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Sarcoptic mange in wild ungulates in the European Alps – A systematic review

Maria Sophia Unterköfler[a,*], Magdalena Schausberger[a], Armin Deutz[b], Gunther Gressmann[c], Anna Kübber-Heiss[d], Ezio Ferroglio[e], Anja Joachim[a]

[a] Institute of Parasitology, Department of Pathobiology, University of Veterinary Medicine Vienna, Austria
[b] District Administration Murau - Veterinary Department, Styria, Austria
[c] Hohe Tauern National Park, Tyrol, Austria
[d] Research Institute of Wildlife Ecology, Department of Interdisciplinary Life Sciences, University of Veterinary Medicine Vienna, Austria
[e] Department of Veterinary Science, University of Turin, Italy

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ABSTRACT

Sarcoptic mange, caused by *Sarcoptes scabiei*, is a disease that affects many species of mammals, including several wild ungulate species in the region of the European Alps, especially the Alpine chamois and the Alpine ibex, which act as parasite reservoirs. Here records of mange in alpine wild ungulates and its spread over time across the eastern parts of the European Alps are reviewed. First cases were recorded from Austria in 1824, and epizootic outbreaks have been described since then from the mountainous regions of Austria (mostly Tyrol, Carinthia, and Styria), Germany (Bavaria), Italy (Udine and Trentino) and Slovenia. Switzerland, by contrast, has so far been free of mange except for cases in wild boar, indicating that this species is not a reservoir host of sarcoptic mites for other ungulate species in the European Alps, and that, so far, the disease in ruminant ungulates is restricted to the eastern and central parts of the Alps. Mutual transmission among wild and domestic ruminants is possible and, together with the protection of vulnerable wildlife, is also a reason for monitoring and, if necessary, intervention to contain mange outbreaks.

1. Introduction

The European Alps are the highest elevation in Europe, with 3000–4300 m a.s.l. in the western ranges, and cover a total area of 298,128 km^2 in Austria, France, Germany, Italy, Liechtenstein, Slovenia, and Switzerland (Bragin and Spiegel, 2020). Many wild animals are native to this area, including large predators like wolf (*Canis lupus*), brown bear (*Ursus arctos*), and European lynx (*Lynx lynx*), as well as eight different species of wild ungulates (Breitenmoser-Würsten et al., 2001; Reimoser and Reimoser, 2010). Alpine chamois (*Rupicapra rupicapra*) are wild Caprinae and are distributed across the entire European Alps, conventionally above the tree line but also in forests. Depending on the terrain, the animals usually live in groups, especially during the summer, females and their offspring forming large herds (Deutz and Greßmann, 2001; Schaschl, 2003; Miller and Kinser, 2020). Other wild Caprinae in the European Alps are Alpine ibex (*Capra ibex*). They live in groups of males or females with their offspring, or during the rutting season, in mixed groups, and prefer high-altitude areas above the tree line. During the 19th century the Alpine ibex nearly became extinct due to overhunting, in combination with unfavourable climatic conditions. Less than 100 animals survived in the Italian Alps in the Gran Paradiso area and were subsequently legally protected and reintroduced to former as well as new habitats (Deutz and Greßmann, 2001; Storch, 2017). The Alpine ibex is focally restricted to smaller areas, as are the European mouflon (*Ovis musimon*), the fallow deer (*Dama dama*), and the sika deer (*Cervus nippon*) (Reimoser and Reimoser, 2010). In contrast, red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*) are widely distributed. Red deer can be found in mountain and flatland forests and live in groups of seasonably variable size (Sternath, 2018). Roe deer inhabit fields and forests up to medium elevations as well as partly above the tree line. In autumn and winter, they inhabit fields in small groups while they tend to be solitary during spring and summer when they retreat to forests (Storch, 2017). Wild ungulates in the European Alps are ruminant herbivores except for wild boar, which are omnivorous and feed on plants and fruits as well as on invertebrates, small mammals, and carrion. Wild boar females live in

* Corresponding author.
E-mail address: Maria.Unterkoefler@vetmeduni.ac.at (M.S. Unterköfler).

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packs together with their offspring, and due to land use changes, rewilding, and to milder winters in the last decades, an increased wild boar population throughout Europe, including the Alps, is noted (Vetter et al., 2015; Sternath, 2018).

Infectious diseases play an important role in wildlife populations and several ecto- and endoparasites can have an impact on the health status of the animals. In Alpine chamois, the most frequent cause of death was reported to be of parasitic origin, especially the burrowing mite *Sarcoptes scabiei* (Vengušt et al., 2022). Sarcoptic mange is an important disease in domestic and wild animals (Pence and Ueckermann, 2002). The mites remain on the host for their complete life cycle and adults. Adult females burrow tunnels into the skin and deposit the eggs in them. Mite antigens (including feces and saliva) induce pruritus and crust formation in the skin of the host (Deplazes et al., 2021). In general, *S. scabiei* is host-specific at the strain level, and different hosts harbour their "own" strain of the mite (Walton et al., 1999). However, closely related hosts can be infected with the same strain (including cross-species transmission), and mites can survive on an aberrant host and cause pseudo-scabies, thus also rendering wildlife-derived *S. scabiei* zoonotic (Pisano et al., 2019; Moroni et al., 2022).

There are several reports on sarcoptic mange in the Alpine region, but many publications are only available in non-English languages. The objective of this review was to systematically analyse and review the existing literature, including the so-called grey literature (e.g. internal reports by national park officials) to make the information accessible to readers in an up-to-date systematic review.

2. Materials and methods

Literature was systematically reviewed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). Studies on suspected or confirmed mange (i.e. infection with *S. scabiei*) in wild ungulates (Alpine chamois, Alpine ibex, European mouflon, fallow deer, red deer, roe deer, sika deer, wild boar) from the European Alps in English, German, or Italian were included. The electronic literature search was carried out using the search engines PubMed®, Google Scholar® and the search engine of the University Library of the University of Veterinary Medicine Vienna, Vetmed:Seeker®. Search terms used were combinations of "Sarcoptes" or "mange" and "Alps", "Europe", "wild ungulates", or the scientific or common names of the mentioned host species. This was repeated in German ("Sarcoptes", "Räude", "Alpen", "Europa", "Wildungulaten", and the scientific or common host names). References of the selected articles were searched for further sources. Additional literature, which was not accessible via search engines, was supplied by experts (AD, GG) working in the field of wildlife ecology and wildlife parasitology. The literature search was carried out in the period from 11.07.2022 to 22.11.2022 by one investigator (MS) and was subsequently reviewed by a second investigator (MU). Data from the literature obtained were collected by two investigators (MS, MU) independently. If available, the data on species and number of affected animals, country, geographic location, and year were included.

A map was created using QGIS 3.22.3. Data were included in the map if geographic location was available at least at the province level and the host species was specified. The number of reported affected animals was categorized in three groups: <100, 100–1000, >1000. If the number of affected animals was not specified it was assigned to the group <100. The year of occurrence was grouped into three periods: before 1980, from 1981 to 2000 and from 2001 to 2020. If data covered two of the defined time periods, they were assigned to the more recent period. Localisations that were reported multiple times in the same species and time period were merged in a single data point.

3. Results

In total 44 sources were identified reporting the mentioned ungulates as hosts of *S. scabiei* in the European Alps (Table 1). In 27 sources geographical locations could be identified at province level or in more detail and were plotted on a map (Fig. 1).

Prior to the first descriptions of sarcoptic mange, a scabies-like rash was reported as early as the 1800s from Austria (Engel, 1958). In Alpine chamois sarcoptic mange was first reported from Styria, Austria, in 1824, followed by reports from Bavaria, Germany, 1826 to 1832. While these first reports were mainly of single animals, subsequent outbreaks were described that decreased animal populations more drastically. The first epizootic occurrence of sarcoptic mange in Alpine chamois was reported in 1870 from Carinthia, Austria, followed by further epizootic outbreaks in Austria in 1900 (Styria and Upper Austria), 1905 (Carinthia), 1910 to 1920 (Salzburg), 1922 (Styria), 1930 (Tyrol and Carinthia), and 1948 (Salzburg) (Schaschl, 2003). In 1949 areas in Bavaria were affected, as well as locations in Carinthia and Udine, Italy. In 1950, sarcoptic mange was reported in Alpine chamois from a new area in Udine with mortality rates of over 80% (Rossi et al., 1995; Schaschl, 2003). In Austria, other ungulate species affected by sarcoptic mange during that period were European mouflon, red deer, and roe deer (Kerschagl, 1955; Köhler, 1970).

After 1950, further epizootic outbreaks in Alpine chamois were reported from Tyrol 1954–1960, and cases were also reported from Bavaria in 1958, from Styria, Salzburg, Carinthia, Udine, and Bavaria in 1960 (Fuchs et al., 2000; Schaschl, 2003). Carinthia and Udine were again affected in 1962, and the epizootic outbreak further spread in Udine from 1963 to 1969. An outbreak in Carinthia from 1972 to 1991 also affected Slovenia in 1973 for the first time, and between 1976 and 1978 over 800 chamois were shot or found dead due to sarcoptic mange (Bidovec et al., 1978; Schaschl, 2003). Salzburg was reported to be affected during the years 1972–1996 with 50–327 cases per year

Table 1
Summary of literature (n = 44) on sarcoptic mange in wild ungulates in the European Alps.

Species	Reference
Alpine chamois	Kerschagl (1955), Kutzer and Onderscheka (1965), Köhler (1970),Wetzel and Rieck (1972), Bidovec et al. (1978), Tataruch et al. (1985), Gräfner and Drost (1986), Miller (1986), Ippen et al. (1987), Braunschweig (1991), Rossi et al. (1995), Salzburger Jägerschaft and Fuhrmann (1997), Rode et al. (1998), Fuchs et al. (2000), Greßmann and Deutz (2001), Berilli et al. (2002), Pence and Ueckermann (2002), Schaschl (2003), Menzano et al. (2004), Carmignola and Gerstgrasser (2007), Menzano et al. (2007), Rossi et al. (2007), Menzano et al. (2008), Rasero et al. (2010), Deutz et al. (2011), Geisel (2012), Schawalder (2012), Rossi et al. (2014), Turchetto et al. (2014), Salvadori et al. (2016), Greßmann et al. (2018), Janovsky et al. (2018), Winkelmayer et al. (2019), Turchetto et al. (2020), Pérez et al. (2021), Obber et al. (2022), Escobar et al. (2022), Vengušt et al. (2022)
Alpine ibex	Kerschagl (1955), Köhler (1970), Miller (1986), Ippen et al. (1987), Fuchs et al. (2000), Pence and Ueckermann (2002), Schaschl (2003), Greßmann and Pichler (2005), Carmignola and Gerstgrasser (2007), Rossi et al. (2007), Rahman et al. (2010), Rasero et al. (2010), Deutz et al. (2011), Greßmann et al. (2018), Janovsky et al. (2018), Winkelmayer et al. (2019), Greßmann (2020), Turchetto et al. (2020), Pérez et al. (2021), Escobar et al. (2022)
European mouflon	Kerschagl (1955), Ippen et al. (1987), Schaschl (2003), Rossi et al. (2007), Rasero et al. (2010), Pérez et al. (2021)
Red deer	Kerschagl (1955), Wetzel and Rieck (1972), Gräfner and Drost (1986), Ippen et al. (1987), Pence and Ueckermann (2002), Schaschl (2003), Rossi et al. (2007), Rasero et al. (2010), Deutz et al. (2011), Winkelmayer et al. (2019)
Roe deer	Kerschagl (1955), Wetzel and Rieck (1972), Gräfner and Drost (1986), Ippen et al. (1987), Pence and Ueckermann (2002), Schaschl (2003), Rossi et al. (2007), Menzano et al. (2008), Deutz et al. (2011)
Wild boar	Wetzel and Rieck (1972), Gräfner and Drost (1986), Ippen et al. (1987), Braunschweig (1991), Pence and Ueckermann (2002), Rasero et al. (2010), Haas et al. (2015, 2018), Meier and Ryser-Degiorgis (2018), Winkelmayer et al. (2019)

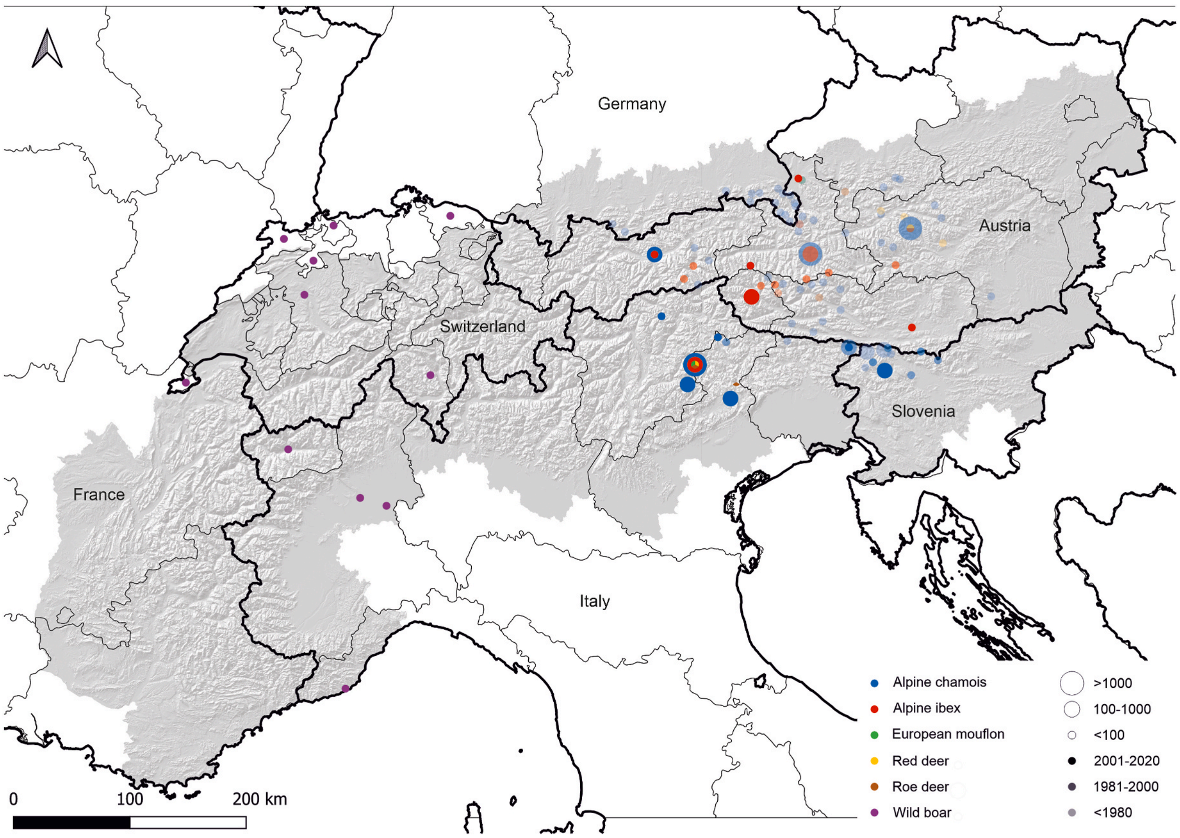

Fig. 1. Map of the European Alps and sarcoptic mange outbreaks in wild ungulates reported in the literature (n = 27). Host species is indicated with colour, the number of reported animals is indicated with size, and the time period is indicated by opacity. Grey area: alpine regions. Thin black lines: administrative boundaries. Thick black lines: country borders. The names of the countries are given. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

(Salzburger Jägerschaft and Fuhrmann, 1997). First outbreaks in Alpine ibex colonies were also reported from Austria during that period (Miller, 1986; Salzburger Jägerschaft and Fuhrmann, 1997; Greßmann and Pichler, 2005; Deutz et al., 2011). Epizootics occurred in areas of Bavaria between 1975 and 1980 and South Tyrol, Italy, in 1976. Further outbreaks were recorded in Slovenia in 1977 and in 1989. From 1995 to 2010 an epizootic outbreak in South Tyrol and Belluno, Italy, affecting both Alpine chamois and Alpine ibex was reported (Schaschl, 2003; Carmignola and Gerstgrasser, 2007; Rossi et al., 2007; Turchetto et al., 2014). Decline of numbers due to sarcoptic mange reached almost 90% in some Alpine chamois populations, and over 90% in an Alpine ibex population, almost leading to its complete eradication. (Carmignola and Gerstgrasser, 2007; Rossi et al., 2007).

Monitoring efforts in Slovenia between 2000 and 2020 identified sarcoptic mange as the most common cause of death (in 42.6% of necropsies) in Alpine chamois but was not considered to threaten the existence of the population in this region (Vengušt et al., 2022). Between 2006 and 2020, several outbreaks in Alpine chamois were monitored in different regions in Trento, Italy with 54.1% of animals found dead with sarcoptic mange (Obber et al., 2022). Alpine ibex, and single cases of European mouflon, red deer, and roe deer were also reported to be affected in Italy (Rossi et al., 2007; Menzano et al., 2008; Rahman et al., 2010; Rasero et al., 2010). In Carinthia and Tyrol numerous cases of mange in Alpine chamois and Alpine ibex were reported between 2009 and 2020 (Greßmann et al., 2018; Janovsky et al., 2018; Greßmann, 2020). In Tyrol 93 to 168 infected animals were reported during this period (Janovsky et al., 2018). For Alpine ibex around 18% mortality was reported (Greßmann, 2020).

Wild boar in the European Alps is also frequently affected by sarcoptic mange (Wetzel and Rieck, 1972; Gräfner and Drost, 1986; Ippen et al., 1987; Braunschweig, 1991; Pence and Ueckermann, 2002; Rasero et al., 2010; Winkelmayer et al., 2019). While in the Swiss Alps sarcoptic mange has not been reported in Alpine chamois, wild boar has recently been reported to be clinically affected in Solothurn, Tessin and Thurgau, Switzerland (Haas et al., 2015). A subsequent serological survey revealed a large geographic distribution of *S. scabiei* in wild boar with a prevalence of up to 12.7% (Haas et al., 2018). In addition, up to 4% of wild boar carry the mite in the western Italian Alps, however clinical cases with skin lesions are rarely observed (EF, unpublished data). In Austria, sarcoptic mange seems to be occurring more frequently in wild boar in recent years (AKH, unpublished data).

4. Discussion

In the European Alps, sarcoptic mange is considered endemic and is widely distributed among Alpine chamois as well as Alpine ibex. Other ruminant ungulates are only sporadically affected, and only if there is high infection pressure. The same can be observed in the Spanish Pyrenees, where the Pyrenean chamois (*Rupicapra pyrenaica*) and the Iberian ibex (*Capra pyrenaica*) are frequently affected (Rossi et al., 2019; Moroni et al., 2021). Chamois and ibex seem to act as reservoir hosts for *S. scabiei*, while other ruminant ungulates can be considered as spill-over hosts, affected only when infection pressure is high. To the authors' knowledge, fallow deer and sika deer have not been reported to be affected from sarcoptic mange in the European Alps. However, they might also serve as spill over hosts for the mites, as cases have been reported from other areas, such as China and Spain (Astorga et al., 2018; Moroni et al., 2021).

Both Alpine chamois and Alpine ibex are listed as "least concern" in the IUCN red list and have stable populations (International Union for

Conservation of Nature). However, especially in the case of the Alpine ibex this status is due to extensive conservation efforts and the populations are not equally stable everywhere. Considering their genetic bottleneck (Deutz and Greßmann, 2001; Storch, 2017), diseases that can decimate populations, such as sarcoptic mange, are still of great importance to conservation medicine.

Although wild boar is affected in the Swiss Alps and in the western Italian Alps, cases of other ungulates have not been reported from there. This epidemiological separation is also reflected in the genetic differences between sarcoptic mites of herbivores, omnivores, and carnivores, and therefore transmission between these wild boar and other ungulates seem unlikely (Rasero et al., 2010).

Possible transmission from wild animals to domestic animals or vice versa, e.g. from chamois to goats (*Capra hircus*) or wild boar to pigs (*Sus scrofa domesticus*) has been observed and might not only pose a risk for domestic animals, but can also play a role in epizootic outbreaks in wildlife. First introductions into naïve wildlife populations have been suspected to derive from domestic animals. (Rossi et al., 2007, 2014, 2019; Meier and Ryser-Degiorgis, 2018). Increased contact with domestic animals due to increased population density and consequently encroachment of wildlife habitats has been associated with first outbreaks in a naive population. Moreover, the higher wildlife population density contributes to a faster spread of the disease within the population (Rossi et al., 2014, 2019; Niederinghaus et al., 2019).

Occurrence of sarcoptic mange within a susceptible naïve population frequently results in high mortality, thereafter, there is a periodic resurgence every 10–30 years. The non-permanent observation of mange outbreaks has been attributed to a permanent persistence of mite infestations within the population and a subsequent development of immunity that prevents the development of clinical disease (Rossi et al., 1995; Greßmann et al., 2018; Pérez et al., 2022). Immunity has been linked to the major histocompatibility complex (MHC), with a positive correlation of MHC heterozygosity or certain alleles and resistance to infectious disease (Buítkamp et al., 1996; Brambilla et al., 2018). Genetic studies have shown that ibex have a lower MHC variation due to the genetic bottleneck of reintroduction after being almost eradicated (Brambilla et al., 2018). In chamois the MHC variation is dependent on the geographic location. Due to their geographically defined habitats, both ibex and chamois have little genetic exchange between populations or groups (Schaschl et al., 2004, 2012). This is considered a major driver of the susceptibility to sarcoptic mange in these species.

In a recent study, Alpine chamois could be categorized into four geographically separate genetic groups (Hoste, 2021), two of which come together in the western Alps where sarcoptic mange is not yet found. It is not clear why this infection has not spread further west, as there are no geographic barriers there (Janovsky et al., 2018). Considering the existing populations of Alpine chamois and Alpine ibex in the Swiss Alps, outbreaks in these areas could lead to severe losses.

Due to climate change, the global average temperature has increased by 1.1 °C compared to pre-industrial levels, and is expected to increase by 1.5–4.4 °C in the future (IPCC, 2023). It is assumed that the ability to respond physiologically to heat by thermoregulation will be a future selection trait in heat-sensitive species (Mason et al., 2017). Increased temperature is a particular problem for cold-adapted species such as ibex and chamois (Semenzato et al., 2020). A possible consequence may be that such species prefer cooler locations to those with better forage availability. This preference would lead to reduced forage selection, increased foraging effort and reduced energy intake. At the same time, the migration of animals to higher altitudes will lead to an increase in the concentration of animals in a smaller available space (Brivio et al., 2019). The unfavourable combination of these factors can promote the spread of disease within a population, and increase the susceptibility to sarcoptic mange in the future. Therefore, to detect changes at an early stage, monitoring of this disease in wild ungulates in the Alpine region should continue.

Endemic ungulate species are part of the biodiversity of the European Alps and can act as indicator species for environmental changes in this unique habitat. Since the first reported cases in 1824, sarcoptic mange has been a concern for wild ungulate health in this special habitat. Monitoring programs are important for the decision on and the planning of interventions to contain outbreaks, to protect vulnerable populations of wildlife, and to evaluate the effectiveness of intervention measures.

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Data availability statement

Additional data is available on request.

Conflicts of interest

The authors of the manuscript hereby submitted "Sarcoptic mange in wild ungulates in the European Alps – a systematic review" by Maria Sophia Unterköfler, Magdalena Schausberger, Armin Deutz, Gunther Gressmann, Anna Kübber-Heiss, Ezio Ferroglio, and Anja Joachim declare that they do not have any conflicts of interests and stated this also in the manuscript.

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