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The dilemma of conserving parasites: the case of Felicola (*Lorisicola*) isidoroi (*Phthiraptera: Trichodectidae*) and its host, the endangered Iberian lynx (*Lynx pardinus*)

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Abstract. 1. Parasites are essential elements in healthy natural ecosystems. Also, they constitute most of the world's biodiversity. Therefore, they deserve to be conserved together with their hosts.

2. The Iberian lynx (*Lynx pardinus*) is the most endangered felid in the world because it only survives in two isolated populations in the Iberian Peninsula, with no more than 300 free-ranging individuals.

3. *Felicola* (*Lorisicola*) *isodoroi* is a louse exclusively parasitic on the Iberian lynx, and it appears to be scarcer and therefore more endangered than its host.

4. Current management activities devoted to the conservation of the Iberian lynx, such as reproduction in captivity for restocking, could compromise the survival of its louse species.

5. In this article we revise the ectoparasites of the Iberian lynx and discuss their potential role for transmission of pathogens.

6. Also, we propose measures which could enhance the survival of *F.* (*L.*) *isidoroi*.

Key words. Conservation programme, ectoparasites, *Felicola* (*Lorisicola*) *isidoroi*, host management, Iberian lynx, parasite conservation, *Trichodectidae*.

Introduction

Should we conserve parasites? It is difficult to respond to this question without setting it in a particular context. The negative impact which many parasites exert on the well-being of millions of people, particularly in tropical and subtropical areas, and to domestic animals worldwide is incalculable in terms of economic and human loss (Cox, 1993). In natural ecosystems also, parasites may become a serious threat to the survival of endangered host species because outbreaks of parasitic diseases can trigger or accelerate population declines (Lyles & Dobson, 1993; Altizer *et al.*, 2007). The majority of mammal species considered threatened by parasites are carnivores or artiodactyls (Pedersen *et al.*, 2007). Most of these species have small and fragmented populations with low genetic variability. For these reasons, parasites that cause or transmit infectious diseases might represent an additional factor that increases stochastic extinction risk (McCallum & Dobson, 1995).

Nevertheless, parasites constitute a significant part of biodiversity. Price (1980) estimated that a half of all known plants and animals are parasites, at least at some moment in their life cycle. More than 10% of the known metazoan species are parasites (Poulin & Morand, 2004), but if we also consider micro-organisms, then parasites are estimated to represent more than half of all living species (de Meeûs & Renaud, 2002); these authors suggest that no species is free from infection by parasites. Zimmer (2000) estimated that the number of parasite taxa is around four times greater than that of free-living taxa. Dobson *et al.* (2008) estimated that between 3 and 5% of

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parasitic helminths are threatened with extinction in the next 50–100 years. In natural scenarios, parasites contribute to maintain biodiversity and, therefore, there is merit in conserving them (Thomas *et al.*, 2005). If modern conservation biology takes into account preservation of ecological processes (conservation above the species level), then parasitism, and therefore parasites, need to be conserved as well (Pérez *et al.*, 2006).

By removing less heterozygous individuals from host populations, parasites are considered responsible for much of the genetic diversity of natural populations (Coltman *et al.*, 1999; O'Brien, 2000). As a major selective force, parasitism is linked to the appearance and evolution of sex (Hamilton, 1980; Howard & Lively, 1994). They have also proved to be useful to infer their host evolutionary and demographic history (Whiteman & Parker, 2005). Some authors have pointed out that parasites have their own evolutionary value and, therefore, must be conserved as much as free-living organisms (e.g. Rózsa, 1992; Samways, 1994; Windsor, 1995).

Parasites are linked to all food webs and important in the regulation of host populations and, potentially, contribute to reduce the impact of toxic pollutants. Therefore, parasite extinctions could negatively impact the health, survival and abundance of a large number of free-living species (Dobson *et al.*, 2008).

The extinction of any host species is likely to cause the loss of other species that depend on it (coextinctions), and this cascade effect is most severe in mutualistic and parasitic interactions, particularly when host-specific parasites are involved because the host is the only suitable habitat for its unique parasites (Stork & Lyal, 1993; Durden & Keirans, 1996; Altizer *et al.*, 2007; Dunn *et al.*, 2009). Even when the host escapes extinction, the survival of its specific parasites is not assured, as in the case of the successful recovery programme that saved the Californian condor, but caused the loss of its host-specific louse (Stork & Lyal, 1993; Anonymous, 2006).

The Iberian lynx, *Lynx pardinus*: an endangered host

The Iberian lynx, *Lynx pardinus* Temminck, 1827 is considered the most endangered felid species in the world and has been categorised as 'critically endangered' by the International Union for Conservation of Nature (IUCN) (2010). Although its former range covered the entire Iberian Peninsula, its distribution suffered a 98% decline during the second half of last century (Rodríguez & Delibes, 1992; Guzmán *et al.*, 2004), and only about 370 individuals currently remain, divided into two isolated breeding populations: the Doñana Natural Space (DNS) and its surrounding biosphere reserve, and the Andújar – Cardeña mountains in Eastern Sierra Morena (ESM), both in Andalusia (Fig. 1).

In 2003, an ex situ conservation programme for the Iberian lynx was initiated. The main goals of this programme

Fig. 1. Current natural distribution of *Lynx pardinus* in two isolated breeding populations (marked in black) and, potentially, of its specific louse, *Felicola* (*Lorisicola*) *isidoroi*. Numbered red dots refer to centres involved in the Iberian lynx conservation programme (see text for details). Scale bar represents 100 km.

are: (i) to establish a captive and viable population (from sanitary, genetic and demographic viewpoints), allowing implementation of both natural and assisted reproduction techniques and (ii) to obtain healthy lynx specimens for their re-introduction into the historic distribution range of this species (Vargas *et al.*, 2008). Within this context, five centres are involved in the programme: (i) *El Acebuche* (Huelva, southern Spain), (ii) *Zoobotánico de Jerez* (Cádiz, southern Spain), (iii) *La Olivilla* (Jaén, southern Spain), (iv) *Silves* (southern Portugal), and (v) *Granadilla* (Cáceres, central Spain) (Fig. 1). At present, a total of 98 lynxes (50 males and 48 females) constitute the whole captive population. From these, 32 were captured in natural habitats (25 from ESM and 7 from DNS) and 66 were born in captivity. Two captive-born lynxes have been released into the wild for the first time, in February 2011. Also, there have been translocations of free-ranging animals from ESM that were released in DNS for genetic reinforcement, as well as in two areas of its former range. In total, 25 lynxes have been translocated since 2009.

As a generalised protocol, all animals involved in the ex situ conservation programme and also those captured for translocations are treated with insecticides pipettes (fipronyl or selamectine) to eliminate ectoparasites to avoid transmission of pathogens (Martínez *et al.*, 2009; del Rey *et al.*, 2011).

Ectoparasites of the Iberian lynx: their role as vectors for pathogens and their potential impact on the host's health

Hitherto, 14 ectoparasite species have been reported from Iberian lynxes: eight ticks, four fleas, one louse and one hippoboscid fly (Table 1). Except for the louse, all of them are temporary, haematophagous parasites which do not show host-specificity (Combes, 2001; Poulin, 2007). As discussed below, most of these ectoparasites have the potential to transmit a wide variety of pathogenic agents and/or to serve as intermediate hosts for other parasites, even with zoonotic implications, that is, can be transmitted to man. Therefore, their occurrence on an endangered host species, like the Iberian lynx, is of concern and their control seems to be reasonable.

The cattle tick, *Rhipicephalus* (*Boophilus*) *annulatus* (Say, 1821) [formerly *Boophilus annulatus*] transmits agents for babesiosis: *Babesia bigemina* (Smith & Kilborne 1893) and *B. bovis* Starcovici, 1893, and anaplasmosis: *Anaplasma marginale* (Theiler, 1910) (Biberstein, 1999). The brown dog tick, *Rhipicephalus* (*R.*) *sanguineus* (Latreille, 1806) is a vector of *Ehrlichia canis* (Donatien & Lestoquard, 1935), which causes canine ehrlichiosis in the USA (Groves *et al*., 1975), as well of *Rickettsia conorii* Brumpt, 1932, the causative agent of the Mediterranean spotted fever in parts of Europe, Asia and Africa (Raoult & Walker, 1990). *Rhipicephalus* (*R.*) *sanguineus* can also transmit Rocky Mountain spotted fever (caused by *Rickettsia rickettsii* Brumpt, 1922) to humans (Weiss, 1988). Nothing is known about the role of *Rhipicephalus* (*R.*) *pusillus* Gil-Collado, 1936 as vector of pathogens, but it has been reported that *R.* (*R.*) *turanicus* Pomerantzev, 1940 transmits *Rickettsia massiliae* Beati & Raoult, 1993 (Matsumoto *et al*., 2005). *Ixodes* (*Ixodes*) *ricinus* (Linnaeus, 1758), the castor bean tick, is vector for *Babesia* spp. producing tick-borne bovine fever, *Anaplasma phagocytophila* (Foggie, 1949) producing red water fever, *Borrelia burgdorferi* Burgdofer, 1982, the agent for Lyme disease, and other pathogens (Marquardt *et al*., 2000). As far as we know, nothing about their role as vectors for pathogens has been reported for the rabbit tick *Ixodes* (*I.*) *ventalloi* Gil-Collado, 1936 and the European dog tick or hedgehog tick *Ixodes* (*Pomerantzevella*) *hexagonus* Leach, 1815.

Table 1. List of ectoparasites recorded from the Iberian lynx

Group	Species	References
Ticks	*Rhipicephalus* (*Boophilus*) *annulatus*	Hueli *et al*. (1991)
	Rhipicephalus (*Rhipicephalus*) *sanguineus*	Hueli *et al*. (1991); Cordero *et al*. (1994)
	Rhipicephalus (*R.*) *pusillus*	Hueli *et al*. (1991); Cordero *et al*. (1994); Millán *et al*. (2007)
	Rhipicephalus (*R.*) *turanicus*	Hueli *et al*. (1991); Millán *et al*. (2007)
	Rhipicephalus sp.	Millán *et al*. (2007)
	Ixodes (*Ixodes*) *ricinus*	Hueli *et al*. (1991)
	Ixodes (*I.*) *ventalloi*	Cordero *et al*. (1994)
	Ixodes (*Pomerantzevella*) *hexagonus*	Hueli *et al*. (1991)
Fleas	*Odontopsyllus quirosi quirosi*	Gil-Collado (1934)
	Spilopsyllus cuniculi	Millán *et al*. (2007)
	Pulex irritans	Millán *et al*. (2007)
	Ctenocephalides canis	Millán *et al*. (2007)
Lice	*Felicola* (*Lorisicola*) *isidoroi*	Pérez and Palma (2001); Millán *et al*. (2007)
Louse flies	*Hippobosca longipennis*	Millán *et al*. (2007)

The European rabbit flea, *Spilopsyllus cuniculi* (Dale, 1878) is known to be vector of the non-pathogenic *Trypanosoma nabiasi* (Railliet, 1895) (Hamilton *et al*., 2005), and the myxomatosis virus (Sobey & Conolly, 1971). The human flea, *Pulex irritans* Linnaeus, 1758, transmits a number of bacteria – such as *Yersinia pestis* Lehmann & Neumann, 1896 – rickettsiae, viruses and is an intermediate host for the tapeworm *Dipylidium caninum* Linnaeus, 1758 (Durden & Traub, 2002). The dog flea, *Ctenocephalides canis* (Curtis, 1826) can act as an intermediate host of cestodes, such as *D. caninum* and *Hymenolepis diminuta* (Rudolphi, 1819) (Arai, 1980).

Regarding trichodectid lice, only few cases of severe infestations by *Trichodectes canis* (De Geer, 1778) have been reported involving wolves (*Canis lupus* Linnaeus, 1758) and coyotes (*Canis latrans* Say, 1823) from North America (Foreyt *et al*., 1978; Mech *et al*., 1985; Jiménez *et al*., 2010). In such circumstances, alopecia, fur-matting, seborrhoea, self-excoriations and skin lesions were attributed to the presence of high numbers of lice; those conditions may lead to secondary infections and to exposure during winter. But, in only two cases lice were considered to be a possible secondary cause of host mortality (Mech *et al*., 1985).

The dog louse-fly, *Hippobosca longipennis* (Fabricius, 1805) is a bloodsucking parasite found mainly associated with carnivores. It can serve as an intermediate host for the filarial nematodes *Dipetalonema dracunculoides* (Cobbold, 1870) and *Acanthocheilonema* sp. (Rani *et al*., 2011). *Hippobosca longipennis* may be a vector of *Rickettsia conorii*, *Leishmania* spp. and *Dermatophilus congolensis* van Saceghem, 1915 (Anonymous, 2005), and a phoretic agent of *Cheyletiella yasguri* Smiley, 1965, a mite causing mange in dogs (Hafez & Hilali, 1978; Wilson & Bram, 1998).

Felicola (Lorisicola) isidoroi: an endangered louse

The family Trichodectidae (Insecta: Phthiraptera: Ischnocera) includes over 380 taxa (species and subspecies), all of which parasitise mammals (Lyal, 1985; Price *et al*., 2003). They can be distinguished from other ischnoceran lice by the presence of three-jointed antennae and tarsi with a single claw.

Pérez *et al*. (1990) studied the lice infesting a total of 38 wild carnivores from southern Spain, collected during the period 1987–1988. Among them, 14 Iberian lynxes from the Doñana population (DNS) were sampled, but no lice could be found. In January 1997, one adult male louse and a nymph were removed from the fur of an Iberian lynx accidentally road-killed in Sierra de Andújar Natural Park (ESM) (Jaén, southern Spain). On the basis of the morphology and biometry of one adult male specimen, Pérez and Palma (2001) described it as the new species *Felicola* (*Lorisicola*) *isidoroi* (Fig. 2). These authors noted the extreme low abundance and prevalence of the louse on its endangered host and proposed measures towards preserving it from extinction, such as avoiding the use of insecticides during handling of captured and captive lynxes. Recently, Millán *et al.* (2007) found specimens (number not determined) of *F.* (*L.*) *isidoroi* on one Iberian lynx out of 26 animals sampled, indicating a low prevalence (3.9%, $n = 26$) and, presumably, a low intensity of parasitism as well. The 26 lynxes examined originated from both DNP ($n = 18$) and ESM ($n = 8$). However, we have had access to the only louse specimen available from that study – a female deposited in the Museo Nacional de Ciencias Naturales (Madrid) – and we have identified it as *Felicola* (*Felicola*) *inaequalis* (Piaget, 1880); hence, it was

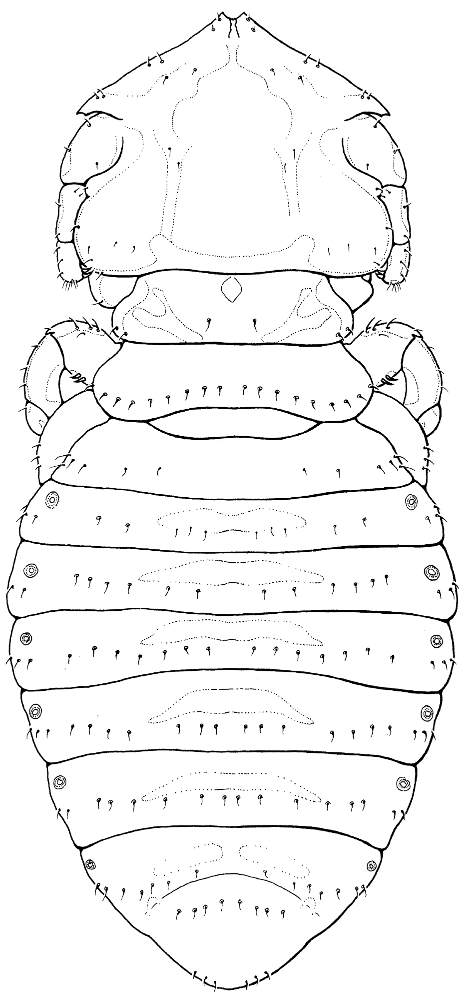

Fig. 2. Male holotype of *Felicola* (*Lorisicola*) *isidoroi*, dorsal view.

incorrectly identified and labelled as *F.* (L.) *isidoroi*. The species *Felicola* (*Felicola*) *inaequalis* is a regular and natural parasite of the Egyptian mongoose, *Herpestes ichneumon* (Linnaeus) (Pérez *et al.*, 1990). Therefore, we can only conclude that the host name of that female louse was incorrectly given as the Iberian lynx, or that the louse was a straggler or contaminant from an Egyptian mongoose onto an Iberian lynx. In either case, there is now no tangible evidence that any of the lice reported by Millán *et al.* (2007) were, in fact, *F.* (L.) *isidoroi*. Therefore, only one lousy lynx has been recorded from a total of 41 (14 + 1 + 26) sampled, with an overall prevalence of 2.4%, and, presumably, a low intensity of parasitism as well. In addition, we have examined 22 skins of Iberian lynxes from different localities preserved in the collection of the Doñana Biological Station (EBD-CSIC), but the treatment that those skins received for their preservation makes difficult the conservation of ectoparasites and, therefore, we did not found any lice. Furthermore, we have examined 24 additional skins kept frozen at the Centro de Análisis y Diagnóstico, Junta de Andalucía. Although they had not received any treatment, we could not found any lice on them. That negative result was not surprising because half of them were from animals from captive breeding centres, where the founders have been treated when brought into captivity.

According to Millán *et al.* (2007), the low numbers of lynxes together with their solitary behaviour would lead to a low number of lynx to lynx encounters and, consequently, to a low level of louse transmission, hence the observed low prevalence. On the other hand, the adult female of *F.* (*L.*) *isidoroi* still remains unknown (Martín-Mateo, 2009).

Further research on the phylogeny, status and geographical distribution of *Felicola (Lorisicola) isidoroi* with recommendations to prevent its extinction

The existential value of a species as a product of evolution should be enough to justify the investment of resources for conserving it. On the other hand, parasites could serve as ecological and evolutionary markers. Within this context some authors questioned the real biological individuality of parasites because of their dependence on their hosts (Dujardin & Dei-Cas, 1999). These authors consider the host–parasite relationship as a 'whole' unit, and that defining a parasite species requires defining its host as well. This system has also been considered as a 'superorganism' which has a 'supergenome' (Combes, 2001).

Because of their direct cycle and host-specificity, lice are ideal models to test coevolution and cospeciation processes by comparing the phylogenies of both lice and hosts species (Hafner & Nadler, 1988; Nadler *et al.*, 1990). Therefore, a molecular characterisation of *F.* (*L.*) *isidoroi* is a difficult task, taking into account its extreme scarcity in the wild. Moreover, as mentioned above, the female of this louse has not been described yet. But, this last objective would involve actions detrimental to the survival of the species, such as killing more specimens for their fixation, slide-mounting and/or preparation for SEM studies.

Clearly, the first priority is to preserve the habitat of *F.* (*L.*) *isidoroi*, i.e. its host (Pérez & Palma, 2001). Thus, we need to do further research to characterise its geographical distribution and its basic epidemiological data such as prevalence and intensity of parasitism. This may be achieved by sampling the fur of Iberian lynxes captured for tagging or to be re-introduced and also of those animals that die by any reason.

Maintaining Felicola (Lorisicola) isidoroi in vivo

Pérez and Palma (2001) recommended that insecticides should not be used for ectoparasite extirpation on lynx specimens captured and maintained in captivity, except in extreme clinical cases. As reviewed before, the welfare of these animals, however, could be compromised because of the potential of pathogen transmission by ectoparasites other than *Felicola* (*L.*) *isidoroi*. An alternative to this would be – before topic treatment with insecticides – to remove the lice manually and transfer them to another live host. The inclusion of *Felicola* (*L.*) *isidoroi* in the Iberian Lynx *Ex situ* Programme has been recently approved by the Iberian Lynx Captive Breeding Committee (I. Sánchez, pers. observ.). Therefore, any living louse that may be found on any wild lynx will be transferred to captive lynxes for its conservation. Environmental enrichment for lynxes kept in captivity would lead to a decrease in behaviours such as locomotion, repeated pacing, vigilance and over-grooming (Mollá *et al.*, 2011) which potentially could reduce their ectoparasitic loads.

In vitro *rearing of* Felicola (Lorisicola) isidoroi

Regarding lice of the family Trichodectidae, *Bovicola caprae* (Gurlt, 1843) and *B. limbata* Gervais, 1844, both ectoparasites of domestic goats, have been reared in vitro (Benítez-Rodríguez *et al.*, 1981, 1985, 1986). The life cycle of both species was completed in the laboratory at 35 ± 1.5 °C and 75 ± 5% relative humidity by using scrapings from goat skin as food and host hair and/or artificial fibres as substrate for lice. These authors also recorded data about adult survival, oviposition rate, and offspring obtained in the laboratory cultures. A similar programme to rear *Felicola* (*L.*) *isidoroi* in vitro could be established, if sufficient specimens can be found from Iberian lynxes.

Promoting legal protection for the Iberian lynx louse?

Several Spanish invertebrate species, most of them insects, have already been recognised as with certain degree of threat and, therefore, included in a concrete IUCN category (Rosas *et al.*, 1992; Verdú & Galante, 2005). Therefore, their protection and conservation is supported by national laws and international conventions as well. Nevertheless, the only louse species included in the IUCN *Red List of Threatened Species* (2010) is *Haematopinus oliveri* Mishra & Singh, 1978, parasitic on the pygmy hog (*Porcula salvania* Hodgson, 1847) from India, despite an estimate of six mammalian lice already extinct, and an expected extinction of a further 92 species (Koh *et al.*, 2004). According to these authors, the loss of species through coextinctions represents a loss of irreplaceable evolutionary and coevolutionary history and, therefore, coextinction would be taken into account in future research, conservation programmes and even legal-related issues.

Conclusion

In this article, we have discussed the plight of the Iberian lynx and its host-specific louse and have argued in favour of their future survival, not only because we have been fortunate to be closely associated with these two iconic species but also, because we strongly believe that parasites deserve to be appreciated, protected and conserved as much as their hosts. Our ultimate purpose is to draw attention to the plight of all parasitic species, which are or will be in danger of extinction as humankind continues to encroach on and consume the natural world.

We believe that most humans are not sufficiently objective when the subject of protecting and saving a biological species from extinction is considered. We fully agree with all the arguments expressed in several pioneer papers on this subject (Windsor, 1990, 1995; Rózsa, 1992; Stork & Lyal, 1993), especially with regard to the subjective way species are treated by those responsible for their protection and preservation. We wholeheartedly echo Windsor's (1990, 1995) 'Equal rights for parasites!', and will end with a quote from Stork and Lyal (1993) because, in our opinion, their wise thoughts have not yet been listened to and considered by the conservation community:

> Those who would not consider a louse to be of the same value as a bird raise an important ethical issue. Most people consider the value of insects, either positive or negative (with perhaps the exception of butterflies), solely in terms of their direct contribution to ecosystems and their direct or indirect effect on humans. When discussing conservation priorities and practices, we need to examine these values rather than simply condemning portions of the animal kingdom to extinction without thought.

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