 pandemic particularly affected Indigenous communities in the rural Amazon, where limited Intensive Care Unit

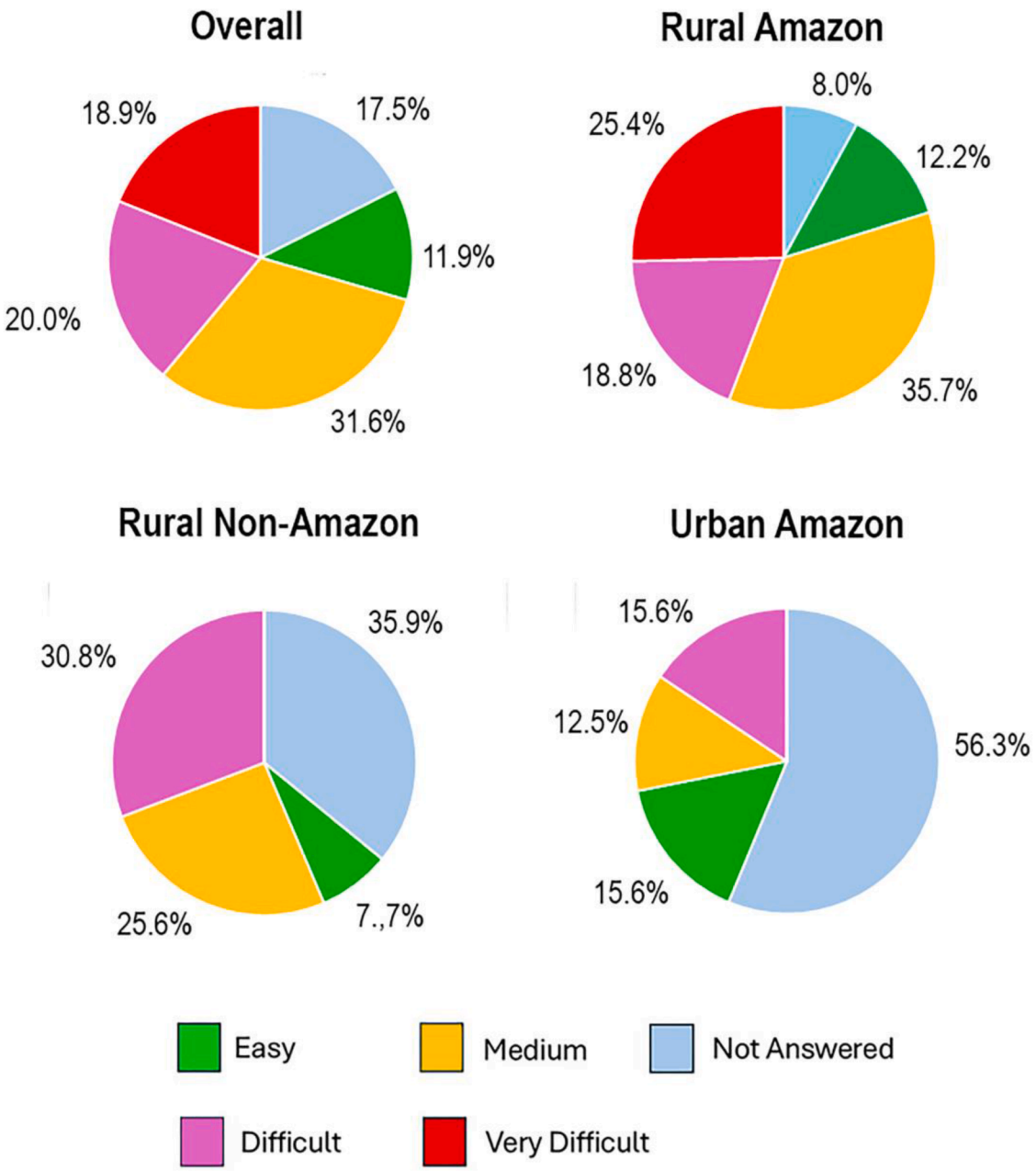


Fig. 6. Detail of the access to health services of the people surveyed: general overview and by location-specific responses.

availability, overcrowded housing, and limited healthcare systems made it difficult to contain the virus and respond effectively (WHO, 2020; ILO, 2020; Amazon Regional Observatory, 2022; Abizaid et al., 2024). The neglect of these populations in terms of health services and poverty may contribute to the underreporting and limited research on diseases, perpetuating a cycle where both the diseases and the affected communities remain understudied. This was reflected in our study, where most rural inhabitants reported difficulties in accessing medical assistance, increasing a significant diagnostic gap and consequent delay in treatment and severe disease progression to chronic conditions (D'Alessandro, 2010). Furthermore, awareness of the health risks posed by these cysts is lower in rural areas, which complicates mitigation of the risk behaviors and further delays timely diagnosis and treatment.

Our study faces some limitations that are important to discuss as they may result in bias in our results. Firstly, the identification of NE was based solely on respondents' observation of liver lesions compatible with NE in pacas, and no histopathological or molecular confirmation of *E. vogeli* infection was performed. Despite the lack of a definitive diagnosis, the reported observation of cyst-like lesions in pacas may indicate potential areas of parasite circulation and the risk of transmission of the disease to humans, particularly through the consumption of infected offal by domestic dogs. These findings underscore the ecological and behavioral dimensions of NE transmission, providing a fundamental basis for addressing this neglected disease. While this identification of the lesion was necessarily perceptive— as they are based on LEK —the coincidence within the reported geographic range in the Amazon region (San José et al., 2023) supports the relevance of these observations despite the lack of parasitological confirmation. Nevertheless, future studies are still needed to confirm the territorial range of the parasite through molecular analysis. Secondly, this study was subject to certain limitations due to its decentralized, community-based design. Even though a consensual structured interview guide and site-specific language adaptations were used to ensure consistency, variability in how different interviewers applied these tools across regions may have

introduced some degree of interviewer bias. Additionally, the high proportion of male respondents may have limited the representation of diverse gender perspectives. These limitations reflect the logistical challenges of conducting fieldwork in remote and culturally diverse settings.

5. Conclusion

Understanding how people are exposed to environmental hazards and risks, particularly wildlife-transmitted diseases, is crucial to developing effective prevention strategies (Sultana, 2021). The risk of NE transmission in the rural Amazon is higher, although urban and non-Amazonian regions may also be exposed through the wild meat trade chain. Domestic animals play a direct role in the transmission and maintenance of zoonotic cycles linked to wild meat practices and particularly *E. vogeli.* Domestic animals enable sylvatic cycles to transition into domestic environments, above all in rural settlements where they are often not subject to sanitary control. This highlights the importance of considering both wildlife handling and domestic animals in health prevention systems. Preventive strategies should focus on their proper sanitary management to address zoonotic diseases related to the wild meat chain, especially in rural areas, that are often overlooked by healthcare systems, by raising awareness and promoting low-cost, culturally appropriate solutions that align with local practices and traditions.

Ethics approval

Research transparency and compliance with medical research ethics protocols, as established by the Declaration of Helsinki ('World Medical Association Declaration of Helsinki', 2013), were strictly followed. We followed the rules and guidelines for applying free, prior and informed consent as detailed in Buppert and McKeehan (2013). No personal information enabling participant identification was collected, and participants were informed of the option to withdraw from the study at any time. The project description, outlining objectives and expected outcomes were provided before accessing the questionnaire. This research was approved by the Ethics Committee of the Executive Directorate of Forestry and Wildlife (Perú) (007–2017-GRL-GGR-ARA-DEFFS), the Cayetano Heredia Peruvian University (Peru) (102,142; 8 May 2019), the Autonomous University of Barcelona (Spain) (CEEAH 4829; 13 December 2019), the Clinic Hospital of Barcelona (Spain) (HCB/2019/1107; 19 December 2019), the Secretary of Environment of Salta (Argentina) (000,180/19–22; 227–121,685/21), and the Aparício Carvalho University Center (Brazil) (2.661.332). This study was also presented to the regional and local authorities in Perú (n° 267–2019-GRLDRSL/30.09.01).

Funding

This work was supported by ERANet-LAC (ERANet17/HLH-0271). F. D.M.S. thanks partial funding for fieldwork from Tides Foundation (Grant #1905–59572), Azara Fundation and S.O.S. Wild Action. M.F.M. acknowledges a doctoral scholarship from the Catalan Agency for Management of University and Research Grants [scholarship FI-SDUR EMC/3345/2020].

CRediT authorship contribution statement

María Fernanda Menajovsky: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Adrià San José:** Software, Methodology, Investigation, Formal analysis, Conceptualization. **Marcela Alvares Oliveira:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation. **Joao Campos-Silva:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Data curation. **Pedro Pérez Peña:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation. **José Eduard Hernández-Guevara:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation. **Jhon Bosmediano:** Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation. **Joe Saldaña:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation. **Fernando Del Moral Sachetti:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation. **Graciela Meza-Sanchez:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation. **Xavier Rodó:** Writing – review & editing, Writing – original draft, Visualization, Validation, Conceptualization. **Pedro Mayor:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Pedro Mayor reports financial support was provided by ERANet-LAC. Fernando Del Moral Sachetti reports financial support was provided by Azara Fundation. Fernando Del Moral Sachetti reports was provided by S.O.S. Wild Action. Fernando Del Moral Sachetti reports was provided by Tides Foundation. Maria Fernanda Menajovsky reports was provided by Catalan Agency for Management of University and Research Grants. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We want to thank all participants from the communities studied, who actively took part in the data collection and surveys, providing valuable information. This participation highlights the significance of community participation in disease control in particular in isolated or neglected communities. We would also like to express our gratitude to Hani R. El Birzi for his advice and to the Wildlife Management Community in the Amazon and Latin America (ComFauna).

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.actatropica.2025.107701.

Data availability

The research data have been included in the supplementary material.

References

Abizaid, C., Takasaki, Y., Coomes, O.T., 2024. COVID-19 and protection measures adopted in rural amazon communities during the first months of the pandemic. Rev. Peru. Med. Exp. Salud Publica 41, 239–246.

Observatory, Amazon Regional, 2022. Organization of the amazon cooperation treaty. Vale do Javari – Brazil-Peru border. Obs. Reg. Amaz. Available online https://oraotca.org/en/health-at-the-borders/vale-do-javari-brazil-peru-border (accessed on 15 November 2024).

Badanta, B., Lucchetti, G., Barrientos-Trigo, S., Fernández-García, E., Tarriño-Concejero, L., Vega-Escaño, J., de Diego-Cordero, R., 2020. Healthcare and health problems from the perspective of indigenous population of the Peruvian Amazon: a qualitative study. Int. J. Environ. Res. Public Health 17 (21), 7728.

... & Bittencourt-Oliveira, F., Teixeira, P., Alencar, A., Menezes, R., Corrêa, C., Neves, L., Rodrigues-Silva, R., 2018. First parasitological, histopathological and molecular characterization of Echinococcus vogeli Rausch and Bernstein, 1972 from Cuniculus paca Linnaeus, 1766 in the Cerrado biome (Mato Grosso do Sul, Brazil). Vet. Parasitol 250, 35–39.

Bosmediano Ramírez, J.L., Ruiz Ramírez, J.B., Gómez Puerta, L., Gavidia, C.M., Mayor, P., Vizcaychipi, K.A., 2023. Equinococosis neotropical en Cuniculus paca (Linnaeus 1766) y *Dasypus novemcinctus* (Linnaeus 1758), en la cuenca alta del Río Itaya, Perú. Rev. vet. 34 (2), 1–6.

Buppert, T., McKeehan, A., 2013. Guidelines For Applying free, Prior and Informed consent: a Manual For Conservation International. Conservation International, Arlington, VA, USA.

Charnley, S., Fischer, A.P., Jones, E.T., 2007. Integrating traditional and local ecological knowledge into forest biodiversity conservation in the Pacific Northwest. For. Ecol. Manage 246 (1), 14–28.

Cook, R.A., Karesh, W.B., 2011. Emerging diseases at the interface of people, domestic animals, and wildlife. Fowler's Zoo Wild Anim. Med. 136.

D'Alessandro, A., Rausch, R.L., 2008. New aspects of neotropical polycystic (Echinococcus vogeli) and unicystic (Echinococcus oligarthrus) echinococcosis. Clin. Microbiol. Rev 21 (2), 380–401.

D'Alessandro, A., 2010. Hidatidosis poliquística tropical por Echinococcus vogeli. Rev. Asoc. Méd. Argent 123, 16–23.

... & das Neves, L.B., Teixeira, P.E.F., Silva, S., de Oliveira, F.B., Garcia, D.D., de Almeida, F.B., Machado-Silva, J.R., 2017. First molecular identification of Echinococcus vogeli and Echinococcus granulosus (sensu stricto) G1 revealed in feces of domestic dogs (Canis familiaris) from Acre. Braz. Parasites Vectors 10, 1–6.

Eckert, J., Deplazes, P., 2004. Biological, epidemiological, and clinical aspects of echinococcosis, a zoonosis of increasing concern. Clin. Microbiol. Rev. 17 (1), 107–135.

... & El Bizri, H.R., Morcatty, T.Q., Valsecchi, J., Mayor, P., Ribeiro, J.E., Vasconcelos Neto, C.F., Fa, J.E., 2020. Urban wild meat consumption and trade in central Amazonia. Conserv. Biol. 34 (2), 438–448.

... & Guzmán, D.A., Diaz, E., Sáenz, C., Álvarez, H., Cueva, R., Zapata-Ríos, G., Barragan, V., 2024. Domestic dogs in indigenous Amazonian communities: key players in Leptospira cycling and transmission?. PLoS Negl. Trop. Dis. 18 (4), e0011671.

Han, B.A., Castellanos, A.A., Schmidt, J.P., Fischhoff, I.R., Drake, J.M., 2021. The ecology of zoonotic parasites in the Carnivora. Trends Parasitol. 37 (12), 1096–1110.

International Labour Organization., 2020. COVID-19 and the World of work: Ensuring no One is Left Behind in the Informal Economy. International Labour Organization, Geneva. Available online. https://www.ilo.org/sites/default/files/wcmsp5/groups/public/@dgreports/@dcomm/documents/publication/wcms_746893.pdf (accessed on 15 November 2024).

Joa, B., Winkel, G., Primmer, E., 2018. The unknown known–a review of local ecological knowledge in relation to forest biodiversity conservation. Land Use Policy 79, 520–530.

... & Knapp, J., Chirica, M., Simonnet, C., Grenouillet, F., Bart, J.M., Sako, Y., Millon, L., 2009. Echinococcus vogeli infection in a hunter, French Guiana. Emerg. Infect. Dis. 15 (12), 2029.

Lloyd-Smith, J.O., 2017. Predictions of virus spillover across species. Nature 546 (7660), 603–604.

... & Mayor, P., El Bizri, H.R., Morcatty, T.Q., Moya, K., Bendayán, N., Solis, S., Bodmer, R.E., 2022. Wild meat trade over the last 45 years in the Peruvian Amazon. Conserv. Biol. 36 (2), e13801.

Mayor, P., Baquedano, L.E., Sanchez, E., Aramburu, J., Gomez-Puerta, L.A., Mamani, V. J., Gavidia, C.M., 2015. Polycystic echinococcosis in pacas, amazon region, Peru. Emerg. Infect. Dis. 21 (3), 456.

Pan American Health Organization (PAHO). (2009). Health services delivery in areas inhabited by indigenous peoples (Washington).

Pandey, P., Vidyarthi, S.K., Vaddella, V., Venkitasamy, C., Pitesky, M., Weimer, B., Pires, A.F., 2020. Improving biosecurity procedures to minimize the risk of spreading pathogenic infections agents after carcass recycling. Front. Microbiol. 11, 623.

Plowright, R.K., Parrish, C.R., McCallum, H., Hudson, P.J., Ko, A.I., Graham, A.L., Lloyd-Smith, J.O., 2017. Pathways to zoonotic spillover. Nat. Rev. Microbiol. 15 (8), 502–510.

R Core Team, 2023. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available online. https://www.R-project.org (accessed on 15 July 2024).

Rodriguez-Morales, A.J., Calvo-Betancourt, L.S., Alarcón-Olave, C., Bolívar-Mejía, A., 2015. Echinococcosis in Colombia—a neglected zoonosis? In Current Topics in Echinococcosis. IntechOpen.

Romig, T., Wassermann, M., 2024. Echinococcus species in wildlife. Int. J. Parasitol.: Parasites Wildl., 100913

... & San-José, A., Mayor, P., Carvalho, B., El Bizri, H.R., Antunes, A.P., Antunez Correa, M., Rodó, X., 2023. Climate determines transmission hotspots of Polycystic Echinococcosis, a life-threatening zoonotic disease, across Pan-Amazonia. Proc. Natl. Acad. Sci. 120 (33), e2302661120.

... & Santos, G.B., do CP Soares, M., Brito, E.M.D.F., Rodrigues, A.L., Siqueira, N.G., Gomes-Gouvêa, M.S., Haag, K.L., 2012. Mitochondrial and nuclear sequence polymorphisms reveal geographic structuring in Amazonian populations of Echinococcus vogeli (Cestoda: taeniidae). Int. J. Parasitol 42 (13–14), 1115–1118.

... & Soares, M.D.C.P., de Souza, A.J.S., Malheiros, A.P., Nunes, H.M., Carneiro, L.A., Alves, M.M., Póvoa, M.M., 2014. Neotropical echinococcosis: second report of Echinococcus vogeli natural infection in its main definitive host, the bush dog (Speothos venaticus). Parasitol. Int 63 (2), 485–487.

... & Sultana, R., Luby, S.P., Gurley, E.S., Rimi, N.A., Swarna, S.T., Khan, J.A., Jensen, P. K.M., 2021. Cost of illness for severe and non-severe diarrhea borne by households in a low-income urban community of Bangladesh: a cross-sectional study. PLoS Negl. Trop. Dis. 15 (6), e0009439.

Tantalean, M.V., Angulo, J.V., Martinez, R.R., Diaz, S.M., 2012. First record of the Echinococcus vogeli (Cesotda, Taeniidae) metacestod in finding in Iquitos. Peru. Peruv. J. Parasitol. 20, 74–76.

Traversa, D., Frangipane di Regalbono, A., Di Cesare, A., La Torre, F., Drake, J., Pietrobelli, M., 2014. Environmental contamination by canine geohelminths. Parasit Vectors 7, 1–9.

... & van Vliet, N., Muhindo, J., Nyumu, J., Enns, C., Massé, F., Bersaglio, B., Nasi, R., 2022. Understanding factors that shape exposure to zoonotic and food-borne diseases across wild meat trade chains. Hum. Ecol. 50 (6), 983–995.

... & Varcasia, A., Tanda, B., Giobbe, M., Solinas, C., Pipia, A.P., Malgor, R., Scala, A., 2011. Cystic echinococcosis in Sardinia: farmers' knowledge and dog infection in sheep farms. Vet. Parasitol 181 (2–4), 335–340.

Vizcaychipi, K.A., Helou, M., Dematteo, K., Macchiaroli, N., Cucher, M., Rosenzvit, M., D'Alessandro, A., 2013. First report of Echinococcus vogeli in a paca in Misiones province, Argentina. Rev. Argent Microbiol. 45 (3), 169–173.

World Health Organization, 2020. WHO Director-General's opening Remarks At the Media Briefing On COVID-19. Available online. https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19—20-july-2020 (accessed on 15 November 2024).

Winders, W.T., Menkin-Smith, L., 2023. Toxocara Canis. StatPearls Publishing, Treasure Island (FL). Available from. https://www.ncbi.nlm.nih.gov/books/NBK538524/.

Wolfe, N.D., Daszak, P., Kilpatrick, A.M., Burke, D.S., 2005. Bushmeat hunting, deforestation, and prediction of zoonotic disease. Emerg. Infect. Dis. 11 (12), 1822.

World Health Organization Office International des Epizooties, 2001. WHO/OIE Manual on Echinococcosis in Humans and Animals: A Public Health Problem of Global Concern. World Organization for Animal Health, Paris, France.

World Medical Association Declaration of Helsinki, 2013. Ethical principles for medical research involving human subjects. JAMA 310 (20), 2191. https://doi.org/10.1001/jama.2013.281053.