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COMMENTARY

The importance of disease management programmes for wildlife conservation

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The unprecedented rate of disease emergence across the globe has raised concern among conservationists. Within the last decades there have been many examples of infectious disease-driven mortality of endangered populations, including the chytridiomycosis panzootic in amphibians and morbillivirus infections in marine mammals. These and other events have provided evidence that disease may pose a significant threat to biodiversity (reviewed in Smith, Acevedo-Whitehouse & Pedersen, 2009) and have highlighted the need for control programmes at different levels, from preventing a disease from being introduced or controlling an already-present disease, to completely eradicating the disease (Wobeser, 2002). Programmes aimed at lowering transmission by vaccination or by limiting contact with domestic animals might considerably reduce the risk of disease-related mortality for endangered populations (Pedersen *et al*., 2007). Lamentably, few such programmes have been fully implemented as part of conservation plans, partly because there is still limited data available to assess disease risks for many wildlife populations; and partly because the required interventions are costly and, in many cases, logistically impractical. As a result, it is difficult to assess the efficacy of disease management measures and determine whether it is necessary, feasible and affordable to develop and implement disease control strategies.

In this context, the featured study by López *et al*. (2009) provides a good example of the importance of a disease management strategy for a critically endangered species and highlights some points that might be relevant to other wildlife disease scenarios. The authors report the outcome of emergency measures to control a feline leukaemia virus (FeLV) epizootic among Iberian lynx. The disease management plan that was implemented to stop the FeLV outbreak from spreading used a multi-pronged approach which included serological surveys, isolation of infected individuals and vaccination of non-infected individuals, as well as selective culling/removal of feral and domestic cats. The authors managed to capture more than 80% of the lynx population and conducted sensitive diagnostic tests to determine the prevalence of the disease and identify suitable candidates for vaccination. This gargantuan effort was sustained for eight months and resulted in the vaccination of a relatively large number of lynxes across the species distribution. The combined measures were reported to be successful in confining the outbreak and preventing a potentially catastrophic outcome for the lynx population in south-western Spain.

López and colleagues highlight two issues that must be taken into account for conservation plans. First, it could be argued that as the disease drove the host population below the density threshold needed for persistence the outbreak would have been self-limiting and, thus, may not have needed any control strategy. However, transmission of FeLV is not dependent on population size; rather, it increases with frequency of contacts between infected and susceptible individuals (Fromont *et al*., 1997). The extremely low population size and small range of the Iberian lynx makes it possible for FeLV to propagate quickly during mating season and potentially kill the entire population. This is further complicated by the fact that, as occurs for most small and isolated populations, the Iberian lynx suffers from low genetic variability and inbreeding (Johnson *et al*., 2004), which can lead to lower immunocompetence, susceptibility to infection and higher disease severity (Spielman *et al*., 2004). Moreover, because the lynx appear to have been relatively unexposed to FeLV in the past, the population would expectedly have little, if any, acquired immunity against the infection. Therefore, the timely and concerted disease management strategy reported by López and colleagues is likely to have been essential to contain the epidemic and avoid a catastrophe for this endangered species.

The second issue that arises from the featured study relates to the financial cost and intense labour which were obviously needed to implement the disease control programme during the active epidemic. López and colleagues' study should compel conservationists to consider the pressing need for designing and implementing disease prevention and monitoring programmes that might help avoid an outbreak altogether. Evidently, it would be virtually unattainable to predict all possible disease outbreaks in a given wild population and carry out surveillance and control strategies for each of them. Nonetheless, it is entirely possible to conduct disease risk assessments to determine which diseases are most likely to affect an endangered population. The Iberian lynx is found near many urban areas, so chances of contact with domestic animals are high. In particular, domestic and feral dogs and cats, which harbour high diversity and prevalence of pathogens, including FeLV (Meli *et al*., 2009), may act as disease reservoirs for the Iberian lynx. Sustained selective culling programmes of the feral populations and vaccination schemes for domestic dogs and cats should help reduce disease risks. However, FeLV outbreaks had not been observed prior to the one reported by López and colleagues even though interactions with domestic carnivores are not likely to have increased in the past couple of decades. This suggests that something must have altered the epidemic triad, allowing the outbreak to occur. It is likely that the artificial feeders and drinking stations that were installed in the recent past increased the frequency of contact between lynxes as well as the chances of intra- and interspecific transmission of FeLV. As López and colleagues rightly discuss, their study provides evidence that the use of such supplementary devices as part of conservation management plans should be carefully evaluated to help reduce the risk of disease outbreaks.

As conservationists, we are just beginning to appreciate the importance of infectious disease for endangered or threatened populations; however, it is urgent that we focus efforts on assessing and prioritizing pathogen risks, so that we can plan surveillance and control strategies. Identifying the populations at highest risk of disease-mediated extinction, the pathogens likely to cause this disease, and the role of domestic reservoirs and abiotic factors in increasing the likelihood of an outbreak will ultimately allow designing surveillance, prevention and control strategies and help optimize conservation efforts. The featured study provides an excellent example of the need to be prepared for disease outbreaks that could be devastating for endangered populations.

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Successful intervention in a disease outbreak in the endangered Iberian lynx: what can we learn?

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Global biodiversity is increasingly under threat and species loss has prompted the argument that our natural world is experiencing a sixth major extinction event (Pimm & Brooks, 2000). Predators are especially vulnerable to extinction as they suffer population losses from many sources such as human–wildlife conflict, over-hunting, decline in prey and habitat loss. (Gaona, Ferreras & Delibes, 1998; Woodroffe, 2000; Treves & Karanth, 2003; Whitman *et al*., 2004). Parasites are increasingly linked to population impacts in wild felid and canid species (Pedersen *et al*., 2007). Many predator species exist in small and fragmented populations, vulnerable to stochastic events and other ongoing sources of population loss, which can drive them locally, if not globally, extinct. The Iberian lynx is a key example of an imperiled predator and is currently the most endangered felid in the world (Nowell & Jackson, 1996; Baillie, Hilton-Taylor & Stuart, 2004). This species may lose the survival battle without intense and continued conservation intervention.

In their paper, López *et al*. (2009) provide an excellent example of endangered species management, which demonstrates the importance of long-term population monitoring programs and the effectiveness of careful intervention design. Through their monitoring program, the authors identify the emergence of feline leukemia virus (FeLV) in the core population of Iberian lynx on the Iberian Peninsula. This pathogen is commonly found in domestic cats, which are considered the primary host (Arjona *et al*., 2007). While previous low-level FeLV exposure had been identified in the Iberian lynx population before the 2007 outbreak (Luaces *et al*., 2008; Meli *et al*., 2009), no associated mortality or other impacts had been identified. Then, inexplicably, FeLV emergence in 2007 causes an outbreak with mortality levels that threaten the survival of the species. Viral sequence from the 2007 outbreak is distinct from previous infections in the population but consistent with transmission from locally infected cats (Meli *et al*., 2009). In response to the outbreak, a FeLV control program is undertaken by the authors and other partners, which utilizes a test, removal and vaccination approach in Iberian lynx coupled with reduction of the sympatric feral cat population. It is successful and FeLV-associated mortality in the Iberian lynx ceases.

What can we learn from the approach taken by López and colleagues? Firstly, intervention for the Iberian lynx disease outbreak is designed and implemented through a partnership approach between many national stakeholders, project participants and experts. Often in wildlife management crises, consultation and inclusiveness of stakeholders is avoided in order to streamline processes and expedite action. But this can backfire when partner agencies and stakeholders are required in downstream management activities. This paper serves as a reminder that wildlife management is better implemented inclusively rather than exclusively.

Secondly, this study demonstrates the dynamic and unpredictable nature of pathogen invasion outcomes in a population. In this case, FeLV invasion in the population was not identified as an important problem but this changed dramatically in the 2007 outbreak. This highlights the danger of defining the threat level of a pathogen for a species. It is becoming clearer that pathogen behavior can vary widely between species, and within and between populations over space and time. A number of factors influence pathogen invasion outcomes as they operate and interact at the level of the host, pathogen and/or the environment, which can influence host susceptibility and/or pathogen virulence and change the nature of an outbreak in a susceptible host population (Hudson *et al*., 2002). Thus, as in forensic sciences, we are reminded to be cautious with 'pathogen profiling' or reliance on expected behavior of a pathogen, as seen here in the divergent nature of FeLV invasion in Iberian lynx or for example, distemper outbreaks in African wild dogs in Botswana (Alexander *et al*., 1996; Alexander *et al*., 2008)

The Iberian lynx story also exemplifies the cascading interactions of infectious disease within ecological communities and underscores the importance of infectious disease in ecosystem-wide processes. The decline of the Iberian lynx is linked to the disappearance of their primary prey species, the wild rabbit *Oryctolagus cuniculus* (Ferrer & Negro, 2004) due to the emergence of Myxomatosis virus in the 1950s and Rabbit Hemorrhagic Viral Disease in the 1980s (Delibes-Mateos, Ferreras & Villafuerte, 2008). Disease-related loss of prey and consequent reduction in the Iberian lynx population has now made this species, in turn, more vulnerable to infectious disease-mediated extinction risks. Had the population been as large as that before the disease-related decline of their prey, it is less likely that this FeLV outbreak would have posed a threat to survival of this species.

Lastly, the importance and value of long-term population monitoring cannot be over emphasized. Long-term monitoring allows population threats to be identified, intervention action taken and success measured against important baseline data. In most cases in wildlife management, we are operating in the dark; we lack funding to properly monitor both the population under question and our intervention outcomes. We are, more often than not, unsure of the long-term effects of our management actions. In short, while we might have significant theoretical assessments, we are often short on empirical studies that provide concrete insight into the control of infectious disease in endangered species. Studies such as this, conducted on a long-term basis, coupled with experimental and modeling approaches, can support the identification of a mechanistic understanding of disease invasion outcomes. This is ultimately the information required if we are to succeed in managing infectious disease threats to endangered species.

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Viral threats and vaccination: disease management of endangered species

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With infectious diseases causing calamitous declines in a wide range of endangered populations, there can no longer be any doubt that diseases are a matter of serious concern for conservation biologists. The outbreak of feline leukemia virus (FeLV) in Iberian lynx *Lynx pardinus* in Spain, described by López *et al*. (2009), involves a depressingly familiar suite of culprits, but also raises some troubling new concerns about disease impacts in endangered species. The outbreak involved a recurring triad of factors: a small, endangered wild carnivore population (the Iberian lynx), a larger population of related domestic animals (domestic cats) and a virus (FeLV).

Small (endangered) populations are unable to maintain virulent viral pathogens independently, as the pathogen rapidly depletes susceptible hosts and burns itself out. Infectious disease threats for endangered wildlife therefore commonly originate from other species. Domestic animals, which have the potential to maintain a wide range of pathogens in relatively abundant populations, are among the most dangerous of these sources and feature prominently in a recent litany that includes canine distemper virus (CDV) in Serengeti lions (Roelke-Parker *et al*., 1996); rabies in Ethiopian wolves (Sillero-Zubiri, Gotelli & King, 1996; Randall *et al*., 2004); rabies and CDV in African wild dogs (Gascoyne *et al*., 1993; Kat *et al*., 1995; van de Bildt *et al*., 2002); CDV and heartworm in Channel Island foxes (Timm *et al*., 2000; Crooks, Scott & Van Vuren, 2001); infectious keratoconjunctivitis in Ibex and Chamois (Giacometti *et al*., 2002); CDV in Lake Baikal seals (Mamaev *et al*., 1996).

The close phylogenetic relationship with domestic carnivores and a high susceptibility to domestic carnivore pathogens has been suggested as one reason why, within mammals, carnivores feature most prominently among species threatened by infectious diseases (Pedersen *et al*., 2007). But, within the carnivores, felids appear to have been less troubled by disease than canids. There may be several reasons for this: domestic cats are probably less numerous in and around wildlife-protected areas than dogs (although there is surprisingly little data available on domestic cat populations in most of these areas); direct and indirect contact rates between domestic cats and wild felids may be lower than between domestic dogs and wild canids; and because felids are generally less social than canids, the spread of diseases within wild felid populations may be less rapid and population-level impacts less severe than in wild canids.

The FeLV outbreak in Iberian lynx in Doñana in 2007, which was the result of disease transmission from domestic cats, was therefore particularly troubling. Clearly, contact between domestic cats and Iberian lynx (presumed to have occurred through fighting) was sufficient to introduce the virus into the population. This, in itself, was not of undue concern to wildlife managers, as FeLV infection, although widespread among domestic cats, had only rarely been reported as a cause of disease in wild felids. In contrast, the Doñana outbreak was characterized by high levels of mortality associated with FeLV infection (often due to secondary infections) and rapid spread of the virus within the lynx population once introduced.

Although the reasons for increased pathogenicity of FeLV infection in this outbreak are not known, the appearance of diseases in a new guise should not be unexpected. Many pathogens, and viruses in particular, have a propensity for host-switching and also for infection in the same host population to result in widely differing outcomes. Co-infections, environmental factors and a myriad of host-related factors can all interact to profoundly affect susceptibility to disease. What is clear is that wildlife managers must be prepared for the appearance of new diseases. As contact between domestic animals and wildlife species increases and environmental conditions change, new patterns of wildlife disease and mortality will inevitably emerge. How, whether

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and when to intervene to tackle these disease problems are major issues in conservation management and the work by López and colleagues makes a major contribution to these discussions.

For over 200 years, vaccination has been one of the most effective and cost-effective preventive health measures for improving the health of both human and domestic animal populations. Vaccination also offers a potential solution for reducing disease threats for endangered species. This is particularly true for viral pathogens transmitted from domestic dogs and cats, for which safe and effective vaccines have already been developed. But, since the vaccination of chimpanzees against polio in Gombe National Park in 1966 (Van-Lawick-Goodall, 1971), vaccinating endangered wildlife has often led to controversy, and decisions to intervene influenced by a complex suite of scientific, practical, political and ethical issues.

In the wake of the deaths of four FeLV-positive lynxes in Doñana, the decision was made to intervene in order to prevent further spread of infection, remove the virus from the population and minimize the risk of future outbreaks. The interventions focused on removal of FeLV-viremic lynxes, vaccination of non-infected lynxes, changing management practices to reduce intra-specific contact (e.g. modification of feeding stations) and reducing contact between lynx and domestic cats (e.g. cat removal). These interventions appeared to have successfully contained the outbreak to within one sub-population.

Several widely debated issues are raised by these interventions. First, the decision to intervene at all is often criticized, with the argument that diseases are natural phenomena and that wildlife managers and veterinarians should not meddle in natural processes. Indeed, parasites and pathogens are important components of natural ecosystems and can play an important role in population regulation. But, the rapid expansion of domestic animal populations is entirely anthropogenic and most wildlife emerging disease threats are associated with human activity (Daszak, Cunningham & Hyatt, 2000).

Second, the question of how to design vaccination intervention strategies has been the subject of much discussion. The failure to evaluate sufficiently the impact of vaccination interventions has previously led to highly damaging controversies (e.g. African wild dog vaccination in East Africa, reviewed by Woodroffe, 2001) and highlighted the critical importance of effective population monitoring and evaluation following any intervention (Knobel *et al*., 2008). However, evaluating the impact of an intervention in endangered wildlife can be difficult. In terms of protecting individuals (and assessing the safety of the intervention), comparison of morbidity and mortality of vaccinated and non-vaccinated individuals can be carried out if some animals remain unvaccinated, and the intensity of population monitoring in Doñana should allow this evaluation to be carried out.

However, the availability of a non-intervention control population for evaluating the effectiveness of interventions and population-level outcomes (such as population persistence) is rarely an option. In the study by López *et al*. (2009), disease management measures were evaluated through monitoring of FeLV infection status in both the Doñana population and Sierra Morena population, and the interventions put in place were considered to have contained the outbreak when no positive lynxes had been detected for a period of four months. However, it can be difficult to determine precisely how an intervention has affected the outcome of an outbreak, particularly when several management strategies are implemented concurrently. In these situations, mathematical models have proved enormously valuable. For example, a spatially explicit individual-based model used to assess the impact of a rabies vaccination campaign on an endangered population of Ethiopian wolves in the Bale Mountains National Park indicated that reactive vaccination had limited the scale of the outbreak and should significantly enhance the persistence of the population (Haydon *et al*., 2006). Models can also guide managers as to whether, and when, in the trajectory of an outbreak implementation of reactive disease control strategies are likely to be effective.

The intervention in Doñana involved the capture of an impressively high proportion of the population, with more than 80% ($n = 34$) of the individuals being trapped and their infection status determined before removal (of viremic individuals) or vaccination (of naïve individuals). An important consideration for undertaking an intervention of this kind must clearly be access to sufficient resources and field capacity, as well as the availability of appropriate and rapid diagnostic tests and technical expertise. Although the intervention resulted in a relatively high level of coverage, with 22 lynxes in Doñana vaccinated out of a total population of 33 (after removal of viremic animals), mathematical models have shown that, by protecting a demographically viable 'core' of individuals, even low-vaccination coverage can be effective in reducing the threat of extinction (Haydon *et al*., 2006; Vial *et al*., 2006), and can be considered where resources or logistic constraints limit access to a larger proportion of the population.

In summary, the case study presented by López *et al.* (2009) provides valuable information for conservation managers about the dangers of infectious diseases and also the potential strategies for managing these threats. There is no doubt that wildlife diseases will continue to appear in endangered populations and we need to be well prepared to respond to these threats. Well-designed interventions that can be monitored and evaluated will do much to help build confidence that interventions to control wildlife disease threats are feasible and can be effective.

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