

Infestation, histology, and molecular confirmation of *Sarcoptes scabiei* in an Andean porcupine (*Coendou quichua*) from the Central Andes of Colombia

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ABSTRACT

Sarcoptic mange is a highly contagious, worldwide disease that affects the skin of mammals, including humans. It is caused by the mite *Sarcoptes scabiei*, however, the information available in wild mammal populations in the world, and particularly in Colombia is limited. Here, we document a new case of sarcoptic mange in an Andean porcupine (*Coendou quichua*) from the Andean region of Colombia. We morphologically and molecularly confirmed the mite as *S. scabiei* and documented the histopathology associated with scabies, and show the different stages of the life cycle of *S. scabiei* from the Andean porcupine skin samples. Our review of reports of additional cases of scabies in wild mammal species in South America showed 15 species, mostly carnivores, artiodactyls, and rodents. Considering the limited information in Colombia, it is urgent to evaluate the risk of this condition on mammals which would contribute to the epidemiological knowledge and the potential implications of sarcoptic mange in the ecology and conservation of wild mammals in the country.

1. Introduction

Sarcoptic mange is a highly contagious, worldwide disease that affects the skin of mammals (Bornstein et al., 2001; Pence and Ueckermann, 2002). About 148 species of mammals, including humans, have been reported with this disease, whose causal agent is a single mite species (*Sarcoptes scabiei* De Geer, 1778) with several strains adapted to the host (Bornstein et al., 2001; Gonzalez-Astudillo et al., 2018; Escobar et al., 2021). *S. scabiei* associated disease is due to a combination of direct skin damage and host reaction to antigenic material from mites, eggs, and feces (Bornstein et al., 2001; Pence and Ueckermann, 2002). The mite is deposited in tunnels excavated in the epidermis that, together, produce a series of characteristic skin lesions. These lesions

include dermatitis, alopecia, hyperkeratosis, and hyperpigmentation of the skin that predispose the affected animal to secondary infections (Pence and Ueckermann, 2002; Niedringhaus et al., 2019). In severely affected animals, the disease can cause apathy, emaciation, dehydration and, in some cases, death (Bornstein et al., 2001; Pence and Ueckermann, 2002; Rossi et al., 2007).

The developmental stages of *S. scabiei* consist of egg, larva, protonymph, tritonymph, and adult (Arlian and Morgan, 2017). The average number of eggs laid by females daily is 2 or 3, which hatch 3–4 days after oviposition (Arlian, 1989; Arlian and Morgan, 2017; Mullen and Oconnor, 2019). The larvae actively crawl out of the burrow onto the skin surface to dig shallow burrows and there they moult to the nymphal stage around 3 days later, just as nymphs moult into adults in

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approximately 3–4 days (Arlian, 1989; Arlian and Morgan, 2017; Mullen and O'Connor, 2019). Morphological characteristics of adult *S. scabiei* mites include an oval, ventrally flattened and dorsally convex body, robust dorsal setae, numerous triangular cuticular spines on its dorsal surface that help them to excavate and cuticular striae with transverse grooves. The spines are more numerous and conspicuous in females than in males (Arlian and Morgan, 2017). Males (213–285 μm long by 162–210 μm wide) are about two thirds the size of females (300–504 μm long by 230–420 μm wide). The gnathosoma (capitalum) consists of short, stout chelicerae and pedipalps. The legs are short, with legs I and II of the females and legs I–III of the males bear a stalked empodium that terminate in a broad pad. While, the two hind pairs of legs of the females and the last pair of legs in the male lack a empodium and instead terminate in long setae or bristles (Arlian and Morgan, 2017).

Limited information is available on sarcoptic mange disease in wild mammal populations (Forchhammer and Asferg, 2000; Tompkins et al., 2015). For example, there are approximately 22 available reports of sarcoptic mange in wild animals in South America, and many of these reports are associated with animals kept in captivity (Alvarado et al., 1966; Whitaker and Dietz, 1987; Pantoja López et al., 1989; Oliveira et al., 2000; Ramos Acuña et al., 2000; Deem et al., 2002; Arzamendia et al., 2012; De Souza Muniz Neta et al., 2012; Corriale et al., 2013; Gomez-Puerta et al., 2013; Robles et al., 2014; Verdugo et al., 2016; Berger et al., 2017; de Almeida et al., 2018; Gonzalez-Astudillo et al., 2018; Teodoro et al., 2018). Particularly in Colombia, one of the countries with the greatest diversity of mammals globally (Ramírez-Chaves et al., 2021), the presence of sarcoptic mange has been reported in porcupines (*Coendou quichua* Thomas, 1899) and a possible case in a kinkajou (*Potos flavus* Schreber, 1774) (Gonzalez-Astudillo et al., 2018; Salcedo-Rivera et al., 2018). In both cases, the individuals presented severe and advanced lesions, distributed throughout the body.

Sarcoptic mange is considered a “low priority disease” in countries such as Colombia (Rentería, 2010), which limits the epidemiological understanding, report and its possible consequences in wild populations (Pence and Ueckermann, 2002; Tompkins et al., 2015). Nonetheless monitoring its incidence in wild animals is important given its ability to affect host density, especially in the case of isolated populations, genetically compromised, or threatened species (Pence and Ueckermann, 2002; Rossi et al., 2007; Gortázar et al., 2016). In this context, and to contribute to the epidemiological knowledge and the potential implications of sarcoptic mange on the ecology and conservation of wild mammal species, we report new case of sarcoptic mange in a porcupine from the Andean region of Colombia and a review of wild mammal species affected by *S. scabiei* on a continental scale.

2. Material and methods

2.1. Data collection

On March 13, 2021, a male individual of *C. quichua* was found dead at the buffer zone of the Selva de Florencia National Natural Park, Municipality of Samaná, Caldas – Colombia (5°29'N, 75°04'W, 1625 m a.s.l.). The porcupine showed advanced epidermal lesions, emaciation, and unfavorable prognosis, and was transferred to the Museo de Historia Natural of the Universidad de Caldas (MHN-UCa) and deposited under catalog number MHN-UCa 3432. To evaluate the lesions and areas most affected by the mite, we performed a general examination of the individual. In addition, we took standard morphometric measurements and weight, and we determined the sex and age of the individual based on cranial development and the presence of all molars. Subsequently, we took skin samples from the lesions found in the abdominal and inguinal region, which were stored in 2 ml eppendorf tubes with 70% ethanol, for the subsequent morphologic and molecular identification (Deem et al., 2002). For the observation of the *S. scabiei* mites, a scraping of porcupine skin samples was made on a slide and a drop of water was added and the sample was later observed under an optical microscope (Nikon Eclipse

E200). The identification was based on morphological characters (Mullen and O'Connor, 2019). We also performed molecular identification of *S. scabiei* mites by amplifying and sequencing the 135 bp mitochondrial 16 S rDNA fragment, using universal primers (Angelone-Alasaad et al., 2014). Following the protocol described by Gonzalez-Astudillo et al. (2018). We analyzed the obtained sequences using the Basic Local Alignment Search Tool - BLAST (Altschul et al., 1990) to determine the closest similarities with other mite species.

For the histological analysis, we fixed the skin samples in 10% buffered formaldehyde for 12 h. The tissue samples were then dehydrated in increasing concentrations of ethanol (30, 50, 70, 80, 90, and 95%) for 30 min at each concentration. The samples were included in Leica histo-resin (inclusion) for 2 weeks (with a refill every 3 days) and polymerized in the same histo-resin to obtain 3 μm sections using a LEICA RM2235 microtome. The sections were placed on glass slides, stained with hematoxylin-eosin (HE), and photodocumented on a Nikon Eclipse E200 photomicroscope.

2.2. Literature review

To detect the number of reports of sarcoptic mange in wild animals in South America, we performed a literature search without time restrictions. The search was performed using the terms “sarcoptes AND wild” for all the publications available in the Scopus and Google Scholar databases, until April 2022. After reviewing the titles and abstracts, we selected those studies that reported on the species parasitized with sarcoptic mange, their condition in captivity or in the wild, and the country where the study was conducted. Studies where experimental infections were performed were omitted. Finally, we generated a table with the information extracted from the selected studies, indicating the mammal families and the condition in captivity or in the wild, in addition to indicating the country, the authors and the year of publication of the study (Table 1).

3. Results

The *Coendou quichua* individual, was identified as an adult male, with a total length of 650 mm and a weight of 1600 g. The macroscopic lesions observed in the skin correspond to hyperkeratosis, and some areas with alopecia, which extend ventrally from the chest to the inguinal region and base of the tail (Fig. 1A and B). Additionally, we observed hyperkeratosis in the mandible and the forelimbs and hindlimbs up to the carpal and tarsal joints, respectively. Laterally, the lesions appeared from the gluteal to the tibial region in both limbs and dorsally at the base of the tail (Fig. 1A and B). The histopathological assessment reflected severe changes included a marked epidermal necrosis and epidermolysis with severe hyperkeratosis-acanthosis and pustules (Fig. 1C and D). We found evidence of multiple intralesional mite structures, characterized by a cuticle with peripheral and dorsal horns, hatched egg fragments and intraepidermal coalescing tunnels (Fig. 1D and E). The morphological characteristics of the adult mites evaluated in the present study match the diagnostic traits described in the literature for *S. scabiei* (Arlian and Morgan, 2017) (Fig. 1F–H). The partial sequence of 16 S was 100% identical with samples of *S. scabiei* obtained from *C. quichua* from the Department of Santander, Colombia [MG645006]. The GenBank accession number for the sequence generated in this study is ON361535.

Histological analyzes allowed the observation of different stages of the life cycle of *S. scabiei* mites within the affected skin of the porcupine (Fig. 2). We identified the frequent presence of permanent burrows dug by fertilized adult females, with the presence of 2–3 eggs and/or eggshells inside (Fig. 2A–C). Likewise, developing eggs were observed within the maternal burrows in the stratum corneum of the skin (Fig. 2D–F). Developing larvae were identified in the superficial layer of the skin (Fig. 2G and H). We observed nymphs below the surface of the skin (Fig. 2I). We identified the predominant presence of adult females

Table 1

Reports of sarcoptic mange in wild mammals in South America from 1966 to 2022. Origin: Captivity or in the Wild.

Taxon	Common name	Species	Origin	Country	References
Bradyrodidae	Brown-throated sloth	<i>Bradypus variegatus</i>	Captivity	Brazil	Oliveira et al. (2000)
Artiodactyla					
Camelidae	Alpaca	<i>Lama pacos</i>	Captivity	Peru	Alvarado et al. (1966)
Camelidae	Alpaca	<i>Lama pacos</i>	Captivity	Peru	Ramos Acuña et al. (2000)
Camelidae	Vicuña	<i>Lama vicugna</i>	Wild	Argentina	Arzamendia et al. (2012)
Camelidae	Vicuña	<i>Lama vicugna</i>	Captivity	Argentina	Sosa et al. (2022)
Camelidae	Vicuña	<i>Lama vicugna</i>	Wild	Peru	Gomez-Puerta et al. (2013)
Camelidae	Vicuña	<i>Lama vicugna</i>	Captivity – Wild	Peru	Angulo-Tisoc et al. (2021)
Cervidae	Brocket deer	<i>Mazama sp.</i>	Wild	Colombia	Instituto Agropecuario Colombiano – ICA et al., 2015
Tayassuidae	Collared peccary	<i>Dicotyles tajacu</i>	Captivity	Brazil	De Souza Muniz Neta et al. (2012)
Carnivora					
Canidae	Crab-eating Fox	<i>Cerdocyon thous</i>	Wild	Brazil	de Almeida et al. (2018)
Canidae	Crab-eating Fox	<i>Cerdocyon thous</i>	Wild	Brazil	Teodoro et al. (2018)
Canidae	Maned Wolf	<i>Chrysocyon brachyurus</i> ^a	Wild	Bolivia	Diaz Luque et al. (2014)
Canidae	Pampas fox	<i>Lycalopex gymnocercus</i>	Wild	Bolivia	Deem et al. (2002)
Canidae	South American Gray Fox	<i>Lycalopex griseus</i>	Wild	Chile	Verdugo et al. (2016)
Canidae	Hoary fox	<i>Lycalopex vetulus</i>	Wild	Brazil	Whitaker and Dietz (1987)
Procyonidae	White-nosed coati	<i>Nasua narica</i>	Wild	Ecuador	Villalba-Briones et al. (2022)
Procyonidae	Kinkajou	<i>Potos flavus</i> ^a	Wild	Colombia	Salcedo-Rivera et al. (2018)
Rodentia					
Erethizontidae	Andean porcupine	<i>Coendou quichua</i>	Wild	Colombia	Gonzalez-Astudillo et al. (2018)
Caviidae	Guinea pig	<i>Cavia porcellus</i>	Captivity	Colombia	Pantoja López et al. (1989)
Caviidae	Guinea pig	<i>Cavia porcellus</i>	Captivity	Peru	Robles et al. (2014)
Caviidae	Capybara	<i>Hydrochoerus hydrochaeris</i>	Captivity	Argentina	Lombardeiro et al. (1983)
Caviidae	Capybara	<i>Hydrochoerus hydrochaeris</i>	Captivity	Venezuela	Riveira (1983)
Caviidae	Capybara	<i>Hydrochoerus hydrochaeris</i>	Captivity	Brazil	Corriale et al. (2013)

^a Animals with lesions similar to those of sarcoptic mange, but unconfirmed.

of *S. scabiei* in tunnels of the epidermis, in which it was possible to identify different structures such as the short and wide gnathosoma, the globose idiosoma, the short and conical legs (I, II and III), covered by a thin chitinous layer (Fig. 2J). Finally, we identified structures associated with the female reproductive system (Fig. 2J), such as the spermatheca (sp), the ovarian nurturing cell (ONC) located inside the ovary (ov), the vitellogenic oocyte (oc) in the oviduct (ovd), as well as the chorionic gland (chg) near the ovipore (op).

Sarcoptic mange affects several wild species in South America (Table 1). In the literature review, reports of 15 species were found, mostly carnivores (seven species), followed by artiodactyls and rodents, with four and three species, respectively, and finally, folivores with one species (Fig. 3). Of the 23 studies found from 1966 to 2022, 43.5% of the cases refer to animals infested with scabies kept in captivity, 52.2% to animals found with this condition in the wild and, 8.6% to animals in the wild with lesions similar to those of sarcoptic mange but unconfirmed.

4. Discussion

Our finding represents the second report (third case) of infestation on a continental scale for *C. quichua* that already had records of sarcoptic mange in Colombia (Gonzalez-Astudillo et al., 2018). The macroscopic lesions recorded match those reported by other authors (Pence and Ueckermann, 2002; Gonzalez-Astudillo et al., 2018; Niedringhaus et al., 2019), which indicates that scabies considerably affect these rodents whose particular coat covered by quills can increase the severity of injuries. Alopecia and intense itching induced by chronic scabies infections may increase energy demands for thermoregulation, cause scratching, and trigger immune responses (Bornstein et al., 2001; Newman et al., 2002). These energy demands can lead to a reduction in body mass and fat reserves (Newman et al., 2002; Verdugo et al., 2016), as may have occurred in this porcupine.

The Andean porcupine, *C. quichua* is distributed from Panama, in western Colombia, to Ecuador, from sea level to 3300 m a.s.l. (Voss, 2003; Ramirez-Chaves et al., 2016). This species is classified as Data Deficient according to the International Union for Conservation of Nature - IUCN (Delgado, 2016) and Vulnerable in Ecuador, according to the red book of mammals in this country (Tirira, 2011). Although little is

known about its natural history *C. quichua* is a solitary, nocturnal and mostly arboreal species but can use natural burrows, its diet is mainly leaves and fruits (Voss, 2015). Natural burrows provide a suitable microclimate for the survival of *S. scabiei* mites, which is why the use of these resting areas by *C. quichua* could favor opportunities for indirect and/or environmental transmission of the mite on a small scale (Kołodziej-Sobocińska et al., 2014; Montecino-Latorre et al., 2019).

The results of our review revealed that sarcoptic mange is spreading geographically among wildlife hosts in South America (Table 1). Possible explanations for these geographic expansions include transmission to populations that lack immune resistance (Peltier et al., 2017). Indeed, the introduction of virulent pathogens and parasites into virgin host populations can lead to significant population declines and localized extinctions (Tompkins et al., 2015; Gonzalez-Astudillo et al., 2018), escalating from outbreaks isolates that can become epizootics (Carvalho et al., 2015). Sarcoptic mange epizootics have been associated with high mortality, but most populations recover (Pence and Ueckermann, 2002). Nonetheless, due to the limited population information on porcupines and kinkajous in Colombia (Ramirez-Chaves et al., 2016; 2020), it is urgent to evaluate the risk of this condition on their populations, which would add to the problems that the species faces that include deforestation and habitat fragmentation driven by agriculture (Delgado, 2016).

It is also interesting to highlight that in the same area (and the same year) where the porcupine was found, there were unpublished observations of two kinkajous (*Potos flavus*) with lesions similar to those reported by Salcedo-Rivera et al. (2018) (Fig. 1S). Both species affected are mainly arboreal (Voss, 2015; Nascimento et al., 2017), and were reported inside a National Park, we expect low contact of both species with domestic animals such as dogs and cattle. In fact, *C. quichua* and *P. flavus*, are considered more susceptible to developing clinical signs of sarcoptic mange compared to domestic animals, due to the lack of immunological resistance and increased susceptibility to environmental stress, which is why wild hosts tend to develop exaggerated anti-inflammatory, anti-immune and anti-complement responses, generating severe sarcoptic mange as in these reported cases (Martin et al., 1998; Arlian and Morgan, 2017). The above shows that there is a need to evaluate the risk of mange on wild mammals in other protected and non-protected areas of the country. Likewise, it is important to

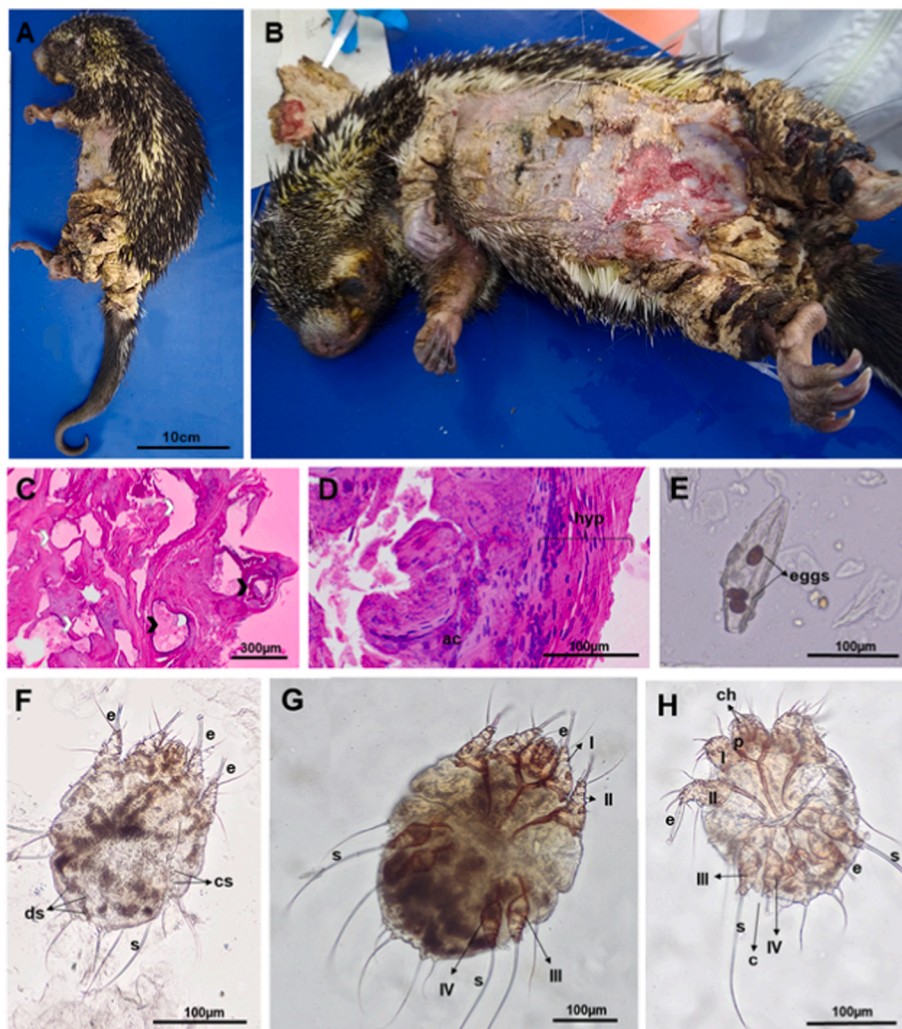


Fig. 1. *Coendou quichua* with macroscopic lesions corresponding to hyperkeratosis and alopecia, which extend ventrally from the chest to the inguinal region and base of the tail, hyperkeratosis is also observed in the mandible and the fore and hind limbs up to the carpal and tarsal joints (A, B). Histopathological microphotographs of mangy skin of *C. quichua*, with the presence of tunnels with (black arrow heads) and without (white arrow heads) mites (*Sarcoptes scabiei*) in the stratum corneum (C) and skin with predominance of hyperkeratosis (hyp) and acanthosis (ac) (D). Light micrographs of: *S. scabiei* eggs (E). Dorsal view of a female with the presence of robust dorsal setae (ds), numerous and conspicuous triangular cuticular spines (cs) on its dorsal surface (F). Ventral view of a female with the presence of the legs short, with legs I and II bear a stalked empodium (e) that terminate in a broad pad, and the two hind pairs of legs (III and IV) terminate in long setae or bristles (s) (G). Ventral view of a male with the legs I, II and III bear a stalked empodium (e) that terminate in a broad pad and the last pair (IV) of legs terminate in long setae (s) (H). ch (chelicerae), p (pedipalps).

consider disease management actions such Sarcoptic mange in Protected Areas, particularly in the PNN Selva de Florencia.

For other species, epizootics with large numbers of deaths and even the extinction of some localized populations, often showing signs of recovery, have been recorded in a variety of different species, such as northern European foxes (*Vulpes vulpes*) (Lindström et al., 1994; Soulsbury et al., 2007) coyotes (*Canis latrans*) in North America, as well as a variety of ungulate species (Pence and Ueckermann, 2002). Thus, sarcoptic mange is considered one of the 10 most threatening diseases for wildlife and is recognized as a new challenge in the conservation of biodiversity worldwide, taking into account that 27% of the current species described as hosts of *S. scabiei* (40/148) are in some suboptimal conservation status (Escobar et al., 2021; Instituto Agropecuario Colombiano – ICA et al., 2015). In fact, several studies propose that wildlife species may serve as “sentinel animals” for human health, by inhibiting the abundance and/or proliferation of parasites through various mechanisms, such as regulation of susceptible host populations or interference with the transmission process, this pattern is called “the dilution effect” (Johnson and Thielges, 2010; Keesing et al., 2010; Ostfeld and Keesing, 2012; Lerner, 2019). Consequently, biodiversity conservation could then limit the abundance of many wildlife and human parasites such as *S. scabiei*.

S. scabiei has been considered as a single species, with lineages associated with different host species, eg *S. scabiei* var. hominis in humans, var. canis in dogs (*Canis lupus familiaris*) and var. vulpes in red foxes (Arlian et al., 1996). Nonetheless, the accuracy of *S. scabiei*

lineages in indicating host specificity is unclear (Fraser et al., 2016). In fact, and as confirmed in this work, the morphological variants of *S. scabiei* show few or no differences (Fig. 1F–H) (Arlian and Morgan, 2017; Mullen and Oconnor, 2019). However, there is biological evidence to support physiological differences between *S. scabiei* lineages expressed as differences in transmission success (Arlian, 1989; Mullen and Oconnor, 2019). In this sense, it is possible that the evaluation of the internal morphological differences of the different lineages or physiological varieties of *S. scabiei* is a key tool for their separation. For example, several studies have evaluated the morphological differences of the reproductive systems and germ cells in adult ticks as an effective tool for the separation of species complexes (Sampieri et al., 2014, 2016; Rivera-Páez et al., 2017; Ospina-Pérez et al., 2020), but there are very few studies about the internal morphology of *S. scabiei*, so it is difficult to carry out comparative analyzes that allow separating the different existing lineages (Desch 2001; Kristjansson et al., 2007; Witaliński 2014; Teodoro et al., 2018). In this sense, the present study contributes with descriptions and histological micrographs of the different stages of the biological cycle of *S. scabiei* within the skin of *C. quichua* (Fig. 2). Likewise, characteristics of the internal and external morphology of adult *S. scabiei* are described, confirming reported aspects related to the life cycle, behavior and physiology of scabies mites (Figs. 1 and 2) (Arlian and Morgan, 2017; Mullen and Oconnor, 2019).

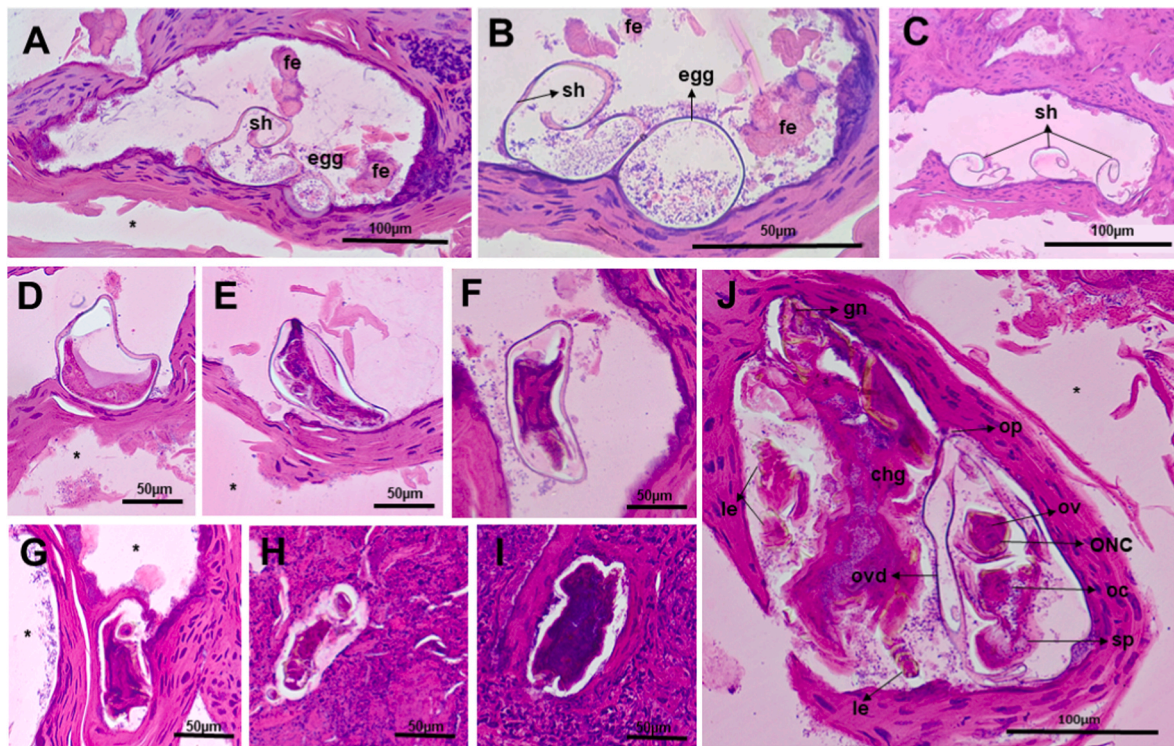


Fig. 2. Histological microphotographs of the development of the mite *S. scabiei* in the skin of the porcupine *C. quichua*. Permanent burrows dug by fertilized adult females, with the presence of a developing egg and the shell of another hatched egg (A, B). Burrows with the presence of three eggshells (sh) and feces (fe), where between two and three eggs are laid daily (C). Developing eggs within burrows in the stratum corneum of the skin, which hatch approximately 3–4 days after oviposition (D–F). Developing larvae in the superficial layer of the skin (G, H). Nymph burrowing just below the skin surface to moult into an adult in 3–4 days (I). Side-axial view of an adult female specimen of *S. scabiei* in a tunnel in the superficial epidermis. The mites have a short and broad gnathosoma (gn), globose idiosoma, short and conical legs I and II, with a delicate chitinous coating (le). Structures associated with the female reproductive system, spermatheca (sp), ovarian nutrient cell (ONC) located inside the ovary (ov), vitellogenic oocyte (oc) in the oviduct (ovd), as well as chorionic gland (chg) close to oviporus (op) are visible (J).

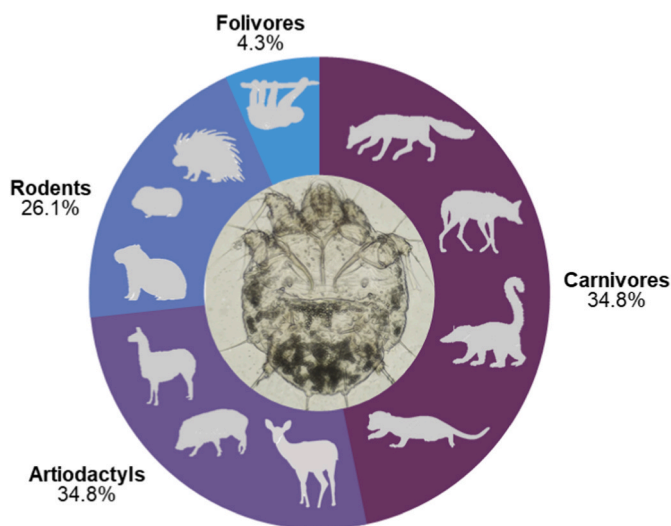


Fig. 3. Wild mammals with sarcoptic mange (*S. scabiei*) in South America.

4.1. Conclusions

Finally, it is important to continue reporting scabies cases in wild animals in Colombia and the Neotropics in general, since the study of pathogens in mammals is still partial (Gonzalez-Astudillo, 2016), and the impact that these diseases may cause in populations with some type of threat such as the Andean porcupine (Tirira, 2011). This records might contribute to the epidemiological knowledge of this neglected

disease (Alasaad et al., 2014) and to the understanding how the populations of some species can be affected. We also recommend evaluating the possible source of infection in the protected area. The staff at the National Park should be involved into the detection of wild animals with scabies and make reports to the national agencies such as the “Sistema sobre Biodiversidad de Colombia” (SiB-Colombia).

Declaration of competing interest

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijppaw.2022.06.009>.

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