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REVIEW

Challenges and opportunities in mitigating sarcoptic mange in wild South American camelids

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Abstract

Vicuñas (*Vicugna vicugna*) and guanacos (*Lama guanicoe*) are the two species of wild South American camelids whose distributions range from Peru to northern Argentina and southern Peru to southern Argentina, respectively. Listed as critically endangered in the 1960s due to poaching, vicuña numbers had been gradually recovering; however, new concerns about population stability have arisen with recent observations of sarcoptic mange outbreaks in this species. Sarcoptic mange is an infectious skin disease caused by the microscopic burrowing mite, *Sarcoptes scabiei*, which infects nearly 150 mammalian species globally, including guanaco and vicuña. Wild camelid populations across Argentina, Bolivia, Chile, and Peru have been affected by sarcoptic mange, with the most severe outbreaks resulting in localized extirpation. Population declines have conservation and economic implications, as many local communities harvest vicuña and guanaco fiber for profit.

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We review the current literature on sarcoptic mange in wild camelids from Argentina, Bolivia, Chile, and Peru to establish a current state of knowledge on spatial prevalence, management, and therapeutics, and identify existing knowledge gaps. Critical next steps include 1) implementation of effective management strategies that limit the transmission of sarcoptic mange, 2) standardization of data collected during community capture (i.e., chaccu) events, 3) assessing the potential role of community captures in mite transmission, and 4) evaluation of treatment options and best practices for implementation. Further, there is a need for capacity building to improve disease diagnostics and surveillance in wild camelids. A multisectoral collaboration between governmental authorities, communities, academic institutions, and national and international organizations focusing on wild South American camelid conservation could contribute to building actions aimed at preventing future outbreaks and mitigating the current burden of sarcoptic mange disease.

KEYWORDS
Andean wildlife, guanaco, *Sarcoptes scabiei*, sarcoptic mange, vicuña, wildlife disease control, wildlife management

Sarcoptic mange is a highly contagious skin disease that causes significant morbidity and mortality among domestic and wild animal species globally (Arlian and Morgan 2017). This disease is also a neglected tropical disease in humans (Mounsey et al. 2016) and is considered an emerging panzootic in wildlife because of its broad distribution and host species range (Escobar et al. 2022). The etiologic agent of sarcoptic mange is the microscopic, burrowing mite, *Sarcoptes scabiei*, which is a generalist parasite documented in over 150 species of mammal (Acebes et al. 2022, Escobar et al. 2022).

At the host level, *S. scabiei* infection induces an inflammatory response (Næsborg-Nielsen et al. 2022) with clinical signs including acute or chronic dermatitis (characterized by severe skin lesions and distinctive hair loss), immunological and physiological shifts (e.g., changes in hematological parameters and body thermoregulation; Pence and Ueckermann 2002, Cross et al. 2016, Arlian and Morgan 2017, Martin et al. 2018), and behavioral changes (Cross et al. 2016, Martin et al. 2018). At the population level, sarcoptic mange is often observed in endemic (low prevalence, stable populations) or epidemic (high prevalence, high mortality) phases. Anecdotal evidence suggests epidemics may occur in naïve or newly vulnerable populations (e.g., stressed by environmental shifts) that transition into endemic states through time (Astorga et al. 2018), though this is not always the case. During epidemic phases, there are conservation implications for affected populations, as outbreaks have led to population collapse in several species, including bare-nosed wombats (*Vombatus ursinus*; Martin et al. 2018, Carver et al. 2023), red fox (*Vulpes vulpes*; Henriksen et al. 1993), Spanish ibex (*Capra pyrenaica*; León-Vizcaíno et al. 1999), guanaco (*Lama guanicoe*; Ferreyra et al. 2022), and vicuña (*Vicugna vicugna*; Monk et al. 2022). However, the dynamics and impact of sarcoptic mange in many wildlife systems remain poorly understood (Astorga et al. 2018).

Transmission of *S. scabiei* among individuals can occur through direct contact (Browne et al. 2022); however, in many systems, indirect transmission may occur through climatically favorable environmental reservoirs (e.g., burrow or den; Browne et al. 2021). There is uncertainty regarding host-specificity of *S. scabiei* despite species-specific variant naming, and no morphological differences have been identified among mites originating from different hosts. Evidence exists for cross-species transmission (Gakuya et al. 2011; Matsuyama et al. 2015, 2019) and recent research supports potential geography-based mite genetic distinctions (Moroni et al. 2023). The increased occurrence of sarcoptic mange epizootics in diverse host species over the last 2 decades has highlighted the conservation importance of this pathogen and revealed our limited understanding of its transmission dynamics (Escobar et al. 2022).

In the past decade, there has been an influx of reports from Andean countries documenting sarcoptic mange in wildlife including Andean foxes (*Lycalopex culpaeus*; Gomez-Puerta et al. 2024, Millán et al. 2024), chilla foxes (*Lycalopex griseus*; Montecino-Latorre et al. 2020), Sechuran foxes (*Lycalopex sechurae*; Villalba-Briones et al. 2022), South American grey foxes (*Lycalopex griseus*; Millán et al. 2024), guanacos and vicuñas (Ferreyra et al. 2022, Sosa et al. 2022), among others. While the increase in reports may reflect funding availability and researcher interest, they could also indicate that *S. scabiei* occurrence is increasing in this region: consistent with observed global trends (Astorga et al. 2018, Escobar et al. 2022). Wild South American camelids (WSAC), which includes guanacos and vicuñas from Argentina, Bolivia, Chile, and Peru (Figure 1), are highly social ungulates currently classified as least concern on the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species given their increasing abundance and broad distributions (Baldi et al. 2016, Acebes et al. 2018). However, sarcoptic mange epizootic events are considered one of the major threats to their health and conservation (Baldi et al. 2016; Acebes et al. 2018, 2022; Montecino-Latorre et al. 2020). A recent review by Acebes et al. (2022) documented sarcoptic mange presence in vicuñas across their distribution and identified challenges in controlling this pathogen in free-ranging WSAC. We expand upon the Acebes et al. (2022) review by including information on guanaco, incorporating records from governmental registers, and exploring diagnostic methods.

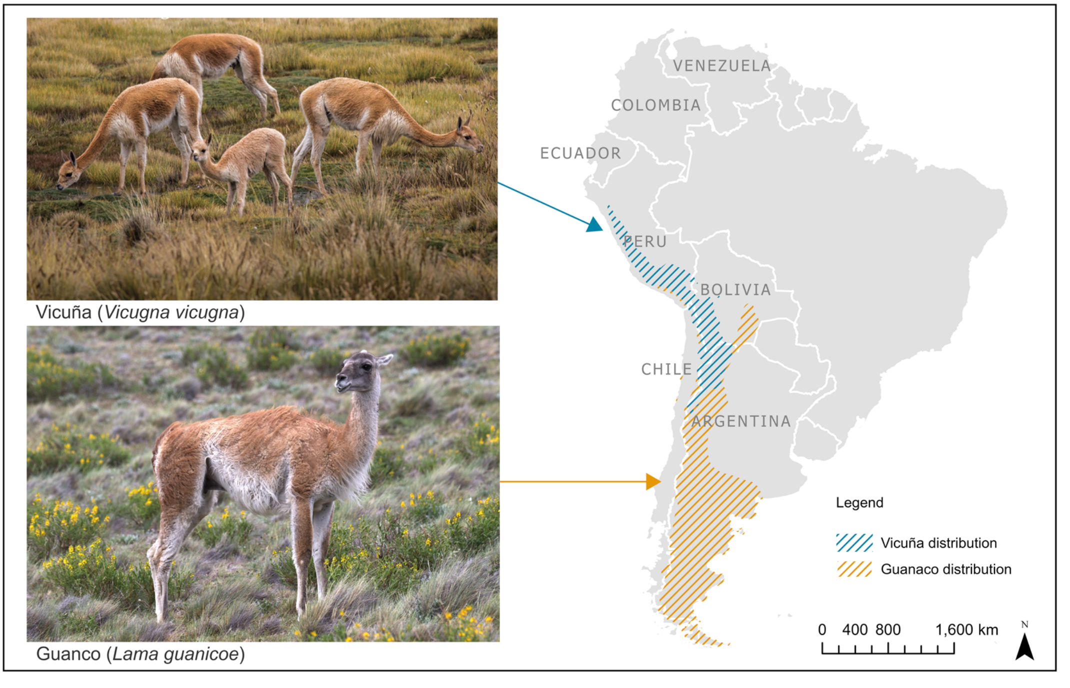

FIGURE 1 Distribution of wild South American camelids: vicuña (*Vicugna vicugna*; hashed blue distribution) and guanaco (*Lama guanicoe*; hashed orange distribution) across all Andean countries (labeled in grey).

Despite the recent efforts made to promote reporting of sarcoptic mange cases in WSAC, analyzing these data for trends is difficult due to limitations in data access, a lack of systematization across reporting agencies, and ambiguous prevalence reporting (i.e., absence of sarcoptic mange and missing data are conflated; Martin et al. 2023). Recent studies have documented localized extinctions of guanacos and vicuñas due to sarcoptic mange (Ferreyra et al. 2022, Monk et al. 2022), and others have demonstrated population-level impacts (Astorga et al. 2018, Montecino-Latorre et al. 2020, Acebes et al. 2022, Ferreyra et al. 2022, Gomez-Puerta et al. 2022); however, there remains a limited understanding of the dynamics and drivers of the disease in these populations (Monk et al. 2022). Specifically, spatiotemporal trends in prevalence (including across political boundaries), abiotic and biotic drivers of disease, treatment options and their efficacy, and guidelines for best practices in management are still poorly understood and defined.

In this review, we summarize peer-reviewed publications, gray literature, and unpublished governmental reports to identify knowledge gaps and opportunities to mitigate the geographic expansion of sarcoptic mange disease in WSAC. We aimed to identify knowledge gaps in 5 key areas: 1) economic and cultural impacts of mange on local Andean communities; 2) spatial distribution and prevalence of mange; 3) identification and diagnosis of sarcoptic mange; 4) origins and drivers of *S. scabiei* in WSAC; and 5) available treatments and their efficacy. Furthermore, we present specific approaches to address identified knowledge gaps, including multisectoral and stakeholder collaboration to enhance the implementation of prevention and control strategies.

METHODS

We conducted this review following the methodology established by the Center for Evidence-Based Conservation (Sutherland et al. 2004). We conducted a search between July and November 2021 using Google Scholar and the bibliographic database of the IUCN South American Camelids Specialist Group, and the queries consisting of multiple combinations of keywords: scientific and common names of the species (i.e., guanacos and vicuñas), the type of information sought (e.g., prevalence of mange), and the potential origins and drivers (Appendix A). The full description of the methodology used for the systematic review of published literature and unpublished government records, the results of the analyses performed, and the raw data assessed are freely available in a report developed by the Wildlife Conservation Society, Peru (Martin et al. 2023). We complement our search results with documents provided by stakeholders involved in current research, management, and conservation of WSAC.

We identified 212 records between 1966 and 2021: 22 published in English and 190 published in Spanish. Records included peer-reviewed publications (reviews, original research articles, short communications, books, and book chapters; $n = 61$) and gray literature (conference abstracts and posters, project abstracts, academic theses and dissertations, guidelines, government reports, policy documents, news releases, videos, and infographics; $n = 151$). All records were subject to an initial screening (title and abstract) to assess topic suitability and duplication. To avoid duplication, we cross-referenced all records (titles, abstracts, authors, and study details) across publication types (e.g., posters, theses, news releases, and peer-reviewed articles). When the same study was disseminated in multiple formats, we counted it only once in the final dataset and retained the version that provided the most complete information. Then, we performed a second screening by reading the full text (Appendix A). For inclusion in this review, documents must have provided quantitative or qualitative information to better understand sarcoptic mange burden and impact in WSAC. We excluded studies that did not address at least one research question (category IV, Appendix A). We considered 122 (57.5% of the 212 records identified) records containing quantitative or qualitative data in this review. This review took three years to curate because we needed to review articles in multiple languages and secure reports from governmental agencies; during that time, we also incorporated relevant scientific articles published beyond our formal review period (2022–2025; $n = 25$ scientific articles). The goal of this review was to gather information from Argentina, Bolivia, Chile, and Peru. The search strategy focused on studies in guanacos and vicuñas but also included information about domestic camelids (i.e., alpaca and llama) and other domestic animals (e.g., dogs and livestock).

We also assessed 1,408 unpublished governmental registers from Peru (n = 1,243) and Bolivia (n = 165) regarding the health records of managed vicuñas. Data were reported by local personnel (Bolivia) and governmental authorities (Peru) from 2008 to 2019, with most records taken after 2015 (n = 1,371 records) during chaccu events, which are community events where vicuña are corralled and their fiber is sheared. All data from Peru were collected in 2015 or after. Records from Bolivia spanned 3 departments, 16 provinces, and 22 districts, and records from Peru were reported from 13 departments, 60 provinces, and 173 districts. All records from Bolivia were from free-ranging vicuñas, while for Peru, 39% were from free-ranging populations (489/1,243), 19% were from mixed management (234/1,243; i.e., communities that have permission to manage both free-ranging and semi-captive vicuñas), and 17% from semi-captive populations (permanently within a fenced area; 205/1,243). The type of management was not documented in 25% (315/1,243) of the records from Peru. Data extracted included the size of the population managed; the number of individuals sheared, captured, or sampled; the location and year of the management event; the number of individuals registered with mange-compatible lesions, dandruff, lice, or ticks; the number of treated individuals; and the number of dead individuals observed. Detailed information on the managed vicuñas was also recorded, including male-to-female ratio, range of age, and general body condition.

RESULTS

WSAC cultural and economic value

Guanacos and vicuñas are medium-sized ungulates native to the arid and semiarid ecosystems of Argentina, Bolivia, Chile, and Peru, with a small remnant population in Paraguay and a few introduced populations also found in Ecuador (Baldi et al. 2016, Acebes et al. 2018). Wild camelids hold a cultural and economic importance for Andean communities, specifically surrounding historical and current practices by which communities collect and use camelid fiber during live-shearing events called chaccus (also spelled chaku; Vilá and Arzamendia 2022). The chaccu is a pre-Columbian tradition that relies on community engagement to corral vicuñas for health assessments and shearing to harvest fiber (Figure 2). Currently, chaccu events are only carried out in Bolivia, Peru, and Argentina; Chile no longer harvests WSAC fiber at a large scale. Fiber harvesting in Bolivia is performed exclusively in free-ranging vicuñas, while in Peru live-shearing events are conducted in both free-ranging and managed (semi-captive) animals. Semi-captive management was implemented in Peru in 1996 (through Módulos de Uso Sustentable de la Vicuña) to increase monitoring and reduce poaching by establishing permanently fenced areas with corrals to facilitate capture, health inspections, and shearing (Quispe Coaquira et al. 2015).

Chaccu events are subject to local and national governmental regulations known as management declarations or DEMA (declaraciones de manejo). As part of these management agreements, information about individual animals (i.e., age, sex, and weight) and general information from the event (i.e., date, location, and total number of animals captured) must be registered and reported. Management and registration activities in Bolivia are carried out by members of the local community, while in Peru these activities may also be performed by private companies (approximately 30%) and events are usually supervised by governmental authorities.

The trade of high-value WSAC fiber is a major source of income for Andean communities. One adult vicuña can provide up to 200 g of fiber every 3 years. Although communities receive around \$280–\$300 USD/kg for the raw fiber, the retail price for processed fiber from manufacturers can reach \$300–\$500 USD/kg (Vilá and Arzamendia 2022). For this reason, the amount of fiber obtained by each animal is a crucial component in the success of this process. However, the quantity of harvested fiber can be affected by the presence of *S. scabiei* in 2 ways: 1) fiber quality and quantity may be directly compromised by disease (e.g., hair loss, matting), and 2) shearing of infested animals may be prohibited by some government legislations (Sahley et al. 2007, Bujaico 2018, Acebes et al. 2022, Vilá and Arzamendia 2022). Indeed, most communities do not shear sick animals, even if governmental restrictions are not in place.

FIGURE 2 Pictures from a vicuña (*Vicugna vicugna*) shearing event (i.e., chaccu) in the Andean Plateau of Peru: vicuña corralled into a netted area while they await inspection and shearing (A), a vicuña with observed dandruff (circled in black; B), and a vicuña with mange-compatible lesions on the left forelimb (white arrow; C) and the left flank and underarm (D).

In Peru and Bolivia, the proportion of WSAC that are sheared during a chaccu is 30%–40% of the total number of animals captured (Calmet and Calmet 2015, Bujaico 2018, Quispe Coaquira et al. 2018), with the average annual number of animals sheared per chaccu in Bolivia (2008–2010, 2012, 2014, and 2017–2019) and Peru (2015–2019) ranging from 34–188 and 33–221 animals, respectively. In Argentina, one study reported shearing 60%–100% of animals captured during a chaccu conducted for training purposes, where fewer animals were caught and most were sheared (n = 2–21 animals), but when larger groups were captured (n = 43) shearing rates were more similar to those reported in Peru and Bolivia (37%; Arzamendia et al. 2008). The total number of animals processed is often limited by the number of available personnel and by the need to minimize animal stress by reducing time in the corral. Because clinical signs of mange may not be detected until animals are being handled, affected individuals can still occupy part of the limited handling window, reducing the time available for shearing healthy animals. Therefore, sarcoptic mange infections, in even a few animals, could result in important economic losses. For example, a 3-year study conducted in the Lucanas Province of Peru, where the annual mange prevalence was 1.4–21.5%, reported a total loss of more than 63.7 kg of fiber due to sarcoptic mange infection during the study, which would be equivalent to $22,300 USD (Bujaico 2018).

If sarcoptic mange continues to limit the quality and quantity of fiber harvested to the detriment of economic profitability, the local communities that manage wild camelids may abandon this responsibility. Without the investment of the communities, WSAC could face other threats (e.g., poaching) that are currently controlled through management agreements, whereby local communities commit to supporting the conservation of WSAC. In addition, the local communities that implement chaccu events are characterized by a high incidence of total or extreme poverty, and only 1% of them use WSAC fiber as their main income (Servicio Nacional de Áreas Naturales Protegidas por el Estado [SERNANP] 2018). Many individuals partake in chaccu events as an extra activity to complement communal income, which is invested in community development, WSAC management (e.g., fence maintenance, hiring park rangers, maintaining shearing equipment), and vicuña conservation. In this context, if the exploitation of the fiber no longer provides the expected economic return, some members of these communities may seek other more profitable opportunities that may be at odds with WSAC conservation (e.g., both legal and illegal mining activity).

Despite the economic impact that sarcoptic mange could present for local Andean communities utilizing WSAC, no research has been done explicitly examining the relationship between disease prevalence and economic loss. This may be due to limited mange data in the government registers. Despite mandatory chaccu activity reporting, disease data were only recently incorporated into the records. Prior to 2015, all disease documentation was optional, and reporting was subject to the willingness of the chaccu coordinator. Therefore, disease data prior to mandatory reporting are sparse and conflated (i.e., cannot distinguish missing data from absence of sarcoptic mange). However, anecdotal reports and testimonies of local community members suggest that the earliest cases of mange in vicuña may have occurred as early as 1998, and that mange likely drove localized extirpations of vicuñas, like those observed in Huanacopampa, Santa Ana de Aucará, Ayacucho, Peru between 2000 and 2004; though, it is possible that mange cases occurred in the region prior to these observations.

In addition to economic importance, WSAC have high cultural value. For example, vicuñas are considered divine creatures and the property of the Pachamama (Mother-Earth) to some Andean Indigenous groups. These cultural beliefs, in addition to strained or underdeveloped relationships between Andean communities, local researchers, and authorities, may prevent interventions during mange outbreaks.

Mange spatial distribution and prevalence in WSAC

The first record of suspected sarcoptic mange affecting WSAC was in guanacos from Chile in 1978 (Puig 1987). We identified provinces where confirmed (diagnosed through laboratory testing) and suspected (only confirmed through visual identification of mange-compatible lesions) sarcoptic mange cases were reported in WSAC from 1978 to 2023 (Figure 3). Confirmed or suspected sarcoptic mange infection in living or dead WSAC was reported by 33% (40/122) of publications and by 82% (1,162/1,408) of unpublished governmental reports from chaccu events in Bolivia and Peru. The location (i.e., province or department of the country) of the cases from published reports included 2 provinces of Argentina between 2005 and 2023, 9 provinces of 3 departments in Bolivia between 2006 and 2018, 4 provinces of 3 departments in Chile between 1978 and 2018, and 7 provinces of 7 departments in Peru between 2009 and 2019 (Figure 3). Additionally, mange-compatible lesions reported in the governmental unpublished records of chaccu events include 11 provinces of 3 departments in Bolivia between 2008 and 2019 and in 36 provinces of 10 departments in Peru between 2015 and 2019. No governmental reports from chaccus were available from Argentina. While these records are extensive, the absence of sarcoptic mange was confounded by the absence of data. Therefore, locations reporting no cases of sarcoptic mange in WSAC could not be considered free of the disease.

Overall, the prevalence reported from live and deceased vicuñas varied considerably over the years, with ranges from 0–100% and 0–94.9%, respectively (Table 1). The number of samples used to estimate prevalence in vicuñas varied across studies and reports (range = 25–58,276 individuals), and it is not clear if all captured

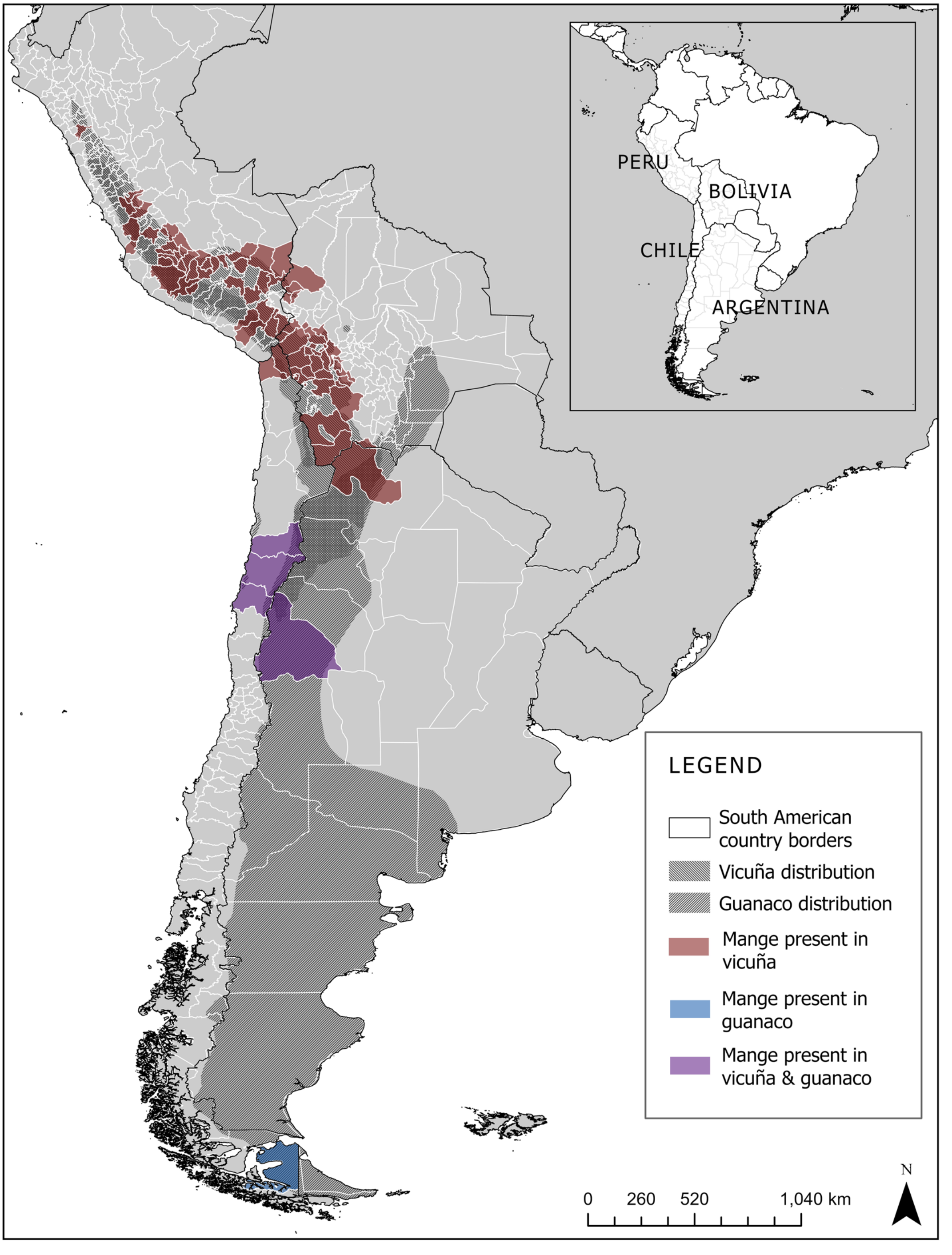

FIGURE 3 Provinces in 4 Andean countries with observed mange-consistent lesions and confirmed sarcoptic mange cases in wild South American camelid (WSAC) species, vicuña (*Vicugna vicugna*) and guanaco (*Lama guanicoe*), from 1978–2023. Reports come from peer-reviewed research and governmental records. If sarcoptic mange was suspected or documented at the Department level, then mange was considered present in the corresponding Provinces that coincide with WSAC distributions.

TABLE 1 Sarcoptic mange (*Sarcoptes scabiei*) prevalence in wild South American camelids (vicuña [*Vicugna vicugna*] and guanaco [*Lama guanicoe*]) in 4 Andean countries from published research and governmental reports.

Country	Year	Diagnostic	Species (status)	Prevalence *n*	Prevalence %	Prevalence 95% CI (%)[a]	Citation	Governmental registers[b]
Argentina	2017	Mange-compatible lesions	Guanacos (dead)	17	88.2	64–98*	Ferreyra et al. (2022)	–
Argentina	2018	Mange-compatible lesions	Guanacos (dead)	13 13	0 15.4	0–27 3.1–43.5*	Ferreyra et al. (2022)	–
Argentina	2017	Mange-compatible lesions	Guanacos (living)	11	36.4	15–65	Ferreyra et al. (2022)	–
Argentina	2018	Mange-compatible lesions	Guanacos (living)	1	0	0–83	Ferreyra et al. (2022)	–
Argentina	2014	Mange-compatible lesions	Vicuñas (dead)	n.r.	0	n.r.	Monk et al. (2022)	–
Argentina	2015	Mange-compatible lesions	Vicuñas (dead)	n.r.	0–75	n.r.	Monk et al. (2022)	–
Argentina	2016	Mange-compatible lesions	Vicuñas (dead)	n.r.	50–100	n.r.	Monk et al. (2022)	–
Argentina	2017	Mange-compatible lesions	Vicuñas (dead)	n.r.	75–100	n.r.	Monk et al. (2022)	–
Argentina	2017	Mange-compatible lesions	Vicuñas (dead)	99 99	0 94.9	0–4 88.4–98.1*	Ferreyra et al. (2022)	–
Argentina	2018	Mange-compatible lesions	Vicuñas (dead)	25 25	0 88	0–16 69.2–96.7*	Ferreyra et al. (2022)	–
Argentina	2005	*S. scabiei* identification	Vicuñas (living)	450	0.9	0–2	Arzamendia et al. (2012)	–
Argentina	2014	Mange-compatible lesions	Vicuñas (living)	n.r.	0	n.r.	Monk et al. (2022)	–
Argentina	2015	Mange-compatible lesions	Vicuñas (living)	n.r.	0–25	n.r.	Monk et al. (2022)	–
Argentina	2016	Mange-compatible lesions	Vicuñas (living)	n.r.	0–75	n.r.	Monk et al. (2022)	–
Argentina	2017	Mange-compatible lesions	Vicuñas (living)	n.r.	0–100	n.r.	Monk et al. (2022)	–
Argentina	2017	Mange-compatible lesions	Vicuñas (living)	347	28.5	24–34	Ferreyra et al. (2022)	–
Argentina	2018	Mange-compatible lesions	Vicuñas (living)	131	12.2	8–19	Ferreyra et al. (2022)	–
Argentina	2019	*S. scabiei* identification	Vicuñas (living)	807	3.5	2.3–4.9	Sosa et al. (2022)	–

(Continues)

TABLE 1 (Continued)

Country	Year	Diagnostic	Species (status)	Prevalence *n*	%	95% CI (%)[a]	Citation	Governmental registers[b]
Bolivia	2008	Mange-compatible lesions	Vicuñas	1,694	0.9	0.6–1.5[1]	—	9
Bolivia	2009	Mange-compatible lesions	Vicuñas	67	0	0–6.5[1]	—	2
Bolivia	2010	Mange-compatible lesions	Vicuñas	671	5.5	4–7.5[1]	—	19
Bolivia	2012	Mange-compatible lesions	Vicuñas	219	1.8	0.5–4.8[1]	—	3
Bolivia	2014	Mange-compatible lesions	Vicuñas	166	1.8	0.4–5.4[1]	—	4
Bolivia	2017	Mange-compatible lesions	Vicuñas	1,896	0	0–0.2[1]	—	54
Bolivia	2018	Mange-compatible lesions	Vicuñas	1,481	1	0.6–1.7[1]	—	31
Bolivia	2019	Mange-compatible lesions	Vicuñas	3,087	0.1	0–0.3[1]	—	43
Bolivia	2006	*S. scabiei* identification	Vicuñas (living)	36	5.6	1–19	Beltrán-Saavedra et al. (2011)	—
Bolivia	2013	*S. scabiei* identification	Vicuñas (living)	84	14.3	8–23	Ruíz Hurtado (2016)	—
Bolivia	2018	*S. scabiei* identification	Vicuñas (living)	92 78	9.8 5.1	5–18 2–13	Beltrán-Saavedra and Mollericona (2020) Beltrán-Saavedra et al. (2019)	—
Chile	2003	*S. scabiei* identification	Guanacos (dead)	371	33.7	29–39	Alvarado Gamez (2004)	—
Peru	2015	Mange-compatible lesions	Vicuñas	54,834	0.5	0.4–0.5[1]	—	252
Peru	2016	Mange-compatible lesions	Vicuñas	50,228	0.5	0.4–0.6[1]	—	246
Peru	2017	Mange-compatible lesions	Vicuñas	58,276	0.4	0.4–0.5[1]	—	260
Peru	2018	Mange-compatible lesions	Vicuñas	47,563	0.8	0.7–0.9[1]	—	235
Peru	2019	Mange-compatible lesions	Vicuñas (living)	101 33	22 100	16–32 87.6–100[1]	Esteban Paytan (2019)	1
Peru	2013	*S. scabiei* identification	Vicuñas (living)	3,929	4	3–5	Chipana and Flores (2018)	—
Peru	2014	*S. scabiei* identification	Vicuñas (living)	4,012	1.7	1–2	Chipana and Flores (2018)	—

TABLE 1 (Continued)

Country	Year	Diagnostic	Species (status)	Prevalence *n*	%	95% CI (%)[a]	Citation	Governmental registers[b]
Peru	2015	*S. scabiei* identification	Vicuñas (living)	9,811 733 3,795 107	36.3 9.4 5 37.4	35–37 7–12 4–6 29–47	Bujaico (2018); Unzueta Lancho (2018); Chipana and Flores (2018); Gálvez-Durand (2016)	—
Peru	2016	*S. scabiei* identification	Vicuñas (living)	9,346 3,622	2.4 3.1	2–3 3–4	Bujaico (2018); Chipana and Flores (2018)	—
Peru	2017	*S. scabiei* identification	Vicuñas (living)	6,139 3,706 3,700	3.4 1.7 1.7	3–4 1–2 1–2	Bujaico (2018); Chipana and Flores (2018), Chipana (2018)	—
Peru	2018	*S. scabiei* identification	Vicuñas (living)	53 102	64.2 61.8	51–76 52–71*	Murillo et al. (2019)	—
Peru	2021	*S. scabiei* identification	Vicuñas (living)	3,724	4.9	4.1–5.6	Serano-Martínez et al. (2024)	—

[a]Proportion of infected animals from the total of individuals sampled. The values in parentheses refer to the sample size (*n*) of the study and the confidence interval (95% CI) calculated using the binom.confint function (Agresti-Coull method) in the binom package in R 3.6.1 (Dorai-Raj 2022, R Core Team 2024). Some sample sizes were not reported (designated as n.r.).

[b]Data extracted from governmental records. The values refer to the number of records (i.e., number of chaccu events).

*Prevalence based on the number of animals reported as suspected sarcoptic mange.

[1]The proportions of the number of vicuñas registered with mange-compatible lesions over the total of sheared, captured, or sampled vicuñas in chaccu events.

individuals were examined or recorded. Notably, for many of these studies, animals were pooled across communities and departments, and across management types (free-ranging or semi-captive) to estimate prevalence. High prevalence of suspected sarcoptic mange was also reported in live and deceased guanacos, with prevalence ranging from 0–36.4% and 0–88.2%, respectively (Table 1). We included individuals with suspected sarcoptic mange in these estimates, though the reasons for considering these animals as suspect were not described, and conclusions from these results may be limited.

Unpublished prevalence data reported during chaccu events were only available from Bolivia and Peru, with prevalence ranging 0–9.8% and 0–100%, respectively. The number of animals sampled per event ranged from 5–373 in Bolivia and 1–4,387 in Peru. Although the total number of managed vicuñas is recorded in every chaccu event and there is mandatory registration of all cases of mange and dandruff, it is unclear whether all vicuñas with mange-compatible lesions are detected because of the short handling time of each animal.

Despite the wide geographic and temporal distribution of reported cases across Argentina, Bolivia, Chile, and Peru, only a few core published studies focused specifically on sarcoptic mange in vicuñas and guanacos (Gomez-Puerta et al. 2013, Astorga et al. 2018, Montecino-Latorre et al. 2020, Acebes et al. 2022, Ferreyra et al. 2022, Monk et al. 2022, Sosa et al. 2022). Furthermore, there were significant differences in reporting between published and unpublished literature. In general, there is limited governmental reporting and published research from Chile and Argentina relative to Bolivia and Peru, preventing comparisons of temporal trends or prevalence across countries. Similarly, published studies in these countries are concentrated in specific locations (e.g., Lucanas in Peru and Franz Tamayo in Bolivia), likely owing to accessibility and logistical limitations.

Prevalence of mange in WSAC varied by the diagnostic method; therefore, comparisons of prevalence across published studies and through time should be performed with caution. Prevalence tended to be higher when diagnosis was based on clinical signs (e.g., pruritus, hyperkeratosis, erythema, and hair loss). Visual identification of mites from skin scrapings may result in underdetection of mange in populations because of the low sensitivity of this technique (see **Diagnosing sarcoptic mange**), potentially resulting in false-negative results. We assumed that overestimation of cases due to misdiagnosis is unlikely because of the unique visual characteristics of lesions associated with sarcoptic mange, and that other pathogens that may cause clinical signs similar to crusted mange have been rarely reported in this region (see psoroptic mange report in domestic camelids; Sosa et al. 2024).

Diagnosing sarcoptic mange

The current gold-standard method for identifying *S. scabiei* is through molecular or morphological identification of the mite following collection (e.g., deep skin scraping) using polymerase chain reactions (PCR)—often using the internal transcribed spacer (ITS)−2 gene region or mitochondrial genes, cytochrome c oxidase subunit 1 (cox1) and 16S ribosomal ribonucleic acid (rRNA)–and light microscopy, respectively (Escobar et al. 2022). Visual observations of mange-compatible lesions may also be effective, but a comparative assessment of the diagnostic methods has not yet been undertaken. Despite mite identification being the recommended best practice, there are limitations to these methodologies that can influence estimates of prevalence (Walton and Currie 2007). While PCR and morphological identification have high specificity for detecting *S. scabiei* mites, they can have low sensitivity when mites are present but in low densities (e.g., early stages of disease; Fraser et al. 2018). In contrast, diagnosing cases through visual observation of skin changes can have low specificity (Valldeperes et al. 2019), as these changes (e.g., reddening, flaking, hair loss, lesions) can be ambiguous during early stages of infection and have similar clinical presentation as other dermatological conditions (e.g., allergic reactions, dermatitis caused by bacterial or fungal pathogens; Foster et al. 2007, Valldeperes et al. 2019).

Visual observation can still be used as a method to identify individuals with suspected mange in the absence of laboratory diagnostics. Sarcoptic mange can present differently depending upon the immune response, which can be immediate (type 1; antibody-mediated response) or delayed (type IV; cell-mediated; Pence and Ueckermann 2002).

Both response types are considered immunopathological, whereby the immune response to infestation causes damage to the host, but type IV is associated with a more severe form of the disease, known as crusted scabies (Næsborg-Nielsen et al. 2022). The type of immune response varies by host species and even among hosts of the same species. For WSAC, common visual signs of sarcoptic mange include intense pruritus, flank and extremity wounds, hair loss, hyperkeratosis (crusted lesions), and reduced movement (Esteban Paytan 2019, Ferreyra et al. 2022). Mange disease progression in WSAC has been described in 3 stages: 1) early, characterized by pruritus, only; 2) advanced, classified by reduced movement or visible lesions on the extremities of the body; and 3) severe, classified by the aforementioned clinical signs and extreme hair loss extending to various parts of the body (Ferreyra et al. 2022). In populations where mange has already been confirmed, visual observation could be used as a non-invasive way to monitor mange occurrence and outbreaks in wild WSAC (Ferreyra et al. 2022). The highest risk for misdiagnosis when using only visual observations is for asymptomatic animals (e.g., animals in the early stages of infection that are pre-clinical). These limitations vary between the individual level and the population level, with higher costs of misdiagnosis at the individual level, particularly if the goal is to identify individuals to remove (i.e., euthanize) or capture for treatment. Conversely, long-term standardized visual observations, even with limitations and levels of uncertainty, could help elucidate disease dynamics over time or compare across WSAC populations and save on resources that would be required to capture and sample individual animals in a population. To our knowledge, there are no reports of disease outbreaks caused by other pathogens causing sarcoptic mange-like skin crusting conditions at a population level in this system, highlighting the potential for use of visual diagnostics as a surveillance method.

In addition to the limitations of diagnostic tests, confirming mange cases in WSAC is complicated by their aversion to human activity (e.g., drone and vehicle surveillance) and logistical challenges in observing groups in the high-plateau region of the Andes. However, chaccu events occur semi-regularly, every 3 to 5 years for a given population, offering a unique opportunity to acquire disease data from WSAC populations. During chaccu events, veterinarians are often not present; thus, personnel trained in visual diagnosis of sarcoptic mange-compatible lesions and sample collection would be valuable. Guidelines for visual diagnosis and sample collection have been published by governmental authorities or academic institutions in Peru (Servicio Forestal y de Fauna Silvestre [SERFOR] 2021), Argentina (Ferreyra et al. 2022, Sosa et al. 2022), Bolivia (Ministerio de Medio Ambiente y Agua [MMAyA] 2021, MMAyA et al. 2021), and Chile (Pérez et al. 2007). These guidelines also describe the disease stage and severity (Appendix B), call attention to the body region afflicted (i.e., ears and around the eyes, axillary, inguinal and perineal regions, flank, and anterior and posterior extremities) and percent of body affected (percent of body experiencing hair loss), and provide protocols for sample collection (e.g., from a carcass).

Origin and drivers

The origin and drivers of sarcoptic mange in WSAC remain unclear. To the best of our knowledge, no study has presented evidence of the source of *S. scabiei* mites (e.g., endemic in populations or introduced by other species), how and why mites establish in certain populations, or the transmission dynamics (e.g., direct contact, environmental) in WSAC populations. Further, much of the available data is not sufficient to identify patterns of outbreaks among populations. Several factors have been identified as drivers of disease dynamics, including interaction with domestic species, WSAC management methods, movement of animals (translocations), and environmental fluctuations (e.g., nutritional stress due to low forage quality).

Wild South American camelids are sympatric with domestic camelids, llama (*Lama glama*) and alpaca (*Lama pacos*), which are species derived from domestication of guanaco and vicuña, respectively, and WSAC may interact and compete with domestic camelids in some regions (Beltrán-Saavedra et al. 2011). Interaction with domestic camelids and other domestic animals has been noted as a potential source for disease observed in WSAC populations (Baldi et al. 2016, Acebes et al. 2018). Further, movement of llama and alpaca herds for forage opportunities and trade has been a suspected cause of geographic spread of mange, though no data are available to support this claim. Indeed, domestic camelids are susceptible to *S. scabiei* infestations and likely share this generalist mite with their wild counterparts (Bornstein 2010, Arzamendia et al. 2012, Browne et al. 2022, Ferreyra et al. 2022), as genetic analyses of *S. scabiei* have shown that wild and domestic camelid mites are genetically similar in South America (Anello et al. 2025, Sosa et al. 2025). Therefore, maintaining healthy domestic camelid herds may mitigate cross-species transmission (Ruíz Hurtado 2016). While vicuñas have been blamed as the source of *S. scabiei* in domestic camelids, some studies suggest that transmission likely occurs in both directions, to some extent (Beltrán-Saavedra et al. 2011). To our knowledge, no study has fully addressed the directionality of cross-species transmission among wild and domestic camelids.

Human activities (e.g., exploitation of WSAC fiber) were also associated with the occurrence of sarcoptic mange in WSAC populations (Vilá and Arzamendia 2022), particularly because of live-shearing management during chaccu events. During chaccu events, animals are artificially forced into confined spaces in large numbers, increasing risk of direct contact and potential transmission of mites between infected and uninfected animals. In addition, transmission may also occur through fomites during shearing if preventive measures are not taken. The off-host environmental durability of *S. scabiei* mites may allow for their persistence on equipment used during chaccus, including on the tarps (made of canvas material) where animals are held for shearing, clothing of personnel, or on the shearing tool (i.e., shearers). These materials may be a source of infection if they are reused across individuals without proper decontamination between animals. General management of WSAC, including free-ranging, semi-captive, or captive herds (see **WSAC cultural and economic value**), is also associated with mange prevalence, with higher observed prevalence in free-ranging WSAC herds relative to captive ones (Angulo-Tisoc et al. 2021). This discrepancy was attributed to preventive healthcare administered to captive individuals, which may include the use of acaricides, post-treatment monitoring, and early detection and amelioration of disease (Unzueta Lancho 2018, Angulo-Tisoc et al. 2021).

In addition to fiber harvesting, WSAC populations are also managed for preservation, and movement of WSAC individuals to bolster populations with low numbers or to restore historical ranges where they have been locally extirpated is common practice (i.e., translocations or reintroduction events). Relocations have helped to restore populations in Chile, Peru, and Ecuador, and are likely occurring in other Andean countries (Bonacic 2000, SERFOR 2016, McLaren 2019); though, we do not have access to all reports. These relocation events are supervised by the national authorities and permits are only administered to animals that exhibit no clinical signs of disease (SERFOR 2016). However, even with experienced personnel selecting and approving animals for movement, there is still the possibility of transporting asymptomatic animals (e.g., early stages of infection) that could be a source of outbreaks in mange-free areas. Currently, there is no standardized protocol or recommendation for preventative treatment of animals eligible for translocation.

Studies have also reported environmental persistence of mites under specific climatic conditions (namely, cool and humid conditions; Arlian et al. 1989, Arlian and Morgan 2017, Niedringhaus et al. 2019), highlighting dens, burrows, and resting areas as potential sources of infection that should be considered in disease mitigation strategies (Martin et al. 2019, Montecino-Latorre et al. 2019, Browne et al. 2021). Wild South American camelids share wallows that are potential sites for environmental transmission to occur in these species (Serrano-Martínez et al. 2024). Favorable environmental conditions for mite persistence could explain seasonal dynamics of mange outbreaks reported in some species, although this is not consistent across systems, with some reporting higher prevalence in, or severity correlated with, autumn and winter (i.e., cold period; Vander Haegen et al. 2013, Bujaico 2018), and others in summer (i.e., warm period; Ferreyra et al. 2022). Seasonal environmental persistence of the mite may also be confounded with seasonal variation in host body condition and immune function, or seasonal changes in hair and fur growth.

Climate change, co-grazing with domestic species, management practices, and changes in weather patterns all may influence resource availability and nutrition (Flores 2015, Ruíz Hurtado 2016). Poor soil quality and pastures can negatively affect animal nutrition and may result in lower immune response that could increase an individual's susceptibility to infection. In addition to poor nutrition, reduced water and pasture availability may promote congregation of animals in areas where resources occur, promoting higher densities and increasing the opportunity for direct transmission. Density-dependent transmission of *S. scabiei* has been documented in some systems (e.g., western gray squirrels [*Sciurus griseus*]; Vander Haegen et al. 2018) but is not the case for all systems (red foxes, Devenish-Nelson et al. 2014; wolves [*Canis lupus*], Almberg et al. 2015; bare-nosed wombats, Carver et al. 2023) and may be predicted by species life-history traits (e.g., solitary or social, monogamy or polygamy, den or burrow use). In WSAC, high densities of animals can be observed in semi-captive management, or populations that are being managed for their fiber and exist in fully fenced or semi-fenced areas. However, in free-ranging populations, WSAC may exhibit smaller, more segregated social groups that may experience fission and fusion of individuals. Thus, additional investigation of density- and frequency-dependent transmission is warranted across these management types.

Treatment options for sarcoptic mange

Few studies have evaluated the efficacy of treatments in domestic and wild South American camelids, limiting conclusions that can be drawn regarding posology (i.e., dosage and frequency) and treatment efficiency, best administration routes (e.g., oral, topical, intramuscular), complementary therapies, environmental control, and the proportion of the population that needs to be treated to observe herd- or population-level effects (though, see Mbuagbaw et al. 2024 for a review of treatments and successes). Notably, most studies were performed on captive camelids, as recapturing wild and semi-captive camelids to test different posologies is challenging. In our reading of the literature, ivermectin (part of the avermectin family of medications) was the most common pharmaceutical used to treat WSAC infected with *S. scabiei* (Appendix C).

Of the documents reviewed, 12 records included information on treating camelids for sarcoptic mange, of which 4 were conducted in vicuñas and guanacos, and the remaining were studies conducted in domestic camelids. The 4 studies focusing on WSAC species treated the animals with parenteral avermectins (ivermectin, moxidectin, or doramectin), with subcutaneous ivermectin being the most commonly used protocol (Appendix C). The dosage of ivermectin ranged from 0.1–0.63 mg/kg, and the frequency of administration included 3 doses via subcutaneous application, each separated by 10, 30, or 40 days (Appendix C). Rates of recovery for WSAC ranged from 9% of animals treated to 100%, likely reflecting drug type and posology.

Some studies have reported *S. scabiei* resistance to ivermectin (Currie et al. 2004, Mounsey et al. 2008, Terada et al. 2010), which can occur following frequent pharmaceutical use over long periods; thus, appropriate administration should be considered. Caveats of published treatment studies include lack of a control group (most treatments occur *in situ*), no criteria for what defines recovery, limited surveillance of recovery or recurrence rates, and no knowledge of underlying factors that may confound treatment outcome (e.g., secondary bacterial infections). This is not meant to criticize published work, as these are limitations of *in situ* treatment of disease in wild populations. Instead, it warrants captive and experimental studies to identify effective mange treatment regimes in WSAC.

A final consideration is whether interference (i.e., treatment) is the appropriate action (Mounsey et al. 2022). From an evolutionary standpoint, treatment may affect natural selection processes. For example, individuals that would otherwise lack effective resistance or tolerance to sarcoptic mange may survive with assistance through treatment administration (Schaschl et al. 2012). Conversely, without knowing the origins of *S. scabiei*, it may be an ethical or even ecological obligation to mitigate mange impacts. If *S. scabiei* was recently introduced to WSAC through human and animal movement, these species may not have had time to evolve resistance or tolerance to *S. scabiei*. Thus, research focused on evidence of unaided survival and recovery, and genomic predictors of these, is warranted. To our knowledge, no study has assessed natural recovery rates of sarcoptic mange in populations of WSAC. Additionally, because recent research has demonstrated dramatic ecosystem-level impacts of sarcoptic mange in vicuña and guanaco (Ferreyra et al. 2022, Monk et al. 2022), there may be an ecological basis for disease management in some contexts.

Legislation on treating WSAC for sarcoptic mange varies among Andean countries. The Bolivian government environmental authority prohibited the treatment of managed, free-ranging vicuñas; albeit, this has not prevented the administration of pharmaceuticals to WSAC by some community members. In contrast, the administration of ivermectin to managed vicuñas is common practice in Peru, but post-treatment monitoring to assess field efficacy is lacking. In Argentina, pharmaceutical treatment of camelids is prohibited, and representatives of the Fauna Division are present at and supervise chaccu events to ensure that treatments are not administered.

There are important economic limitations associated with post-treatment surveillance. Chaccu events can cost up to $2,000 USD to perform, and there is resistance from local communities to coordinate a second chaccu solely for treatment purposes (i.e., recapture and treatment). Animals that would be targeted during a second chaccu are unlikely to provide profitable quantities of fiber because they have been recently sheared. During chaccu events, Peruvian communities often administer preventive treatments with ivermectin to both symptomatic and perceivably healthy animals with doses that may or may not be at the correct concentration for the animal's size. A single dose of ivermectin to both diseased and healthy individuals may confer some population-level benefits if the dose is sufficient to induce broad-scale protection for a duration that breaks the lifecycle of the mite, or it may have little effect if the drug posology (dose and frequency) does not have sufficient efficacy in molting mites and hatching eggs (Feng et al. 2023). There are also possible risks that frequent low-dose treatments could increase the risk of acaricide resistance, although given the low apparent frequencies with which treatment is currently administered to WSAC, this risk may be minimal. Treatment regulations for WSAC are complicated by the common use of pharmaceuticals in sympatric domestic camelids. Community members have been using ivermectin for decades in domestic livestock, and at increasing concentrations to control for prevalent parasites. Thus, acaracide-resistant *Sarcoptes* mites may already be present in these systems, both in domestic and wild camelids, but not because of WSAC treatment.

Since communities rely on profit from fiber harvest, there is pressure at the local scale to take management action, even if the management method is not recommended by authorities; thus, practices in these communities are unlikely to change. Therefore, it is of interest to find effective alternatives to the current treatment methods that could be applied during the chaccu events (i.e., a pharmaceutical that only requires one administration and is long-lasting; e.g., fluralaner; Sala et al. 2024). One consideration in the discussion of treatment includes unintended consequences, as preventive treatments may have cascading impacts on the environment. Previous studies have shown that ivermectin administered to domestic animals is largely excreted in its unmetabolized form in feces (Strong et al. 1996, O'Hea et al. 2010, Mesa et al. 2017, Powell et al. 2018). The eliminated ivermectin may exert selection pressure on various parasites that are found in the environment and affect the biodiversity that exists in these habitats, particularly invertebrate fauna responsible for ecological processes such as manure degradation, soil fertilization, and seed dispersal (Konopka et al. 2022). To date, the levels of ecotoxicity at chaccu sites associated with the use of ivermectin in WSAC are unknown, and studies focusing on this potential environmental contamination and the extent to which it presents any meaningful risk are needed.

Occasionally, complementary therapeutics are administered in addition to pharmaceutical acaricides, though not all countries or communities employ these practices. Complementary therapeutics include supplementary nutrients (e.g., vitamin complex, high nutrient diet, and mineral remedies; Gomez-Puerta et al. 2013), medical support (e.g., intravenous fluids and antibiotic administration), incorporation of medicinal plants into diet, and non-pharmaceutical topical treatments, which include application of sulfur and burnt oil-based ointment to mange-compatible lesions (Bujaico and Zuñiga 2016). Alternative support could be provided through the use of antibiotics for secondary bacterial infections, intravenous fluids, and high-calorie nutrition that improve the general condition of the host (Kido et al. 2014, Couper and Bexton 2016, SERFOR 2021); though, these may only be applicable in captive camelids.

Non-pharmaceutical supportive treatments have mixed support. The use of burnt oil-based ointment is prohibited by Peruvian governmental authorities; instead, they recommend the application of Trichlorfon (a pesticide in paste form) as an alternative topical therapy. The use of burnt oil as a topical treatment for mange in animals can be harmful because the insulative properties of fur may be lost when oil is applied, thus disrupting thermoregulation processes. In addition, to our knowledge, no study has demonstrated the effectiveness or benefits of burnt oil in eliminating mite infestations, though natural-based oils (e.g., extracted from plants) have been reported to alleviate pruritus in skin diseases of humans and mice (Lee et al. 2010, Tabassum et al. 2014). Additional non-pharmaceutical treatment practices that have been reported in domestic camelids include use of medicinal plants, animal and mineral remedies, and human body remedies, rituals, or other traditional techniques (e.g., agitations and massages; Quiso Choque 2014). Despite the frequent use by local community members, these non-pharmaceutical treatments could present severe risk for animal welfare—even when accompanied by allopathic treatment with endectocides—and their efficacy has not been established.

KNOWLEDGE GAPS AND POTENTIAL RESEARCH DIRECTIONS

Research on sarcoptic mange in WSAC has increased in the last 20 years, showing that the disease is present in guanacos and vicuñas from all countries where WSAC are distributed, including Argentina, Bolivia, Chile, and Peru. Despite increasing interest in understanding mange in WSAC, there is a considerable lack of information, particularly regarding guanacos. Based on the main knowledge gaps and challenges identified, we present options to mitigate the burden and limit the expansion of mange in WSAC across their native countries (Table 2). Some recommendations are capable of immediate implementation and would not require substantial resources or capacity building. Others would require collaboration among governmental agencies, research institutes, and local communities.

The first major knowledge gap is regarding the treatment of infected WSAC and the impact of sarcoptic mange on the morbidity and mortality of individuals and populations, which have not been sufficiently studied. These aspects could be addressed in future research through controlled trials to elucidate the safest and most efficacious therapeutic protocols, and the clinical relevance and conservation implications of the disease. Secondly, the economic impact of sarcoptic mange in WSAC populations for Andean communities requires further investigation, which could be explored by enhancing capacity building of local governmental institutions and participatory research to study sarcoptic mange during chaccu events. Thirdly, there is no conclusive evidence of the origin and drivers of sarcoptic mange infection in WSAC despite the widespread detection. For instance, data obtained from the published and unpublished records were insufficient to demonstrate whether management type (e.g., fenced) increased the prevalence of the disease. Further studies could focus on identifying the drivers responsible for the acquisition and spread of sarcoptic mange in WSAC, including cross-species transmission with livestock. In addition, innovative techniques such as satellite tracking and collaborations across research teams in different countries could elucidate whether WSAC are spreading mites across political boundaries (e.g., through animal movement).

We identified heterogeneity in the results of the published studies and important distinctions in study designs (e.g., wide variation in sample sizes), and note that there are fewer studies available for WSAC from Argentina and Chile (especially those focused on guanacos). In addition, many studies presented incomplete or inadequate reporting of data. Therefore, we recommend standardization of methodologies, which could follow consensus of international experts along with international collaboration to support local research teams and improve study designs. Current unpublished governmental registers lack laboratory tests for diagnosing sarcoptic mange in managed vicuñas and records are often incomplete, highlighting the potential to improve data collection and recording of animal health information at chaccu events. In addition to standardizing methodologies and information collected, making formal training opportunities for official governmental veterinarians and local management groups to learn mange identification procedures and sample acquisition skills would minimize errors and missing data. The use of digital tools (i.e., online databases) could help capture and systematize information derived from chaccu events. Our review also calls for the establishment of national surveillance programs that would allow

TABLE 2 Addressing knowledge gaps regarding sarcoptic mange disease in wild South American camelids (WSACs). We summarize the knowledge gap or challenge identified, the current best practices based on published literature, the opportunities for addressing the knowledge gap or challenge, what resources would be required, and long-term goals.

Identified challenge	Recommended best practices	Opportunities	Resources required	Long-term goals
Non-standardized diagnostic methods for *Sarcoptes scabiei*	Visual documentation of disease should be confirmed using additional methods (polymerase chain reaction [PCR] or microscopy)	Visual observations of sarcoptic mange at chaccu events could be accompanied by skin scrapings from a subset of animals to confirm *S. scabiei* presence	Training for government personnel and community members to facilitate sample collection and laboratory diagnostics	Studies of diagnostic tools (e.g., LAMP), host immune response, and genetic variability of mites for development of serological tests and more sensitive and specific diagnostics
Limited geographic surveillance and nonstandard surveillance techniques and reporting for sarcoptic mange	Standardized protocols for sarcoptic mange documentation and population estimation in WSAC across their known ranges Standardized scoring methods and reporting for disease severity, including a category for uncertain cases (e.g., early stages of disease or ambiguous signs)	Integrated surveillance programs for both domestic and wild camelids through community events (chaccus) and governmental surveillance Implement digital tools to simplify data collection and management (e.g., SMART, Kobotoolbox, Epicollect 5, Avenza maps, Earth Ranger, ECOSCOPE) Host workshops to encourage collaboration and exchanging of experiences among research teams across South American countries Engage international mange experts to develop experimental designs for understanding mange prevalence Standardized protocols have been created by authorities of Argentina, Bolivia, Chile, and Peru	National and international support to implement uniform methods Finances for broad-scale surveillance (e.g., helicopter surveys) and training for sarcoptic mange identification (e.g., signs and symptoms) Support for workshops or conferences for government officials, biologists, and international advisors to meet	Longitudinal studies investigate mange-host interaction, mange pathophysiology in WSAC, and disease dynamics Assess ecological factors that may drive spread and occurrence within and between WSAC populations (e.g., climate, weather events, habitat quality)
Possible disease transmission during community events (chaccus)	Limit transmission with capture hygiene, including using a single needle per animal when administering injectables, employing preventive measures during shearing (e.g., disinfecting shearers between animals), avoiding overcrowding of animals in fenced management areas, and limiting handling time	Implement hygiene protocols at governmental management events and community events (chaccus)	Support for training of local management groups in sanitary shearing techniques	Garner support from public and private investors for the conservation of WSAC to alleviate financial burden on Andean communities

TABLE 2 (Continued)

Identified challenge	Recommended best practices	Opportunities	Resources required	Long-term goals
Limited information on treatment regimens and opportunities for treatment application: 1) Partial or indiscriminate treatment of sarcoptic mange in WSAC and potential for mite resistance to acaricides 2) Lack of standard and tested treatment regimen for successful mange treatment in WSAC	Assess the merits of preventative use of acaricides (ivermectin and moxidectin) Treat wild WSAC when posology can be completed (e.g., minimum of 2 doses separated by a 14-day interval) through mark-recapture or a temporary hold in captivity Set standardized criteria for what classifies as a recovered individual following treatment	Document treatments administered during chaccu events, including details regarding pharmaceutical, posology of administration (i.e., dosage, number of doses, and the interval between doses), number of individuals treated, and if recovery is achieved	Community outreach campaigns regarding the research-informed use of acaricides and the important ecological value of vicuñas	Experimental treatment trials in to test most effective posology, dose interval, pharmaceuticals (ivermectin or other), and delivery (e.g., oral, topical, etc.) Assess safety and efficacy of longer lasting pharmaceuticals in WSAC that would only require one administration (e.g., fluralaner) Assess optimal individual and population-level therapeutic intervention strategies
Separate research and management efforts by governmental entities and local communities	Employ interdisciplinary and multifaceted studies to evaluate the socio-economic impact of the disease for local communities Improve dialogue between Andean communities and stakeholders involved in WSAC management	Increase national and international awareness of the impact of mange for WSAC conservation and the sustainable development of Andean communities Engage local communities in participatory epidemiology	Community outreach by stakeholders to better understand the challenges faced by local communities and support for training and engagement of local managers	Investigate the socio-economic and political landscape of vicuña conservation across Andean countries Perform interdisciplinary studies to estimate the economic impact of mange for local communities Investigate the effects of human encroachment and management on WSAC fitness and disease status
Limited understanding of the origin of sarcoptic mange in WSAC	Surveillance and sampling of other species	Engage in opportunistic sarcoptic mange surveillance in domestic animals and other wild camelid and non-camelid species	Collaboration among private land holders, academic institutions, and government agencies to coordinate sample collection and access to samples for research use	Mite genomic studies to uncover invasion and epidemiological histories

for the monitoring of affected WSAC populations, rapid identification of outbreak events, and evaluation of different strategies to limit disease impacts and the spread of mites, including research-informed use of endectocides by both veterinarians and local communities. Finally, effective prevention strategies require a multi-sectoral approach, including government support, community involvement, and collaborative research to generate technical and educational materials for official veterinarians, local communities, and stakeholders to promote animal welfare and best management practices during fiber exploitation of WSAC.

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CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflicts of interest.

ETHICS STATEMENT

This study was based exclusively on a review and synthesis of previously published literature. No new data were collected, and no experiments involving animals, humans, or other living organisms were conducted. As such, ethical approval from an institutional animal care and use committee (IACUC) or equivalent ethics board was not required.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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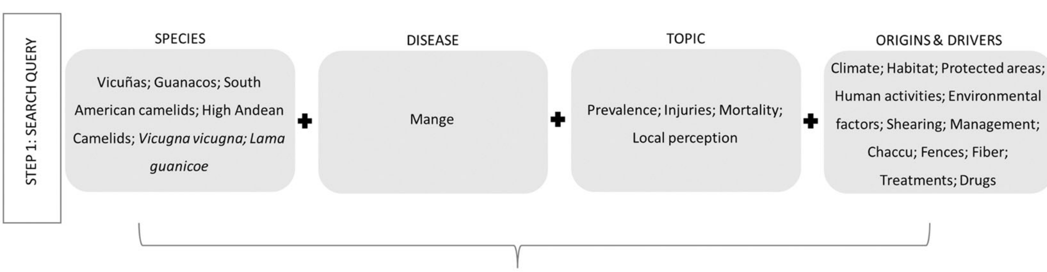
APPENDIX A: Keywords used in search queries to find relevant scientific publications. Several combinations of words in the following list were used to design search queries. Queries were made in both English and Spanish. Documents were screened using title and abstracts and then classified into the categories defined Pullin and Knight (2001 and 2003; step 2).



STEP 2: FILTERING CRITERIA

Level of evidence	Criteria
I	Strong evidence from a well-designed study (conceptually well-designed, randomized, and controlled experiment) with an appropriate sample size.
II-1	Evidence from a well-conceptualized and controlled study, but without randomization.
II-2	Evidence from a study based on the comparison of differences between places or situations, seeking to correlate factors with the independent variable.
II-3	Evidence derived from several time series or robust results of uncontrolled experiments.
III	Expert opinions based on qualitative field results, descriptive studies and expert committee reports.
IV	Inadequate evidence due to methodological problems (indicators, samples, duration, etc.) or evidence without support or explanation.

APPENDIX B: Classification of sarcoptic mange in managed vicuñas recommended by the governmental authorities from Peru. Table adapted from the recommendations by Servicio Nacional Forestal y de Fauna Silvestre (SERFOR), Servicio Nacional de Sanidad Agraria (SENASA), Instituto Nacional de Innovación Agraria (INIA), and Servicio Nacional de Áreas Naturales Protegidas por el Estado (SERNANP; SERFOR 2021).

Severity of the disease	Extent of hair loss	Type of lesions	Clinical signs
Mild or early stage	<10% of the body	Skin inflammation (dermatitis) and minor crusted-lesions	Mild itching and scratching
Moderate	10–40% of the body	Hyperkeratosis and onset of crusted-lesions	Severe itching and scratching
Severe	40–60% of the body	Severe hyperkeratosis, significant crusted-lesions, dermatitis with evident borders, and otitis externa	Extreme itching and scratching
Highly advanced stage	60–100% of the body		

APPENDIX C: Treatment protocols applied in wild (vicuña [*Vicugna vicugna*] and guanaco [*Lama guanicoe*]) and domestic (alpaca [*Vicugna pacos*] and llama [*Lama glama*]) camelids worldwide ($n = 12$ records).

Country	Species	Drug	Dose in mg/kg[a] (age class)	Route[b]	Number of doses	Interval between doses (days)	Number of treated animals[c]	Recovery rates (%)[d]	References of published data
Argentina	Llama	Ivermectin	0.4	SC	2	14	NA	NA	Arzamendi et al. (2012)
Germany	Alpaca	Moxidectin	0.2	SC	8	21	4	100%	Beck (2020)
	Llama	Moxidectin	0.2	SC	8	21	3	67%	
	Alpaca and llama	Doramectin	0.5	Pour-on	NA	NA	7	0%	
Greece	Guanaco	Moxidectin	0.2	SC	2	10	2	100%	Papadopoulos and Fthenakis (2012)
Italy	Llama	Ivermectin Fluralaner	0.2 5.0	SC Oral	2 1	~60 NA	1[e] 1[e]	0% 100%	Sala et al. (2024)
Peru	Vicuña	Ivermectin	0.1 (juveniles) 0.2 (adults)	SC	NA	NA	1,646	95%	Bujaico and Zuñiga (2016)
		Ivermectin	0.4	SC	3	30	12	25%[f]	Gálvez-Durand (2016)
		Doramectin	0.3				11	9%[g]	
		Ivermectin	0.2 0.63	SC	3	40	NR	NA	SERFOR (2021)[h]
	Alpaca	Ivermectin	0.2	SC	2	7	10	100%	Ramos Acuña et al. (2000)
			0.2	IM	2	7	10	100%	
			0.3	SC	2	7	10	100%	
			0.3	IM	2	7	10	100%	
		Ivermectin	0.26	SC	1	NA	15	NA	Laboratorios MIDAF (2005)

(Continues)

Country	Species	Drug	Dose in mg/kg[a] (age class)	Route[b]	Number of doses	Interval between doses (days)	Number of treated animals[c]	Recovery rates (%)[d]	References of published data
		Ivermectin	0.2	SC	NA	NA	NA	NA	Agrovet Market (2012)
		Ivermectin	0.2	SC	NA	NA	NA	NA	República del Ecuador (2013)
		Ivermectin	0.26 0.325	SC	NA	NA	2	100%	MIDAF (2007)

[a]Posology of the treatment.

[b]Route of drug administration: subcutaneous (SC), intramuscular (IM), oral, or pour-on.

[c]Number of vicuñas treated using the same therapeutic protocol and in the same period (i.e., month and year). NA indicates information was not available or not reported.

[d]Proportion of vicuñas reported as recovered after treatment, although the definition of recovery was not provided.

[e]Same individual received both treatments.

[f]Only 3 individuals with moderate infection completed the treatment protocol and all demonstrated full recovery.

[g]Only 3 individuals with moderate infection completed the treatment protocol and 1 demonstrated full recovery.

[h]Recommended treatment protocol by Peruvian government authorities to be applied in captured free-ranging animals presenting severe clinical signs of sarcoptic mange.