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REVIEW

Sarcoptic mange outbreaks in vicuñas (Cetartiodactyla: Camelidae): A scoping review and future prospects

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Abstract

Sarcoptic mange is considered an emerging disease-causing countless epizootics and significantly affecting wild mammals worldwide. The vicuña (*Vicugna vicugna*) is a medium-sized South American wild camelid inhabiting Andean ecosystems, where several populations are live-sheared by Andean peasant communities as a way of providing an economic income to the people while promoting vicuña conservation. Institutions and scientists have shown concern for the impact and extent of sarcoptic mange in several vicuña populations across their range, as well as the lack of consistent knowledge about this disease in the species. Here, we perform a review about sarcoptic mange distribution throughout the vicuña's native range, evidence of effects of age and sex, the modes of transmission and the veterinary treatments employed. The review retrieved a few scientific papers, but found several reports and academic studies mostly considered as 'grey literature'. Mange was recorded across the entire native vicuña range (Argentina, Bolivia, Chile and Peru). Mange prevalence varied across vicuña studies (up to 60% prevalence in some populations) and severely affected a number of populations, being an important source of mortality. Mange was reported as more frequent in adults than in offspring. The modes of mange transmission remain unclear, although direct transmission between infected and healthy animals seems to be the most likely, including the transmission between domestic camelids and vicuñas. Regarding the treatments employed, ivermectin was the most frequently used. We further identified several gaps in knowledge and point to future research lines, which seek to promote both species conservation and the maintenance of live-shearing vicuñas under sustainable approaches in low-income Andean peasant communities.

KEYWORDS
camelids, emerging disease, managed species, prevalence, Sarcoptes scabiei

1 | INTRODUCTION

Infectious diseases have rarely been cited as the primary cause of global species extinctions. Yet the interaction of pathogens with other driving forces such as habitat loss, overexploitation or climate change in already-endangered species can lead to local and global extinction (Pedersen et al., 2007; Smith et al., 2009; Tompkins et al., 2015). Sarcoptic mange is a common, highly contagious skin disease of

mammals caused by the burrowing mite *Sarcoptes scabiei* (Pence & Ueckerman, 2002). It is considered an emerging panzootic disease-causing epizootics that can significantly affect wild mammals (Astorga et al., 2018; Escobar et al., 2022). Mange is responsible for alopecia, epidermal crust, and pruritic dermatitis, even leading to death due to secondary infections, starvation, and hypothermia (Bornstein et al., 2001; Smith et al., 2009). Mange has especially impacted populations already threatened by other factors, even triggering local extinctions (Escobar et al., 2022; Pence & Ueckerman, 2002).

The occurrence of sarcoptic mange in novel geographical areas, affecting new host species, and with increased severity has alerted experts (Astorga et al., 2018; Escobar et al., 2022). Sarcoptic mange has been widely documented in artiodactyls and carnivores worldwide. These two groups include many domestic animals that can act as reservoirs or vectors of pathogens shared with the wild fauna, particularly with their wild relatives (Astorga et al., 2018; Pedersen et al., 2007; Smith et al., 2009). Sarcoptic mange has been widely documented in canids (grey wolf *Canis lupus*, coyote *Canis latrans*, red fox *Vulpes vulpes*), ungulates (white-tailed deer *Odocoileus virginianus*, wild boar *Sus scrofa*), black bear (*Ursus americanus*) and raccoon (*Procyon* genus) from North America (Niedringhaus et al., 2019). In Europe, mange has been described in carnivores such as the red fox *Vulpes vulpes* (Pisano et al., 2019), some ungulates (e.g., Iberian ibex *Capra pyrenaica*, wild boar, Iacopelli et al., 2020; Moroni et al., 2021; Turchetto et al., 2020) and lagomorphs (Cardells et al., 2021). Mange has been commonly reported in koalas (*Phascolarctos cinereus*), dingoes (*Canis lupus dingo*) and wombats (Vombatidae family) from Oceania (Martin et al., 2018). Mange has also been described in wildlife from Asia, especially infesting ruminants (e.g., mountain gazelles *Gazella gazella*, Nubian ibex *Capra nubiana*, Arabian oryx *Oryx leucoryx* and blue sheep *Pseudois nayaur*; Astorga et al., 2018). Several African mammals such as wild primates (gorillas and chimpanzees, *Gorilla* and *Pan* genera, respectively) and ungulates (e.g., impala *Aepyceros melampus*, wildebeest *Connochaetes* genus, buffalo *Syncerus caffer*, kudu *Tragelaphus* genus and sable antelope *Hippotragus niger*) have also been affected by mange (Astorga et al., 2018). In Latin America, sarcoptic mange is commonly cited in dogs and livestock (Astorga et al., 2018). It has also been reported in South American camelids (SACs), particularly in the domestic alpaca *Vicugna pacos* and llama *Lama glama*, in which mange has been acknowledged as the most common parasitic disease (Bornstein & de Verdier, 2010; Lusat et al., 2009; Twomey et al., 2009). Domestic SACs are found in many zoos worldwide and are increasingly imported in USA and Europe for fiber production, breeding, and as pack and companion animals (Bornstein & de Verdier, 2010). However, the impact of mange on wildlife populations is poorly known (Astorga et al., 2018). Very recent studies point to severe impacts on some species, for example, foxes (genus *Lycalopex*) in Chile (Montecino-Latorre et al., 2020). Mange has also been reported in Chile as an early threat in vicuñas (*Vicugna vicugna*) and guanacos (*Lama guanicoe*), the two wild SACs (Montecino-Latorre et al., 2020). Mange was further responsible for a sharp decline of vicuña and guanaco populations in a protected area of Argentina (Ferreyra et al., 2022). In Peru, this disease is considered a problem for some vicuña populations (Gomez-Puerta et al., 2021). Indeed, experts recently highlighted that sarcoptic mange may represent an emerging threat to wild SACs (Astorga et al., 2018). Similarly, there is broad consensus among experts on the species, public administrations, non-governmental organizations (NGOs), the South American Camelid Specialist Group (SSC-IUCN), and the "Convention for the Conservation and Management of the Vicuña", that this parasitic disease currently represents a threat for several vicuña populations (Acebes et al., 2018).

The vicuña is a medium-sized, highly social ungulate inhabiting arid and semiarid ecosystems of Argentina, Bolivia, Chile, Ecuador and Peru, from 3,000 to 5,000 m.a.s.l. (Franklin, 2011). The species is currently classified as Least Concern on the IUCN Red List of Threatened Species (Acebes et al., 2018). Nevertheless, the vicuña was near the brink of extinction in the 1960s due to hunting and over-exploitation for its meat, skin and fiber. National and international regulations, together with the efforts of scientists and naturalists, led to its recovery through the initial ban of the international trade of its fiber, the control of poaching, and the later sustainable non-consumptive use by peasant Andean communities (Acebes, 2020; Lichteinstein & Vilá, 2003). These communities live-shear vicuñas and trade its fiber, one of the finest and most valued in the world, with a market price of about USD 500/kg, thus contributing to their livelihood (Kasterine & Lichtenstein, 2018). Vicuña is a key component of the Andean biocultural heritage, as well as an example of nature's contribution to people (Vilá & Arzamendia, 2020). Fiber harvesting mostly occurs in wild populations and secondarily in captive populations (Lichteinstein & Vilá, 2003). Despite the increased concern, so far there is no comprehensive assessment of sarcoptic mange in vicuñas across their range. Moreover, the interaction of mange with other well-known threats for the species, such as poaching, habitat loss, competition with domestic SACs and livestock or climate change, may threaten some vicuña populations, even leading to local population extinctions (Acebes, 2020; Acebes et al., 2018; Ferreyra et al., 2022).

Considering the scarcity of knowledge on sarcoptic mange in vicuña, we conducted a scoping review of this parasitic disease in vicuña populations across its entire continental range, identifying its distribution, prevalence, effects by age and sex, molecular characterization of the mite *S. scabiei*, modes of mange transmission and veterinary treatments employed. Finally, we identified several gaps in knowledge and point to future research lines.

2 | MATERIAL AND METHODS

We conducted a scoping literature review of sarcoptic mange in vicuñas following the guidelines for reviews of Tricco et al. (2018). In doing so, we searched peer-reviewed scientific papers, conference proceedings, institutional reports, and academic studies (PhD and MSc Thesis and Final Degree Projects). The protocol followed a strict method to guarantee transparency and to minimize sources of bias. We performed bibliographic queries in ISI Web of Science (WoS), Scopus and SciELO databases. Further, we searched ResearchGate (www.researchgate.net) and Google Scholar. We used the following

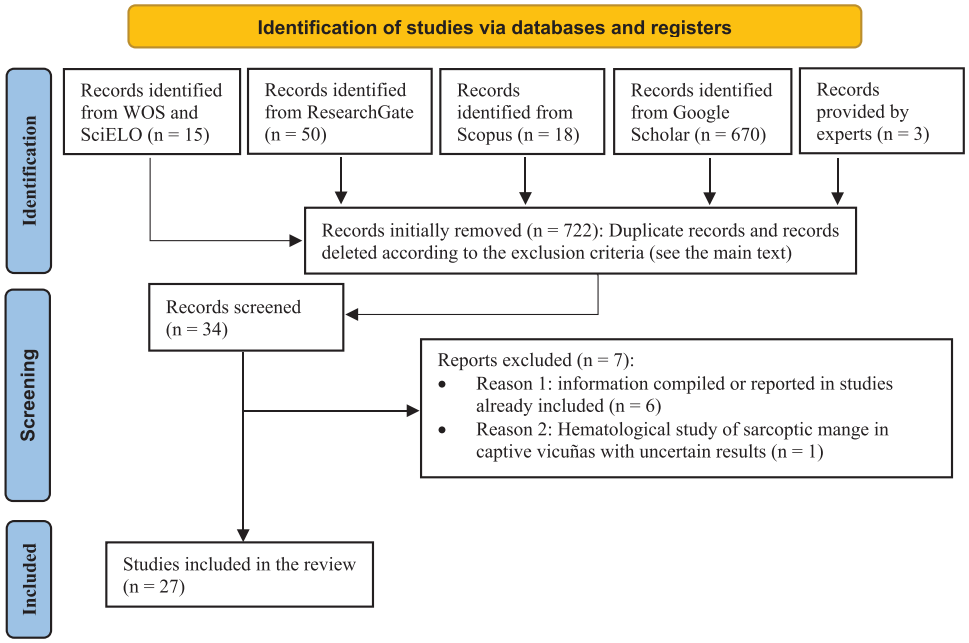

FIGURE 1 Flow diagram including the research queries, databases and registers used in each step

keyword strings: (camelids* OR "*Vicugna vicugna*" OR vicuna*) AND ("sarcoptic mange" OR *Sarcoptes*). We further searched the Spanish translation of these terms (camélidos* OR "*Vicugna vicugna*" OR vicuña*) AND ("sarna sarcóptica" OR "*Sarcoptes*"). The search was conducted in titles, abstracts and keywords in English and Spanish-written documents in the above-cited databases. Our search was not restricted to a specific period. The selection process initially excluded articles including (1) camelid species other than vicuñas (i.e., guanaco, llama, alpaca, Bactrian camel *Camelus bactrianus* and one-humped dromedary *Camelus dromedarius*); (2) parasitosis of SACs outside of its native range. Subsequently, we refined the screening process with minor deletions. We also considered information (reports and proceedings) provided by experts in SACs not found with the mentioned search engines (Figure 1).

From each publication, we extracted the following information, when available: (1) year and type of publication; (2) year when the field study was conducted (to understand when the mange was detected); (3) geographical area affected; (4) prevalence of sarcoptic mange and percentage of animals dead due to the disease; (5) seasonality pattern of mange; (6) origin or causes of transmission; (7) histopathology of mange; (8) molecular characterization of *S. scabiei*; (9) veterinary treatments; and (10) whether the vicuñas were from managed or unmanaged populations for fiber production. Managed populations could be either wild or captive.

3 | RESULTS AND DISCUSSION

To our knowledge, this is the first scientific contribution providing evidence on the global extent and prevalence of mange in vicuñas. Our review further shows the scarcity of scientific papers published on sarcoptic mange in this species to date (Table 1). This highlights the relevance of considering grey literature for understanding the impact of sarcoptic mange disease in vicuñas, including unpublished records, academic studies, technical reports from environmental NGOs, and information from natural resource agencies (Escobar et al., 2022; Table 1). We thus advocate for more scientific studies shedding light on the epidemiology of sarcoptic mange in vicuñas, as it indeed seems to be occurring (e.g., Angulo-Tisoc et al., 2021; Ferreyra et al., 2022; Gomez-Puerta et al., 2021; Mayhua, 2021; Montecino-Latorre et al., 2020). This recent increase in mange research mirrors the concern amongst scholars of this parasitic disease in vicuñas.

All cases retrieved were published in 2010–2021 (Table 1), although three studies were conducted or started previous to these years (Arzamendia et al., 2012; Beltran-Saavedra et al., 2011; Mollericona et al., 2018). This may be explained by recent mange outbreaks in vicuña populations and the concomitant paucity of scientific papers to date, which fits with the current emergence of sarcoptic mange in wildlife worldwide (Astorga et al., 2018; Escobar et al., 2022). Furthermore, this trend coincides with the widespread perception among vicuña specialists, who consider either poaching or sarcoptic mange to be the most important threats to the species (Acebes et al., 2018).

Sarcoptic mange in vicuñas causes erythema, intense pruritus, alopecia and severe skin lesions (thick, fissured, lichenified and crusted), leading to poor body condition, difficulty in movement and feeding, increased vulnerability to predators and even death. Lesions appear on the limbs, abdomen, chest, axillae, perineum and head (Gomez-Puerta et al., 2013; Unzueta, 2018; Castillo et al., 2019; Ferreyra et al., 2022; Figure 2). Histopathologically, sarcoptic mange in vicuñas is described as dermatitis characterized by hyperkeratosis, parakeratosis, hyperplasia of sebaceous glands, absence of hair follicles and presence of an inflammatory infiltrate with a predominance

TABLE 1 Recorded publications used in this study (n = 27) of sarcoptic mange in vicuña populations (Vicugna vicugna) across their native range (Argentina, Bolivia, Chile and Perú), including scientific papers and 'grey literature'

Country	Study year	Study area	Vicuña management	Language	Type of publication	Main findings	Reference
Argentina	2003-2005	Cieneguillas, Pozuelos Biosphere Reserve, Jujuy	Live-sheared wild vicuñas	English	Non-SCI pub	Mange prevalence: 0.88% (4/450). Individuals infested with mange did not show different behavioral patterns than those healthy	Arzamendia et al., 2012
	2014	Rodeo, Jujuy	vicuñas in captivity	Spanish	Proceedings	Mange prevalence (9.16%, 11/120 animals), mortality (5%) and lethality (54.5%).	Aráoz et al., 2016
	2017–2018	San Guillermo National Park, San Juan	Unmanaged	English	SCI-pub	Average annual proportion of mange in live vicuñas (28%), rising to 93% in dead vicuñas.	Ferreyra et al., 2022
	Unknown	Jujuy	Unknown	Spanish	Proceedings	Characterization of skin lesions caused by *S. scabiei*	Medina et al., 2021
Bolivia	2006	National Integrated Management Natural Area Apolobamba	Live-sheared wild vicuñas	Spanish	Non-SCI pub	Mange prevalence: 5.6% (2/36). This low prevalence is not representative since infected animals or in poor condition are avoided to be sheared.	Beltran-Saavedra et al., 2011
	2013	7 communities from La Paz and Oruro departments	Live-sheared wild vicuñas	Spanish	Degree/MSc Thesis	Mange prevalence: 0 (0/12 animals) - 46.2% (6/13 animals)	Ruíz, 2016
						Mange prevalence: 0 (0/16 animals) - 30.8% (4/13 animals)	
	2017	Sarcarí, Villazón	Live-sheared wild vicuñas	Spanish	Technical report	Mange prevalence: 3.17 % (6/189)	Arzamendia et al., 2017
	2008–2017	La Paz, Oruro, Potosí, Tarija and Cochabamba	Live-sheared wild vicuñas	Spanish	Technical report	Mange prevalence (2008 - 2017 period): La Paz (0 - 17.5%)	Mollericona et al., 2018
						Mange prevalence (2008 - 2017 period): Oruro (0 - 11.4%)	
						Mange prevalence (2008 - 2017 period): Potosí (0 - 3.17%)	
	2018	National Integrated Management Natural Area Apolobamba	Live-sheared wild vicuñas	Spanish	Proceedings	Mange prevalence: 9.8 % (9/92 animals)	Mollericona et al., 2019
	2018	National Integrated Management Natural Area Apolobamba	Live-sheared wild vicuñas	Spanish	Technical report	Mange prevalence: 4.8 - 22.2% (9/92 animals)	Beltrán-Saavedra & Mollericona, 2019a
	2018	ANMI Pampa Tholar de las Vicuñas, Villazón, Potosí	Live-sheared wild vicuñas	Spanish	Proceedings	Mange prevalence: 5.1% (4/78 animals)	Beltrán-Saavedra et al., 2019
	2018	ANMI Pampa Tholar de las Vicuñas, Villazón, Potosí	Live-sheared wild vicuñas	Spanish	Technical report	Mange prevalence: 0 - 19.1% (maximum in the Sarcarí community)	Beltrán-Saavedra & Mollericona, 2019b

(Continues)

TABLE 1 (Continued)

Country	Study year	Study area	Vicuña management	Language	Type of publication	Main findings	Reference
Chile	2011-2016	Atacama region	Unmanaged	Spanish	Non-SCI pub	2 records of mange in vicuñas	Vargas et al., 2016
	2016	Lauca National Park, Las Vicuñas National Reserve, and Monumento Salar de Surire	Unmanaged	Spanish	Degree/MSc Thesis	Mange reported in vicuñas of Arica and Parinacota region	Villalón, 2016
	2020	Protected areas	Unmanaged	English	SCI-pub	Mange cases in protected areas of Chile	Montecino-Latorre et al., 2020
	201–2018	Protected areas	Unmanaged	Spanish	Book chapter	Registered cases of mange in vicuñas from Nevado Tres Cruces National Park (Atacama)	Vargas & Bonacic, 2020
Perú	2012	Lucanas community, Ayacucho region	Live-sheared wild vicuñas	English	SCI-pub	Mange prevalence: 12% (24/200)	Gomez-Puerta et al., 2013
	2015	Lucanas community and Pampa Galeras - Barbara D'achille National Reserve, Ayacucho region	Live-sheared wild vicuñas	Spanish	Non-SCI pub	Mean mange prevalence: 26.71% (1646/6162 vicuñas). Up to 62% (617/996 vicuñas) in Lucanas community. Topical application of an ointment prepared from burning engine and sulfur, spread on areas visibly affected by the parasite plus subcutaneous application of ivermectin 1%. 98% recovered (1277/1249) while 2 % died after treatment.	Bujaico & Zúñiga, 2015
	2014	Reserva Paisajística Nor Yauyos-Cochas, Tanta, Yauyos, Lima	Live-sheared wild vicuñas	Spanish	Technical report	Mange main cause of death (64% of vicuñas)	Flores, 2015
	2015–2017	Lucanas peasant communities, Ayacucho region	Live-sheared wild and captive vicuñas	Spanish	Degree/MSc Thesis	Mange prevalence: 21.52% (2015); 1.42% (2016) and 3.8% (2017), Total = 9.7%; 2,452/25,296. Males (9.6%) more affected than females (6.1%); juveniles (7.64%) more affected than adults (5.83%) and calves (2.31%). Mange infestation considerably decreased fiber incomes for Andean communities	Bujaico, 2018

(Continues)

TABLE 1 (Continued)

Country	Study year	Study area	Vicuña management	Language	Type of publication	Main findings	Reference
	2015	Andahuaylas and Aymaraes provinces, Apurímac region	Live-sheared wild vicuñas	Spanish	Degree/MSc Thesis	Mange prevalence: 0.3 - 16.9% (1/331; 68/402). Males (5.73%) more affected than females (3.68%), and adults (6.28%) more than juveniles and calves (3.14%)	Unzueta, 2018
	2019	San Antonio de Tanta, Lima	Live-sheared wild vicuñas	Spanish	Proceedings	Mange prevalence: 37%	Castillo et al., 2019
	2018	Huarccoy and Huaquirca (Apurímac), San Juan de Ondores (Junín) and Trapiche (Puno)	Live-sheared wild vicuñas	Spanish	Proceedings	Mange prevalence: 61.8% (63/102)	Murillo et al., 2019
	2018	San Pedro de Coris and Pampalca (Huancavelica), Pampa Galeras National Reserve (Ayacucho) and Nor Yauyos Landscape Reserve	Live-sheared wild vicuñas	Spanish	Proceedings	Sarcoptic mange was widely distributed. Vicuñas with mange showed lower levels of white blood cells, monocytes and glucose, and higher levels of total proteins compared to vicuñas without mange	Siguas-Robles et al., 2019
	2018	Cuzco Region	Live-sheared wild and captive vicuñas	Spanish	Non-SCI pub	Mange prevalence in: (a) wild vicuñas: 6.1% (48/777) and (b) captivity: 0.2% (6/2049). 85.1% (46/54) in adults and 14.8% (8/54) in juveniles. 40.7% males (22/54) and 59.2% females (32/54)	Angulo-Tisoc et al., 2021
	2018	Chilca, Palccoyo, Phacco and Sibina Sallma, Canchis province, Cuzco	Live-sheared wild vicuñas	English	SCI-pub	Mange prevalence: 19.3% (3/181 animals); Molecular characterization of *S. scabiei* from vicuñas	Gomez-Puerta et al., 2021
	2019	Pampa Galeras - Barbara Dachille National Reserve, Ayacucho region	Live-sheared wild vicuñas	Spanish	Degree/MSc Thesis	Mange prevalence: 13.95%. Successful results with ivermectin treatment (200 μg/kg bodyweight)	Mayhua, 2021

FIGURE 2 Wild vicuña (*Vicugna vicugna*) affected by sarcoptic mange (*Sarcoptes scabiei*) in Pampa Galeras-Bárbara d'Achille protected area (Ayacucho, Peru) that was captured for a pharmacological study (a); and vicuña captured in a roundup in 2019 showing severe skin lesions on limbs, abdomen, axillae and chest from Lucanas peasant community, Ayacucho, Peru (b). Credits: H. Castillo

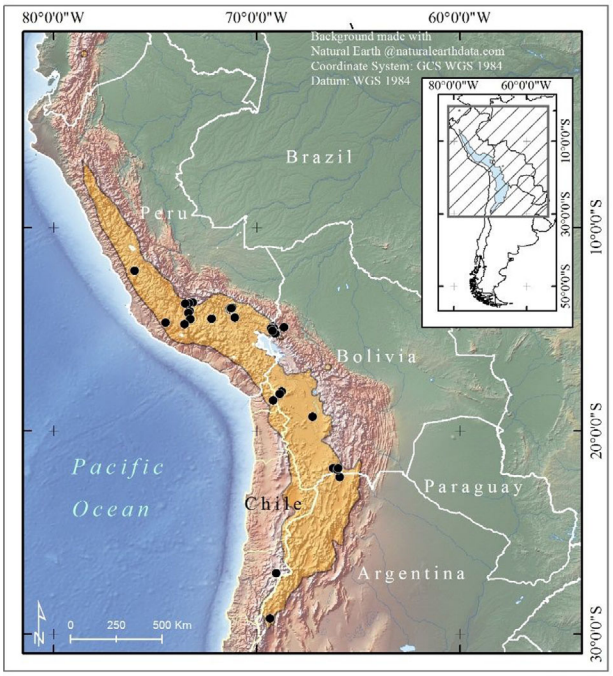

FIGURE 3 Recorded cases of sarcoptic mange in vicuña populations (*Vicugna vicugna*) throughout its distribution (black dots). Ochre polygon represents the extant vicuña distribution, excluding Ecuador, where the species was introduced (https://www.iucnredlist.org/)

of macrophages, plasma cells, neutrophils and eosinophils (Aráoz et al., 2016; Medina et al., 2021). The identified mite was *S. scabiei* (Beltran-Saavedra et al., 2011; Bujaico, 2018; Ruíz, 2016; Unzueta, 2018). Regarding the seasonality of sarcoptic mange, the scarcity of studies did not reveal a consistent pattern. Bujaico (2018) reported the most frequent cases of mange in vicuñas in Southern Peru from May to July, which corresponds to the cold and dry period. But there may be some bias since the assessments were restricted to the period of captures. On the other hand, Ferreyra et al. (2022) found that vicuñas were more likely to have advanced stages of the disease in February (summer-wet), compared to May or September.

Sarcoptic mange was reported in several vicuña populations across their native range (Castillo, 2018), pointing to novel and wide geographical areas affected in Peru, Bolivia, Argentina and Chile (Figure 3). The severity and impact of mange varied among vicuña studies, ranging from 0.39 % to 62% of prevalence (Table 1). In Peru, mange was reported in several vicuña populations, and with high prevalence: the most affected populations come from the Lucanas peasant community in Southern Peru (up to 62%, 617/996 vicuñas; Bujaico & Zúñiga, 2015), and the Tanta peasant community in Central Peru (37%, Castillo et al., 2019). In Bolivia, mange ranges from 0.39% in Caripe, Oruro (Mollericona et al., 2018) to 46.2% in Ucha Ucha, La Paz, in the western area of the country (Ruíz, 2016). Mange prevalence in vicuña populations from Chile is unknown, but anecdotally seems to show an increasing trend and is considered the second-most important threat to the species after poaching (Montecino-Latorre et al., 2020; Vargas et al., 2016; Villalón, 2016). The situation in Argentina is quite contrasting: in some vicuña populations mange prevalence is incidental (below 1% in Jujuy, Arzamendia et al., 2012), while in others mange prevalence reached 24% (115/478 vicuñas, San Guillermo National Park, San Juan; Ferreyra et al., 2022).

Furthermore, this infectious disease has been reported as responsible for the sharp decline of some vicuña populations in Peru (Flores, 2015). In San Guillermo National Park (San Juan, Argentina), mange was responsible for high-mortality epidemics (Ferreyra et al., 2022). Here, the vicuña population decreased 68% in one year (2017-2018) and mange was identified as the main cause of death, leading to a high risk of local extinction (94% of vicuña carcasses showed clinical signs compatible with mange: 116/124 vicuñas; Ferreyra et al., 2022). The severity and impact of *S. scabiei* in this population could be due to lack of exposure to the disease previously. In fact, molecular characterization revealed that *S. scabiei* from vicuñas and guanacos shared the same genotype, which is consistent with a single source, recently introduced and of rapid spread in this area (Ferreyra et al., 2022). Ten microsatellite

marker SARMs were used (33-38, 40, 41, 44 and 45); mites presented relatively low allelic richness, being monomorphic in almost all loci and showing low genetic variability (Ferreyra et al., 2022). Phylogenetic analyses of *S. scabiei* cox-1 sequences from vicuñas from the Southern Peruvian Andes suggest that the origin of sarcoptic mange could be associated with *S. scabiei* from canids (Gomez-Puerta et al., 2021). However, to demonstrate this it would be necessary to molecularly analyze *S. scabiei* from canids sharing habitat with vicuñas, adding the use of genetic markers such as microsatellites. Moreover, in this study, the polymorphism in the ITS-2 sequence of *S. scabiei* showed three haplotypes previously identified in *S. scabiei* from Pyrenean chamois (*Rupicapra pyrenaica*), water buffalos (*Bubalus bubalis*), and humans, as well as five previously unreported haplotypes (Gomez-Puerta et al., 2021).

Sarcoptic mange in guanaco, the other wild SACs, is less known. This disease has severely affected guanacos in San Guillermo National Park (Ferreyra et al., 2022). Here, mange prevalence was estimated at 33%, producing a 77% decrease in guanaco density (Ferreyra et al., 2022). In Chile, guanaco infections have also been reported in several protected areas, initially as scattered cases (Vargas et al., 2016), but mange seems to be increasing and expanding across the territory (Montecino-Latorre et al., 2020). In domestic SACs within their native range, where there is no strict pharmacological control of mange, it is considered an endemic disease affecting multifamily herds in rural communities with prevalences as high as 40% (Leguía, 1991). However, mange has been mainly reported outside of their native range, in Europe and the United States, where mange is the most common skin problem (D'Alterio, 2006; Rosychuk, 1989; Tait et al., 2002). For example, in Sweden, 44% of alpaca breeders responding to a survey reported that mange was their biggest concern affecting their alpaca herds (Bornstein & de Verdier, 2010). Mange is one of the most frequently diagnosed ectoparasites in SACs in England and Wales (Halsby et al., 2017). In the UK, 23% of producers were concerned about mange (Tait et al., 2002), in which 52.1% of alpaca herds and 14% of llama herds had mange (Lusat et al., 2009). In Switzerland, alpaca owners considered mange as one of the four most frequent health problems (Bornstein & de Verdier, 2010; Burri et al., 2005). Furthermore, sarcoptic mange is considered an extremely contagious and serious zoonosis in the phylogenetically related Old World camels (dromedary and Bactrian camel) and the second most common parasitic disease (e.g., Parsani et al., 2008; Kotb & Abdel-Rady, 2015; Ahmed et al., 2020).

Regarding the epidemiological studies that examined mange effects by sex, two studies reported higher prevalence in males than in females (9.6 vs 6.1% respectively, Bujaico, 2018; 5.73% and 3.68% respectively, Unzueta, 2018). Another article did not report differences (Gomez-Puerta et al., 2021), while other studies reported higher prevalence in females than in males (59.2% vs 40.7% respectively of affected animals; Angulo-Tisoc et al., 2021). A higher prevalence in males could be due to the polygynous mating system in vicuña, in which male interactions with other individuals are more frequent and intense than amongst females (Vilá, 1990), but results did not show a clear sex pattern in mange affection. Hence, further research is needed. Mange prevalence was lower in offspring than in adults (Bujaico, 2018; Ferreyra et al., 2022; Unzueta, 2018), but showed contrasting results in adults and juveniles (Bujaico, 2018; Unzueta, 2018; Angulo-Tisoc et al., 2021; Table 1). Regarding the modes of mange transmission, the main contagious form described in the literature is the cross-transmission between healthy and infected animals by direct contact (Escobar et al., 2022; Pence & Ueckerman, 2002). In vicuñas, direct transmission could take place during mating, during male-male, male-female and mother-calf interactions or indirectly in communal dust bathing areas and dung piles that are shared by individuals of the same herd, by neighboring herds and even by domestic camelids (Arzamendia et al., 2012; Ferreyra et al., 2022). Mange transmission may also occur due to poor management practices when vicuñas are live-sheared in Andean ancestral roundups known as *chaccu* (Mayhua, 2021). The *chaccu* is a traditional method conducted by Andean communities involving the capture of wild vicuñas into large corrals to harvest their fiber and release them (Vilá & Arzamendia, 2020), during which the density of vicuñas increases. Mange transmission can also take place by cross-species transmission between vicuñas and guanacos. Ferreyra et al. (2022) postulated that the guanaco could have acted as a bridge species for mange transmission between known infected llamas and vicuñas in San Guillermo National Park. Hence mange transmission may account for cross-species transmission between wild and domestic SACs (Ferreyra et al., 2022; Mayhua, 2021; Ruíz, 2016) since SACs are highly social ungulates that share forage and spatial resources. This knowledge is, in any case, scarce and needs further epidemiological research.

Mange was more frequently detected in live-sheared wild populations, for example, in vicuñas from Apurimac and La Paz communities in Peru (Unzueta, 2018) and Bolivia (Ruíz, 2016), respectively (Table 1). Mange was also reported in live-sheared populations in captivity, for example, some vicuña populations from Lucanas communities in Peru (Bujaico & Zuñiga, 2015) and Jujuy, Argentina (Aráoz et al., 2016). Infected animals were also reported in unmanaged wild populations from Argentina (San Guillermo National Park; Ferreyra et al., 2022) and Chile (Vargas & Bonacic, 2020; Vargas et al., 2016). It is worth mentioning that most mange studies were done on wild vicuñas that were captured for shearing so that researchers had the opportunity to study mange impact and severity in the species. The prevalence of mange is likely to be higher in some cases since severely infected animals could be kept out of the roundups (Beltran-Saavedra et al., 2011; Mayhua, 2021). On the other hand, mange prevalence in wild unmanaged populations is more difficult to detect and monitor, and only severely affected vicuñas may be easily identified. This is the case in Chile, where mange prevalence in vicuña populations is scarcely known (Montecino-Latorre et al., 2020; Vargas et al., 2016).

Although there is little information regarding the handling of sarcoptic mange in vicuñas, two treatments have been used with uncertain outcomes (Bujaico & Zuñiga, 2015; Gomez-Puerta et al., 2013): (i) ivermectin, delivered by manual subcutaneous injection and (ii) an ointment based on sulfur and used engine oil that is spread into the affected areas (Bujaico, 2018; Bujaico & Zúñiga, 2015). The latter has been further employed by Andean peasant communities from Peru in domestic camelids. A recent study showed that 67% of infected vicuñas recovered after being treated with a single subcutaneous dose of ivermectin, but when repeating the treatment with a second dose, 100% of

vicuñas recovered (Mayhua, 2021). The best treatment achieved was a dose of 200 μg/kg bodyweight ivermectin in both treatments (Mayhua, 2021). Sarcoptic mange treatments in alpacas and llamas have been widely documented outside of their native range (Beck, 2020; Bornstein & de Verdier, 2010; Twomey et al., 2009). For example, Twomey et al. (2009), successfully controlled *S. scabiei* in alpacas with repeated subcutaneous 200 μg/kg bodyweight ivermectin. Treatments with topical amitraz and repeated doses of subcutaneous injections of ivermectin (Castilla-Castaño et al., 2021) or moxidectin were also effective in both domestic SACs (Beck, 2020). However, the lack of veterinarians or properly trained personnel, and the difficulty of repeating treatments in wild vicuñas makes success less likely.

The increase in sarcoptic mange in vicuñas could be explained by multiple interacting factors: (i) The global population growth in the last decades has doubled in the last 20 years (up to 500,494 vicuñas) leading to increased population density (Acebes et al., 2018). According to the Forestry Service and Wild Fauna from Peru, the density of vicuñas could play a key role in these epidemics (pers. comm.), as has been reported in other wild ungulates (Iacopelli et al., 2020) and overall host species (Escobar et al., 2022). Likewise, the high density of vicuñas has been hypothesized as a key factor in the spread of contagious disease between healthy and sick animals in wild unmanaged populations (Ferreyra et al., 2022). (ii) The social and gregarious behavior of camelids facilitates direct transmission between individuals (Ferreyra et al., 2022). (iii) Vicuñas co-occur and share habitat with infected llamas and alpacas, which are widely distributed throughout the Andean mountains and at high population densities (Ruíz, 2016). A recent study hypothesized that mange-infected llamas were responsible for outbreaks in wild vicuñas (Ferreyra et al., 2022). However, sarcoptic mange is detected in vicuña populations that occur with and without domestic SACs. (iv) Vicuñas occur in already overgrazed and degraded pastures, which can also eventually compete for forage with domestic SACs, making them more vulnerable to mange (Ruíz, 2016). (v) Infected domestic SACs can be translocated with poor or no sanitary controls to areas with healthy vicuñas (Ferreyra et al., 2022). (vi) Mismanagement can occur related to the capture and live-shearing of animals, including incomplete preventive veterinary treatments, management without animal welfare, and stress due to crowded roundup (Ruíz, 2016; Arzamendia et al., 2017; Mayhua, 2021).

Overall, concern about this situation has compelled authorities to initiate "research programs", especially on populations whose survival is at risk (Acebes et al., 2018). Sarcoptic mange causes huge economic losses to local peasant communities due to the price drop of vicuña fiber (Ruíz, 2016; Bujaico, 2018; Mayhua, 2021). Likewise, this was already reported for domestic SACs, with economic losses of around 95% for peasant communities (Leguía, 1991). In summary, the effects of sarcoptic mange on vicuñas, as in other host species, maybe underestimated considering that available data on outbreaks often come from anecdotal reports and grey literature (Escobar et al., 2022). We do not believe that sarcoptic mange will lead to the extinction of the vicuña. However, the interaction of mange with other drivers described as threats for the species, such as poaching triggered by international illegal market demands of vicuña fiber, habitat loss, competition with domestic SACs and livestock, climate change and unappropriated management practices may threaten some vicuña populations, even leading to local population extinction (Acebes et al., 2018; Acebes, 2020). Given that vicuña recovery is linked to its sustainable use by Andean peasant communities, the solution cannot come from banning this ancestral activity but should ensure the strict application of protocols and practices of animal welfare and sustainability (Arzamendia et al., 2017). We thus advocate for increased collaboration among wildlife ecologists, veterinarians, conservation organizations and local and national authorities (Pedersen et al., 2007).

Finally, we identify some gaps in knowledge and future research lines on mange in vicuñas based on the scarce information currently existing for this species, but in line with previous reviews in different host species (Astorga et al., 2018; Escobar et al., 2022): (i) Long-term studies of sarcoptic mange on wild SACs to determine if populations can return to pre-epidemic conditions and how populations respond to mange over time; (ii) Investigation of whether vicuña populations show different levels of resistance to the infection; (v) Determination of whether there are variants of *S. scabiei* causing different degrees of mange severity in vicuña populations; (vi) Explaining the variability in disease severity among individuals and between sexes within a population and the factors driving mange infestation and impacts on equally exposed individuals and populations, including determining whether stressed animals are more vulnerable; (iv) Studies that focus on modes of transmissions addressing the following questions: What is the relationship between mange in domestic SACs, livestock and wild SACs? Is the origin wild or domestic, native or introduced animals? Are dogs (particularly feral dogs) or foxes the source or contributing to mange transmission as hypothesized by Gomez-Puerta et al. (2021)? A recent molecular study of *S. scabiei* on vicuñas indicates that canids are possibly involved in transmitting sarcoptic mange to vicuñas; (vii) Since some vicuña populations are live-sheared, determining the best management practices to minimize mange infection; (viii) Assessing the feasibility of veterinary treatments and, if so, determining the best treatment options. For example, when should a given population be treated? Should only infected animals be treated or the whole population (i.e., preventive treatment)?

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHIC STATEMENT

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to.

No ethical approval was required as this is a review article with no original research data.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study is based on a review, with all the information available within the manuscript.

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