BIOLOGY AND MANAGEMENT OF SARCOPTIC MANGE IN WILD CAPRINAE POPULATIONS

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ABSTRACT

Sarcoptic mange is a cosmopolitan disease affecting the skin of both domestic and wild mammalian species, and human as well. In Eurasia, sarcoptidosis (also known as sarcoptic mange or scabies) affects mountain ungulates (Caprinae) among other wild hosts, with epizootic outbreaks inducing variable mortality rates. This fact, coupled with the important ecological and socio-economic values of such mammalian hosts led to many research projects focused to addressing ecological, physiological, behavioural, genetic and pathological effects of the disease. Nevertheless, information about management of sarcoptic mange in free-ranging populations is scarce and scattered, with contradictory results and lack of consensus on basic aspects of the disease. In this work, we revise the effect of sarcoptic mange in wild Caprinae, both at individual, pathological and population epidemiological levels, as well as the current tools and management strategies for its detection, diagnosis, prevention and control. Specific management programs for preventing and controlling the disease in wild Caprinae populations must be based in reliable epidemiological data. The efficacy and safety of different management approaches remain to be experimentally tested.

Keywords: control, monitoring, management, modelling, sarcoptic mange, wild Caprinae

Running head: Sarcoptic mange in wild Caprinae

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INTRODUCTION

Animal diseases are a topic of concern, firstly, because animals can act as reservoirs or vectors of pathogens which can affect humans (zoonosis). Secondly, wildlife and livestock share a number of diseases which poses an indirect zoonotic risk and causes economic losses (Gortázar et al. 2016). Finally yet important, wildlife diseases can affect host densities. This is particularly relevant for small populations of threatened species (Peterson & Ferro 2012). Moreover, information obtained when monitoring wildlife diseases is pivotal for the adaptive management of populations.

Wild caprines (subfamily *Caprinae*), as large herbivores, are keystone and umbrella species of mountain habitats (Found 2016) as well as valuable game species. In addition, they represent a potential source of new genetic material for improving livestock or to ensure its adaptation to less productive conditions. However, more than 70 % of wild caprine species show some degree of threat, with more than 30 % considered "endangered" or "critically endangered", due to overexploitation (hunting), alteration, loss and fragmentation of habitats and competence with domestic species (Schackleton 1997).

During last decades, a number of mange outbreaks caused by the mite *Sarcoptes scabiei* have been reported in wild free-ranging populations of different Caprinae species. Sarcoptic mange has also been reported affecting animals kept in captivity in zoological gardens (Yeruham et al. 1996).

The reported mortality rates induced by mange varies significantly among host species and populations (Fernández-Morán et al. 1997, Rossi et al. 2007), but for most outbreaks there is a lack of information about such rates. Despite some reported values exceeded 95 % (Fandos 1991), the complete extinction of a host population by *S. scabiei* has not been reported.

Such induced mortality not only means loss of renewable natural resources, but also a threat for some host species/populations which, in turn, may have potential impact on the dynamics of mountain ecosystems. Within this context, our revision on sarcoptic mange affecting wild Caprinae populations is also aimed to serve as a reference for managers.

METHODS

We conducted a search in the ISI Web of Science using several keywords, such as: sarcoptic mange, ungulates, Caprinae or management. Some references focussed on management of this disease in other type of hosts (e.g., carnivores) were also considered. This primary source of information was complemented with abstracts and proceedings of specialized congresses (World Conference on Mountain Ungulates, European Congress on Genus *Capra*, or Rencontres du Groupe d'Etudes sur l'Ecopathologie de la Faune Sauvage de Montagne (GEEFSM)).

RESULTS AND DISCUSSION

Sarcoptic mange affects a number of wild Caprinae species throughout Eurasia (Table 1) with a striking absence of similarly-affected species in other continents. A recent review of sarcoptic mange affecting American wildlife (Niedringhaus et al. 2019) includes big horn sheep (*Ovis canadensis*) as a host for *Sarcoptes scabiei* (Cowan 1951). This was possibly a case of mite misidentification since this host is affected by psoroptic mange (*Psoroptes ovis*) throughout North America (Lange et al. 1980, Ramey et al. 2000). In North America, sarcoptic mange affects mainly carnivores, such as red foxes (*Vulpes vulpes*), wolves (*Canis lupus*), coyotes (*C. latrans*) and black bears (*Ursus americanus*) (Niedringhaus et al. 2019).

Spatio-temporal dynamics of sarcoptic mange in mountain ungulates

Rossi et al. (2007) described the spatial advance of mange in a Northern chamois (*Rupicapra rupicapra*) population from the Dolomite Alps during a 10 year period. Mange spread as an “oil spot”, combined with “jumps” of 9-20 km/year. In average, these authors estimated an advance of the disease frontline of 5.5 ± 7.1 (range 0 – 22.8) km/year. A similar advance speed (6-7 km/year) was reported by Fernández-Morán et al. (1997) for the initial phase of a sarcoptic mange outbreak affecting a population of Southern chamois (*R. pyrenaica*). In the Sierra Nevada Natural Space (SNNS, southern Spain) the first scabietic Iberian ibex (*Capra pyrenaica*) was observed in 1992, and ten years later the disease had spread through the whole mountain range and surrounding areas with an estimated mean mange front speed of around 9 km/year (Granados et al. 2007).

Epidemiological surveys in humans and wild animals reveal a remarkable persistence (endemization) of scabies in the affected populations and a common pattern consisting of periodic fluctuations (“waves”) with cycles ranging between 10 and 30 years (Orkin 1975, Arlian 1989, Rossi et al. 1995). When naïve populations experience their first contact with the mite, they can suffer high rates of mange-induced mortality. However, on occasion of later waves, lower levels of mortality are registered due to selection of resistant individuals and strengthening of herd immunity (Rossi et al. 1995, Guberti & Zamboni 2000).

Monthly prevalence of sarcoptic mange shows a seasonal pattern linked to social and breeding behaviour of hosts, which influence mite transmission and load (Pérez et al. 2017), but also likely related to temperature and rainfall during the previous months (Pérez et al. 1997). In chamois populations from the Alps, the highest prevalence is reached in January (Rossi et al. 2007), while in the Iberian ibex population from SNNS prevalence peaks in March (Granados et al. 2007) (Fig. 1). In both populations a second smaller peak occurred in September.

Parasite-host relationships: pathophysiology of sarcoptic mange

Sarcoptic mange is a catabolic process triggered by the arrival of mites (either through direct contact with infected animals or from *fomites*) to the host skin. All the developmental mite stages (larvae, nymphs and adults) are able to penetrate host skin and excavate galleries in the superficial epidermic layers (Bornstein et al. 2001). Within these galleries, mites move, breed, deposit eggs, excrements, exuviae and other products with antigenic properties. In scabietic Iberian ibexes, the deriving typical skin lesions include acanthosis, hyperkeratosis, rete ridges, spongiotic oedema, serocellular and eosinophilic crusts, exocytosis foci, apoptotic cells and sebaceous gland hyperplasia with inflammatory infiltrate consisting mainly in lymphocytes, macrophages and eosinophils (Oleaga et al. 2012, Espinosa et al. 2017c). Scabietic ibexes also show anaemia and suffer secondary infections by opportunistic bacteria penetrating the damaged skin (Pérez et al. 2015, Espinosa et al. 2017c). Histopathological evaluation of non-dermal tissues reveals structural changes in specific organs, including lymphoid hyperplasia, leucocytosis, congestion and amyloid deposits (Espinosa et al. 2017c). Sarcoptic mange also induces systemic inflammation. In Alpine and Iberian ibex, serum concentration of acute phase proteins, such as alpha-1-acid glycoprotein, serum amyloid A and, to a minor extent, haptoglobin and ceruloplasmin, increase with the severity of the disease (Rahman et al. 2010, Ráez-Bravo et al. 2015). In addition, sarcoptidosis increases the oxidative stress and decreases antioxidant status of Iberian ibex, which may contribute to the pathogenesis (Espinosa et al. 2017a). Sarcoptic mange is also a stressful factor for scabietic animals, which may have faecal glucocorticoid metabolite concentrations up to 60 times higher than healthy ibex (Pérez et al. 2019).

Scabietic ibex usually show a weight loss (Pérez et al. 2015) since the disease prevents infected animals from taking advantage of higher food availability during periods of vegetative growth of plants due to its chronic catabolic consumptive nature (Carvalho et al. 2015). A delay in the rhythm of ossification during the skeletal growth period in mangy male Iberian ibexes has been reported (Serrano et al. 2007). Regarding the same host species, mange affects more severely males than females (López-Olvera et al. 2015). While sarcoptic mange can cause death in affected hosts, there is clear evidence that resistance to the disease may develop in both naturally (Alasaad et al. 2013) and experimentally-infested Iberian ibex (Castro et al. 2018). Increasing immunoglobulin G concentrations against *S. scabiei* seemed to constitute a protective response in Southern chamois but not in Iberian ibex (Lastras et al. 2000). In experimentally-infested Iberian ibex, a lower clinical severity of sarcoptic mange and subsequent recovery from the disease has been associated with a higher local (skin level) activation of genes modulating antigen presentation, therefore leading to a lower systemic immune and inflammatory response (Ráez-Bravo 2019).

Regarding the same host species, the effects of sarcoptic mange on the demography of affected populations may go beyond the immediate induced mortality (Table 2), since downregulation of the reproductive performance may occur in parallel, through a reduction of testicular mass in males (Sarasa et al. 2011) and negative effects on follicular maturation and ovulatory capacity of females (Espinosa et al. 2017b). Future studies on the effect of the disease on the recruitment rate of affected populations are needed to better understand how the parasite influences the demographical trend of its host populations.

Tools for monitoring sarcoptic mange in wild ruminant hosts

The difficulty to maintain *Sarcoptes* mites *in vitro* has limited knowledge on biology, host-parasite relationships, development of vaccines, or drug resistance, among other topics regarding this parasite (Mounsey et al. 2012). Moreover, research on free-ranging wildlife models further restricts the access to samples and complicates surveillance.

Visual diagnosis

Visual diagnosis of sarcoptic mange is the reference field diagnostic method (Pérez et al. 2011). However, it may generate false negatives, particularly in the early stages of the disease, when skin lesions may be small-sized, hidden by fur and/or located in zones particularly difficult to be observed from distance (e.g., axillar or inguinal areas). False positives may also occur, because of other skin diseases (eg, lice infestation or dermatophilosis) or conditions such as moulting. While the sensitivity of this method is high (87.14 %), the specificity is low (60.71 %) (Valldeperes et al. 2019), and both sensitivity and specificity are affected by factors such as age, sex and period of the year. Due to these limitations, the combination of visual diagnosis with the detection of mites and their eggs in skin scrapings or in skin digested with KOH is considered the gold standard method (Valldeperes et al. 2019).

However, the diagnosis of scabies in skin scrapings can be complicated in case of suboptimal sampling technique, limited skin tissue collected, suboptimal preservation of samples and/or low mite burdens (Rambozzi et al. 2004, Mounsey et al. 2012). Difficulties in correctly identifying affected individuals under field conditions have prompted studies on alternative diagnostic methods.

Photographic traps

Camera trapping, in large use for wildlife research, conservation and documentation purposes worldwide, has also proved useful for mange surveillance in wolf (*Canis lupus*) (Oleaga et al. 2011), red fox (*Vulpes vulpes*) (Carricondo-Sánchez et al. 2017), coyote (*Canis latrans*) (Brewster et al. 2017), racoon dog (*Nyctereutes procyonoides*) (Saito & Sonoda 2017), wild boar (*Sus scrofa*) (Haas et al. 2015), white-tailed deer (*Odocoileus virginianus*), and nilgai (*Boselaphus tragocamelus*) (Brewster et al. 2017).

Moderate to severe cases of mange can be readily identifiable in photos and videos, however seasonal changes in coat patterns (eg, moult) may confound diagnostic (Brewster et al. 2017).

Trained dogs

Trained dogs (detector or sentinel dogs) (Fig. 2) have proved effective in detecting dead or moribund scabietic chamois in the Alps (Alasaad et al. 2012). Over 15 months of study, these dogs allowed the collection of 292 carcases and the localization and capture of 63 sick individuals, with apparently no false positive cases.

Thermography

The hair loss induced by the disease favours heat loss (Cross et al. 2016). Under these conditions, the energetic cost of infection may become critical especially in cold climates, which characterize high mountain habitats. Moreover, dermatitis due to mange implies a local temperature increase in the skin areas affected. Both factors make thermography a promising surveillance method for mange (Fig. 3). Although the first assessments of thermographic cameras found impaired sensitivity at distances over 100 m (Arenas et al. 2002), current available devices allow working with distances longer than 1000 m.

Immunodiagnostic

A rise of *S. scabiei* specific immunoglobulin G has been reported in scabietic animals of several species (Wooten et al. 1986, Arlian et al. 1996, Lastras et al. 2000, Bornstein et al. 1995, Sarasa et al. 2010). This has led to the development, evaluation and validation of different in house or commercial enzyme-linked immunosorbent assays (ELISAs) to detect specific antibodies to *S. scabiei* in wild species, reaching sensitivity and specific values over 90 % (Rambozzi et al. 2004, Haas et al 2015b, Ráez-Bravo et al. 2016).

As compared to other diagnostic methods, the detection of antibodies allows retrospective epidemiological studies on sample banks permitting comparison within and among areas (Haas et al. 2018). Immunodiagnostic methods have been a key tool to reveal the presence of *S. scabiei* in hosts and zones where it was only suspected or not confirmed by mite identification (Haas et al. 2018). This is particularly relevant for species which are more elusive and difficult to detect visually on field, and/or species where mange courses silently or causing only mild lesions.

Molecular tools

Methods for collecting single *S. scabiei* mites for DNA extraction have been recently revised and improved (Alasaad et al. 2008, Alasaad et al. 2009, Soglia et al. 2009). Recent results regarding molecular genetics allow a better understanding of the epidemiology of mange (eg, gene flow between different hosts and *Sarcoptes* populations) (Walton et al. 1999, Zahler et al. 1999, Rasero et al. 2010). These molecular techniques can also be used for diagnostic purposes, especially when working with small skin samples (Angelone-Alasaad et al. 2015). The internal transcribed spacer

(ITS)-2 region in nuclear rDNA is the most-frequently gene used for *S. scabiei* diagnosis (Peltier et al., 2018). However, Angelone-Alasaad et al (2015) reported universal conventional and real-time PCR diagnosis tools for *S. scabiei* based on mitochondrial DNA.

The complete mitochondrial genome of *S. scabiei* has been recently elucidated (Ueda et al. 2019). These results support the possibility of transmission of *Sarcoptes* mites between different host species. In a near future, knowledge on the complete genome of this mite species might become a powerful tool for designing a vaccine and effective treatments against mange.

GPS-GSM radiocollars

Monitoring animals with conventional radio-tracking is a challenging task in mountainous habitats, since topography limits fast displacements and, therefore, triangulation and location of marked animals. Such problems disappear with the use of GPS-GSM radio-collars, which allow monitoring location and activity of animals virtually in real-time. This technology also facilitates estimating survival rates (Alasaad et al. 2013) and home range (Viana et al. 2018), as well as location, capture, sample and data collection and, eventually, treatment of selected animals, which could become a basis of a strategy for management of mange in free-range populations.

Epidemiological modelling

Modelling the dynamics of a disease affecting a wild species helps to explore relationships between epidemiology and host demography, and for identifying both empirical and theoretical subjects and topics requiring further attention (Leung & Grenfell 2003). On the other hand, modelling allows reducing the number of experimental animals (Mounsey et al. 2010).

Several model-based studies focused on chamois have been used to estimate key parameters regarding mange epidemiology, such as a threshold host density below which the outbreak would become extinct or would not be able to propagate, and to explore the effect of mass or selective culling intensities in controlling the demographic impact of the disease in naïve host populations (Guberti & Zamboni 2000, Lunelli 2010, Turchetto et al. 2014). In a long-term study of chamois mange in the endemically infected Austrian Alps, the temporal and spatial analysis of a large number of cases resulted in the detection of clusters with seasonal and inter-annual occurrence (Fuchs et al. 2000).

Linking climate and host density with scabies epidemiology, estimating first wave and re-infection outcomes at the population level, analysing the optimal timing for treatment and/or the application of complementary/alternative control measures of the disease, including *laissez-faire*, or exploring scabies epidemiology within a multi-host species scenario are topics which can be addressed through simulation or modelling.

From prevention to eradication: options for managing the disease in the wild

Managing a disease in a wild animal population implies the application of initiatives in order to restrict or limit the effects caused by the disease or other management options in such population. Several approaches or strategies can be used for accomplish such objective: prevention, control and eradication (Wobeser 1994).

Eradication consists in completely clearing an affected population from a disease. In the real world, this is a hard reachable goal due to logistic, cultural and economic constraints, with rare exceptions being available (Freuling et al. 2013, Rossi et al. 2015). Otherwise, this extreme would not be advisable in several cases, since native pathogens exert a pivotal role in naturally controlling host populations and significantly contribute to biodiversity and have their own evolutionary value (Rózsa 1992, Windsor 1995).

Control of sarcoptic mange implies implementing actions targeted to increase the mortality rate and/or reduce the reproductive rate of *Sarcoptes* mites. Regarding the Iberian ibex from SNNS, in the 1990s this option basically consisted in the identification and removal of infested and dead hosts, coupled with the disinfection of carcass location in order to reduce the probability of mange transmission (Pérez et al. 1996). Currently, in front of the poor success of these measures registered under field conditions and the high unattainable effective culling rates predicted by the simulation models, the selective removal of infested animals is recommended to be limited to individuals in the generalized chronic phase of the disease, mainly for ethical and humanitarian reasons (Espinosa et al. 2020).

Control of sarcoptic mange in domestic livestock is also an important issue for preventing the transmission of the disease to wildlife. In the Iberian Peninsula, all major outbreaks of sarcoptic mange in free-ranging Caprinae reported during the last decades originated from contacts with scabietic poorly managed livestock (Leon-Vizcaino et al. 1999, Lavin et al. 2000).

Amongst feasible control actions that can be considered, treatment of infested animals is particularly controversial. One issue is the preferable antiparasitic drug or class to use in the field (Fang 2016, Rowe et al. 2019). So far, the macrocyclic lactone, ivermectin, has been largely used for treating captive and free-ranging scabietic chamois (Lavin et al. 2000) and Iberian ibex (León-Vizcaíno et al. 2001, Sánchez-Isarria et al. 2008b), although its usefulness in wild free-ranging populations has not been unambiguously demonstrated. Other drugs (pyrethroids, formamidines, organophosphates, phenylpyrazoles, isoxazolines (e.g., fluralaner) or botanical extracts) could help control of mange. In general, drugs achieving long period of activity could be recommended (Van Wick & Hashem 2019). Anyway, treatment of wildlife for consumption should be done in accordance of withdrawal times, which may inhibit the use of long-acting drugs.

Promising results have been obtained in relation to the biological control of different mites: *Acarus siro*, *Tyrophagus putrescentiae*, *Dermatophagoides farinae* and *Lepidoglyphus destructor* (Erban et al. 2009, Ahmed et al. 2016), *Varroa destructor* (Alquisia-Ramírez et al. 2014, Alquisia-Ramírez et al. 2017), or *Psoroptes cuniculi* (Dusntand-Guzmán et al. 2017) among others, with *Bacillus thuringiensis* toxins. Moreover, the massive use of *B. thuringiensis* toxins seems to be safe for the environment (Addison et al. 2006). This deserves attention and experimental research for assessing its usefulness in sarcoptic mange control.

Another important aspect to keep in mind is the extent of control actions. Traditionally, the best option consisted in treatment of a large proportion of the population (Wobeser 1994, Pérez et al. 1996). Its implementation in free-ranging wildlife populations can become unaffordable, from economic and logistic viewpoints. On the other hand, the natural recovery of a number of scabietic animals (Alasaad et al. 2013, Castro et al. 2018) suggest that capture and treatment of selected specimens could be the best option in terms of cost-effectiveness. Nevertheless, more studies are needed to address the efficacy and safety of massive treatment programs, compared to those based in a selective approach. Finally, the season in which these control measures become more effective must be investigated (Pérez et al. 1996).

Preventing sarcoptic mange occurrence in naïve wild Caprinae populations implies reducing their probability of encounters with infected individuals (including asymptomatic ones) of any host species which may harbour *Sarcoptes* mites. To achieve this, physical and immunological barriers may be considered as well as restriction or modification of management/conservation activities, such as wildlife relocations (Pérez et al. 1996).

Immunization against mange could become an effective method for managing mange (Van Neste 1986, Arlian et al. 1994), since immunized animals are able to produce antibodies to a higher number of *S. scabiei* antigens when comparing with infested animals (Morgan & Arlian 1994). A recent study reported a 74.3 % of recovery in experimentally-infested rabbits after vaccination with a chitinase-like protein from *Sarcoptes scabiei* (Shen et al. 2018). Anyway, potential benefits and costs should be addressed when designing vaccinating programs to be implemented in free-ranging wildlife populations.

Fences could prevent or limit the spread of diseases and, in general, can contribute to achieve conservation benefits, but they also have costs. For example, fences have been used to keep captive breeding stock reservoirs of *Capra pyrenaica* free of mange (Espinosa et al. 2017d). On the other hand, wildlife mobility and landscape connectivity are pivotal in wildlife conservation and management, so fencing of wildlife should become a last-resort action (Woodroffe et al. 2014).

Other preventing measures deserving attention include: (i) management at the wildlife-livestock interface to reduce possible cross-transmission to the detriment of naïve wildlife; (ii) the veterinary control of livestock; (iii) in case of translocations, the exhaustive surveillance of source populations coupled with the exhaustive quarantine (including a two-fold anti-parasitic treatment) of individuals to be translocated; (iv) avoiding introduction of alochtonous species (wild ruminants and other mammal game species; or (v) regulating access of domestic animals to natural spaces in which the disease is endemic and/or show epizootic events (Pérez et al. 1996, Sánchez-Isarria et al. 2008a, Arenas-Montes et al. 2009).

Finally, other sympatric wild and domestic mammalian species may act as maintenance hosts of mange, conforming a multi-species scenario (León-Vizcaino et al. 1999; Iacopelli et al. 2020). This has implications for the management of scabies and for monitoring programs as well.

Biosecurity and biosafety

Humans can become infected when handling scabietic animals (e.g., capturing, sampling, transport and/or carcass management) (Menzano et al. 2004). To minimize the risk of transmission of *S. scabiei* between such individuals and other animals, including people, we must apply biosecurity and biosafety protocols. The carcasses with evident or suspected mange should be buried, incinerated, frozen or placed in approved landfills (Niedringhaus et al. 2019). Capture devices and vehicles for carcass or infested animals transportation must be cleaned and disinfected. Handling equipment (e.g., blindfolds, strectchers, leg snares for physical restraint, backpacks) must also be frozen overnight, thoroughly washed or treated with disinfectant. It would also be advisable to warn the public of the transmission risks when they exist (Niedringhaus et al. 2019). When possible, the staff must use personal protective equipment (PPE) (Fig. 4), and exterior clothing should be changed and treated in a similar way that contaminated handling equipment.

CONCLUSIONS

Sarcoptic mange is a natural or biological factor controlling host population numbers and dynamics. Accordingly, goals and strategies for the management of this disease in the wild must be quite different compared to those applicable in humans and/or domestic animals.

Independently of contexts and views, intensive surveillance in the mange outbreak areas is pivotal to generate reliable data sets on the main epidemiological variables (such as prevalence, intensity and mortality rate) and understand the disease dynamics and temporal trend. Based on this information, specific management plans should be implemented for each population of susceptible hosts, consisting of preventive and control measures (including *laissez-faire* option, when applicable). These measures will also take into account available human and material resources, and will periodically reviewed for efficacy and sustainability according to meaningful indicators.

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FIGURE LEGENDS

Figure 1. Comparative dynamics of monthly prevalence of sarcoptic mange affecting *Capra pyrenaica* and *Rupicapra rupicapra* in Sierra Nevada Natural Space (southern Spain) and Italian Alps, respectively, during the period 2006-2007.

Figure 2. Trained dogs proved to be very useful in following and finding sick (alive) (A) and dead (B) chamois affected by sarcoptic mange. Photos courtesy of Roberto Permunian. Figure 2A was previously published by Alasaad et al., 2012 (*BMC Veterinary Research* 8: 110).

Figure 3. Thermography of a male Iberian ibex with scabietic lesions in the abdominal region.

Figure 4. The use of personal protective equipment (PPE) prevents the risk of *S.scabiei* transmission to personnel involved in handling infested samples, animals or carcasses.

HOST SPECIES	LOCATION	REFERENCES
Aoudad (*Ammotragus lervia*)	Zoological garden (Israel)	Yeruham et al. 1996
	Sierra Espuña (southeastern Spain)	González et al. 2004
Alpine ibex (*Capra ibex*)	Eastern Alps (Italy, Austria, Slovenia)	Rossi et al. 2007
Iberian ibex (*Capra pyrenaica*)	South and eastern Spain	León Vizcaino et al. 1999
Nubian ibex (*Capra nubiana*)	Zoological garden (Israel)	Yeruham et al. 1996
Asiatic ibex (*Capra sibirica*)	Tien-Shan (Kazakistan, former Soviet Union)	Vyripaev 1985
	Xinjiang (China)	Li et al. 2018
Blue sheep (*Pseudois nayaur*)	Karakhoram (Pakistan)	Dagleish et al. 2007
Goral (*Naemorhedus goral*)	Sichuan (China)	Li et al. 2018
Formosan serow (*Capricornis swinhoei*)	Central Mountain Range (Taiwan)	Chen et al. 2012
Himalayan serow (*Capricornis thar*)	Uttarakhand (India)	Khanyari et al. 2016

	Sichuan (China)	Li et al. 2018
Japanese serow (*Capricornis crispus*)	Japan (several prefectures)	Matsuyama et al. 2019
European mouflon (*Ovis aries musimon*)	Cazorla Segura y Las Villas Natural Park (southern Spain)	León Vizcaino et al. 1992
	Eastern Alps (Italy)	Rossi et al. 2007
Southern chamois (*Rupicapra pyrenaica*)	Cantabrian mountain range (northern Spain)	Fernández-Morán et al. 1997
Northern chamois (*Rupicapra rupicapra*)	Eastern Alps (Germany, Austria, Slovenia, Italy)	Miller 1985, Rossi et al. 2007

Table 1. Checklist of Eurasian Caprinae host species affected by sarcoptic mange.

HOST SPECIES	LOCATION	MORTALITY RATE AND PERIOD	REFERENCES
Aoudad (*Ammotragus lervia*)	Sierra Espuña (SE Spain)	86 % (1991-1995)	González et al. 2004
Iberian ibex (*Capra pyrenaica*)	SCSLVNP [1] (S Spain)	97 % (1987-1991)	Fandos 1991
Asiatic ibex (*Capra sibirica*)	Tien-Shan Mount Range (Central Asia)	58.4 % (1974-1978)	Vyripaev 1985
Southern chamois (*Rupicapra pyrenaica parva*)	Asturias (NW Spain)	80.6 % (1993-1994)	Fernández-Morán et al. 1997
Northern chamois (*Rupicapra rupicapra*)	Dolomite Alps (Italy)	9.3 – 88.2 % (1995-2004)	Rossi et al. 2007

[1] SCSLVNP: Sierras de Cazorla, Segura y Las Villas Natural Park

Table 2. Mortality rates related to sarcoptic mange outbreaks found in the literature.