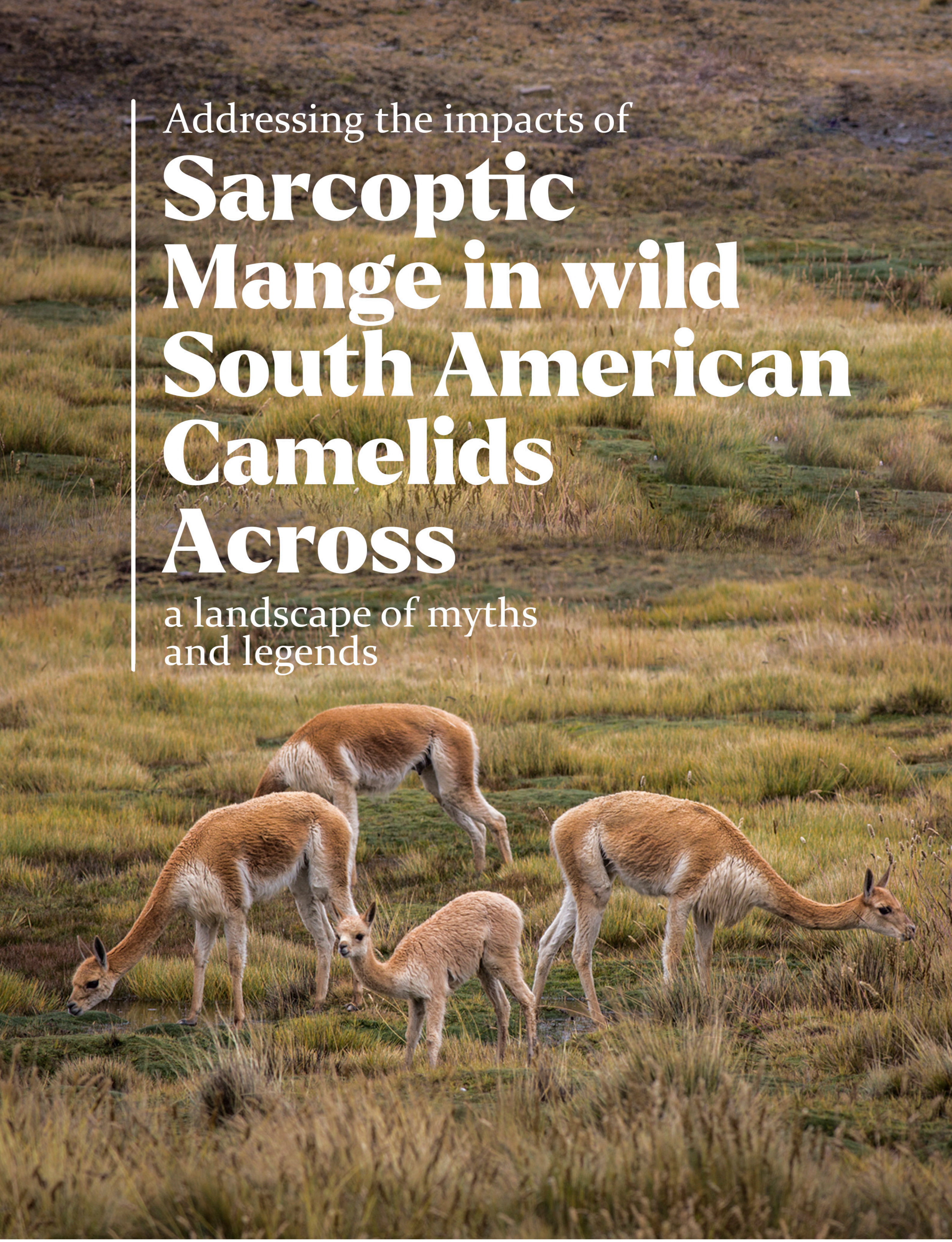
Addressing the impacts of

Sarcoptic Mange in wild South American Camelids Across

a landscape of myths and legends



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White Paper. Adressing the impacts of sarcoptic mange in wild South American camelids across a landscape of myths and legends

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Susan Walker - WCS

SNAPP Team: Diseases in Wild South American Camelids

Vicuñas (*Vicugna vicugna*) and guanacos (Lama guanicoe) are two species of wild South American Camelids (SAC) distributed from southern Argentina and Chile to central Peru. In addition to being key components of the ecosystems they inhabit, they are part of food chains and local economies. Listed as critically endangered in the 1960s due to poaching, vicuña numbers were gradually recovering until recently, when an outbreak of sarcoptic mange began to threaten their populations. Sarcoptic mange is an infectious skin disease caused by the *Sarcoptes scabiei* mite and detected worldwide in many species, affecting guanaco and vicuña populations in Argentina, Bolivia, Chile, and Peru. The most extreme outbreak was recorded in San Guillermo National Park in northeastern Argentina, where 90% of vicuñas and guanacos died of mange between 2016 and 2018. Sarcoptic mange not only threatens guanacos and vicuñas, but can also spread rapidly to domestic animals, threatening the economy of the communities that depend on them.

Recognizing that the greatest challenges to conservation and sustainable development require innovative solutions, the Science for Nature and People Partnership or SNAPP (https://snappartnership.net) seeks rapid, tangible, and lasting benefits for conservation and sustainable development through collaborative work among teams from diverse organizations to ideate, systematize and analyze data, and provide solutions to the challenges posed to people and nature. In this case, we have formed the working group “Andean Camelid Disease” to collaboratively identify management strategies to control sarcoptic mange to promote the health of SACs, their ecosystems, surrounding livestock, and the members of Andean communities that rely on the management of these species. **Our collaborative work seeks to bring together and connect experts from different disciplines and representatives of partner organizations from government and civil society in charge of and interested in the management and conservation of vicuñas and guanacos.**

Omar Torrico - WCS

Executive summary

Guanacos (*Lama guanicoe*) and vicuñas (*Vicugna vicugna*) are wild camelids (referred to herein as South American Camelids or SACs) native to Argentina, Bolivia, Chile, Peru and Paraguay. They are of high cultural and economic importance for Andean communities, specifically because of their high-value fiber. However, the quantity and quality of harvested fiber has been negatively affected by sarcoptic mange infestations. Sarcoptic mange—a skin disease caused by the microscopic burrowing mite, Sarcoptes scabiei—is considered an emerging panzootic[1] in wildlife and has been threatening the health and, therefore, the conservation of SAC populations where high prevalence of sarcoptic mange have been associated with important population declines. Recent reports suggest that the circulation and impact of this disease has increased, although the origin and drivers behind this remain unclear.

As part of the project *Addressing the impacts of Sarcoptic Mange in Wild South American Camelids across a Landscape of Myths and Legends*, under the Science for Nature and People Partnership (SNAPP), we conducted a systematic review of published documents (i.e., peer-reviewed publications and gray literature) and unpublished government registers from Bolivia and Peru of managed vicuñas at *chaccu* events to fill knowledge gaps and propose recommendations for future research and the implementation of effective preventive and control strategies to mitigate sarcoptic mange burden within SAC populations. This study has focused on summarized and analyzed published and unpublished data regarding (i) prevalence, spatio-temporal distribution, and risk factors for sarcoptic mange in SACs, (ii) best management practices to prevent disease burden, and (iii) therapeutic opportunity and feasibility.

Using data from published records, the prevalence of mange in living SACs ranged from 0.9% (out of 450 vicuñas in Argentina in 2005) to 64.2% (out of 53 vicuñas in Peru in 2018), despite the wide variation in the studies' sample sizes (from 12 guanacos to 25,296 vicuñas). Based on unpublished data from government records of *chaccu* events, the percentage of vicuñas with mange-compatible lesions out of the total of animals managed ranged from 0% (out of 5-346 individuals between 2009 and 2019) to 28.6% (out of 7 individuals in 2018) in Bolivia and from 0% (out of 1 - 2,463 individuals between 2015 and 2018) to 100% (out of 33 individuals in 2019) in Peru. In addition, there was a large variation in the number of registered animals per event, ranging from 5 to 373 in Bolivia and from 1 to 4,387 in Peru. Nonetheless, the unpublished data from government records are limited by uncertainties in record-taking procedures and individual animal assessment and, therefore, should be interpreted with caution.

The incidence of sarcoptic mange in SAC populations was mainly suggested to be associated with cross-species transmission due to an increase in areas shared with other infected domestic species (e.g., domestic camelids), although this hypothesis has not been explicitly tested. The type of SAC handling during *chaccu* events was also suggested as a potential risk factor for disease spread due to the stress associated with the process, temporary animal overcrowding and transmission by fomites used on infested animals. Therefore, to reduce the risk of disease transmission in managed populations, it is essential to have personnel trained in capture and live-shearing techniques to reduce stress during *chaccu* events and in good management practices—e.g., the implementation of preventive hygienic measures during live-shearing; drug administration only when the entire dosage regimen can be completed; avoiding animal overcrowding in fenced off zones and limited handling to reduce

1 A panzootic is defined as the occurrence of a high number of cases of a disease that spreads across several countries, a continent or globally. It is the equivalent of a pandemic in humans.

stress. These practices may decrease both direct transmission and host susceptibility through increased endogenous cortisol production due to stressful situations.

While no differences were observed between prevalence estimates of free-ranging and semi-captive vicuñas among published studies, a higher mean proportion of vicuñas with mange-compatible lesions was identified among semi-captive populations examined during *chaccu* events. However, data from both published and unpublished documents presented biases and incomplete reporting, limiting the conclusions about the relationship between the type of handling and the prevalence of sarcoptic mange.

Although ivermectin appeared to be the primary pharmaceutical reported to treat infected vicuñas (no data was available for guanacos in South America) among the published documents, available information on treatment options and post-treatment monitoring was insufficient to identify effective and safe protocols intended for SACs. For example, only two studies reported follow-up information from treated individuals, but did not provide complete information on the treatment outcomes. A substantial number of managed vicuñas (n= 49,569) were reported in the government registers as having been treated during *chaccu* events, including 45 individuals in Bolivia between 2008 and 2019 (range of animals treated at 18 *chaccu* events: 0.3% out of 308 individuals to 14.3% out of 14 individuals) and 49,524 individuals in Peru between 2015 and 2018 (range of animals treated at 296 *chaccu* events: 0% out of 581 individuals to 100% out of 88 individuals). However, no information regarding therapeutic protocol nor post-treatment monitoring was available in the unpublished government records and hence the unpublished data was not considered in the analyses of treatment options. Despite its apparent high efficacy, extensive use of ivermectin has the potential to contribute to the development of mite resistance. Communities often administer preventive treatments with ivermectin (to both symptomatic and perceivably healthy animals), despite efforts to raise awareness among community members that this practice is unlikely to control mange in SAC populations managed and increases the risk of acaricide resistance. Given the risks of antiparasitic resistance, we highlight the need for strategic and limited administration of ivermectin as well as to find alternative therapeutic strategies that could be easily applied during *chaccu* events. Furthermore, preventive treatments are likely to have cascading impacts on the environment. The eliminated ivermectin may exert selection pressure on various parasites and affect local biodiversity. However, the levels of ecotoxicity at *chaccu* sites associated with the use of ivermectin in SACs have been overlooked and studies focusing on this potential environmental contamination are urgently needed.

While this document serves as a resource consolidating available information regarding sarcoptic mange in SACs, several knowledge gaps remain. There were discrepancies among results and reporting completeness among studies, particularly for guanacos and SAC populations in Argentina and Chile, as well as a paucity of information specific to the sanitary conditions of vicuñas managed at *chaccu* events. Available information was insufficient to (i) elucidate the clinical relevance and conservation implications of sarcoptic mange in SAC populations, (ii) assess disease dynamics and the extent of *S. scabiei* distribution, (iii) identify the origin and drivers of outbreaks, and (iv) identify effective therapeutic protocols and best practices. Therefore, we present specific recommendations to address remaining knowledge gaps and control the burden and expansion of mange in SACs across their native countries that are intended to be adequate for immediate implementation and minimal resources or capacity building, including:


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- **Combine different diagnostic methods to improve mange diagnosis**, prioritizing mite detection in populations with an unknown status of the disease, followed by monitoring through visual tracking after confirmation of the sarcoptic mange propagation.

- **Expand surveillance to better understand the actual distribution of mange across the range**, conducting national and international censuses using the same protocol in all countries and implementing integrated surveillance programs in domestic and wild camelids as well as in domestic animals, and other wild animals (e.g., carnivores), and environments.

- **Engage local communities to contribute in multifaceted mange research (e.g., participatory epidemiology)**, by improving dialogue between Andean communities and stakeholders involved in SAC management.

- **Promote the use of "best practices" during SAC handlingevents**, such as using a single needle per animal when administering injectables; disinfecting shears between animals; applying veterinary care to injured animals; avoiding animal overcrowding in fenced management areas; limiting handling time; avoiding preventive ivermectin administration to minimize the risk of mite resistance and applying treatments only when the correct posology can be completed (e.g., minimum two doses separated by a 14-day interval; not recommended to treat free-ranging SACs). This also requires **support for the training of local handling groups in capture and shearing techniques, emphasizing the importance of following sanitary and handling guidelines during chaccu events and in sanitary examinations of SACs**. Furthermore, training in how to identify mange infection (e.g., what mange-infected skin looks like, where on the body to check, etc.) will boost confidence in reported mange from *chaccu* events.

- **Standardize sarcoptic mange reports to reduce the heterogeneity across available information for rapid identification of outbreaks and implementation of prevention and control strategies, particularly in government records**, by improving existing multisectoral collaborations and promoting new ones among government authorities (e.g. animal health authority, wildlife authority), Andean communities, academics, and stakeholders to systematize data collection for, and reporting of, sarcoptic mange in SACs.

- **Encourage future research** focused on assessing the efficiency of current and future treatments, elucidate the clinical relevance of the ectoparasites among SACs, identifying alternative treatments to limit parasite resistance and environmental toxicity, and researching the socio-economic and socio-political landscape of vicuña conservation and sustainable use across the range countries.

Additionally, we also present general recommendations for long-term objectives to address sarcoptic mange in SACs, such as encouraging studies to develop diagnostic methods and explain mange-host interaction and disease dynamics, encourage greater public-private investment in the conservation of SACs (to take this cost burden off the local communities), and promote further studies focusing on ecological factors as agents of spread of sarcoptic mange within and between SAC populations.

Susan Walker - WCS

01

Introduction

Guanacos (*Lama guanicoe*) and vicuñas (*Vicugna vicugna*) are medium-sized and highly social ungulates naturally inhabiting arid and semiarid ecosystems in Argentina, Bolivia, Chile, Paraguay and Peru (introduced populations are also found in Ecuador) (Baldi et al., 2016; Acebes et al., 2018; Acebes, Vargas & Castillo, 2022). These wild native camelids (referred to herein as South American Camelids or SACs) are of prominent cultural and economic importance for Andean communities, specifically surrounding traditional and current practices used by communities to collect and utilize camelid fiber during live-shearing events called *chaccus* (Vilá & Arzamendia, 2022). **The *chaccu* is a pre-Columbian tradition that consists in a "communitarian method" to group and enclose vicuñas in a determinate zone using the "funnel system" (i.e., a method using crowding pens to funnel animals into the cattle chute).** *Chaccu* participants walk approximately 3 km in a straight line holding a rope with colorful banners, forming a "human barrier" to prevent vicuñas from escaping this barrier that progressively closes-in on the animals and directs them toward an enclosure. The animals are then manually restrained, externally checked for diseases and selected for shearing.

Currently, *chaccu* events are virtually carried out in Bolivia and Peru —Argentina and Chile no longer harvest SAC fiber on a large-scale. In Bolivia, fiber can only be obtained from free-ranging vicuñas, while in Peru these live-shearing events are conducted on either free-ranging or semi-captive animals. Semi-captive management was implemented in Peru in 1996 through the Modules for the Sustainable Use of the Vicuña or MUS (acronym in Spanish for "Módulos de Uso Sustentable de la Vicuña"). In order to promote vicuña conservation, this type of management was created to increase monitoring and reduce poaching by creating permanently fenced-off areas with cattle chutes for capture, animal health examination, sanitary control, and selection for shearing(Coaquira et al., 2015). *Chaccu* events are regulated by local and national governmental authorities through management authorizations, currently known as management statements or DEMA (abbreviation in Spanish for "declaraciones de manejo"). As part of these management agreements, general information of the event (i.e., date, starting hour, and geolocation, including the name of the place and its coordinates/altitude), as well as individual data of animals managed (i.e., age, gender, and weight) must be compulsorily recorded, even if the animals were not selected for shearing. The management and recording process in Bolivia is only carried out by members of the local community, while in Peru this activity can also be performed by private companies (approx. 30%), usually supervised by government authorities.

The trade of SAC high-value fiber is a major source of income for Andean communities. One adult individual can provide up to 200g of fiber every three years. Although communities receive around \$280-\$300 USD/kg for the raw fiber (personal communication, official data by Peruvian authorities from 2022), the selling price for processed fiber from manufacturers can reach \$300-\$500 USD/kg (Acebes, Vargas & Castillo, 2022; Vilá & Arzamendia, 2022). For this reason, the amount of fiber obtained from each animal is essential to the success of the process. However, fiber production can be affected by the presence of sarcoptic mange disease, which reduces the fiber quantity harvested at *chaccu* events because of direct consequences of the infestation and the prohibition of shearing infested animals (Sahley, Vargas & Valdivia, 2007; Bujaico Mauricio, 2018; Acebes, Vargas & Castillo, 2022; Vilá & Arzamendia, 2022). Sarcoptic mange–caused by the generalist ectoparasite *Sarcoptes scabiei*–is a highly contagious skin disease that results in significant morbidity among humans and domestic and wild animal species worldwide, and has recently been added to the World Health Organization's (WHO) list of neglected tropical diseases (Arlian & Morgan, 2017). Despite several studies highlighting the economic impact that sarcoptic mange could represent for local Andean communities utilizing SACs, no research has been done explicitly examining the relationship between disease prevalence and economic loss. This lack of information may be due to the absence of data being reported from *chaccu* events. Though records are mandatory during *chaccus*, disease data only started to be requested after 2015. Prior to 2015, all documentation related to mange presence was optional and reporting depended on the willingness of the *chaccu* coordinator. Therefore, disease data prior to mandatory reporting are sparse and confounding (e.g., does a *chaccu* event with no reports of sarcoptic mange suggest that no disease was present, or was disease present but not recorded?). However, based on anecdotal reports (e.g., testimonies from local community members), cases of mange have been observed since 1998, and a possible extirpation of vicuñas might have occurred between 2000 and 2004 in Huanacopampa, Santa Ana de Aucará (Ayacucho, Peru) due to this disease.

In addition to economic impact, sarcoptic mange has also been considered one of the major threats to the health and conservation of SACs (Baldi et al., 2016; Acebes et al., 2018; Montecino-Latorre et al., 2020; Acebes, Vargas & Castillo, 2022). Although they are currently classified by the IUCN as a "Least-concern species" (i.e., not threatened with extinction) given their increasing abundance and wide occurrence in several protected areas (Baldi et al., 2016; Acebes et al., 2018), a recent systematic screening has reported observations of sarcoptic mange in vicuña populations in all countries within their natural range (Acebes, Vargas & Castillo, 2022). Furthermore, currently available data demonstrates low genetic variability of *S. scabiei* mites sampled from guanacos and vicuñas suggesting a single introduction event followed by rapid geographic spread (Acebes, Vargas & Castillo, 2022). Thus, while camelid populations are seemingly stable, sarcoptic mange is present across their geographic distribution and outbreaks could pose population-level threats, given the difficulty of controlling disease in free-ranging animals (Acebes, Vargas & Castillo, 2022).


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Sarcoptic mange has been recently described as an emerging panzootic in wildlife due to its global distribution and ability to parasitize a wide variety of species (Escobar et al., 2022). *S. scabiei* is recognized as a predominately host-specific mite with distinct variants affecting approximately 148 domestic and wild species, worldwide (Acebes, Vargas & Castillo, 2022; Escobar et al., 2022). The dynamics and impacts of this disease in wildlife at the population level is still poorly understood (Arlian & Morgan, 2017; Astorga et al., 2018; Acebes, Vargas & Castillo, 2022). While reports of the long-term impact of mange disease on populations vary by species, many studies have indicated conservation concerns for populations affected by mange due to observed reductions in population densities and changes to animal behaviors (Astorga et al., 2018; Escobar et al., 2022). For example, sarcoptic mange has been associated with mortality of cheetahs in Kenya (Gakuya et al., 2012), kit foxes in California (Cypher et al., 2017), and bare-nosed wombats in Australia (Martin, Fraser, et al., 2018). In addition, host specificity has been questioned after genetic analyses showed evidence of cross-species transmission (e.g., by predator-prey contact; (Fazal et al., 2016; Matsuyama et al., 2019; Escobar et al., 2022). **In the SAC system, sarcoptic mange likely spreads among domestic and wild camelids, but the potential for transmission among SAC and non-SAC species (e.g., domestic carnivores, cattle, sheep, or humans), remains unclear.**

Robert Wallace - WCS

The life-cycle of *S. scabiei* (including egg, larva, protonymph, tritonymph, and adult phases) is completed in approximately 2 weeks (Arlian & Morgan, 2017). Adult, female *S. scabiei* mites can produce more than 40 eggs during their lifespan of up to 40 days (Arlian & Morgan, 2017). Mites seek out hosts through stimuli including odor and thermal receptors (body odor and heat) and CO_2 emission detection (i.e., breathing), and infestation is positively associated with the distance between mite and host (mite detection of stimuli is limited by distance) (Arlian & Morgan, 2017). Once on the host, the mites burrow into the epidermis of the host's skin, leading to acute or chronic infections. No diagnostic tools can predict whether an infected host will develop the chronic and most severe phase of the disease (Astorga et al., 2018), characterized by severe dermatitis that produces a distinctive hair loss. The chronic phase is often associated with secondary bacterial infections and an exacerbated inflammatory response with extreme cases progressing to sepsis and/or death (Escobar et al., 2022). Clinical manifestations are not limited to skin lesions, and affected hosts can show immunological, physiological (e.g., hematological parameters and body thermoregulation), and behavioral (e.g., altered movement patterns) disorders (Carvalho et al., 2015; Cross et al., 2016; Martin, Fraser, et al., 2018). Mortality induced by S. scabiei infestation is not uncommon, and in some vulnerable populations, localized extirpation has been observed (e.g., bare-nosed wombat, Andean vicuñas, and Spanish ibex; (León-Vizcaíno et al., 1999; Martin, Burridge, et al., 2018; Monk et al., 2022).

Direct contact with infested hosts is the main mode of transmission, suggesting a higher incidence may be expected among gregarious species, in populations with high densities, or among species that engage in direct interactions (e.g., predator–prey systems) (Almberg et al., 2012; Arlian & Morgan, 2017). Nonetheless, transmission can also occur indirectly. *S. scabiei* mites can survive and remain infectious for at least one week in environments with low temperatures (between -25 and 15°C) and high relative humidity (above 75%). While in environmental reservoirs, mites will actively seek out new hosts using odor and temperature cues (Arlian et al., 1984). Suitable environmental reservoirs may include resting areas, dens, and burrows, and may provide a transmission pathway in species that are otherwise solitary (Montecino-Latorre et al., 2019; Escobar et al., 2022). The environmental persistence of mites under specific climatic conditions could also explain the seasonality of mange outbreaks reported in some species (Vander Haegen, Orth & Linders, 2013). However, these trends have not been observed in SAC, as high mange prevalence has been reported both during autumn-winter (i.e., cold and dry period) (Bujaico Mauricio, 2018) and summer (warm and wet period) (Ferreyra et al., 2022).

New concerns regarding the threat of sarcoptic mange to SAC health and conservation have been raised following reports of the disease in SACs in several Andean communities and the collapse of a wild vicuña population following a sarcoptic mange outbreak event (Acebes, Vargas & Castillo, 2022; Ferreyra et al., 2022). However, information needed to understand the potential threat of mange in SAC is lacking. The drivers of sarcoptic mange spread in SACs is unknown, although it is presumed that severe infections would be more likely in individuals who have not been previously exposed to the disease (Montecino-Latorre et al., 2020; Acebes, Vargas & Castillo, 2022; Ferreyra et al., 2022; Gomez-Puerta et al., 2022). To our knowledge, no study has documented natural recovery (i.e., without pharmaceutical intervention) of SACs from sarcoptic mange; however, this does not exclude the potential. Additionally, no information exists regarding the severity of disease associated with first-time infections relative to second exposures. However, recent documentation of the localized extinction event in vicuña populations (Ferreyra et al., 2022; Monk et al., 2022) suggests that under specific conditions, SACs may not recover from infection without intervention. The interaction between

Andean communities and SACs (e.g., utilization of SAC fiber) may also influence the occurrence of sarcoptic mange in SAC populations (Vilá & Arzamendia, 2022). After participating in a *chaccu* event as part of a workshop facilitated by Wildlife Conservation Society in October 2022 in Peru, attending government authorities and experts from academia have highlighted the need to have personnel trained in capture and live-shearing techniques during *chaccu* events to reduce the risk of disease transmission in populations managed. In addition, good management practices (e.g., the implementation of hygienic measures during live-shearing to reduce transmission; administration of pharmaceutical treatment only when the entire dosage regimen can be completed; avoiding animal overcrowding in fenced off areas; and limited handling to reduce stress) may decrease both direct transmission and host susceptibility. Finally, factors that have influenced the assumed geographic spread of sarcoptic mange (though, notably, historic records of mange observational data are lacking) across SAC distributions remain poorly understood. One hypothesis is that increasing SAC population densities have facilitated transmission through direct contact, and may be exacerbated through increased habitat sharing with potential domestic host species (e.g., domestic camelids, livestock, free-roaming companion animals) (Montecino-Latorre et al., 2020; Acebes, Vargas & Castillo, 2022; Escobar et al., 2022).

Despite extensive efforts made by government authorities, local communities, and academic partners, knowledge about sarcoptic mange in SACs is limited, and information is distributed across many platforms, making access to data difficult. Furthermore, discrepancies in reporting among organizations limit inferences that can be drawn and prevent informed management decisions from being made. The project *Addressing the Impacts of Sarcoptic Mange in Wild South American Camelids across a Landscape of Myths and Legends* under the Science for Nature and People Partnership (SNAPP) is a multisectoral initiative to better understand the impacts of sarcoptic mange on SACs. Although there are several examples where sarcoptic mange has had large population-level impacts on SACs, there is still limited understanding of the dynamics, drivers, and consequences of the disease in these populations. In particular, disease prevalence in different countries, its increase or decrease over time, risk factors for its occurrence, treatment effectiveness, and best management practices to prevent the disease are still unknown. We conducted a systematic review to summarize the current knowledge of mange in SACs—from across agencies—to clarify these issues and collate all SAC-related mange data in one place. **Specifically, we aimed to address four major research questions: (i) What is the prevalence of mange in South American Camelids? / (ii) Does management via live-shearing of SACs increase the prevalence of mange? / (iii) Is there any correlation between environmental conditions and the prevalence of mange? / (iv) What is the effectiveness of pharmaceutical treatments?** We utilized peer-reviewed publications, gray literature, and unpublished government reports on sarcoptic mange in Andean SACs to describe the geographic extent of sarcoptic mange outbreaks, assess efficacy of preventive and control strategies to mitigate sarcoptic mange burden, identify remaining knowledge gaps, and discuss recommendations for future research.

Ana Gallegos - WCS

02

Sarcoptic mange in South America Camelids (SAC): a systematic literature review

2.1. METHODOLOGY OF THE REVIEW

Search strategy for identification of published literature

This systematic review was conducted following the methodology established by the Center for Evidence-Based Conservation (Sutherland et al., 2004). We searched Google Scholar and the bibliographic base of the IUCN South American Camelids Specialist Group between July and November 2021, using 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 (see Table 1 for keywords and Appendix 1 for used queries). We supplemented our search results with documents produced by stakeholders involved in current research, management, and conservation of SACs.

Table 1. Keywords used in multiple combinations for creating the queries.

Species	Disease	Type of information	Origins and drivers	Others
Vicuñas Guanacos South American camelids High Andean Camelids *Vicugna vicugna* *Lama guanicoe*	Mange	Prevalence Injuries Mortality	Climate Habitat Protected areas Human activities Environmental factors Shearing Management *Chaccu* Fences Fiber Treatments Drugs	Local perception

All documents included in the review were organized in a bibliographic library using Zotero. Data extracted from the records were entered into a Microsoft Excel database designed exclusively for this study. This form contained predetermined variables: characteristics of publications (query, source, title, first author, year, country), type of the study, animal species included in the study, methodology conducted, characteristics and quality of the study, and sources of heterogeneity along with the qualitative and quantitative data in order to answer the research questions.

Database and quality assessment of published documents

Two hundred twelve documents, published in English (n= 22) and Spanish (n= 190) between 1966 and 2021, were identified. Documents 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 documents were submitted to a selection process that was conducted independently by two authors (L. Hostos and A. Gallegos) and verified independently by one author (E. Isasi-Catalá). After selecting relevant documents by title and abstract, a second screening was carried out through reading full-text for their eligibility. To be included in this review, the documents should offer quantitative information to estimate the impact of mange on SAC populations or qualitative/descriptive information to better understand the sarcoptic mange burden in SACs. This review process considered all documents presenting information on sarcoptic mange in wildlife, with emphasis on the search for gray literature. Then, selected documents were individually classified into the categories defined by Pullin and Knight (2001, 2003) (Table 2).

Table 2. Criteria for classifying the level of evidence in documents and studies according to Pullin and Knight (2001) and Pullin and Knight (2003).

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.

Documents or studies classified in categories I and II were considered for quantitative analyses, studies classified in category III were considered for qualitative analysis, and studies classified in category IV or that did not contribute to answering at least one research question were excluded from the review. A total of 122 documents containing quantitative, qualitative, and/or perception data that could be relevant to answer research questions were included in the review (see Appendix 2). In addition, documents containing quantitative data (category I and II) underwent a second quality assessment to evaluate their study design. Criteria used to assess these documents included: clear scientific questions, consistent variables or indicators to answer the question(s) proposed, satisfactory data collection (e.g., randomized), adequate study design and sample size, absence of biases and/or measures to reduce them, use of controlled conditions, and appropriate statistical treatment. Documents were ranked from zero to ten according to the ten criteria, and documents scoring six or higher were considered to be of sufficient quality to be included in quantitative analyses.

The goal with this systematic review was to gather information from Argentina, Bolivia, Chile, and Peru. The search strategy focused on studies in guanacos and vicuñas, but we also included information about domestic camelids (i.e., alpaca and llama) and other domestic animals (e.g., dogs and livestock) to

evaluate the potential origin of the disease in SACs as well as treatment options applied elsewhere, including other countries such as Germany and Greece. In addition to data on prevalence estimates, spatio-temporal variations, preventive measures, and treatment options, we also extracted the authors' perceptions about mange in SACs regarding prevalence trends, climatic factors, influence of management on the occurrence and frequency of outbreaks, and effectiveness and utility of veterinary treatments (n= 66 documents).

Government records of management and sanitary conditions of SACs from Bolivia and Peru

We also analyzed data from 1,408 unpublished government records from Peru (n= 1,243) and Bolivia (n= 165) regarding the sanitary conditions of managed vicuñas. Data was registered mostly by local personnel (Bolivia) and by government authorities (Peru) during *chaccu* events from 2008 to 2019, with the majority of records taken after 2015 (n= 1,371 records that include all of Peru and 128 of Bolivia; Figure 1).

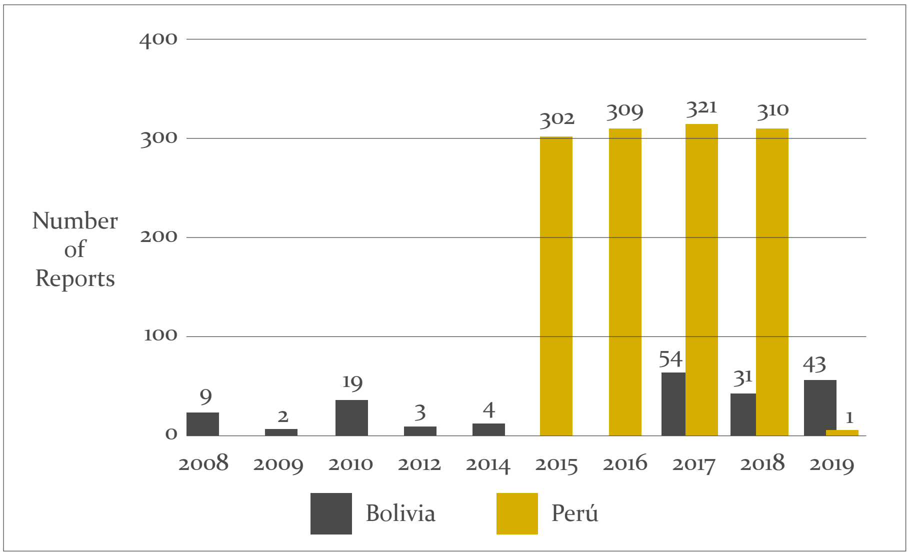

Figure 1. Number of unpublished, government reports from chaccus recorded every year from 2008-2019 for Bolivia (in blue) and Peru (in red).

Records from Bolivia included 3 departments, 16 provinces, and 22 districts, and records from Peru included 13 departments, 60 provinces, and 173 districts. All records from Bolivia were of free-ranging vicuñas while 39% (489/1,243) from Peruvian authorities' records referred to free-ranging populations, followed by mixed management (19%, 234/1,243)—meaning managements carried out in the communities that have the authorization to manage both free-ranging and semi-captive vicuñas—and the fewest reports came from semi-captive populations that are permanently within a fenced off area (17%, 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 recorded number of individuals with mange-compatible lesions, dandruff, lice, or ticks; the number of treated individuals; and the number of dead individuals observed. Detailed information on managed vicuñas was also recorded, including male-to-female ratio, range of age, and general body condition.

2.2. SURVEILLANCE

2.2.1. Diagnostic methods

From a total of 122 studies that met our quality criteria, 41 (34%) reported searching for sarcoptic mange in living or dead SACs (including 4 news releases). Only 23 out of 41 publications (56%) described the method used to determine an animal as infected or suspected of being infected (from now on referred to as "suspected individuals"), although the criteria used for considering an animal as suspected was unclear. Mite detection from mange-compatible lesions was used to detect mange in 17 studies (74%) and in 6 of them the variant of the S. *scabiei* (var. *aucheniae*) was reported without describing the method used to identify the variant. Only visual identification of mange-compatible lesions was used in the remaining 6 studies (26%), 5 on living animals and 1 on both living and dead animals.

Sarcoptic mange in managed vicuñas during *chaccu* events in Bolivia and Peru (referring to unpublished data from government records) is almost exclusively assessed through visual identification of mange-compatible lesions through a rapid physical examination while measuring their weight (CSA_0066). This is a fast process as to reduce the handling time of managed vicuñas, and more rigorous identification methods are not used due to the limited number of veterinarians (or other trained professionals) present to collect samples from affected animals (even though scrapings can be required in specific cases; e.g., research or active surveillance). In addition, reporting disease in shearing records was not mandatory until 2015, and before this period the presence of mange was not systematically recorded to support the diagnosis of sarcoptic mange. Since no individual information on clinical signs was available in the records reviewed by our study to corroborate the presence of sarcoptic mange infection, all individuals from these events with reported sarcoptic mange considered as "suspected individuals" herein.

S. scabiei mites is usually identified by skin scraping —using a scalpel blade to deeply scrape the periphery of infected skin or lesions— followed by visual identification using light microscopy. However, obtaining the mite and locating it in a skin scraping sample can be difficult, as the mite is microscopic and burrows into the epidermis. Despite having the highest specificity, diagnosis by skin scrapings is extremely variable and depends on the number of mites obtained in the sample, which can vary based on the stage of infection (e.g., low number of mites in early stages). A recent study by Fraser et al. (2018) has shown that the detection method with the highest sensitivity is performing PCR on skin scrapings, which could be an alternative or supplementary test for identifying animals with low levels of mite infestation. While more effective, this technique can be costly compared to microscopy, and may not be useful if funding is lacking.

Visual observation should be used as a method to identify individuals with 'suspected' mange, with laboratory diagnostics to follow to confirm it (e.g., mite detection). However, in populations where mange has already been confirmed, a systematic assessment of lesions using visual observation could be used as a non-invasive way to monitor mange occurrence and/or outbreaks in wild SACs (Ferreyra et al., 2022). Misdiagnosis cannot be dismissed when only using visual observations, particularly in the case of asymptomatic animals (e.g., animals in the early stages of infection that are pre-clinical). Furthermore, other dermatological diseases can have similar clinical presentations, such as other parasitic diseases, immune-mediated dermatological diseases, hypersensitivity reactions, pemphigus-like conditions, nutritional/metabolic disorders, or other types of dermatitis caused by bacterial or fungal pathogens (Foster, Jackson & D'Alterio, 2007; Valldeperes et al., 2019).

Of the six studies that identified infected animals through systematic visualization, three described the lesion, conditions, and behaviors that were used for the diagnostics of mange. These conditions included hair loss, reduced movement, belly and extremity wounds (CSA_0033); skin wounds, without giving details (CSA_0155); intense pruritus, reduced movement, hyperkeratosis (crusted-lesions), and significant hair loss (CSA_0211). The latter also classified the disease in stages, with descriptions for early (only pruritus), advanced (reduced movement and/or visible lesions on the extremities of the body), and severe (all clinical signs and extreme hair loss extending to various parts of the body) and used only one observer to avoid biases. The remaining studies either found no affected animals (CSA_0055) or did not provide the clinical signs sought to identify animals positive for sarcoptic mange (CSA_0086; CSA_0129).

The accuracy of visual observations to determine mange presence and prevalence will largely depend on the experience of the observer. In addition to a 5-year National Plan managed by SENASA to control sarcoptic mange in vicuñas, Peruvian authorities have published a national protocol to assist with the diagnosis and classification of the disease during *chaccu* events (CSA_0066). Suspected animals can be identified by the presence of dermatitis (skin inflammations), crusted-lesions, hair loss, and itching. The severity of the disease should be assessed by the location (i.e., ears and infraorbital areas, axillary, inguinal and perineal regions, belly, and anterior and posterior extremities) and extension (area of injured skin based on hair loss) of observed lesions, as well as clinical signs and their intensity in the affected animals (Table 3). Finally, the protocol also recommends the identification of affected vicuñas in semi-captivity to further evaluate the efficacy of the strategies applied to control the disease.

Table 3. Classification of sarcoptic mange in managed vicuñas recommended by the government authorities from Peru: SERFOR, SENASA, INIA, and SERNANP.

Severity of the disease	Extension 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		

* Adapted table extracted from the protocol established by SERFOR (National Forest and Wildlife Department), SENASA (National Agricultural Sanitation Department), INIA (National Institute for Agricultural Innovation), and SERNANP(-Department of Natural Protected Areas by the Government) (CSA_0066).

Promote the correct identification of sarcoptic mange cases is a multinational effort. Argentina, Bolivia, and Chile also have guidelines for the correct identification of infected animals that include of animals with mange-compatible lesions to help identify infected vicuñas. All protocols target stakeholders involved in the monitoring and conservation of SACs and include the particularities of their own country. In Argentina, based on the study conducted in the San Guillermo National Park (Ferreyra *et al.*, 2022), two researchers (M. Uhart and H. Ferreyra) have developed the guidelines Guía de acciones ante la detección de sarna en camélidos silvestres. Dirección Nacional de Conservación - Administración de Parques Nacionales, where they described the main clinical signs of animals with sarcoptic mange at each infection stage (very similar to those presented in Table 3) and included a "Decision Tree" to guide the necessary actions to adopt when detecting SACs with mange-compatible lesions. Chile has a document with instructions on the categorization of disease stages, the assessment of body conditions of SACs, and the procedure and materials for sample collection, which was developed using the Argentine guidelines. The Bolivian protocol points out that animals with mange-compatible lesions that can be observed at long distances (e.g., during a census) and with movement disorders (e.g., difficult walking, with legs wide open) should be classified as moderately to severely affected (MMAyA *et al.*, 2021; MMAyA, SERNAP & ACOFIV, 2021); in addition to recommending and giving technical instructions for sampling dead animals during censuses, annual monitoring of vicuña populations, or casual findings.

2.2.2. Spatio-temporal distribution of mange outbreaks in SAC populations

Confirmed or suspected sarcoptic mange infection on living or dead SAC was reported by 33% (40/122) of publications and by 82% (1,162/1,408) of unpublished government records from Bolivia and Peru (each corresponding to one *chaccu* event). The location of the cases (i.e., province and/or department of the country) were identified in 95% (38/40) of the published studies, including 2 provinces in Argentina between 2005 and 2018, 9 provinces in 3 departments in Bolivia between 2006 and 2018, 4 provinces in 3 departments in Chile between 1978 and 2018, and 7 provinces in 7 departments in Peru between 2009 and 2019 (Table 4). Additionally, managed vicuñas with mange-compatible lesions were reported in the government unpublished records in 11 provinces in 3 departments in Bolivia between 2008 and 2019 and in 36 provinces in 10 departments in Peru between 2015 and 2019.

The first record of suspected sarcoptic mange affecting SACs was in guanacos from Chile in 1978 (CSA_0075). However, most recent cases of infected and suspected sarcoptic mange in SACs have been reported in 2019 in 3 provinces in Peru (Churcampa, Chincha, & Lucanas) and in 2 in Bolivia (Antonio Quijarro & Nor Lípez). The specific location of reported sarcoptic mange cases in SACs from 1978 to 2019 is shown in Figure 2. However, it should be noted that the absence of sarcoptic mange was confounded by the absence of data (i.e., lack of reported mange could indicate that mange was not observed, or that disease information was not recorded). Consequently, localities reporting no cases of sarcoptic mange in SACs could not be considered free of the disease.

Figure 2. Spatial distribution of reported sarcoptic mange cases in SACs across Argentina, Bolivia, Chile and Peru between 1978 and 2019.

Table 4. Spatio-temporal distribution of sarcoptic mange cases in living and dead SACs considered as infected or suspected of being infected, based on 39 published records and 234 unpublished data from government records provided by Bolivian and Peruvian authorities.

Country	Province	Species	Disease status (animal condition)[a]	Period[b]	Reference of the published records	Government records[c]
Argentina	Jujuy	Vicuñas	infected (living and dead)	2005-2014	CSA_0053; CSA_0177	-
	San Juan	Guanacos	infected (living) and suspected (dead)	2017-2018	CSA_0211	-
		Vicuñas	infected (living) and suspected (dead)	2017-2018	CSA_0211	-
		Not specified[d]	suspected (dead)	2014	CSA_0114	-
	Not reported[e]	Not specified	suspected (living)	2017	CSA_0129	-
Bolivia	Antonio Quijarro	Vicuñas	suspected +	2019	-	1
	Bautista Saavedra	Vicuñas	infected (living) and suspected +	2008-2018	CSA_0209	3
	Cercado	Vicuñas	infected (living) and suspected +	2010	CSA_0209	3
	Franz Tamayo	Vicuñas	infected (living) and suspected +	2006-2018	CSA_0011; CSA_0028; CSA_0209	10
	Ladislao Cabrera	Vicuñas	infected (living) and suspected +	2010-2013	CSA_0028; CSA_0209	1
	Modesto Omiste	Vicuñas	infected (living) and suspected +	2017-2018	CSA_0159; CSA_0209	1
	Nor Lípez	Vicuñas	suspected +	2018-2019	-	2
	Pacajes	Vicuñas	suspected +	2010	-	1
	Sajama	Vicuñas	infected (living) and suspected (living and dead)+	2008-2018	CSA_0028; CSA_0209	8
	Sacar	Vicuñas	infected (living)	2009	CSA_0209	-
	Sud Lípez	Vicuñas	infected (living) and suspected +	2012-2014	CSA_0209	3
	Sur Carangas	Vicuñas	infected (living) and suspected +	2009-2012	CSA_0209	8
	La Paz*	Vicuñas	infected (living)	2008-2018	CSA_0048; CSA_0209	-
	Oruro*	Vicuñas	infected (living)	2009	CSA_0209	-

Chile	Copiapó	Vicuñas	suspected (living)	2012-2013	CSA_0086	-
	Huasco	Guanacos	suspected (living)	2017	CSA_0073	-
	Parinacota	Vicuñas	suspected (living and dead)	2013-2016	CSA_0019; CSA_0086	-
	Tierra del Fuego	Guanacos	infected (dead) and suspected (living and dead)	1978-2003	CSA_0063; CSA_0072; CSA_0075; CSA_0170	-
	Arica y Pari-nacota*	Vicuñas	suspected (living)	2018	CSA_0033	-
	Atacama*	Guanacos	suspected (living)	2011-2014	CSA_0207	-
		Vicuñas	suspected (living)	2012	CSA_0207	-
Perú	Abancay	Vicuñas	suspected +	2015	-	1
	Andahuaylas	Vicuñas	infected (living) and suspected +	2015-2017	CSA_0013	3
	Antabamba	Vicuñas	suspected +	2018	-	1
	Apurímac	Vicuñas	suspected +	2018	-	1
	Aymaraes	Vicuñas	infected (living) and suspected +	2015	CSA_0013	1
	Azangaro	Vicuñas	suspected +	2017-2018	-	3
	Canchis	Vicuñas	suspected +	2015-2018	-	5
	Cangallo	Vicuñas	suspected +	2015	-	1
	Carabaya	Vicuñas	suspected +	2015-2017	-	2
	Chincha	Vicuñas	suspected (living)+	2017-2019	CSA_0173	1
	Chucuito	Vicuñas	suspected +	2015-2018	-	8
	Churcampa	Vicuñas	infected (living), suspected (living)+	2015-2019	CSA_0017; CSA_0021; CSA_0155	1
	Cotabambas	Vicuñas	suspected +	2015-2018	-	6
	El Collao	Vicuñas	suspected +	2015-2018	-	5
	Espinar	Vicuñas	suspected +	2016	-	1
	Grau	Vicuñas	suspected +	2017	-	1
	Huamanga	Vicuñas	suspected +	2017	-	1
	Huanca Sancos	Vicuñas	suspected +	2015-2018	-	1
	Huancavelica	Vicuñas	suspected +	2015-2017	-	4

Perú	Jauja	Vicuñas	suspected (living)	2018	CSA_0017	2
	Junín	Vicuñas	suspected +	2017-2018	-	-
	Lampa	Vicuñas	suspected +	2017	-	9
	Lucanas	Vicuñas	infected (living), suspected (living)+	2012-2019	-	2
	Mariscal Nieto	Vicuñas	suspected +	2016	CSA_0004; CSA_0005; CSA_0017; CSA_0088; CSA_0140; CSA_0179; CSA_0189; CSA_0202; CSA_0205	95
	Parinacochas	Vicuñas	suspected +	2015	-	1
	Paruro	Vicuñas	suspected +	2015	-	1
	Quispicanchi	Vicuñas	suspected +	2015	-	1
	San Antonio de Putina	Vicuñas	suspected +	2015-2018	-	11
	Sánchez Cerro	Vicuñas	suspected +	2016	-	1
	Sandia	Vicuñas	suspected +	2018	-	1
	Santiago De Chuco	Vicuñas	suspected +	2016	-	2
	Sucre	Vicuñas	suspected +	2017	-	1
	Tarma	Vicuñas	suspected +	2016-2018	-	5
	Victor Fajardo	Vicuñas	suspected +	2015-2017	-	4
	Yauli	Vicuñas	suspected +	2015-2018	-	6
	Yauyos	Vicuñas	infected (living) and suspected (living and dead)+	2013-2016	CSA_0153; CSA_0188; CSA_0190; CSA_0203	2
	Apurímac, Ayacucho, Puno, Junín*	Vicuñas	infected (living) and suspected (living) +	2015-2019	CSA_0132; CSA_0206	5
	No reportado	Vicuñas	suspected (living)	2009	CSA_0047	-

a Refers to whether affected animals were reported as infected or suspected of being infected by sarcoptic mange. In parenthesis whether the studies included dead or living individuals, and the symbol + refers to the inclusion of managed vicuñas during chaccu events.
b Reported year or range of years between the oldest and the most recent report.
c Data of managed vicuñas presenting sarcoptic mange-compatible lesions registered in government unpublished records. The values refer to the number of records, each corresponding to one chaccu event.
d Data was not provided by species of SACs separately.
e Neither the province nor the department of the country was provided.
* Department(s) of the country where one or more studies were conducted as the province was not provided.

2.2.3. Reported prevalence

Number of publications reporting prevalence

Few studies have been conducted to estimate the prevalence of sarcoptic mange in SACs. However, we identified 20 documents reporting the number of infected individuals (living and/or dead) with confirmed sarcoptic mange and the total number of animals sampled. Of those records, 14 (70%) met the criteria to be included in the quantitative analysis, including 7 (50%) from Peru, 4 (29%) from Bolivia, 2 (14%) from Argentina, and 1 (7%) from Chile (Table 5). Included studies were published between 2003 and 2019, with the majority published in the last decade.

The proportion of managed vicuñas in *chaccu* events suspected to be infected with sarcoptic mange was also calculated (Table 5). Summarized unpublished data from government reports from Bolivia and Peru corresponded to 220,215 sheared, captured, or sampled vicuñas (n= 210,934 from Peru and n=9,281 from Bolivia) during 1,159 events between 2008 to 2019 (mostly after 2015). Recapture rates were unable to be estimated due to unknown individual identifications for each animal. Two records were excluded because the registered number of affected animals was higher than the total number of animals managed.

We detected significant heterogeneity across published and unpublished records. Thus, the following estimated prevalences, even with low confidence intervals, need to be interpreted cautiously. In addition, prevalence estimations were highly variable according to diagnostic methods, across geographic locations, and throughout time. We also researched whether the management type of SACs was associated with the prevalence of sarcoptic mange. However, this hypothesis could not be tested due to data limitations.

Heterogeneity of prevalence estimates across studies and unpublished government records

Overall, prevalence estimates based on living vicuñas varied considerably over the years (from 0.9% to 64.2%). The number of samples used to estimate prevalence varied across studies (range: 36-25,296 individuals). One study from Argentina estimated the prevalence of sarcoptic mange in living guanacos to be as high as 33.3% (albeit, a small sample size was used; 12 individuals). Infection data from dead SACs were used in two studies, including one on guanacos (n= 30 animals) and vicuñas (n= 124 animals) from Argentina (CSA_0211) and one on guanacos (n= 371 individuals) from Chile (CSA_0063). Ferreyra et al. (2021) found no infection in both guanacos and vicuñas using observational methods (i.e., confirmation of mange-compatible lesions), while the prevalence of *S. scabiei* was estimated to be 33.7% in guanacos from Alvarado Gamez *et al.* (2004). High prevalence of suspected sarcoptic mange was reported in dead guanacos (88.2% in 2017, although only 15.4% in 2018, CSA_0211) and dead vicuñas (94.9% in 2017, and 88% in 2018, CSA_0211) in Argentina as well as living vicuñas in Peru (61.8% in 2018, CSA_0132), although the reasons for considering these animals as “suspect” was not described and conclusions from these results may be inaccurate.

Based on unpublished data (i.e., *chaccu* data), the prevalence of suspected sarcoptic mange in vicuñas ranged from 0% to 28.6% in Bolivia and from 0% to 100% in Peru along with a large variation in the number of animals recorded per event (range: 5-373 in Bolivia and 1-4,387 in Peru). Although the total number of managed vicuñas is recorded at every *chaccu* event, and a visual inspection is performed on all animals prior to shearing and/or release due to mandatory record-taking of all cases of mange and dandruff, it is unclear whether all vicuñas with mange-compatible lesions are detected because of the short time the members of the community have for handling and shearing. Therefore, **it is unclear if missing data corresponds to absence of the disease. Furthermore, it is likely that the proportions of reported mange-affected animals are imprecise due to overestimates and underestimates.** Finally, government records correspond to specific SAC populations (only managed ones) and these results could not be extrapolated to the whole country.

Table 5. Prevalence and proportion estimations of sarcoptic mange based on published data of infected and suspected SACs (n= 14 peer-reviewed studies) and unpublished data extracted from government records of suspected vicuñas (n= 1,159 *chaccu* events) by country, year, and diagnostic method.

Country	Year	Diagnostic	Species (status)	Prevalence/ Proportion (N, [95% CI])[a]	Reference of published data	Government records[b]
Argentina	2005	*S. scabiei* identification	Vicuñas (living)	0.9% (450, [0 - 2%])	CSA_0177	-
	2017	Mange-compatible lesions	Vicuñas (living)	28.5% (347, [24 - 34%])	CSA_0211	-
			Vicuñas (dead)	0% (99, [0 - 4%]); 94.9% (99, [88.4 - 98.1%])*	CSA_0211	-
			Guanacos (living)	36.4% (11, [15 - 65%])	CSA_0211	-
			Guanacos (dead)	88.2% (17, [64 - 0.98%])*	CSA_0211	-
	2018	Mange-compatible lesions	Vicuñas (living)	12.2% (131, [8 - 19%])	CSA_0211	-
			Vicuñas (dead)	0% (25, [0 - 16%]); 88% (25, [69.2 - 96.7%])*	CSA_0211	-
			Guanacos (living)	0% (1, [0 - 83%])	CSA_0211	-
			Guanacos (dead)	0% (13, [0 - 27%]); 15.4% (13, [3.1 - 43.5])*	CSA_0211	-
Bolivia	2006	*S. scabiei* identification	Vicuñas (living)	5.6% (36, [1 - 19%])	CSA_0011	-
	2008	Mange-compatible lesions	Vicuñas	0.9% (1694, [0.6 - 1.5%]) †	-	9
	2009	Mange-compatible lesions	Vicuñas	0% (67, [0 - 6.5%]) †	-	2
	2010	Mange-compatible lesions	Vicuñas	5.5% (671, [4 - 7.5%]) †	-	19
	2012	Lesiones compatibles con sarna	Vicuñas	1.8% (219, [0.5 - 4.8%]) †	-	3

Bolivia	2013	Identificación de *S. scabiei*	Vicuñas (living)	14.3% (84, [8 - 23%])	CSA_0028	-
	2014	Mange-compatible lesions	Vicuñas	1.8% (166, [0.4 - 5.4%]) †	-	4
	2017	Mange-compatible lesions	Vicuñas	0% (1896, [0 - 0.2%]) †	-	54
	2018	*S. scabiei* identification	Vicuñas (living)	9.8% (92, [5 - 18%]); 5.1% (78, [2 - 13%])	CSA_0048; CSA_0159	-
		Mange-compatible lesions	Vicuñas	1% (1481, [0.6 - 1.7%]) †	-	31
	2019	Mange-compatible lesions	Vicuñas	0.1% (3087, [0 - 0.3%]) †	-	43
Chile	2003	*S. scabiei* identification	Guanacos (dead)	33.7% (371, [29 - 39%])	CSA_0063	-
Perú	2013	*S. scabiei* identification	Vicuñas (living)	4% (3929, [3 - 5%])	CSA_0140	-
	2014	*S. scabiei* identification	Vicuñas (living)	1.7% (4012, [1 - 2%])	CSA_0140	-
	2015	*S. scabiei* identification	Vicuñas (living)	36.3% (9811, [35 - 37%]); 9.4% (733, [7 - 12%]); 5% (3795, [4 - 6%]); 37.4% (107, [29 - 47%])	CSA_0004; CSA_0013; CSA_0140; CSA_0153	-
		Mange-compatible lesions	Vicuñas	0.5% (54 834, [0.4 - 0.5%]) †	-	252
	2016	*S. scabiei* identification	Vicuñas (living)	2.4% (9346, [2 - 3%]); 3.1% (3622, [3 - 4%])	CSA_0004; CSA_0140	-
		Mange-compatible lesions	Vicuñas	0.5% (50 228, [0.4 - 0.6%]) †	-	246
	2017	*S. scabiei* identification	Vicuñas (living)	3.4% (6139, [3 - 4%]); 1.7% (3706, [1 - 2%]); 1.7% (3700, [1 - 2%])	CSA_0004; CSA_0140; CSA_0202	-
		Mange-compatible lesions	Vicuñas	0.4% (58 276, [0.4 - 0.5%]) †	-	260
	2018	*S. scabiei* identification	Vicuñas (living)	64.2% (53, [51 - 76%]); 61.8% (102, [52 - 71%])*	CSA_0132	-

Perú		Mange-compatible lesions	Vicuñas	0.8% (47 563, [0.7 - 0.9%]) †	-	235
	2019	Mange-compatible lesions	Vicuñas (living)	22.8% (101, [16 - 32%]); 100% (33, [87.6 - 100%]) †	CSA_0155	1

a Proportion of infected animals over 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 (R Core Team, 2022). The symbol † refers to the proportions of the recorded number of vicuñas with mange-compatible lesions over the total of sheared, captured, or sampled vicuñas at chaccu events.

b Data extracted from government records. The values refer to the number of records, each corresponding to one chaccu event.

* Prevalence based on the number of animals reported as suspected of being infected with sarcoptic mange in published studies, although the criteria used was unclear.

Prevalence of mange according to diagnostic methods

Prevalence differed according to the method used for diagnosing mange in living SACs and tended to be higher when diagnostics were based on clinical signs (e.g., pruritus, hyperkeratosis, erythema, and absence of hair follicles). Locating mites in skin scrape samples can often result in under detection of mange in a population due to the low sensitivity of scraping techniques (see topic 2.2.1), potentially resulting in false-negative results. Moreover, we assumed that overestimation of cases due to misdiagnosis is unlikely due to the characteristic visual lesions associated with sarcoptic mange.

Spatio-temporal variability of prevalence estimates based on published data extracted from peer-reviewed studies using S. scabiei identification for mange diagnosis

To evaluate whether the prevalence of mange in SACs differed spatio-temporally, we compared 22 estimates from 10 (71%) studies with similar designs (i.e., infected living individuals that were diagnosed by *S. scabiei* identification). Results refer to living vicuñas from Argentina, Bolivia, and Peru, only (no data was available from Chile or guanacos (Table 6).

Based on 6 studies in Peru and 4 in Bolivia, the mean prevalence estimates of *S. scabiei* in Bolivia (11.9%, standard deviation [SD]: 0.147, range: 0-38.9%) were higher compared to Peru (10.4%, SD: 0.134, range: 0.3-37.4%) and to the estimated prevalence from one study conducted on live animals in Argentina (0.9% in the province of Jujuy). It is worth noting that, despite the low prevalence observed in Argentina, a recent study reported a dramatic reduction in a SAC population in San Guillermo National Park associated with a mange outbreak (Ferreyra *et al.*, 2022). This study has not been considered in this section, as they use systematic observation as a diagnostic method, which could lead to misleading comparisons. However, if we did not consider the diagnostic method, Argentina would show a higher mean prevalence (15.6%, SD: 0.164) than both countries.

Franz Tamayo (38.9% out of 18 vicuñas) and Ladislao Cabrera (30.8% out of 13 vicuñas) were the Bolivian provinces with the greatest prevalence estimates. The highest prevalence in Peru (64.2% out of 53 vicuñas) was estimated based on one study conducted in the provinces of Huarccoy and Huaquirca, San Juan de Ondores and Trapiche in the departments of Apurímac, Junín, and Puno, respectively. Province-specific prevalences were not reported (CSA_132).

Bautista Saavedra (Bolivia), Franz Tamayo (Bolivia), and Lucanas (Peru) were the only three provinces with more than one prevalence estimate. No cases were observed in the Bolivian province of Bautista Saavedra over the surveillance years while Franz Tamayo experienced an increase in prevalence of more than 30% in the last decade. Most estimates from Lucanas were lower than 5% with a pronounced increase in 2015 to 36.3%. We report peaks in prevalence estimates (> 30%) in 2013, 2015, and 2018 across these regions. Although these observations could represent true temporal variation in mange prevalence in vicuñas, we cannot rule out potential biases due to an increase in publications or to studies designed to focus on infected populations in later years.

Contradictory results were observed between two studies conducted in the same year (2015) and locality (province of Lucanas in Peru). A high mange prevalence (36%) was reported by Bujaico Mauricio et al. (2015) based on 2,111 infected vicuñas under semi-captive management that were sampled during 36 *chaccu* events in the year. A significant decrease was observed in subsequent years (2016 and 2017) that was associated with a control and treatment (i.e., 0.2 mg/kg ivermectin) program for mange executed in 2015 (Bujaico & Zuñiga, 2016; Bujaico Mauricio, 2018). Conversely, Chipana and Flores (2018) cited a lower prevalence in this same region (5%) but it was limited to individuals within the Pampa Galeras – Barbara D'Achille National Reserve and the number of *chaccu* events included was not specified. Therefore, the reasons for the large differences between the results of these studies are not clear.

Table 6. Prevalence estimations by provinces over the years using published data extracted from 11 peer-reviewed studies of living vicuñas diagnosed with sarcoptic mange by *S. scabiei* identification.

Country	Province	Year	Prevalence (N, [95% CI]) [a]	Reference of published data
Argentina	Jujuy	2005	0.9% (450, [0.3 - 2.3%])	CSA_0177
Bolivia	Bautista Saavedra	2006	0% (10, [0 - 32.1%])	CSA_0011
		2013	0% (22, [0 - 17.5%])	CSA_0028
	Franz Tamayo	2006	7.7% (26, [1 - 25.3%])	CSA_0011
		2013	38.9% (18, [20.2 - 61.5%])	CSA_0028
	Ladislao Cabrera	2013	30.8% (13; [12.4 - 58%])	CSA_0028
	Modesto Omiste	2018	5.1% (78, [1.6 - 12.8%])	CSA_0159
	Sajama	2013	3.2% (31, [0 - 17.6%])	CSA_0028
	La Paz [b]	2018	9.8% (92, [5 - 17.8%])	CSA_0048
Perú	Andahuaylas	2015	16.9% (402, [13.6 - 20.9%])	CSA_0013
	Aymaraes	2015	0.3% (331, [0 - 1.9%])	CSA_0013
	Lucanas	2013	4% (3929, [3.4 - 4.6%])	CSA_0140

Perú		2014	1.7% (4012, [1.3 - 2.1%])	CSA_0140
		2015	36.3% (9811, [35.4 - 37.3%]); 5% (3795, [4.3 - 5.7%])	CSA_0004; CSA_0140
		2016	2.4% (9346, [2.1 - 2.7%]); 3.1% (3622, [2.6 - 3.7%])	CSA_0004; CSA_0140
		2017	3.4% (6139, [3 - 3.9%]); 1.7% (3706, [1.3 - 2.2%]); 1.7% (3700, [1.3 - 2.2%])	CSA_0004; CSA_0140; CSA_0202
	Yauyos	2015	37.4% (107, [28.8% - 46.8%])	CSA_0153
	Huarccoy y Huaquirca (Apurímac), San Juan de Ondores (Junín), and Trapiche (Puno) [c]	2018	64.2% (53, [50.7 - 75.7%])	CSA_0132

a Refers to the number of infected animals over the total of vicuñas 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 (R Core Team, 2022).
b Department(s) in the country where one or more studies were conducted as the province was not provided.
c Information was not specified by province or department.

Variability in the proportion of suspected mange infection in managed vicuñas based on unpublished data from government records from chaccu events

We also researched spatio-temporal variability in mange prevalence of managed vicuñas recorded during *chaccu* events (n= 1,159). Over the years, the mean proportion of registered vicuñas with mange-compatible lesions increased in Peru and seemed variable in Bolivia, including peaks every 2 years along with subsequent reductions (Figure 3).

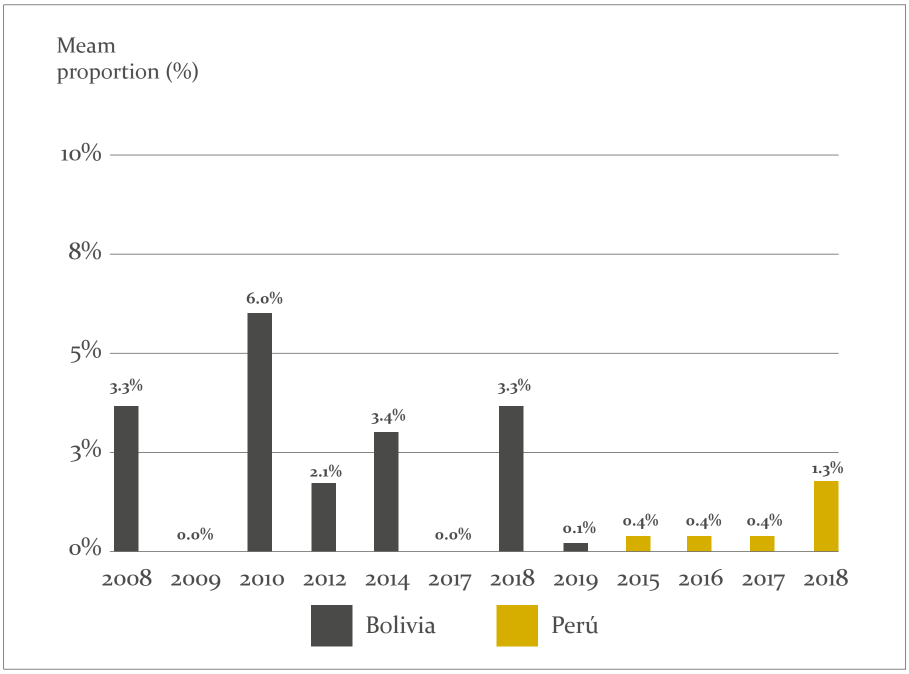

Figure 3. Mean proportion of vicuñas recorded with mange-compatible lesions during *chaccu* events between 2008 and 2018. The 2019 estimation was omitted because it included only one event showing a proportion of 100% of 33 animals.

The mean proportion was the highest in La Paz in Bolivia (8.4%, SD: 0.09), followed by the Peruvian departments of Apurímac (1.8%, SD: 0.11) and Ica (1.8%, SD: 0.05) (Graph 4). At the province level, the highest proportion of affected vicuñas recorded in Bolivia was 28.6% (of 7 individuals) in Franz Tamayo (La Paz) in 2018. In Peru, 100% of the 33 managed vicuñas were recorded with suspected sarcoptic mange infection in the only *chaccu* event reported, in the province Lucanas (Ayacucho) in 2019.

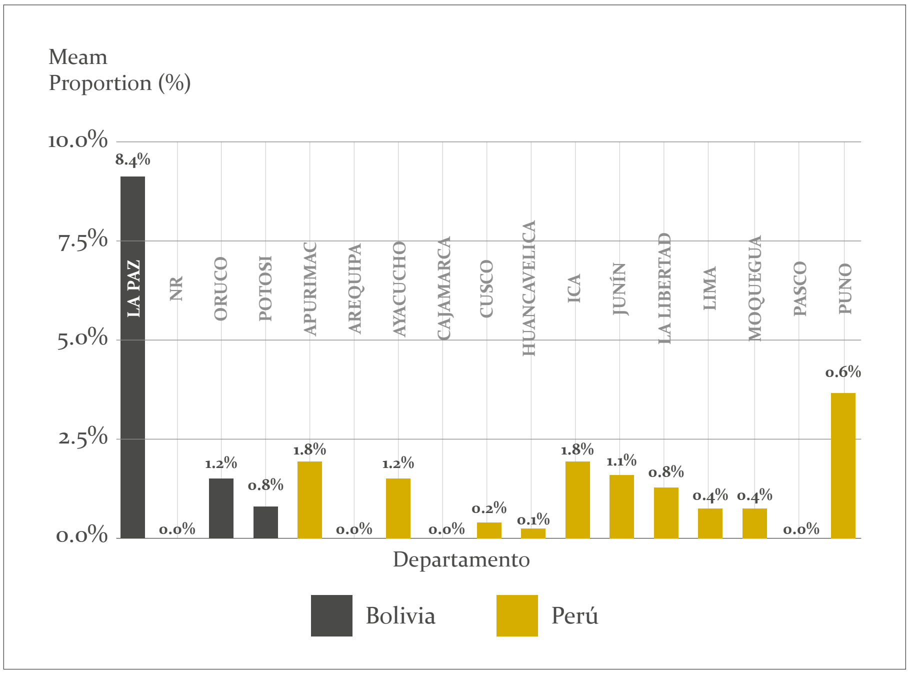

Figure 4. Mean proportion of vicuñas recorded with mange-compatible lesions during *chaccu* events Bolivia (in blue) and Peru (in red). NR refers to the records where the department and/or province were not specified.

We also compared the proportion of suspected mange-infected vicuñas over the years across the provinces (Table 7). **We observed that most locations have reported an increase in prevalence following 2017. Few exceptions were observed in the provinces Bautista Saavedra (Bolivia) and Andahuaylas (Peru) with higher proportions in 2008 and 2015, respectively.**

Table 7. Mean proportion of vicuñas with mange-compatible lesions recorded in unpublished government records (n= 99) from *chaccu* events.

Country	Department	Province	Year	Mean proportion (Standard Deviation)[a]	No. of events[b]
Bolivia	La Paz	Bautista Saavedra	2008	11% (DE: 0.05)	2
			2018	7.7% (DE: N/A)	1
		Franz Tamayo	2008	0.7% (DE: 0)	5
			2018	13.9% (DE: 0.11)	5
		Pacajes	2010	14.3% (DE: N/A)	1

Perú	Apurímac	Abancay	2015	6.7% (DE: N/A)	1
		Andahuaylas	2015	0.8% (DE: 0.02)	9
			2016	0% (DE: 0)	7
			2017	0.1% (DE: 0)	9
			2018	0% (DE: 0)	5
		Antabamba	2016	0% (DE: N/A)	1
			2017	0% (DE: N/A)	1
			2018	3.7% (DE: N/A)	1
		Apurímac	2018	22.7% (DE: N/A)	1
		Aymaraes	2015	0% (DE: 0)	6
			2016	0% (DE: 0)	6
			2017	0% (DE: 0)	6
			2018	0% (DE: 0)	6
		Cotabambas	2015	1.8% (DE: 0.02)	3
			2016	0% (DE: 0)	2
			2017	0.3% (DE: 0.01)	3
			2018	31.6% (DE: 0.55)	3
		Grau	2015	0% (DE: 0)	2
			2016	0% (DE: 0)	2
			2017	0.7% (DE: 0.01)	2
			2018	0% (DE: 0)	2
	Ica	Chincha	2015	0% (DE: 0)	2
			2016	0% (DE: 0)	2
			2017	6.4% (DE: 0.09)	2
			2018	0% (DE: N/A)	1

a Refers to the number of vicuñas recorded with mange-compatible lesions over the total of sheared, captured, or sampled vicuñas using data extracted from unpublished government records. The values in parentheses refer to the standard deviation of proportions estimates. N/A: Not applicable.
b Refers to the number of *chaccu* events included per year.

Prevalence according to the type of management

In addition to the spatial and temporal data, we analyzed data from 8 studies (57%) with similar designs (i.e., infected living individuals that were diagnosed by *S. scabiei* identification) reporting the types of management carried out in infected vicuñas (Table 8).

Prevalence estimates of infected free-ranging vicuñas ranged from 0.9% (out of 450 individuals in Argentina) to 37.4% (out of 107 animals in Peru). Similar results were obtained using data from 2 studies on semi-captive infected vicuñas, with prevalence estimates ranging from 0.3% (out of 331 individuals, CSA_0013) to 36.3% (out of 9,811 individuals, CSA_0004).

Based on unpublished government records from *chaccu* events in Peru, a higher mean proportion of vicuñas with mange-compatible lesions was identified among semi-captive populations (20.3% out of 43,116 individuals from 170 events, SD: 0.44) and there was a slight difference between free-ranging (0.7% out of 73,725 individuals from 392 events, SD: 0) and mixed management (0.6% out of 56,804 individuals from 202 events, SD: 0). All vicuñas from Bolivia were free-ranging and the mean proportion of affected vicuñas was 1.4% (SD: 0.02). The proportion of affected vicuñas recorded with mange-compatible lesions also varied through time according to the type of management, including a decrease by 0.8% among free-ranging animals in Bolivia in the last 10 years and an increase of 0.6% in Peru (Table 8). Similarly, there was an increase in the proportion of affected vicuñas under both semi-captivity and mixed management.

Table 8. Prevalence estimates of sarcoptic mange by type of management over the years using data from 8 peer-reviewed studies (published data) on infected living vicuñas with sarcoptic mange diagnosed by *S. scabiei* identification and from unpublished government records of suspected vicuñas with mange-compatible lesions at *chaccu* events. It does not include records where the type of management was not recorded.

Country	Management	Year	Prevalence (N, [95% CI])[a]	Reference of published data	Government records[b]
Argentina	Free-ranging	2005	0.9% (450, [0.3% - 2.3%])	CSA_0177	-
		2006	5.6% (36, [0.6% - 19.1%])		-
		2008	0.9% (1694, [0- 1.5%])		9
		2009	0% (67, [0 - 6.5%])		2
		2010	5.5% (671, [4 - 7.5%])		19
		2012	1.8% (219, [0.5 - 4.8%])		3
Bolivia	Free-ranging	2013	14.3% (84, [8.2% - 23.5%])	CSA_0028	-
		2014	1.8% (166, [0.4 - 5.4%])		4
		2017	0% (1896, [0 - 0.2%])		54
		2018	9.8% (92, [5% - 17.8%]); 5.1% (78, [1.6% - 12.8%])	CSA_0048; CSA_0159	-
			1% (1481, [0.6 - 1.7%])	-	31
		2019	0.1% (3087, [0 - 0.3%])	-	43

Perú	Free-ranging	2015	16.9% (402 [13.6 - 20.9%]); 37.4% (107, [28.8% - 46.8%])	CSA_0013; CSA_0153	-
			0.3% (17 545, [0.2 - 0.4%])	-	88
		2016	0.7% (19 764, [0.6 - 0.8%])	-	104
		2017	0.7% (19 374, [0.6 - 0.8%])	-	105
		2018	0.9% (17 042, [0.8 - 1.1%])		95
	Semi-captivity	2015	36.3% (9,811, [35.4% - 37.3%]); 0.3% (331, [0 - 1.9%])	CSA_0004; CSA_0013	-
			0.3% (10 560, [0.2 - 0.4%])	-	42
		2016	2.4% (9346, [2.1% - 2.7%])	CSA_0004	-
			0.4% (8438, [0.2 - 0.5%])	-	38
		2017	3.4% (6139, [3% - 3.9%])	CSA_0004	-
			0.1% (13 535, [0.1 - 0.2%])	-	45
		2018	0.6% (10 550, [0.5 - 0.8%])	-	44
		2019	100% (33, [87.6 - 100%])	-	1
	Mixed	2015	0.4% (12 422, [0.3 - 0.6%])	-	49
		2016	0.4% (15 650, [0.3 - 0.5%])	-	55
		2017	0.6% (15 735, [0.5 - 0.7%])	-	52
		2018	0.9% (12 997, [0.7 - 1%])	-	46

a Refers to the number of infected animals over the total of vicuñas sampled using published data or to the number of vicuñas recorded with mange-compatible lesions over the total of sheared, captured, or sampled vicuñas using data extracted from unpublished government records. 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 (R Core Team, 2022).

b Refers to the number of *chaccu* events conducted by year.

Although semi-captivity and management in fenced-off zones are frequently reported as a major risk factor for sarcoptic mange spread among SACs, the limited or missing data from studies and unpublished reports limited our ability to identify any potential associations between management and the prevalence of sarcoptic mange. Therefore, further studies using the same experimental design, randomized sampling, and controlled conditions would help to better understand the influence of different types of management on the prevalence of sarcoptic mange in these SACs managed during *chaccu* events.

2.3. ORIGIN AND DRIVERS OF MANGE SPREAD IN SACS

To date, no study has presented evidence of the origin, emergence, and dissemination of sarcoptic mange in SAC populations. The data collated here was not sufficient to identify spatial patterns of outbreaks events among populations. However, most of the 33 published documents containing qualitative data highlighted both contact with domestic animals and management methods as the main causes for the emer-

gence of sarcoptic mange in wild camelids. Other reasons included: relocation of animals (repopulation activities), nutritional stress induced by low quality grazing areas, and overpopulation/overgrazing in regions with high animal density. Below, we briefly discuss the main causes and drivers presented by these published documents.

Contact with domestic animals

It is common that wild camelids (vicuñas and guanacos) overlap and compete for pastoral grazing areas with domestic camelids in some regions (Beltrán-Saavedra et al., 2011), increasing the risks of disease transmission among wild camelids and domestic livestock. **According to the IUCN, the growing incidence of sarcoptic mange among SAC populations is associated with the introduction of domestic camelids within their territory without sanitary controls (Baldi et al., 2016; Acebes et al., 2018).** In addition, llama and alpaca farmers often move their domestic camelids in search of better pastures, which could facilitate the spread of mange (through the movement of infected animals). Therefore, maintaining healthy alpacas and llamas could mitigate cross-species mange transmission across SAC populations. Conversely, some studies suggest that SACs are the origin of infectious diseases in domestic camelids (Beltrán-Saavedra et al., 2011; Ruiz Hurtado, 2016). Previous studies showed a higher prevalence of sarcoptic mange in free-ranging SACs compared to captive populations, and attributed this discrepancy to better sanitary conditions and preventive healthcare experienced by captive individuals (Angulo-Tisoc et al., 2021) (which may include the use of acaricides, post-treatment monitoring, and early detection of diseases; Angulo-Tisoc et al., 2021; CSA_0013). There are no reports of sarcoptic mange transmission from wild or domestic camelids to cattle or sheep. To our knowledge, no study has fully addressed the directionality of cross-species transmission among wild and domestic camelids.

Management of SAC populations

Human activity has also been suggested as the driver of sarcoptic mange emergence. This includes human-driven contact events, including fenced live-shearing management and increased population densities. In addition, treatments administered to SACs during shearing events are frequently incomplete (single-dose of acaricides), and individuals are unlikely to be monitored due to unknown individual identification and the difficulty associated with recapturing treated animals. These treatment practices may promote antiparasitic resistance, and do not allow for managers to understand efficacy of treatments and recurrence rates or identify potential underlying diseases interfering in the recovery (e.g., secondary bacterial infections). From an evolutionary standpoint, treatment may interfere in natural selection processes, whereby less resistant or resilient individuals may survive due to interference by treatment, despite being less immunologically competent.

Ecological and behavioral characteristics

Ecological characteristics may increase the odds of sarcoptic mange outbreaks in SACs (Tompkins et al., 2015; Acebes, Vargas and Castillo, 2022; Escobar et al., 2022). **Natural stressors such as harsh winters or droughts could increase susceptibility of immunosuppressed individuals due to resource limitations.**

Climate change could exacerbate the geographical expansion of sarcoptic mange. Along with other factors, SAC distributions are associated with availability of food and water (CSA_0055). Changes in temperature, humidity, and precipitation could reduce the abundance of water sources and the nutritional quality of grazing areas. Poor soil quality and pastures negatively affect animal nutrition, resulting in immunosuppressed animals that could be more vulnerable to sarcoptic mange. In addition to poor nutrition, reduced water and pasture availability may promote congregation of animals in areas where resources occur (i.e., high densities), increasing the frequency of direct transmission. For example, a previous study demonstrated an association between mange outbreaks[2] in gray squirrel (*Sciurus griseus*) populations in an urban area of Washington (USA) with habitat loss and fragmentation due to an increased host density and, consequently, a higher probability of direct transmission (Vander Haegen et al., 2018). Furthermore, overgrazing can limit the quality and quantity of food (CSA_0028, CSA_0187, CSA_0188). These factors have been highlighted by Ruiz Hurtado (2016) in different locations in Bolivia, describing an association between the presence of mange and a decrease in food resources caused by habitat loss due to changes in land-use (i.e., quinoa cultivation) and overgrazing by llamas (CSA_0028). High animal densities are also observed in semi-captive SACs. In this sense, fences are considered a way to facilitate management, but regular monitoring of pasture quality and water sources is required within these enclosed areas to ensure sufficient nutritional levels.

The potential of a more pathogenic *S. scabiei* variant spilling-over from other animal species into mange-free camelid populations has also been considered in previous studies (Andrews, 1983; Rachowicz et al., 2005; Tompkins et al., 2015; Escobar et al., 2022; Monk et al., 2022). Climate change, increased animal densities, and other factors that impact food and water availability could promote inter-specific contact and increase the opportunity for cross-species transmission (though, examples of cross-species transmission in the literature are limited).

Anthropogenic animal movement is another avenue for transmission and spillover of disease into previously unaffected populations. The movement of animals, whether for recreational (e.g., pet trade), economical (e.g., farming), or conservation (e.g., reintroductions to historical range) purposes can result in the range expansion of wildlife diseases (Gerhold & Hickling, 2016; Beckmann et al., 2022), and much thought has gone into ameliorating these risks when moving animals (Sainsbury & Vaughan-Higgins, 2012). **The relationship between human movement of animals and sarcoptic mange transmission is important to consider when performing translocations of SACs i.e., relocating guanacos or vicuñas to regions with low population density or historical ranges where they have been locally extirpated.** These relocation events are supervised by national authorities that only permit the selection of animals with no clinical signs of diseases (SERFOR, 2016). However, even ensuring that experienced personnel participate in the identification of sarcoptic mange when inspecting the animals, we cannot exclude the possibility of transporting asymptomatic animals (e.g., early stages of infection) that could be a source of outbreaks in free-mange areas.

Finally, an important risk factor for the spread of sarcoptic mange and the establishment of the disease within a population is the gregarious behavior of SACs that facilitates direct transmission. In addition, these animals share wallows and dunghills, which may increase the likelihood of environmental transmission. This behavior may also be aggravated by climate change as increases in temperature can favor the environmental persistence of mites, representing a major obstacle to disease control.

2 An outbreak is defined as one or more related cases of a disease.

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2.4. TREATMENT OPTIONS FOR SARCOPTIC MANGE

Existing therapeutic protocols for SACs and other species

Seventeen records (8%, 17/212) included information on treating camelids against sarcoptic mange worldwide, of which 3 (18%) were conducted on vicuñas in Peru between 2013 and 2016. The remaining 14 publications referred to studies conducted in domestic camelids of South America (n= 6), SACs but without reporting the drug or the dosage used (n= 6), and wild or domestic camelids located outside South America (n= 2). No study was conducted on guanacos from South America. Although 49,569 vicuñas have been treated during 18 *chaccu* events in Bolivia—even though the treatment of free-ranging vicuñas is prohibited by Bolivian authorities—and 296 in Peru (range of treated animals: 0.3% of 308 individuals to 14.3% of 14 individuals in Bolivia and 0% of 581 individuals to 100% of 88 individuals in Peru), no data of the therapeutic protocol was available and it is unknown the posology used or whether all treatments referred to administration of endectocides. Therefore, in this section we only considered data from published studies.

The three studies focusing on vicuñas treated the animals with parenteral avermectins (ivermectin or doramectin); with subcutaneous ivermectin being the most commonly used protocol. The dosage of ivermectin ranged from 0.1 to 0.63 mg/kg, and the frequency of administration included 3-doses via subcutaneous application, each separated by 30 or 40 days (Table 9). **Among the existing protocols for treating sarcoptic mange in captive wildlife, multiple doses of 0.2-0.4 mg/kg subcutaneous ivermectin appear to be the most effective treatment to completely eliminate clinical signs (Rowe, Whiteley & Carver, 2019).** High dosages were associated with a shorter recovery period (21 days) in Spanish ibex (León-Vizcaíno et al., 2001). Similarly, ivermectin is the main drug used in free-range wildlife with a higher dosage range (0.17-0.8 mg/kg), which can be administered subcutaneously using rifle darts, or orally as medicated food in captured animals (Rowe, Whiteley & Carver, 2019; Moroni et al., 2022).

Only one study focused on treating two captive guanacos exclusively with parenteral milbemycin (moxidectin, 2 doses of 2 mg/kg/SC with an interval of 10 days between them) in Greece (Papadopoulos & Fthenakis, 2017), showing that mange-compatible lesions disappeared after 53 days in both individuals. Most studies on domestic camelids (i.e., llamas and alpacas) reported the use of multiple-doses of parenteral avermectins (mostly ivermectin) and milbemycins with a recovery rate ranging from 67% (2 out of 3 llamas) to 100% (all 10 alpacas) within 55 days on average (Table 9). Both avermectins (ivermectin and doramectin) and milbemycins (moxidectin) are macrocyclic lactones intensively used to control ectoparasites. Even at low dosages, these drugs are widely distributed in the animal body and their metabolic elimination is slow. However, their route of administration (e.g., parenteral vs. orally) and potential interspecies/interindividual variation can affect their pharmacokinetics. A more rapid effect was observed in several infected rabbits treated with ivermectin compared to those with similar clinical conditions but treated with doramectin (Kaya et al., 2010). In contrast, previous studies on mange-infected animals have reported higher efficacy and prolonged plasma concentrations after a single-dose of doramectin and moxidectin compared with ivermectin administration (El-Khodery et al., 2009; Gokbulut et al., 2010). The longer half-life of moxidectin allows its use in long-acting formulations, but the lack of tests in wild animals limits its use in wildlife, including SACs.

Ivermectin resistance and alternative treatments

Despite its apparent high efficacy, the extensive use of ivermectin can contribute to the emergence of mite resistance. Several biological factors of the mites might influence the resistance to ivermectin, such as mite genetic variability and recombination rates (Xu et al., 1998; Prichard, 2001; Currie et al., 2004). Nonetheless, the excessive use of ivermectin is an important risk factor for increased multiplication of resistant mites that could be widespread through animal movement and contaminate other habitats. Potential alternative therapeutic strategies have been described, although they have yet to be tested in SACs. For example, a single dose of moxidectin pour-on (0.5 mg/kg) was more effective in individual recovery and mite clearance in buffalos compared to parenteral ivermectin. In addition, topical administration of both keratolytics and ectoparasiticides (e.g., amitraz, despite being toxic to animals) along with the parenteral treatment have been associated with successful outcomes in domestic camelids (Lau et al., 2007; Deak et al., 2021). In contrast, the sole use of topical selamectin (6.0 mg/kg) was ineffective in preventing the death of foxes with severe disease (Cypher et al., 2017). Oral treatments with avermectins or milbemycins could be another option to treat free-ranging wildlife populations severely affected by sarcoptic mange (Rajković-Janje, Manojlović & Gojmerac, 2004; Wick & Hashem, 2019). However, identifying drugs with prolonged plasma concentration, determining the variability in medicated food intake between individuals, ecotoxicity and antiparasitic resistance, and ensuring the safety of these treatments are among the main barriers to implement large-scale treatment regimens (Moroni et al., 2022) and need to be addressed in future research. The oral and topical use of fluralaner (isoxazoline class) has also been reported as a novel treatment of sarcoptic mange in wild animals (e.g., black bear and bare-nosed wombats) because of its long half-life, safety, and high cost-effectiveness (Wick & Hashem, 2019; Wilkinson et al., 2021), an option that could be explored for future uses at population levels and also in SACs.

Evaluating treatment effectiveness and side effects

Two studies carried out treatment follow-up of 1,646 individuals (CSA_0005-Bujaico & Zuñiga, 2016) and of 23 individuals (CSA_0153-Gálvez-Durand 2016). The proportion of recovered vicuñas varied from 9% (1 out of 11 infected individuals treated with multiple doses of 0.3 mg/kg doramectin) to 95% (1,570 out of 1,646 individuals infected treated with 0.1-0.2 mg/kg of ivermectin; the number of doses was not described). Although based on a very limited number of studies, recovery of the vicuñas seemed to be associated with the 0.1-0.2 mg/kg ivermectin. However, no study has used a systematic criterion of clinical signs to evaluate the effectiveness of the treatment protocols (e.g., presence and severity of lesions before and after treatment) nor reported the findings in each post-treatment evaluation period (i.e., at 10, 31, and 42 days after the start of the treatment in CSA_0005-Bujaico & Zuñiga 2016 or at the end of the therapeutic protocol in CSA_0153-Gálvez-Durand 2016). In fact, the therapeutic protocol and post-treatment monitoring were insufficiently reported by both studies, as they did not report, or provided incomplete information about the posology used (CSA_0005-Bujaico & Zuñiga, 2016), the methodology for the diagnosis of sarcoptic mange (CSA_0005-Bujaico & Zuñiga 2016), and the technique used for tracking treated animals (CSA_0005-Bujaico & Zuñiga 2016; CSA_0153-Gálvez-Durand 2016). In addition, in the study comparing ivermectin with doramectin, only 26% (6 out of 23) of treated animals with moderate infection completed the treatment protocol (CSA_0153-Gálvez-Durand 2016).

The study reporting the highest recovery rate (95%) of recaptured animals after 42 days supplemented the therapeutic protocol with topical administration of sulfur and burnt oil-based ointment in mange-compatible lesions, despite not being supported by academic groups, and with environmental control of the mite with cypermethrin (6 ml/L) in wallows (CSA_0005-Bujaico & Zuñiga, 2016), which could limit (re)infection of vicuñas by eliminating *S. scabiei* persisting in the environment. However, the criteria used for considering a vicuña as "recovered" was not described, although it appeared to be its survival after 42 days post-treatment. As no information on post-treatment clinical evaluation was available, the proportion of treated animals that showed recovery (i.e., reduced severity of infection) is unknown, and it is also unclear whether these individuals would require additional treatments for complete recovery. In this same study, 81 deaths were reported from 349 severely affected animals during a 42-day surveillance period, which may be an underestimate given the follow-up duration.

Without having a control group, specific parameters to define successful "recovery", and sufficient observation time pre-and post- treatment administration, it is difficult to identify successful treatment regimens. Given the logistical challenges associated with recapturing treated animals to evaluate their recovery, treatment outcomes are usually evaluated through recapturing a small proportion of treated animals or visually following released individuals. However, this requires that individuals followed are representative of the population (e.g., received the same treatment dose, are diverse in age and sex, are diverse in mange progression) to avoid biased estimates of recovery rates. **Therefore, enhanced methodologies in longitudinal studies on treated SACs are needed to determine post-release survival, reinfection rates, and the most effective treatment protocol.** Moreover, adverse reactions to antiparasitic treatments in vicuñas and guanacos are unknown (or undocumented). However, side effects of ivermectin in wild animals include gastroenteritis in non-human primates (Kalema-Zikusoka, Kock & Macfie, 2002) and death associated with drug toxicity in cervids (Menzano et al., 2008). Information regarding pharmacokinetic and pharmacodynamics of the drugs used in SACs as well as their safety in these species need to be clarified through randomized controlled-trials.

Supplementary treatments

In addition to the treatment with ivermectin, two studies reported complementary treatments with parenteral vitaminic complex (CSA_0179) and topical administration of sulfur and burnt oil-based ointment in mange-compatible lesions (CSA_005). The use of burnt oil-based ointment is forbidden by Peruvian authorities that recommended a paste for external application based on Trichlorfon (commercially known as SARNAVET) as an alternative topical therapy. We also do not support the use of burnt oil as topical treatment in animals, considering the compelling evidence showing the negative consequences of oil spill on wildlife, particularly in marine mammals (Prabowo & Bae, 2019; Frasier et al., 2020; Wallace et al., 2020; King, Elliott & Williams, 2021). **Oils can directly affect wildlife health and negatively impact long-term survival and reproduction through inhalation, ingestion and dermal absorption (Helm et al., 2014; Tseng & Ziccardi, 2019).** In the latter case, the insulation of the fur and thus the thermoregulation process is lost. In addition, to our knowledge, no study has fully proven the effectiveness and benefits of burnt oil in eliminating mite infestation, although natural-based oils (e.g., extracted from plants) have been reported to alleviate pruritus in skin diseases (Lee, Heo & Kim, 2010; Tabassum & Hamdani, 2014).

Supportive therapies in captive animals such as use of antibiotics for secondary bacterial infections, intravenous fluids, and high-calorie nutrition that improve the host's general clinical condition are also highly recommended to treat infected animals (Kido et al., 2014; Couper & Bexton, 2016; Martin, Fraser, et al., 2018; SERFOR, 2021).

Non-pharmaceutical treatment practices have been reported in domestic camelids, such as medicinal plants, animal and mineral remedies, and human body remedies, as well as rituals and other traditional techniques (e.g., agitations and massages) (Quiso Choque, 2014). However, these non-pharmaceutical treatments could present severe risks to animal welfare—even when accompanied by allopathic treatment with endectocides—since they are frequently used by local community members and their efficacy has not been established.

Overall considerations

While the environmental authorities of the Bolivian Government prohibited the treatment of the managed free-ranging vicuñas, the administration of ivermectin compounds is commonly carried out on managed vicuñas in Peru. However, we identify significant limitations in evaluating the effectiveness of treatment protocols for sarcoptic mange in SACs. First, there are important economic limitations for recapturing treated animals. *Chaccu* events can cost approximately $2,000 USD, and local communities are reluctant to coordinate a second *chaccu* for sanitary purposes only (i.e., recapture and treatment), where target animals are unlikely to provide profitable quantities of fiber (since they have recently been sheared). This logistical limitation is also reflected in SERFOR's protocol, whereby the suggested interval between treatment doses is 40 days, despite the widely supported and recommended 15-day interval reported in the scientific literature based on the life cycle of the parasite. Secondly, the communities often administer preventive treatments with ivermectin (to both symptomatic and perceivably healthy animals), despite efforts to raise awareness among community members that this practice is unlikely to control mange in the managed

SAC populations and increases the risk of acaricide resistance. However, because 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—and thus, behavioral changes in these communities are unlikely to occur. Therefore, it is of interest to find alternatives to these unsupported treatment methods that could be easily applied during *chaccu* events. Finally, preventive treatments are likely to have cascading impacts on the environment. Previous studies have shown that ivermectin administered to domestic animals is largely excreted in its unmetabolized form by the feces (Strong et al., 1996; O'hea et al., 2010; Mesa et al., 2017; Powell, Foster & Evans, 2018). The eliminated ivermectin may not only exert selection pressure on various parasites that are found in the environment, but may also 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). However, to date, the levels of ecotoxicity at *chaccu* sites associated with the use of ivermectin in SACs are unknown and studies focusing on this potential environmental contamination are urgently needed.

Table 9. Treatment protocols applied in wild and domestic camelids worldwide (n= 11 records).

Country	Specie	Drug	Dose (mg/kg)[a]	Route [b]	No. of doses	Interval between doses	No. of treated animals[c]	Recovery rates[d]	References of published data
Germany	Alpacas	Moxidectin	0.2	SC	8	21	4	100%	CSA_0200
	Llamas	Moxidectin	0.2	SC	8	21	3	67%	
	Alpacas and Llamas	Doramectin	0.5	C	NR	NR	7	0%	
Argentina	Llamas	Ivermectin	0.4	SC	2	14	NR	NR	CSA_0177
Greece	Guanacos	Moxidectin	0.2	SC	2	10	2	100%	CSA_0181
Peru	Vicuñas	Ivermectin	0.1 (juveniles) 0.2 (adults)	SC	NR[e]	NR	1646	95%	CSA_0005
		Ivermectin	0.4	SC	3	30 días	12	25% [e]	CSA_0153
		Doramectin	0.3				11	9% [f]	
		Ivermectin	0.2 0.63	SC	3	40 días	NR	NR	CSA_0066*

Perú	Alpacas	Ivermectin	0.2	SC	2	7	10	100%	CSA_0042
			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	NR	15	NR	CSA_0076
		Ivermectin	0.2	SC	NR	NR	NR	NR	CSA_0079
		Ivermectin	0.2	SC	NR	NR	NR	NR	CSA_0096
		Ivermectin	0.26 0.325	SC	NR	NR	2	100%	CSA_0107

a Posology of the treatment
b Route of drug administration: subcutaneous (SC), intramuscular (IM) or pour-on.
c Number of vicuñas treated using the same therapeutic protocol and in the same period (i.e., month and year)
d Proportion of vicuñas reported as recovered after treatment, although the definition of "recovery" was not provided
e Only 3 individuals with moderate infection completed the treatment protocol and all demonstrated full recovery
f Only 3 individuals with moderate infection completed the treatment protocol and 1 demonstrated full recovery
* Recommended treatment protocol by Peruvian government authorities to be applied in captured free-ranging animals presenting severe clinical signs of sarcoptic mange.
NR - Information not available/not reported

2.5. SOCIOECONOMIC IMPACTS IN ANDEAN COMMUNITIES DUE TO INFECTED SACS

Given the cultural and economic importance of SACs for Andean communities (e.g., obtaining SAC fiber), sarcoptic mange can also impact the economy and culture of local communities interacting with SACs (Sahley, Vargas & Valdivia, 2007; Vilá & Arzamendia, 2022). Generally, the proportion of sheared SACs is 30%-40% of total captured animals (Calmet & Calmet, 2015; Bujaico Mauricio, 2018; Quispe Coaquira et al., 2018). **Therefore, infestations by sarcoptic mange, even in a few animals, could result in important economic losses caused by the reduction of fiber harvested since the shearing of infested animals is prohibited.** A 3-year study conducted in Lucanas (Ayacucho, Peru) reported a mean of 2,896 sheared vicuñas (approximately 35% of captured animals) per year (Bujaico Mauricio, 2018). This same study reported an overall loss of more than 63.7 kg of fiber due to sarcoptic mange corresponding to $22,300 USD within the period studied that included 23 *chaccu* events in 2015, 23 events in 2016, and 36 events in 2017.

The high cultural value of these species for communities may impede some animal health interventions. For example, vicuñas are considered divine creatures and are part of the Pachamama (Mother Earth) to some Andean indigenous groups, preventing human intervention. In addition, the absence of a close relationship between Andean communities and local researchers results in low community engagement in epidemiological studies. Both situations may jeopardize the control of the disease and limit the implementation of preventive interventions.

The aforementioned specifically impacts the immediate effects of uncontrolled mange outbreaks. However, the expansion of the *S. scabiei* range and burden could have more severe long-term consequences, both for the conservation of guanacos and vicuñas and for the local communities. If sarcoptic mange becomes an uncontrolled problem that limits quality and quantity of fiber harvested, the local communities that manage wild camelids may abandon this responsibility if it is not economically profitable. Without the investment of the communities, SACs could face other threats, such as poaching, that is currently controlled through management agreements for the sustainable harvest of SACs (whereby the communities commit to support the conservation of these species). In addition, local communities that implement the *chaccu* events are characterized by a high incidence of total or extreme poverty and only 1% of them are engaged in the harvest of SAC fiber as their main activity (CSA_0189). Some members of these communities carry out *chaccu* events as an extra-activity to complement communal income, which is invested in community development, SAC management (e.g., fence maintenance, hiring park rangers, 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 profitable opportunities, some of which may be at odds with SAC conservation (e.g., illegal mining activity).**

Omar Torrico - WCS

2.6. PERCEPTIONS ON THE EXTENSION OF THE SARCOPTIC MANGE PROBLEM IN SACS

We summarized authors' opinions and perceptions related to sarcoptic mange in SAC populations from 49 publications, using mainly gray literature (78%). In particular, we capture authors' perception on (i) the magnitude of sarcoptic mange in SAC populations, its spatial spread and temporal trends; (ii) the perceived drivers for its spread (i.e., environmental factors and management practices); and (iii) the effectiveness of veterinary treatments.

Among publications reporting the situation of sarcoptic mange in guanacos (n= 11), most authors (55%) considered that guanaco populations are "moderately" affected by the disease and only few studies considered them 'highly' (27%, 3/11) or 'rarely´ (18%, 2/11) affected. In vicuñas (n= 20 publications), the prevalence was described to be either "high" (40%, 8/20) or "low" (35%, 7/20), but few have considered it as "moderate" (25%, 5/20). In both SAC species, prevalence was mostly reported as "increasing" (55%, 6/11 in guanacos and 55%, 11/20 in vicuñas), followed by "unknown" (36%, 4/11 publications of guanacos and 30%, 6/20 of vicuñas). Remaining records described the prevalence as "stable" (9%, 1/11 in guanacos and 10%, 2/20 in vicuñas) or "declining" (5%, 1/20 in vicuñas).

The perception on the origin and drivers of sarcoptic mange in guanacos was extracted from 5 publications. Without providing evidence, all studies speculated that infection results from close contact with domestic animals and most (80%, 4/5) associated its occurrence with human activities (e.g., obtaining SAC fiber during *chaccu* events). Likewise, the establishment of the disease in vicuñas was perceived as a consequence of management (93%, 25/27)—including live-shearing (44%, 11/25), fenced off management (12%, 3/25), and overcrowding (4%, 1/25) during chaccus—wallowing and dust baths (8%, 2/25), and SACs proximity to livestock (32%, 8/25). In addition, in 8 of 9 (89%) publications on vicuñas, the authors claimed that the type of management is associated with the expansion of mange across populations.

Four publications perceived treatments as 'successful', including allopathic treatment (75%, 3/4), such as 0.2 mg/kg of ivermectin or any long-acting endectocide, and topical administration of sulfur and diazinon (an organophosphate insecticide) added to burned engine oil (25%, 1/4). Treating free-ranging SAC populations infected was debated within the scientific community and among other stakeholders. For example, four publications advocated the use of antiparasitic and topical treatments in SACs to bolster population densities while controlling mange. In contrast, two studies considered the treatment of infected vicuña populations unnecessary to avoid interfering with the natural selection process (Beltrán-Saavedra et al., 2011; Ruiz Hurtado, 2016).

Robert Wallace - WCS

03

Knowledge gaps on sarcoptic mange in SACs

Table 10 presents the main knowledge gaps identified in each topic addressed in this systematic review.

Table 10. Knowledge gaps identified in this systematic review.

ID	Topic	Knowledge gaps
I	Diagnosing sarcoptic mange	–Sarcoptic mange detected by skin scraping and mite visualization through microscopy has low sensitivity while polymerase chain reaction (PCR) detection methodology has high sensitivity, but requires special training and more resources (e.g., access to a molecular lab). –Diagnosing sarcoptic mange via visual observation of mange-compatible lesions has low specificity (depending on observer experience), and low sensitivity (in populations with low prevalence). –There is not a test that is both highly sensitive and highly specific to diagnose sarcoptic mange in individuals that are asymptomatic or in the early stages of infection.
II	Spatial distribution of outbreaks	–There is a lack of studies specifically focusing on the distribution of sarcoptic mange in vicuñas and guanacos. –Limited information from Argentina and Chile prevents inferring temporal trends or comparisons of prevalence to be made more broadly across SAC populations. –Available data from Bolivia and Peru were mainly concentrated in specific locations (e.g., Lucanas in Peru and Franz Tamayo in Bolivia), likely due to accessibility and logistical reasons.
III	Prevalence estimates	–There is incomplete or insufficient reporting of data and methodology in prevalence studies, such as not including descriptions of the methodology used to estimate sample sizes or type of sampling used. The method for diagnosing sarcoptic mange in SACs was not provided in 44% of studies. –Different methods of diagnosis prevent direct comparison of prevalence across studies.

IV	Origin and Drivers	– The origin of outbreaks remains unknown, although most studies speculate that infected livestock could be the cause of outbreaks in SAC populations. – The influence of several drivers of disease dynamics remains unclear, including the correlation between prevalence and increased animal density (e.g., in fenced off management during *chaccu* events), stressful animal handling, cross-species transmission, and environmental contamination and dispersion through wallowing/dust baths.
V	Effective treatments	– There is limited information evaluating treatments of both hosts and populations. – Conclusions that can be drawn from studies that have assessed efficacy of treatments are limited by small sample sizes and insufficient post-treatment monitoring. – Treatment information was not always reported, limiting our understanding of the effect of posology (i.e., dosage and frequency), administration routes (although pour-on seems to be ineffective), supplementary therapies, environmental control, and the proportion of the population that needs to be treated. – No study has tested the efficacy of the main proposed treatments (i.e., ivermectin, doramectin, and moxidectin).
VI	Impact of sarcoptic mange	– The impact of *S. scabiei* mites on SAC health (e.g., morbidity and mortality) remain poorly understood. – There are very limited and outdated estimations of the economic impact among local communities (e.g., impact of reduced fiber quality).

Fabián Beltrán - WCS

04

Recommendations

Based on the results of this systematic review and the main knowledge gaps identified, we present general and specific recommendations to control the burden and expansion of mange in SACs across their native countries. Some recommendations are intended allow immediate implementation and would not require substantial resources or capacity building. Others will require collaboration among government agencies, research institutes, and local communities.

Combine different diagnostic methods to improve mange diagnosis.

- Confirmatory tests based on mite detection should be prioritized in populations with an unknown status of the disease, followed by monitoring through visual tracking after confirmation of sarcoptic mange propagation.

- In addition to documenting visual observations of mange during *chaccu* events, a subset of captured animals should be randomly selected for additional sampling, including skin scrapings (for confirmation by other methods, e.g., PCR and microscopy). This recommendation will require improving the local capacity for monitoring SAC populations and training to ensure confidence in visual observations of sarcoptic mange. Specifically, we suggest promoting training government personnel and community members with didactic materials to collect samples and perform laboratory tests on a regular basis.

Expand surveillance to better understand the actual distribution of mange across the range.

- Conduct national and international censuses using the same protocol in all countries in order to know population sizes and focus on the hotspots of the disease.

- Implement integrated surveillance programs in domestic and wild camelids as well as domestic animals, other wild animals (e.g., carnivores), and environments and perform genetic analyses on found mites across hosts to identify the source and spread of mange outbreaks. In addition, particular efforts should be made to investigate the presence of sarcoptic mange in unstudied SAC populations.

Engage local communities to contribute in multifaceted mange research (e.g., participatory epidemiology).

- Perform interdisciplinary studies to evaluate the clinical relevance of sarcoptic mange for SAC populations and to estimate the socio-economic impact of the disease for local communities.

- Improve dialogue between Andean communities and stakeholders involved in SAC management.

- Increase national and international awareness of the impact of mange for SAC conservation and the sustainable development of Andean communities.

Promote using "best practices" during wild SAC management events

- Assess if handling and sanitary protocols are being correctly implemented during *chaccu* events. For example, using one needle per animal when administering injectables, employing preventive measures during shearing (e.g., disinfecting shearers between animals), having the ability to provide veterinary care to injured animals during *chaccu* events, avoid animal overcrowding in fenced off management zones, and limit handling time.

- Avoid preventive ivermectin administration to minimize risk of mite resistance. Treatments should only be performed when the correct posology can be completed (e.g., minimum two doses separated by a 14-day interval). In addition, it is not recommended to treat free-ranging SACs—if treatment is unavoidable (e.g., animal ethics), treated animals should be marked and kept in captivity. Implementing these new recommendations in communities where current *chaccu* methods are engrained will require a major outreach campaign regarding both the harmful effects of overusing acaricides and the important ecological value of vicuñas along with financial support.

- Support training of local management groups in capture and shearing techniques. Training should aim to emphasize the importance of following sanitary and handling guidelines during *chaccu* events and in sanitary examinations of SACs. Furthermore, training in how to identify mange infection (e.g., what mange-infected skin looks like, where on the body to check, etc.) will boost confidence in mange reported at *chaccu* events. Mange assessment should occur prior to the translocation of any SACs.

- Refining disease information gathering during *chaccu* events by training government authorities and technicians in communities in data recording processes with potential implementation of digital tools to simplify data collection, such as free and easy-to-use applications that do not require internet connection (e.g., SMART, Kobotoolbox, Epicollect 5, Avenza maps).

- Systematically document the treatments applied at *chaccu* events, including adequate information on drugs used, the posology of administration (i.e., dosage, number of doses, and the interval between doses), and number of individuals treated.

Standardize sarcoptic mange reports to reduce heterogeneity across available information, particularly in government records.

- It is essential that future reports include a clear definition of “suspected” and “infected” animals. In cases where only systematic observations are used, authors should consider “infection” based on the presence of animals with behavioral disorders in populations with high prevalence of mange.

- The stage of the disease in infected animals should be included in the reports of mange cases in SACs, following harmonized protocols produced by authorities in Argentina, Bolivia, Chile, and Peru.

- Encourage collaboration between research teams and public authorities across countries to exchange experiences (e.g., laboratory diagnostic techniques, sampling and data collection). These collaborative groups could also design studies with standardized methodologies with the support of international experts (e.g., through workshops or webinars) to estimate sarcoptic mange prevalence from representative population samples (e.g., use of the random selection method) and evaluation of treatment protocols (e.g., definition of recovery after treatment).

Future research needed to elucidate remaining knowledge gaps (Table 10).

– Perform case/control studies in captive and/or natural settings to evaluate the efficiency of current and future treatments through collaboration between research teams, communities, and public and private institutions. This could also allow the identification of alternative treatments for semi-captive SACs that limit parasite resistance (e.g., to ivermectin) and environmental toxicity.

– Perform longitudinal studies to determine the clinical relevance of ectoparasites among SACs and research the frequency of asymptomatic cases and reinfection rates.

– Perform studies on captive animals to test the potential of the use of longer-lasting pharmaceuticals with unknown pharmacokinetics/safety/dose in camelids.

– Investigate the socio-economic and socio-political landscape of vicuña conservation and sustainable use across the countries within SACs' distribution range and carry out interdisciplinary studies to estimate the socio-economic impact of mange on local communities.

Additionally, we also introduce general recommendations for long-term objectives to address sarcoptic mange in SACs:

– Watch the development of the diagnostic space.

  * Encouraging studies on diagnostic tools (e.g., LAMP), host immune response, and genetic variability of the mites in search of new targets for potential serological tests (detecting either mite antigens or host antibodies) may contribute to the development of a more sensitive and specific test for routine diagnosis.

– Perform longitudinal studies to investigate mange-host interaction, mange pathophysiology in SACs, and disease dynamics.

– Encourage greater public/private investment in the conservation of SACs (to take this cost burden off the local communities).

– Considering that the general health condition of susceptible hosts may be a major risk factor for the establishment of sarcoptic mange in wildlife, more studies focusing on ecological factors as agents of spread of sarcoptic mange within and between SAC populations (e.g., pasture/habitat quality) are urgently needed.

Diego Pérez - WCS

05

Conclusions and future directions

Research on sarcoptic mange in SACs has increased in the last 20 years, showing that the disease is present in guanacos and vicuñas in all countries where SACs are naturally distributed, including Argentina, Bolivia, Chile, and Peru. Despite increasing interest, there is a considerable lack of information, particularly regarding guanacos. First, the treatment of infected SACs, as well as the impact of sarcoptic mange on the morbidity and mortality of these populations, have not been properly studied. These aspects should be addressed in future research through randomized controlled trials to elucidate the most effective therapeutic protocol and the clinical relevance and conservation implications of the disease. Secondly, the economic impact of sarcoptic mange in SAC populations on Andean communities requires further research, which could be explored by improving capacity building in local government institutions and participatory research to study sarcoptic mange during *chaccu* events. Third, there is no evidence of the origin and drivers of sarcoptic mange infection in SACs despite widespread detection. For instance, data obtained from published and unpublished records were insufficient to demonstrate whether management and type of management (e.g., fenced off) increase the prevalence of the disease. Further studies should focus on identifying the drivers responsible for the spread and proliferation of sarcoptic mange in SACs, including cross-species transmission with livestock and other affected wildlife. In addition, innovative techniques such as satellite tracking and collaboration across research teams in different countries could elucidate whether SACs are spreading mites across political boundaries (e.g., through animal movement). Finally, additional studies focusing on ecological factors as agents of sarcoptic mange spread within and between SAC populations (e.g., type and quality of pastures/habitat) are needed to better understand disease dynamics.

This review identified the prevalence of sarcoptic mange and spatio-temporal distribution of outbreaks in guanacos and vicuñas. However, prevalence studies are sparse, and we could not make a precise comparison of the prevalence estimates across countries or species due to heterogeneity in study findings, variability of study designs (e.g., wide variation in studies' sample sizes) and small number of studies on SACs from Argentina and Chile (especially on guanacos). In addition, many studies were excluded due to incomplete or insufficient data reporting. Therefore, we recommend standardization among methodologies of studies, which could follow consensus by international experts, along with international collaboration to support local research teams and improve study designs. Based on unpublished documents, the lack of laboratory tests for diagnosing sarcoptic mange among managed vicuñas and the incomplete (and on some occasions, incorrect) data recorded highlight *chaccu* events as priority for intervention to improve data recording and the collection of animal health information. In addition to defining the methodology and the information that needs to be collected during *chaccu* events, it is important to promote the training of government officials, veterinarians, and local management groups in data collection to avoid errors and missing data. The use of digital tools could help capture and systematize information regarding the sanitary conditions of managed SACs. Our review also calls for the creation of national surveillance programs that will allow monitoring affected SAC populations, fast identification of outbreaks, and evaluation of the implementation of different strategies to limit the spread of mites, including more responsible use of endectocides by both veterinarians and local communities. Finally, effective prevention strategies require a multisectoral approach, including government support, community involvement, and collaborative research to generate technical and educational materials for government officials, veterinarians, local communities, and stakeholders to promote animal welfare and best management practices during fiber exploitation from SACs.

Appendices

Appendix 1. Queries used in the search strategy for identification of published literature

Topic	Query
Prevalence	Vicuña* AND Sarna AND “Percepción local”
	Vicuña* AND Sarna AND Prevalencia AND “Percepción local”
	Vicuña* AND Sarna AND Mortalidad AND “Percepción local”
	Guanaco* AND Sarna AND “Percepción local”
	Guanaco* AND Sarna AND Prevalencia AND “Percepción local”
	Guanaco* AND Sarna AND Mortalidad AND “Percepción local”
	“Camélidos sudamericanos” AND Sarna AND “Percepción local”
	“Camélidos sudamericanos” AND Sarna AND Prevalencia AND “Percepción local”
	“Camélidos sudamericanos” AND Sarna AND Mortalidad AND “Percepción local”
Environmental	Vicuña* AND Sarna AND Clima AND “Percepción local”
	Vicuña* AND Sarna AND Hábitat AND “Percepción local”
	Vicuña* AND Sarna AND Áreas protegidas AND “Percepción local”
	Vicuña* AND Sarna AND Factores ambientales AND “Percepción local”
	Vicuña* AND Sarna AND Prevalencia AND Clima AND “Percepción local”
	Vicuña* AND Sarna AND Prevalencia AND Hábitat AND “Percepción local”
	Vicuña* AND Sarna AND Prevalencia AND Áreas protegidas AND “Percepción local”
	Vicuña* AND Sarna AND Prevalencia AND Factores ambientales AND “Percepción local”
	Vicuña* AND Sarna AND Mortalidad AND Clima AND “Percepción local”
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Management	Vicuña* AND Sarna AND Esquila AND “Percepción local”
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Treatment	Vicuña* AND Sarna AND Tratamiento AND "Percepción local"
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Appendix 2. List of publications included in the Systematic Review.

ID	Citation
CSA_0002	WCS Perú. (2020). Sarna en el campo: un nuevo grupo de trabajo SNAPP aborda la propagación de la sarna.
CSA_0003	Ladera Sur. (2020). Alarma por posible aumento de sarna en la fauna silvestre: zorros, guanacos y vicuñas serían los más afectados.
CSA_0004	Bujaico Mauricio N. (2018). Efecto de la prevalencia de la sarna (*Sarcoptes scabiei var. aucheniae*) en la producción y comercialización de la fibra de vicuña (*Vicugna vicugna*) en la comunidad campesina de Lucanas - Ayacucho.
CSA_0005	Bujaico N, Zuñiga M. (2016). Control y tratamiento de sarna (Escabiosis) en vicuñas de la comunidad campesina de Lucanas – Reserva Nacional de Pampa Galeras. Ayacucho Perú.
CSA_0006	Agrariape. (2010). La Sarna: el peor enemigo de la vicuña.
CSA_0007	Corporación Nacional Forestal (CONAF). (2016). Inician tratamiento de vicuñas afectadas por sarna SAG y CONAF en Parque Nacional Nevado Tres Cruces.
CSA_0008	Pérez C, Arredondo F, Turra L. (2007). Manejo sanitario de la vicuña.
CSA_0009	TV Perú. (2016). Ayacucho: 17% de vicuñas son afectadas por sarna.
CSA_0011	Beltrán-Saavedra LF, Nallar-Gutiérrez R, Ayala G, Limachi JM, Gonzales-Rojas JL. (2011). Estudio sanitario de vicuñas en silvestría del Área Natural de Manejo Integrado Nacional Apolobamba, Bolivia.
CSA_0013	Unzueta Lancho LA. (2018). Sarna en vicuñas (*Vicugna vicugna*) en las provincias de Aymaraes y Andahuaylas de la región Apurímac.
CSA_0014	Agrovet Market. (s/d). Sarna en Camélidos Sudamericanos.
CSA_0015	Instituto Nacional de Tecnología Agraria (INTA). (2020). Sarna en camélidos silvestres, preocupa en la región Catamarca-La Rioja.
CSA_0016	Deutsche Welle. (2020). La lana de vicuña: "Hay una brecha entre la conservación y el desarrollo económico".
CSA_0017	Siguas-Robles O, Zárate D, Travi G, Boza F, Esteban M, Rubio AV, Paucar R & Bonacic C. (2019). Análisis del agente causal y valores hematológicos y química sérica de vicuñas (*Vicugna vicugna*) con sarna en Perú.
CSA_0019	Villalon Ríos SS. (2016). Identificación de sarna en camélidos sudamericanos en Parque Nacional Lauca, Reserva Nacional Las Vicuñas y Monumento Natural Salar de Surire.
CSA_0021	Correo. (2015). Sarna en vicuñas deja grandes pérdidas económicas.

CSA_0026	Bonacic C, Bonacic D, Muñoz A, Riveros JL, Vargas S, Soto J. (2016). Estrategia Multisectorial para la Conservación de Camélidos Silvestres Sudamericanos de la Región de Atacama.
CSA_0027	RPP. (2012). Junín: Más de dos mil vicuñas afectadas por sarna y caspa.
CSA_0028	Ruiz Hurtado CR. (2016). Identificación y caracterización de la presencia de ectoparásitos y endoparásitos en vicuñas (*Vicugna vicugna*) en comunidades de los departamentos de La Paz y Oruro.
CSA_0029	SERNANP. (2017). Aprovechamiento de fibra de vicuña en la Reserva Nacional Pampa Galeras Bárbara D´Achille generó importantes ingresos económicos a la comunidad campesina de Lucanas en el 2017.
CSA_0030	Lichtenstein G, Oribe F, Grieg-Gran M, Mazzucchelli S. (2002). Manejo Comunitario de Vicuñas en Perú.
CSA_0033	Flores Calle S. (2019). Conservación y recuperación de las poblaciones de la vicuña del norte (*Vicugna vicugna mensalis*) en la región de Arica y Parinacota.
CSA_0034	Vargas S, Lapeze J, Mamani J. (2016). Manejo de vicuña (*Vicugna vicugna*) para esquila desde la construcción colectiva: Estudio de caso en la Cuenca de Pozuelos, Jujuy, Argentina.
CSA_0037	La República. (2015). Sarna en vicuñas: una enfermedad mortal que afecta la producción de fibra en Ayacucho.
CSA_0038	El Cimbronazo. (2017). Una Cuestión De Enfoque: sobre la muerte de vicuñas en la Reserva de Biosfera San Guillermo.
CSA_0041	Ellis V, Varela B, Fernández M, Chiaradia N, Kloster D, Mansilla A, Perrig P, Pritchard C, Middleton A, Sheriff M, Donadio E. (2017). Evolución e impacto de un brote de sarna sarcóptica en las poblaciones de camélidos del Parque Nacional San Guillermo, San Juan.
CSA_0042	Ramos Acuña H, Catrejón Valdez M, Valencia Mamani N, Sas Zevallos P. (2000). Control de sarna sarcóptica (*Sarcoptes scabiei var. aucheniae*) en alpacas (*Lama pacos*) en Perú, con Ivermectina 1 % P/P inyectable de larga acción.
CSA_0045	Quiso Choque V. (2014). La sabiduría andina en la sanidad de alpacas y llamas en las comunidades de Cangalli - Ilave - El Collao - Puno.
CSA_0046	De Lamo DA. (2016). Camélidos sudamericanos: historia, usos y sanidad animal.
CSA_0047	Torres Asmad RJ. (2016). Frecuencia y distribución geográfica de parásitos gastrointestinales en estercoleros de *Vicugna vicugna* de la Reserva Nacional Pampa Galeras Bárbara D’Achille (Lucanas-Ayacucho-Perú), febrero 2016.
CSA_0048	Mollericona JL, Beltrán F, Wallace R, Loayza O, Uruño L, Murillo J. (2019). Estudio de parásitos en vicuñas (*Vicugna vicugna*) del parque nacional y área natural de manejo integrado nacional (PN-ANMIN) Apolobamba, Bolivia.
CSA_0050	Córdova Bührle FA. (2013). Descripción de la situación sanitaria que afecta a la ganadería familiar campesina altiplánica aymara de Caquena y Guallatire, región de Arica y Parinacota.
CSA_0051	Soto N, Skewes O, González BA. (2018). Conservación y manejo del guanaco en Magallanes, Chile: desde la recuperación poblacional a la revalorización mediante cosecha. En: GECS News N°7.
CSA_0052	WCS Perú. (2017). Se evaluó el estado de salud y conservación de la vicuña en la Reserva Paisajística Nor Yauyos Cochas.
CSA_0053	Aráoz V, Aguirre DH, Viñabal AE, Acuña F, Abalos M, Micheloud JF. (2016). Descripción clínico-patológica en brotes de sarna sarcóptica en vicuñas (*Vicugna vicugna*) y llamas (*Lama glama*) de la provincia de Jujuy, Argentina.
CSA_0054	Agrariape. (2014). Ayacucho: 12% de vicuñas de Iruro estarían infestadas con sarna.

CSA_0055	Arzamendia Y, Baldo J, Rojo V, Samec C, Vilá B. (2014). Manejo de vicuñas silvestres en Santa Catalina, Jujuy: investigadores y pobladores en búsqueda de la sustentabilidad y el buen vivir.
CSA_0057	Cajahuaman Vasquez AJ. (2018). Análisis de la crianza de vicuñas en cautiverio en el Parque Conservacionista de Wislamachay: Comunidad Campesina San Antonio de Rancas - Pasco.
CSA_0059	Instituto Nacional de Tecnología Agraria (INTA). (2016). Situación de los camélidos en catamarca.
CSA_0063	Alvarado Gamez LF, Skewes Ramm O, Brevis Ibáñez C. (2004). Estudio de sarna clínica en guanaco (Lama guanicoe) silvestre, en el sector centro-sur de Isla Tierra del Fuego, Chile.
CSA_0065	Marino A, Rodríguez V. (2016). Memoria del Taller de Síntesis “Nociones ecológicas clave para el manejo del guanaco en Patagonia”.
CSA_0066	SERFOR, SERNANP, SENASA. (2021). Protocolo Nacional para el Tratamiento y Control de la Sarna en Vicuñas.
CSA_0067	Quina Quina EY. (2015). Diagnóstico de la crianza y caracterización fenotípica de las llamas k’ara (Lama glama) en Marcapomacocha, región Junín.
CSA_0071	Caman Salazar JE. (2018). Causas de mortalidad en alpacas y su impacto económico, en la SAIS Tupac Amaru.
CSA_0072	Skewes O, Gonzalez F, Maldonado M, Ovalle C, Rubilar L. (2000). Desarrollo y evaluación de técnicas de cosecha y captura de guanacos para su aprovechamiento comercial y sustentable en Tierra del Fuego. En: González et al., Manejo sustentable de la vicuña y el guanaco.
CSA_0073	Servicio Agrícola y Ganadero (SAG). (2017). Oficio: Medidas adoptadas por el SAG frente a presencia de guanacos con sarna en región Atacama.
CSA_0074	CONAF. (2021). CONAF llama a celebrar Día de la Vida Silvestre con tenencia responsable de mascotas.
CSA_0075	Puig S. (1987). Ecología poblacional del guanaco (*Lama guanicoe,* Camelidae, Artiodactyla) en la reserva provincial de la Payunia, Mendoza.
CSA_0076	Laboratorios MIDAF. (2005). Tratamiento y Control de Sarna en Camélidos Sudamericanos (*Sarcoptes scabiei var. aucheniae*) Prueba de Eficacia contra la Sarna Sarcoptica en Alpacas.
CSA_0079	Agrovet Market. (2012). La Sarna en Alpacas y su control con Alpamec L.A.
CSA_0082	Beltrán-Saavedra et al. (2014). Estudio coproparasitario y ectoparasitario en alpacas (*Vicugna pacos* Linnaeus, 1758) de Apolobamba, con nuevos registros de Phthiraptera (Insecta) e Ixodidae (Acari), La Paz – Bolivia.
CSA_0084	Coeli E. (2012). Difusión y sistematización de buenas prácticas con énfasis en todos los eslabones de la cadena de valor de la alpaca en Ecuador.
CSA_0086	Corporación Nacional Forestal (CONAF). (2014). Informe XXXI Reunión ordinaria Comisión técnico-administradora - Convenio de la Vicuña.
CSA_0087	ANDINA. (2017). Países sudamericanos se reúnen en cusco para trabajar por la vicuña.
CSA_0088	Inforegión. (2012). Alertan epidemia de sarna en vicuñas.
CSA_0090	Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO). (2005). Situación actual de los camélidos sudamericanos en Bolivia.
CSA_0092	SENASA. (2017). Arequipa: Senasa supervisa campaña de prevención y control de sarna en alpacas.
CSA_0093	Rojas M, Lobato I, Montalvo M. (1993). Fauna parasitaria de camélidos sudamericanos y ovinos en pequeños rebaños mixtos familiares.
CSA_0096	República del Ecuador. (2013). Plan de acción nacional para el manejo y conservación de la Vicuña en el Ecuador (Anexo I).

CSA_0098	Stemmer A, Valle-Zárate A. (2016). La llama de Ayopaya: un recurso zoogenético originario de Bolivia y desafíos para su conservación.
CSA_0100	Germana Cavero C, Chaquilla O, Santos G, Ferrari M, Krusich C, Kindgard FM. (2016). Estudio socio-económico de los pastores andinos de Perú, Ecuador, Bolivia y Argentina.
CSA_0102	Zacari Ma, Pacheco LF. (2005). Depredación vs. problemas sanitarios como causas de mortalidad de ganado camélido en el Parque Nacional Sajama.
CSA_0104	Yucra Cano LE. (2017). Sistema de comercialización y situación sociocultural, económica y ambiental de la cadena de producción de la fibra de alpaca en el distrito de Macusani, provincia de Carabaya, Puno.
CSA_0105	Mamani Paredes J, Condemayta Condemayta Z, Calle Charaja L. (2009). Causas de mortalidad de alpacas en tres principales centros de producción ubicados en puna seca y húmeda del departamento de Puno.
CSA_0107	MIDAF. (2007). Demostración de la eficacia de ivermectina al 1,3% l.a. (sparmec 1,3% l.a.) en el tratamiento y control de parásitos externos en alpacas en la zona sierra, Puno, Perú.
CSA_0110	Crispín Cunya M. (2008). Productividad y distribución de fibra de alpaca en la región de Huancavelica: un análisis comparativo entre Huancavelica y Puno.
CSA_0114	Ferreyra H, Donadío E, Uhart M. (2020). Un brote de sarna sarcóptica diezma las vicuñas del Parque Nacional San Guillermo, Argentina. En: González BA. La Vicuña Austral.
CSA_0120	El Federal. (2017). Hallan vicuñas muertas en una reserva natural próxima a la mina Veladero.
CSA_0121	Montecino-Latorre D, Napolitano C, Briceño C, Uhart MM. (2020). Sarcoptic mange: An emerging threat to Chilean wild mammals?
CSA_0124	Torres J. (2001). Estrategia y Plan de acción de la Biodiversidad para el departamento de Ayacucho como base de su desarrollo sostenible.
CSA_0125	Choquevilca Lira W, Canales Sierra L. (2017). Proyectos Multipropósito en Agua y Gestión Integrada de Recursos Hídricos.
CSA_0126	Sumar Kalinowski J. (1997). Evolución y desarrollo de la ganadería camélida en el Altiplano de Latinoamérica.
CSA_0127	Autoridad Binacional Autónoma del Sistema Hídrico TDPS (ALT). (2004). Manejo integral de la cuenca del Rio Suchez.
CSA_0128	Pozo O. (2012). Informe pecuario en el Parque Nacional Sajama.
CSA_0129	Diario de Cuyo. (2016). Un censo arrojó que en San Guillermo hay 452 vicuñas y 272 guanacos.
CSA_0132	Murillo Vega Y, Gallegos Carrillo A, Gálvez-Durand Besnard J. (2019). Primeros alcances de la evaluación nacional de la sarna sarcóptica en Vicuñas (*Vicugna vicugna*) durante Chacus realizados por las comunidades campesinas en Perú.
CSA_0138	SERFOR. (2021). Se aprueba protocolo nacional de tratamiento y control sanitario para reducir sarna en vicuñas.
CSA_0140	Chipana J, Flores A. (2018). Implementación del monitoreo integral del manejo de flora y fauna silvestre en las Áreas Naturales Protegidas.
CSA_0147	Alarcón Flores OC, Beltrán Aguilar OA, Galdós Huaco Y, Valencia Carnero N. (2016). Mejoramiento de la capacidad adaptativa de los pobladores rurales de los distritos de Tisco, Callalli y San Antonio de Chuca de la provincia de Caylloma a los efectos adversos del cambio climático, región Arequipa. En: Tupia Uribe. Perfiles de proyectos de inversión pública en materia ambiental Tomo II.
CSA_0148	Mandura Crispín G. (2007). Plan de desarrollo concertado del distrito de Ocongate (2007 – 2018).

CSA_0150	Mendoza Ramírez AC. (2015). Crianza y manejo genético de llamas en las provincias de Pasco y Daniel Alcides Carrión en la región Pasco.
CSA_0151	Paniagua Cahuana JE. (2017). Efecto de las tecnologías productivas del proyecto de mejoramiento de capacidades productivas agropecuarias en la crianza de camélidos sudamericanos en las comunidades campesinas de distrito de Palca, Tacna - 2017.
CSA_0153	Jessica Gálvez-Durand Besnard. (2016). Evaluación de efectividad de dos tratamientos antiparasitarios contra sarna en vicuñas.
CSA_0154	El Tribuno. (2019). chaccu, esquila sustentable de vicuñas y para estudio.
CSA_0155	Esteban Paytan M. (2019). Niveles de proteínas totales, albúmina y componentes hematológicos en vicuñas (*Vicugna mensalis*) con sarna.
CSA_0156	Cafrune MM, Romero SS, Aguirre DH. (2016). Parasitosis de los camélidos sudamericanos en el Noroeste Argentino (NOA).
CSA_0157	Aued MB, Caballero J, Marinero F, Rizzetto A, Esquivel J, Godoy H, Esquivel I, Saavedra A, Sandoval AJ, Corvalan F, Palazuelos P, Montaño E, Peker A, Costa Alvarez A, Brunet J. (2018). Situación poblacional de camélidos silvestres en el Parque Nacional San Guillermo (PNSG) asociada a un brote de sarna sarcóptica.
CSA_0159	Beltrán-Saavedra LF, Mollericona JL, Uruño L, Ramos V, Murillo NJ, Loayza O, Wallace R. (2019). Niveles de abundancia parasitaria y su relación con la condición corporal de Vicuñas (V*icugna vicugna*, Molina 1782) en el sur de Bolivia.
CSA_0164	EbA Montaña. (2014). Ruedo en las Alturas. En: LA ONU Y LA COP 20. Boletín del Sistema de Naciones Unidas en el Perú.
CSA_0165	Corporación Nacional Forestal. (2008). Plan de manejo del Parque Nacional Lauca.
CSA_0168	OIE. (2018). Informe de la reunión del grupo de trabajo de la OIE sobre la fauna silvestre.
CSA_0169	Zárate R, Valencia JC. (2010). Enfermedades del guanaco en vida silvestre - Plan nacional de conservación del guanaco (*Lama guanicoe*) en Chile, 2010 - 2015.
CSA_0171	Valdebenito M. (2008). Estudio de Prevalencia de Hidatidosis en Guanacos de Tierra del Fuego Chile.
CSA_0173	Correo. (2019). Manejo de vicuñas en semi cautiverio provocarían contagio de sarna.
CSA_0174	Gobierno Regional de Ica. (2019). Ejecución del chaccu sanitario sin esquila Año 2019 Camélido Sudamericano (Vicuña) - II Audiencia Pública de Rendición de cuentas del Gobierno Regional de Ica.
CSA_0175	WCS Bolivia. (2014). Informe Anual de Actividades 2014.
CSA_0176	Casey CS, Orozco-terWengel P, Yaya K, Kadwell M, Fernández M, Marín JC, Rosadio R, Maturrano L, Hoces D, Hu Y, Wheeler JC, Bruford MW. (2018). Comparing genetic diversity and demographic history in codistributed wild South American camelids.
CSA_0177	Marín JC, Casey CS, Kadwell M, Yaya K, Hoces D, Olazabal J, Rosadio R, Rodriguez J, Spotorno A, Bruford MW, Wheeler JC. (2007). Mitochondrial phylogeography and demographic history of the Vicun˜a: implications for conservation.
CSA_0179	Arzamendia Y, Neder LE, Marcoppido G, Ortiz F, Arce M, Lamas HE, Vilá BL. (2012). Effect of the prevalence of ectoparasites in the behavioral patterns of wild vicuñas (Vicugna vicugna).

CSA_0180	Gomez-Puerta LA, Olazabal J, Taylor CE, Cribillero NG, Lopez-Urbina MT, Gonzalez AE. (2013). Sarcoptic mange in vicuña (*Vicugna vicugna*) population in Peru.
CSA_0181	Peri Lau, Peter B. Hill, Jan Rybnícek and Lynne Steel. (2007). Sarcoptic mange in three alpacas treated successfully with amitraz.
CSA_0182	Papadopoulos E., Fthenakis G.C. (2012). Sarcoptic mange in guanacos: transmission to sheep and goats and treatment with moxidectin.
CSA_0183	D.F. Twomey, E.S. Birch, A. Schock. (2008). Outbreak of sarcoptic mange in alpacas (Vicugna pacos) and control with repeated subcutaneous ivermectin injections.
CSA_0184	Ramos E, Ramos R. (2009). Determinación de la Soportabilidad Forrajera de los Cercos Permanentes para el Manejo de la Vicuña (*Vicugna vicugna*) en la Reserva Nacional de Salinas y Aguada Blanca Arequipa Perú.
CSA_0186	Terrel Payano W, Valenzuela Calderón H, Pantoja Aliaga C. (2020). Capacidad de carga de un pastizal altoandino para la conservación y manejo sostenible de la vicuña.
CSA_0187	SERNANP. (2016). Plan Maestro Reserva Paisajística Nor Yauyos - Cochas 2016-2020.
CSA_0188	WCS Perú. (2017). Evaluación preliminar: Estado sanitario de la vicuña (Vicugna vicugna) en la comunidad campesina de Tanta, Yauyos, Lima.
CSA_0189	Flores E. (2015). Diagnóstico Situacional y Línea de Base para el Manejo de Vicuñas en el Sector Moyobamba - Granja Comunal de Tanta.
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