Recommendations for the management of sarcoptic mange in free–ranging Iberian ibex populations

J. Espinosa, J. M. Pérez, A. Raéz–Bravo, P. Fandos, F. J. Cano–Manuel, R. C. Soriguer, J. R. López–Olvera, J. E. Granados

Abstract
Recommendations for the management of sarcoptic mange in free–ranging Iberian ibex populations. In recent decades, sarcoptic mange has become the main driver of demographic changes in Iberian ibex (Capra pyrenaica) populations in the Iberian Peninsula. Given this species’ economic and ecological importance, priority must be given to management measures aimed at limiting the effects of this disease. However, despite the wealth of research on sarcoptic mange in ibex, no common patterns of action are yet available to manage this disease under field conditions. The lack of national and international protocols aimed at controlling sarcoptic mange has favoured the spontaneous emergence of various disease management initiatives in Spain. However, very little information is available concerning this trend and what there is tends to be available only as ‘grey literature’ or is consigned to the memory of local observers. Traditional strategies designed to combat this disease include the administration of medicated feed and the non–selective culling of mangy ibex. Here, we propose a management approach that takes into account aspects relating to the ecology and conservation of ibex populations, as well as public–health–related factors. Our recommendations are based on knowledge of the disease and host–parasite interaction, and aim to promote long–term advances in its control. Moreover, we discuss the efficacy of the measures traditionally used in mange management. The overall aim is to encourage debate between wildlife managers and motivate the development of alternative management strategies.

Key words: Capra pyrenaica, Conservation, Management strategies, Sarcoptes scabiei, Wild populations

Resumen
Recomendaciones para el manejo de la sarna sarcóptica en poblaciones silvestres de cabra montés. En las últimas décadas, la sarna sarcóptica se ha convertido en la principal causa de los cambios demográficos en las poblaciones silvestres de cabra montés (Capra pyrenaica) de la península ibérica. Dada la importancia ecológica y económica de esta especie, se debe dar prioridad a las medidas de gestión destinadas a limitar los efectos de esta enfermedad. Sin embargo, a pesar del gran número de estudios que existen sobre la sarna sarcóptica en la cabra montés, actualmente no hay ningún protocolo de actuación común para el manejo de esta enfermedad sobre el terreno. La ausencia de protocolos nacionales e internacionales destinados a controlar la sarna sarcóptica ha favorecido la aparición espontánea de diversas iniciativas de gestión en España. Sin embargo, existe muy poca información sobre esta tendencia y la que hay solo suele estar disponible en la literatura gris o en la memoria de los observadores locales. Algunas de las estrategias tradicionales diseñadas para combatir esta enfermedad son la administración de piensos medicados y el sacrificio generalizado de los animales afectados. En este trabajo, proponemos un enfoque de gestión que tenga en cuenta aspectos relacionados con la ecología y la conservación de la cabra montés, además de factores relacionados con la salud pública. Nuestras recomendaciones se basan en el conocimiento de la enfermedad y la interacción entre el parásito y el hospedador y tienen por objeto impulsar progresos a largo plazo en su control. Además, analizamos la eficacia de las medidas utilizadas tradicionalmente en el manejo de la enfermedad. El objetivo general es fomentar el debate entre los gestores de fauna silvestre y motivar la elaboración de estrategias de gestión alternativas.

Palabras claves: Capra pyrenaica, Conservación, Estrategias de gestión, Sarcoptes scabiei, Poblaciones silvestres
José Espinosa, Department of Animal Health, Instituto de Ganadería de Montaña (IGM), CSIC–ULE, Facultad de Veterinaria, Campus de Vegazana s/n., 24071 León, Spain.— Jesús María Pérez, Departamento de Biología Animal, Biología Vegetal y Ecología, Universidad de Jaén, Campus Las Lagunillas s/n., 23071 Jaén, Spain. — Arián Ráez–Bravo, Jorge Ramón López–Olvera, Wildlife Ecology & Health group (Wild&EH) and Servei d’Ecopatologia de Fauna Salvatge (SEFaS), Departament de Medicina i Cirurgia Animals, Facultat de Veterinària, Universitat Autònoma de Barcelona (UAB), 08193, Bellaterra, Barcelona, Spain.— Paulino Fandos, Agencia de Medio Ambiente y Agua, Isla de la Cartuja, E–41092 Sevilla, Spain. — Francisco Javier Cano–Manuel, Departamento Actuaciones Forestales, Delegación Territorial, Consejería de Agricultura, Pesca, Ganadería y Desarrollo Sostenible, Granada, Spain.— Ramón Casimiro Soriguère, Estación Biológica de Doñana (CSIC), Av. Américo Vespucio, s/n., E–41092 Sevilla, Spain.— José Enrique Granados, Espacio Natural Sierra Nevada, Carretera Antigua de Sierra Nevada km 7, E–18071 Pinos Genil, Granada, Spain.

Corresponding author: José Espinosa. E–mail: jespic@unileon.es

ORCID ID: J. Espinosa: 0000-0002-9036-1402; J.M. Pérez: 0000-0001-9159-0365; A. Ráez–Bravo: 0000-0002-3190-1659; P. Fandos: 0000-0002-9607-8931; R. C. Soriguère: 0000-0002-9165-7766; J. López–Olvera: 0000-0002-2999-3451; J. E. Granados: 0000-0002-9787-9896
Introduction

Awareness of the importance of actively managing infectious diseases in wild animals is a relatively novel phenomenon. Until recently, the general attitude was that ‘nature can manage on its own’. However, the presence of humans and the enormous pressure they exert on the environment as a means of satisfying their requirements distorts this natural balance and artificial control measures are needed (Lyles and Dobson, 1993). Two good examples of such distortions are the elimination of large predators and the loss of biodiversity (Packer et al., 2003; Keesing et al., 2006). In many zones, this has led to an unsustainable overabundance of wild animals in their chosen habitats, which creates ideal conditions for the flare–up of disease (Rossi et al., 2005; Gortázar et al., 2006; Vicente et al., 2007).

If these diseases are zoonotic in character or imply a threat to human economic activities, human action becomes inevitable as, for example, in the cases of rabbits in wild carnivores (Pastoret and Brochier, 1999), classical swine fever in wild boar (Kaden et al., 2000) and tuberculosis in badgers (Woodroffe et al., 2005). Furthermore, the emergence of virulent forms of infectious agents or highly susceptible hosts may also jeopardize the structure of wild populations (Woodroffe, 1999), as occurred in the case of sarcoptic mange caused by the Sarcoptes scabiei mite.

In the Iberian ibex (Capra pyrenaica), sarcoptic mange is at the root of the most serious demographic changes affecting this mountain ungulate in the Iberian Peninsula (Fandos, 1991; Pérez et al., 1997), to the extent that representative populations have become severely depleted and others are currently threatened (e.g. ibex populations in the Ports of Tortosa and Beceite and in the Game Reserve of Muela de Cortes) (unpublished data). Although sarcoptic mange is a constant threat to all populations of this mountain ungulate, currently this disease has not curbed the demographic trend of this species. However, the ecological, economic and social importance of the ibex (Granados, 2001), together with the sanitary risks that sarcoptic mange poses, obliges authorities and wildlife managers to instigate management control measures. One of the great inherent difficulties is that, like other infectious diseases (Kock et al., 2018), mange epidemics break out unexpectedly, often for obscure reasons (Pence and Ueckermann, 2002).

As well, the pathogenesis of sarcoptic mange (in terms of morbidity, mortality and population effects) generally varies greatly from one affected area to another (Fandos, 1991; Mömmer, 1992; Pérez et al., 1997; Fernández-Morán et al., 1997) and its effects are difficult to predict in affected populations for the first time. Given that the eradication of this disease is practically impossible (Wobeser, 2002), attempts are made to reduce its impact to ‘tolerable’ levels using a variety of control strategies areas; as such, management tasks designed to combat this disease are extremely complex.

Despite the amount of research that has been carried out on sarcoptic mange in the ibex, no common evidence–based management strategy designed to combat this disease under field conditions exists. This absence of any national or international protocol for sarcoptic mange has led to the emergence in Spain of spontaneous disease management initiatives that lack any consensus regarding which strategies are the most appropriate. Traditional strategies include the administration of medicated feed or the non–selective culling of mangy ibex. However, many management techniques generate serious social conflicts between animal rights activists, hunters and the local environmental agencies in charge of hunting activities. Furthermore, very little information is available on this question and what is available is generally either ‘grey literature’, that is, unpublished reports and conference proceedings, or it simply resides in the memories of local observers (Sánchez–Isarría et al., 2007a, 2007b). For this reason, we believe that it is essential to draw up a series of proposals for improved management and control of the spread of mange in the Iberian ibex.

We believe that the selection of the most appropriate management techniques requires a clear understanding of the cause and ecology of this disease, as well as full knowledge of the course of the disease in individual ibex and the population biology of the parasite–host interaction. In light of the four categories used for the management of wildlife diseases (prevention, control, eradication and doing nothing i.e. laissez–faire) (Wobeser, 1994, 2002; Artois et al., 2001, Artois, 2003), here we propose action that lies halfway between laissez–faire and control, given that prevention and eradication under field conditions is an extremely complex task. We use published scientific evidence on sarcoptic mange in the ibex to develop a more ‘ecological’ approach to the management of this disease, which we believe is the best strategy for both the conservation of the species and future prevention. Additionally, we discuss the effectiveness of the measures traditionally used in mange management. We hope that this work will stimulate a debate among wildlife managers and motivate the development of alternative management strategies. Our aim is to promote a consensus regarding the best measures to adopt when confronted with sarcoptic mange, while ensuring optimal conservation of ibex.

Preliminary considerations

Initially, it is important to highlight certain aspects of the disease that will serve as premises in control strategies: (1) As a parasitic disease whose main mode of transmission is direct contact, sarcoptic mange can be categorized as a density–dependent process (Pence and Windberg, 1994; León–Vizcaíno et al., 1999). (2) The clinical course in affected individuals (and therefore its effect on populations) is variable (Fandos, 1991; Gortázar et al., 1998; González–Candelas et al., 2004). Effects will be conditioned by intrinsic factors relating to each individual and/or population (sex, age, genetics, health status, previous contact with the mite, etc.) and/or extrinsic factors (time of year, population density, infective dose, availability of trophic resources, etc.) (Rossi et al., 2007; Sarasa et al., 2010; López–Olvera et al., 2015; Pérez et al., 2017). (3) Except in residual or highly fragmented populations, in which the
compared to traditional management measures, will be less invasive action based on scientific evidence that, the population biology of the parasite–host interaction. affects the individual), as well as intimate knowledge of the ecology of the disease (including how the disease management technique requires a clear understanding of populations. The selection of the most appropriate ma for managing sarcoptic mange in free–ranging ibex populations (Espinosa et al., 2017b).

Management proposals against sarcoptic mange and discussion

Here we suggest a series of alternative strategies for managing sarcoptic mange in free–ranging ibex populations. The selection of the most appropriate management technique requires a clear understanding of the ecology of the disease (including how the disease affects the individual), as well as intimate knowledge of the population biology of the parasite–host interaction. In the case of mange in ibex, we propose selective, less invasive action based on scientific evidence that, compared to traditional management measures, will provide more long–term benefits and better protection against future mange outbreaks.

In the interaction between sarcoptic mange and the Iberian ibex, four pathological phases or periods have been used to characterize the severity of infestations, according to the percentage of skin surface affected: 0, ibexes without skin lesions; 1, skin surface affected < 25%; 2, skin surface affected > 25 and < 50%; 3, skin surface affected > 50 and < 75%; and 4, skin surface affected > 75%) (León–Vizcaíno et al., 1999; Pérez et al., 2011). Given this, our management proposals focus exclusively on the selective culling of ibex in the chronic or final phases of the disease (phases 3 and 4). We rule out massive culling in mangy ibex populations and attempts to control the disease in the wild using pharmacological treatments. As we argue below, we believe that selective culling of ibexes in the final phases of the disease is the most appropriate and most reasonable measure for tackling sarcoptic mange in the ibex.

Selective removal of infested ibexes

From a clinical point of view, under natural conditions the multi–systemic clinical picture is severe and entails a very marked reduction in body condition, disorders of haematological and biochemical parameters (Pérez et al., 2015), septicaemic processes (Espinosa et al., 2017d), oxidative stress phenomena (Espinosa et al., 2017c), and an increase in inflammation biomarkers causing tissue damage in dermal and non–dermal tissues (Raéz–Bravo et al., 2015; Espinosa et al., 2017d), all of which greatly reduce survival possibilities and/ or hamper the recovery of ibexes in chronic phases of disease. For ethical and humanitarian reasons, the ending of the suffering of infected animals is necessary. In addition, ibex that have reached these stages of the disease can be a direct or indirect potential source of infestation for the rest of the population (Arlia et al., 1984; Pérez et al., 2011). Thus, unlike a non–intervention (laissez–faire) strategy (Wobeser, 2002), our low–level intervention approach will help reduce the risks of mange transmission within a population.

Sarcoptic mange has side–effects that, in final phases of the disease, negatively affect the reproductive physiology of both male and female ibex (Sarasa et al., 2011; Espinosa et al., 2017a) and hinders their reproductive success. This makes them ineffective in prolonging the species and therefore unable to transmit to their offspring any type of response developed against the disease. In addition, given that mange is transmitted mainly by direct contact, recently born young are likely to be infected and to increase the affected population. This assumption is based on the observation of very young ibex with sarcoptic mange in herds with mangy adult specimens (Espinosa et al., 2017a), as well as the finding of mangy carcasses of juvenile ibex (J. E. Granados, pers. comm.). Thus, severely ill ibexes, with a low reproductive capacity and with a high risk of spreading the infestation to the rest of ibex population are determining factors to selectively remove these individuals and thus contribute to the control of the disease.
In all cases, the selective culling of these ibex must be carried out whenever possible by specialized staff using firearms. Capture using anaesthetic darts or systems of physical restraint that involves the pharmacological administration of a lethal drug—and therefore further manipulation—is a far more laborious and costly process (e.g. additional staff, the transfer of carcasses for incineration, etc.) with greater chances of failure on the welfare ground (due to additional capture–related stress; López–Olvera et al., 2009). The thorough disposal of the mangy skin of culled ibex reduces the possibilities of disease contamination and transmission and, unlike laissez–faire strategies (Wobeser, 2002) that advocate leaving dead ibex in the wild, eliminates a risk factor for the rest of the ibex population and for sympatric species.

Effects of massive lethal control of sarcoptic mange

Attempts to reduce or eliminate sarcoptic mange from the population by culling all mangy ibex—regardless of the severity of lesions—may also have unintended consequences on the population. No effective results for this type of management measure have ever been reported. For example, the spread of mange in Northern chamois (Rupicapra rupicapra) in the Eastern Alps (Italy, Austria and Slovenia) and Southern chamois in the Cantabrian Mountains (Spain) could not be controlled by culling visibly infected individuals (Meneguz et al., 1996; Fernández–Morán et al., 1997). One of the problems of this technique is that, in the event of epizootic outbreaks of disease, most of the large–scale culls take place before epidemiological studies of the response of the population to the disease are performed and so do not discriminate between ibex in regression stages and those that are resistant to the disease. We believe that ibex in the initial and intermediate stages of the disease (phases 1 and 2) (León–Vizcaíno et al., 1999; Pérez et al., 2011) should never be removed from the population (fig.1).

In the initial stages of the disease (Phases 1 and 2), the identification of sarcoptic mange with binoculars or telescopes can be confused in ibexes that, although without being parasitized by S. scabiei, show alterations of the coat due to the seasonally heavy shedder (Valdeperes et al., 2019). Experimental infestations carried out on ibex from the Sierra Nevada Natural Space showed a wide variety of clinical responses varying from animals that progressed to severe or chronic phases to others that developed self–limiting clinic processes with mange lesions covering less than 50 % of the body surface, spontaneous regression lesions (move from phases 3–4 to 2–1) and even full recovery (Espinosa et al., 2017c) (fig. 2). Furthermore, scientific evidence show that a considerable proportion of mangy ibex recover naturally (Alasaad et al., 2013). Similar results were obtained in experimentally infested Northern chamois (R. rupicapra) in the Alps (Menzano et al., 2002).

As well, the loss of genetic diversity from the population through the removal of resistant ibex or those in a recovery stage can have long–term negative consequences and even give rise to future, more severe epidemics due to a loss of herd immunity (Ebinger et al., 2011). The culling of diseased animals can even select for increased virulence as it means that there will be a greater number of relatively more susceptible hosts available for pathogens; this, in turn, stimulates pathogens to transmit more quickly to susceptible hosts to avoid being culled along with their hosts (Choo et
Ovis canadensis nelsoni - in free–ranging Iberian ibex populations.

Until designed studies have demonstrated its efficacy, treatment with Ivermectin is likely not warranted. To date, there is no proof as to its effectiveness. In 2019, we believe that this strategy is impractical as considering the appearance of larger populations in the natural environment (Artois et al., 2011; Crozier and Schulte–Hostede, 2014). For example, the distribution of medicated feed at specific points can involve the aggregation of animals and therefore greater contact. Social structure of the ibex is large and inaccessi bleeding (López–Olvera et al., 2009). Therefore, it may never be possible to successfully implement long–term sarcoptic mange control in free–ranging ibex populations since dispensing drugs in this fashion implies no control of doses, no guarantee of repeated individual treatment, and very little acquired knowledge of effective therapeutic doses. It is also important to know whether other sympatric species act as reservoirs of the disease and contribute to its maintenance in the target host population, as shown in other multi–species models (Gakuya et al., 2012).

We also believe that other ecological, ethical and public health issues must be addressed when contemplating the free dispensing of drugs in the natural environment (Artois et al., 2011; Crozier and Schulte–Hostede, 2014). For example, the distribution of medicated feed at specific points can involve the aggregation of animals and therefore greater contact and an increase in infestation rates (Anderson and May, 1978). Environmental pollution via excreta with antiparasitic residues can cause a loss of biological diversity amongst invertebrate, vertebrate and microbial fauna, which in turn can be competitors in exogenous phases of other parasites (Verdú et al., 2018). Another important aspect is the development of acquired resistance by parasites to the chemicals contained in the medication, which, due to the selective pressure in resistant organisms, is a clear risk in any program dependent upon the continued and widespread use of chemotherapy (Wobeser, 2002). This is significant not only for the treatment of mange in the ibex but also for the management of disease in domestic livestock and even in humans. Other less–well–known effects, such as the teratogenic effects of Ivermectin intake during pregnancy or lactation, must also be taken into account (Bialek and Knobloch, 1999).

The abuse of antiparasitic drugs can also affect the nature of the parasite–host interaction. For example, it is well known that previous contact with the mite induces a more intense and effective immune response in re–infestations (Sarasa et al., 2010). Thus, host–parasite relationships can be modified by continuous...
interference to the immune system as a result of the lack of sufficient parasitic antigens able to produce efficient and protective stimulation (Pedersen and Fenton, 2015). Therefore, the development of a correct immune response and the appearance of resilient ibex may be delayed or interrupted. Even if treatment does manage to eliminate mites from mangy ibex, recovered animals will not acquire long-lasting immunity and re-infestation may occur (Pederson, 1984; Wobeser, 2002). Another unintended consequence of the non-selective use of antiparasitic drugs in the wild is the possible modification of the balance with other parasites in both healthy and mangy ibex (Pérez et al., 2003; Thomas et al., 2005). Based on the above, we believe that in free-ranging species the application of uncontrolled antiparasitic treatment is inappropriate since evidence of proven efficacy is lacking and there is no solid scientific base to support its use as a management measure. Until such scientific support is obtained, this type of management measure should be limited exclusively to the control of sarcoptic mange in captive wildlife (Rowe et al., 2019) or domestic livestock sharing territory with the ibex, thereby ensuring the safe and efficient control of a significant risk factor for the ibex population (Granados, 2001). On the other hand, it will be interesting to evaluate the efficacy of the new generation of isoxazoline parasiticides as an alternative to the use of macrocyclic lactones in the treatment of sarcoptic mange in ibex (Van Wick and Hashem, 2019). For more information on the success of such treatment in wild species, treated animals will have to be fitted with radio-collars to guarantee better individual monitoring.

Finally, we believe that, bearing in mind the considerations outlined above, the culling of mangy ibex in chronic phases is justified. The public can be
Table 1. Summary of attempts to treat mange in free-ranging wildlife and reported results. Treatments in captive wildlife are excluded: I, infestation (OM, Otodectic mange; PM, Psoroptic mange; SM, sarcoptic mange).

| Host species                                      | I    | Severity       | Treatment and doses                                                                 |
|--------------------------------------------------|------|----------------|-------------------------------------------------------------------------------------|
| Mednyi artic fox (Alopex lagopus semenovi)        | OM   | Unreported     | Alugan spray and ivermectin<br>Unknown doses                                        |
| Cheetah (Acinonyx jubatus) and others             | SM   | Mild to severe | Ivermectin: one doses<br>(200 μg/kg SC)                                             |
| Bighorn sheep (Ovis canadensis)                   | PM   | Mild or severe | Ivermectin ‘bio–bullet’.<br>Doses unknown strategy                                  |
| Red fox (Vulpes vulpes)                           | SM   | Unreported     | Ivermectin; one doses (300 μg/kg SC)                                               |
| Southern hairy nosed wombat (Lasiorhinus latifrons)| SM   | Mild or severe | Ivermectin: one doses (300 μg/kg SC)                                               |
| Bare–nosed wombat (Vombatus ursinus)              | SM   | Mild to moderate| Ivermectin: two doses (400–800 μg/kg SC) +<br>Amitraz: one doses (0.025% topical wash) |
| Mountain gorilla (Gorilla beringei beringei)      | SM   | Mild to severe | Ivermectin: one doses (170–670 μg/kg IM) +<br>Antibiotic and vitamin supplements    |
| Hanuman langur (Semnopithecus entellus)           | SM   | Moderate       | Tebrub: 30 doses (250 mg PO)<br>Mebhydrolin: 30 doses (25 mg PO)<br>Ivermectin: one doses (1 mg/kg SC)<br>Chlorpheniramine maleate: one dose (10 mg SC) |
| Vicuña (Vicugna vicugna)                          | SM   | Mild to severe | Ivermectin (unknown doses)                                                          |
| Giraffe (Giraffa camelopardis)                    | SM   | Moderate to severe| Unreported                                                                         |
| Agile wallaby (Macropus agilis)                   | SM   | Moderate       | Ivermectin: two doses (300 μg/kg SC)                                               |
| Gorilla (Gorilla beringei beringei)               | SM   | Severe         | Ivermectin: two doses (200 mg/Kg SC) +<br>Antibiotic                               |
| Iberian ibex (Capra pyrenaica)                    | SM   | Mild to severe | Foxim: two doses (500 mg/l topical wash) +<br>Ivermectin: two doses (02 mg/kg SC)    |
| Koala (Phascolarctos cinereus)                    | SM   | Unreported     | Amitraz: two doses (0.025% topical wash)                                           |
| Host species | Severity | Treatment and doses | Effects on population | Reference |
|--------------|----------|---------------------|-----------------------|-----------|
| Mednyi artic fox | OM  | Unreported | Alugan spray and ivermectin | Non–significant increase in cub survival; effect on population viability unknown | Goltsman et al. (1996) |
| Cheetah | SM | Mild to severe | Ivermectin: one doses | Recovery of some treated individual; inconclusive long–term population effects | Gayuka et al. (2012) |
| Bighorn sheep | PM | Mild or severe | Ivermectin 'bio–bullet.' | Not reported, but dismissed as a management strategy | Jessup et al. (1991) |
| Red fox | SM | Unreported | Ivermectin; one doses (300 μg/kg SC) | Ineffective results both in the individual and in the population | Newman et al. (2002) |
| Southern hairy nosed wombat | SM | Mild or severe | Ivermectin: one doses (300 μg/kg SC) | Ineffective results both in the individual and in the population | Ruykys et al. (2013) |
| Bare–nosed wombat | SM | Mild to moderate | Ivermectin: two doses (400–800 μg/kg SC) + Amitraz: one dose (0.025% topical wash) | Recovery of some treated individual; population effects unknown | Skerratt et al. (2004) |
| Mountain gorilla | SM | Mild to severe | Ivermectin: one doses (170–670 μg/kg IM) | Recovery of all affected animals and mange control in the gorilla population | Kalema–Zikusoka et al. (2002) |
| Hanuman langur | SM | Moderate | Tebrub: 30 doses (250 mg PO) + Mebhydrolin: 30 doses (25 mg PO) | Recovery only of animals with parenteral treatment; population effects untested | Chhangani et al. (2001) |
| Vicuña | SM | Mild to severe | Ivermectin (unknown doses) | Inconclusive treatment results | Gómez–Puerta et al. (2013) |
| Giraffe | SM | Moderate to severe | Unreported | Treated animals recovered. Certain success at the population level | Alasaad et al. (2012) |
| Agile wallaby | SM | Moderate | Ivermectin: two doses (300 μg/kg SC) | Successful on an individual level and mange control in the gorilla population | McLelland and Youl (2005) |
| Gorilla | SM | Severe | Ivermectin: two doses (200 mg/Kg SC) | Successful on an individual level and mange control in the gorilla population | Graczyk et al. (2001) |
| Iberian ibex | SM | Mild to severe | Foxim: two doses (500 mg/l topical wash) | Dismissed as a management strategy at the population level | León–Vizcaíno et al. (2001) |
| Koala | SM | Unreported | Amitraz: two doses (0.025% topical wash) | Complete success at the individual and population level | Brown et al. (1982) |
 convinced of the need to remove some specimens without culling all affected ibex. Using solid arguments
without applying extreme management measures the aversion generated by human intervention in the
control of the disease in wildlife can be minimized.

Conclusions
Parasites are natural parts of ecosystems and for this reason the presence of parasites in hosts does not
necessarily imply that these wild populations are in danger of disappearing. Wildlife is a societal resource
and provides ecological services that are vital for sustaining economies and human health. However, sometimes
(as in the case of sarcoptic mange in Spanish ibex) a parasitic disease causes the death of a part
of the population, thereby endangering the economic activities (e.g. ECO–tourism, hunting) that are derived
from it. When attempting to control the disease and limit its effects, a lack of information and the need to
make decisions quickly in a ‘crisis’ situation lead to the application of strategies that are not appropriate for
the management of the disease. We believe that the management of diseases in wild animals generally requires solid scientific evidence grounded on corrective measures with potentially irremediable consequences for the future of the wild population. Short–term specific measures including pharmacological treatment and mass culls are too costly, too limited in duration and have little effect on overall population health. Given that it is difficult to predict where and when the next outbreak of sarcoptic mange will occur, further research is needed on the real effectiveness of the different management strategies of sarcoptic mange in field conditions, with proven results that may help wildlife managers in the decision–making process.

Acknowledgements
The authors acknowledge the support during this study from the Sierra Nevada Natural Space staff and the Consejería de Medio Ambiente (Junta de Andalucía). The scientific results on which this work is based were financed by the projects CGL2012–40043–C02–01, CGL2012–40043–C02–02 and CGL2016–80543–P (MEC, Spanish Government) and by the PAIDI Research Group RNM–118 from the Junta de Andalucía. We would also like to thank Michael Lockwood for the English revision. The authors would like to thank two anonymous expert reviewers and journal editors for their valuable comments on the manuscript.

References
Acevedo, P., Cassinello, J., 2009. What we know about Capra pyrenaica biology and ecology: A critical review and proposal for forthcoming agenda. Mammal Review, 39: 17–32.
Alasaad, S., Ndeereh, D., Rossi, L., Bornstein, S., Permunian, R., Soriguier, R. C., Gakuya, F., 2012. The opportunistic Sarcoptes scabiei: a new episode from giraffe in the drought–suffering Kenya. Veterinary Parasitology, 185: 359–363.
Alasaad, S., Granados, J. E., Fandos, P., Cano–Manuel, F. J., Soriguier, R. C., Pérez, J. M., 2013. The use of radio–collars for monitoring wildlife diseases: a case study from Iberian ibex affected by Sarcoptes scabiei in Sierra Nevada, Spain. Parasites & Vectors, 6(1): 242.
Anderson, R. M., May, R. M., 1978. Regulation and stability of host parasite population interactions: I. Regulatory processes. Journal of Animal Ecology, 47: 219–247.
Arlian, L. G., Runyan, R. A., Achar, S., Estes, S. A., 1984. Survival and infestivity of Sarcoptes scabiei var. canis and var. hominis. Journal of the American Academy of Dermatology, 11: 210–215.
Artois, M., 2003. Wildlife infectious disease control in Europe. Journal of Mountain Ecology, 7: 89–97.
Artois, M., Blancou, J., Dupeyroux, O., Gilot–Fromont, E., 2011. Sustainable control of zoonotic pathogens in wildlife: how to be fair to wild animals? Revue Scientifique et Technique–OIE, 30: 733.
Artois, M., Delahay, R., Guberty, V., Cheeseman, C., 2001. Control of infectious diseases of wildlife in Europe. Veterinary Journal, 162: 141–152.
Bialek, R., Knobloch, J., 1999. Parasitic infections in pregnancy and congenital parasitoses. II. Helminth infections. Zeitschrift für Geburtshilfe und Neonatologie, 203: 128–133.
Bornstein, S., Mörner, T., Samuel, W. M., 2001. Sarcoptes scabiei and sarcoptic mange. In: Parasitic diseases of wild mammals, 2nd edition: 107–120 (W. M. Samuel, M. J. Pybus, A. A. Kocan, Eds.). Iowa State University Press, Ames, Iowa, U.S.A.
Brown, A. S., Seawright, A. A., Wilkinson, G. T., 1982. The use of amitraz in the control of an outbreak of sarcoptic mange in a colony of koalas. Australian Veterinary Journal, 58: 8–10.
Caughley, G., Sinclair, A. R. E., 1994. Wildlife Ecology and Management. In: Blackwells Science: 334 (Editors). Editorial, Cambridge, Massachusetts, U.S.A.
Chhangani, A. K., Mathur, B. R. J., Mohnot, S. M., 2001. First record of mange (sarcoptic mange) in free ranging Hanuman langur (Semnopithecus entellus) and its treatment around Jodhpur (Rajasthan), India. Intas Polivet, 2: 261–265.
Choo, K., Williams, P. D., Day, T., 2003. Host mortality, predation and the evolution of parasite virulence. Ecology Letters, 6: 310–315.
Crozier, G. K. D., Schulte–Hostedde, A. I., 2014. The ethical dimensions of wildlife disease management in an evolutionary context. Evolutionary Applications, 7: 788–798.
Dobson, A. P., Hudson, P. J., 1992. Regulation and stability of a free–living host–parasite system: Trichostrongylus tenuis in red grous. II. Population models. Journal of Animal Ecology, 61: 487–498.
Donnelly, C. A., Woodroffe, A. R., Cox, D. R., Bourne, F. J., Cheeseman, C. L., Clifton–Hadley, R. S., Wei, G., Gettinby, G., Gilks, P., Jenkins, H., Johnston, W. T., Le Fevre, A. M., McInerney, J. P., Morrison,
W. I., 2006. Positive and negative effects of widespread badger culling on tuberculosis in cattle. *Nature*, 439: 843–846.

Ebbinga, M., Cross, P., Wallen, R., White, P. J., Treanor, J., 2011. Simulating sterilization, vaccination, and test-and-remove as brucellosis control measures in bison. *Ecological Applications*, 21: 2944–2950.

Esponosa, J., 2018. Caracterización de la patología asociada a diferentes grados de infestación por *Sarcoptes scabiei* en cabra montés (*Capra pyrenaica*). Implicaciones en la gestión de la sarcoptidosis. PhD thesis, University of Murcia, Spain.

Esponosa, J., Granados, J. E., Cano–Manuel, F. J., López–Olvera, J. R., Ráez–Bravo, A., Romero, D., Soriguer, R. C., Pérez, J. M., Fandos, P., 2017a. *Sarcoptes scabiei* alters follicular dynamics in female Iberian ibex through a reduction in body weight. *Veterinary Parasitology*, 243: 151–156.

Esponosa, J., López–Olvera, J. R., Cano–Manuel, F. J., Fandos, P., Pérez, J. M., López–Graelaís, C., Ráez–Bravo, A., Mentaberre, G., Romero, D., Soriguer, R. C., Granados, J. E., 2017b. Guidelines for managing captive Iberian ibex herds for conservation purposes. *Journal for Nature Conservation*, 40: 24–32.

Esponosa, J., Pérez, J. M., López–Olvera, J. R., Ráez–Bravo, A., Cano–Manuel, F. J., Fandos, P., Soriguer, R. C., Granados, J. E., Romero, D., 2017c. Evaluation of oxidant/antioxidant balance in Iberian ibex (*Capra pyrenaica*) experimentally infested with *Sarcoptes scabiei*. *Veterinary Parasitology*, 242: 63–70.

Esponosa, J., Ráez–Bravo, A., López–Olvera, J. R., Pérez, J. M., Lavín, S., Tvarijonaviciute, A., Cano–Manuel, F. J., Fandos, P., Soriguer, R. C., Granados, J. E., Romero, D., 2017d. Histopathology, microbiology and the inflammatory process associated with *Sarcoptes scabiei* infection in the Iberian ibex (*Capra pyrenaica*). *Parasites & Vectors*, 10: 596.

Fandos, P., 1991. *La cabra montés* (*Capra pyrenaica*) en el Parque Natural de las Sierras de Cazorla, Segura y las Villas. ICONA-CSIC, Madrid.

Fernández–Morán, J., Gómez, S., Ballesteros, F., Quirós, P., Benito, J., Fellu, C., Nieto, J., 1997. Epizootiology of sarcoptic mange in a population of cantabrian chamois (*Rupicapra pyrenaica parva*) in Northwestern Spain. *Veterinary Parasitology*, 73: 163–171.

Gakuya, F., Ombui, J., Maingi, N., Muchemi, G., Ogara, W., Soriguer, R. C., Alasaad, S., 2012. Sarcoptic mange and cheetah conservation in Masai Mara (Kenya): epidemiological study in a wildlife livestock system. *Parasitology*, 139: 1587–1595.

Goltzman, M., Kruchenkova, E. P., Macdonald, D. W., 1996. The Mednyi arctic foxes: treating a population imperilled by disease. *Oryx*, 30: 251–258.

Gómez–Puerta, L. A., Olazabal, J., Taylor, C. E., Cribillero, N. G., Lopez–Urbina, M. T., Gonzalez, A. E., 2013. Sarcoptic mange in vicuna (*Vicugna vicugna*) population in Perú. *Veterinary Record*, 173: 269–269.

González–Candel, M., León–Vizcaíno, L., Cubero–Pablo, M. J., 2004. Population effects of sarcoptic mange in Barbary sheep (*Ammotragus lervia*) from Sierra Espuña Regional Park, Spain. *Journal of Wildlife Disease*, 40: 456–465.

Gortázar, C., Acevedo, P., Ruiz–Fons, F., Vicente, J., 2006. Disease risks and overabundance of game species. *European Journal of Wildlife Research*, 52: 81–87.

Gortázar, C., Villafuerte, R., Blanco, J. C., Fernández–De Luco, D., 1998. Enzootic sarcoptic mange in red foxes in Spain. *Zeitschrift für Jagdwissenschaft*, 44: 251–256.

Graczyk, T. K., Mudakikwa, A. B., Cranfield, M. R., Ellenberger, U., 2001. Hyperkeratotic mange caused by *Sarcoptes scabiei* (Acariformes: Sarcoptidae) in juvenile human–habituated mountain gorillas (*Gorilla gorilla beringei*). *Parasitology Research*, 87: 1024–1028.

Granados, J. E., 2001. Distribución y estatus de la cabra montés (*Capra pyrenaica*, Schinz 1838) en Andalucía. PhD thesis, University of Jaén, España.

Jessup, D. A., De Forge, J. R., Sandberg, S., 1991. Biobulletin vaccination of captive and free–ranging bighorn sheep. In: *Wildlife production: conservation and sustainable development*, 429–434 (L. A. Reneker, R. J. Hudson, Eds.). University of Alaska, Fairbanks, USA.

Kaden, V., Lange, E., Fischer, U., Strebelow, G., 2000. Oral immunisation of wild boar against classical swine fever: evaluation of the first field study in Germany. *Veterinary Microbiology*, 73: 239–252.

Kalema–Zikusoka, G., Kock, R. A., Macfie, E. J., 2002. Scabies in free–ranging mountain gorillas (*Gorilla beringei beringei*) in Bwindi Impenetrable National Park, Uganda. *Veterinary Record*, 150: 12–15.

Keesing, F., Holt R. D., Ostfeld, R. S., 2006. Effects of species diversity on disease risk. *Ecology Letters*, 9: 485–498.

Kido, N., Omiya, T., Kamagaya, C., Wada, Y., Takahashi, M., Yamamoto, Y., 2014. Effective treatment for improving the survival rate of raccoon dogs infected with *Sarcoptes scabiei*. *Journal of Veterinary Medical Science*, 76: 1169–1172.

Kock, R. A., Orynbayev, M., Robinson, S., Zuther, S., Singh, N. J., Beauvais, W., E. Morgan, E. R., Kerimbayev, A., Khomenko, S., Martineau, H. M., Rystæva, R., O. Marova, Z., Wolfs, S., Hawtowte, F., Radoux, J., Milner–Gulland, E. J., 2018. Saigas on the brink: Multidisciplinary analysis of the factors influencing mass mortality events. *Science advances*, 4(1): eaao2314.

León–Vizcaíno, L., de Ybánez, M. M. R., Cubero, M. J., Ortiz., J. M., Espinosa, J., Pérez, L., Simón, M. A., Alonso, F., 1999. Sarcoptic mange in Spanish ibex from Spain. *Journal of Wildlife Disease*, 35: 647–659.

León–Vizcaíno, L., Cubero, M. J., González–Capitel, E., Simón, M. J., Pérez, L., de Ybánez, M. M. R., Ortiz, J. M., González–Candel, M., Alonso, F., 2001. Experimental ivermectin treatment of sarcoptic mange and establishment of a mange–free population of Spanish ibex. *Journal of Wildlife Disease*, 37: 251–258.
and Infection, 133: 559–568.
Rowe, M. L., Whiteley, P. L., Carver, S., 2019. The treatment of sarcoptic mange in wildlife: a systematic review. Parasites & Vectors, 12: 99.
Ruykys, L., Breed, B., Schultz, D., Taggart, D., 2013. Effects and treatment of sarcoptic mange in southern hairy–nosed wombats (Lasiorhinus latifrons). Journal of Wildlife Diseases, 49: 312–320.
Sánchez–Isarría, M. A., Hermoso, J., Theureau de la Peña, J., Casanova, G., Burgui, J. M., Sanchís, G., Arévalo, P. R. S., 2007a. Metodología empleada en la estrategia del control de la sarna sarcóptica en la cabra montés de la Reserva Valenciana de Caza de la Muela de Cortes entre los años 2002–2007 (Valencia). In: Tendencias actuales en el Estudio y Conservación de los caprinos europeos: 255–268 (J. E. Granados Torres, J. Cano–Manuel León, P. Fandos, R. Cadenas de Llano Aguilar, Eds.). Junta de Andalucía, Granada, Spain.
– 2007b. La ivermectina como tratamiento de la sarna sarcóptica en el medio natural: vías de aplicación. In: Tendencias actuales en el Estudio y Conservación de los caprinos europeos: 269–276 (J. E. Granados Torres, J. Cano–Manuel León, P. Fandos, R. Cadenas de Llano Aguilar, Eds.). Junta de Andalucía, Granada, Spain.
Sarasa, M., Rambozzi, L., Rossi, L., Meneguz, P. G., Serrano, E., Granados, J., González, F. J., Fandos, P., Soriguer, R. C., González, G., Joachim, J., Pérez, J. M., 2010. Sarcoptes scabiei: specific immune response to sarcoptic mange in the Iberian ibex Capra pyrenaica depends on previous exposure and sex. Experimental Parasitology, 124: 265–271.
Sarasa, M., Serrano, E., Soriguer, R. C., Granados, J. E., Fandos, P., González, G., Joachim, J., Pérez, J. M., 2011. Negative effect of the arthropod parasite, Sarcoptes scabiei, on testes mass in Iberian ibex, Capra pyrenaica. Veterinary Parasitology, 175: 306–312.
Skerratt, L. F., 2003. Clinical response of captive common wombats (Vombatus ursinus) infected with Sarcoptes scabiei var. wombatii. Journal Wildlife Disease, 39: 179–192.
– 2005. Sarcoptes scabiei: an important exotic pathogen of wombats. Microbiology Australia, 26: 79–81.
Skerratt, L. F., Skerratt, J. H., Martin, R., Handsyde, K., 2004. The effects of sarcoptic mange on the behaviour of wild common wombats (Vombatus ursinus). Australian Journal of Zoology, 52: 331–339.
Thomas, F., Bonsall, M. B., Dobson, A. P., 2005. Parasitism, biodiversity, and conservation. In: Parasitism and Ecosystems: 124–139 (F. Thomas, R. F. Renaud, J. F. Guégan, Eds.). Oxford University Press, Oxford, UK.
Valdédeperes, M., Granados, J. E., Pérez, J. M., Castro, I., Ráez–Bravo, A., Fandos, P., López–Olvera, J. R., Serrano, E., Mentaberry, G., 2019. How sensitive and specific is the visual diagnosis of sarcoptic mange in free–ranging Iberian ibexes? Parasites & Vectors, 12(1): 1–7.
Van Wick, M., Hashem, B., 2019. Treatment of sarcoptic mange in an American Black Bear (Ursus americanus) with a single oral dose of Fluralaner. Journal of Wildlife Diseases, 55: 250–253.
Verdú, J. R., Cortez, V., Martínez–Pinna, J., Ortiz, A. J., Lumaret, J. P., Lobo, J. M., Sánchez–Piñero, F., Numa, C., 2018. First assessment of the comparative toxicity of ivermectin and moxidectin in adult dung beetles: Sub–lethal symptoms and pre–lethal consequences. Scientific Reports, 8(1): 14885.
Vicente, J., Höfle, U., Garrido, J. M., Fernández De–Mera, I. G., Acevedo, P., Juste, R., Barral, M., Gortazar, C., 2007. Risk factors associated with prevalence of tuberculosis–like lesions in wild boar and red deer in South Central Spain. Veterinary Research, 38: 451–464.
Wobeser, G. A., 1994. Investigation and management of disease in wild animals. In: Plenum: 265 (Editors). Springer Science and Business Media, New York.
– 2002. Disease management strategies for wildlife. Revue Scientifique Et Technique (International Office of Epizootics), 21: 159–178.
Woodroffe, R., 1999. Managing disease threats to wild mammals. Animal Conservation, 2: 185–193.
Woodroffe, R., Donnelly, C. A., Cox, D. R., Bourne, F. J., Cheeseman, C. L., Delahay, R. J., Gettinby, G., McInerney, J. P., Morrison, W. I., 2005. Effects of culling on badger Meles meles spatial organization: implications for the control of bovine tuberculosis. Journal of Applied Ecology, 43: 1–10.
Woodroffe, R., Donnelly, C. A., Jenkins, H. E., Johnston, W. T., Cox, D. R., Bourne, F. J., Cheeseman, C. L., Delahay, R. J., Clifton–Hadley, R. S., Gettinby, G., Gilks, P., Hewinson, R. G., McInerney, J. P., Morrison, W. I., 2006. Culling and cattle controls influence tuberculosis risk for badgers. Proceedings of the National Academy of Sciences, U.S.A., 103: 14713–14717.