

Approaches to Disease Control in Domestic Canids for the Conservation of Endangered Wild Carnivores¹

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Introduction

Disease is an increasing threat to many of the world's endangered and rare carnivores. Wildlife managers are increasingly being required to deal with both the threat and reality of disease outbreaks in canids, but they are relatively poorly equipped to do so. In addition, the required evidence is often lacking to assess which strategy might be best employed in any given situation.

To date, rabies and canine distemper have been of the greatest concern, causing severe population declines and local extirpations in a range of species such as black-footed ferrets, Channel Island foxes, Ethiopian wolves, African wild dogs, and lions (Funk *et al.* 2001, Cleaveland *et al.* 2002, Woodroffe *et al.* 2004). These and other pathogens that have caused outbreaks are generalists – they have the ability to infect a wide range of species (Cleaveland *et al.* 2002). Indeed, epidemiologic theory predicts that pathogens that cause major host mortality or that reduce fertility are unlikely to be able to persist in small populations (Lyles and Dobson 1993). These generalist pathogens must therefore persist in another reservoir population (Haydon *et al.* 2002), from which they can spill over and cause a single or repeated epidemics in an endangered population of conservation interest. Control of canid diseases in wildlife can therefore be aimed at reducing disease incidence in either the reservoir or the target population of concern (Table 1), or at reducing transmission between these two groups. In this paper, we review and illustrate these general approaches and outline important factors that might influence their success.

Reduce transmission between reservoir and target populations

Manage interactions between host species

Reducing interaction between reservoir hosts and target hosts that are threatened should be effective in reducing the threat

of disease. This could be achieved by eliminating range overlap between the reservoir and target species, i.e., physically separating the species. For example, bighorn sheep (*Ovis canadensis*) have been protected from pneumonia and scabies transmitted from domestic sheep (*Ovis aries*) by barring domestic sheep from buffer zones surrounding bighorn populations (Jessup *et al.* 1991). Physical separation could also be achieved or enhanced by fencing; indeed fences around Kruger National Park may partially explain the absence of evidence of exposure to canine distemper virus and canine parvovirus among wild dogs (van Heerden *et al.* 1995). In theory, separation of hosts could be achieved in national parks, where the reservoir is a domestic species and there are no boundary transgressions. In reality, however, controlling free-ranging domestic dogs as well as wild canids is a substantial challenge and may be nearly impossible in many situations. Even where fences have been used to physically separate host species, such as in Madikwe in South Africa, this did not prevent an outbreak of rabies inside the Park, probably due to the ease with which small carnivores such as jackals can cross some fences (Hofmeyr *et al.* 2000). Furthermore, when wild carnivores occur or range outside national parks, such as when following migrating herds, disease transmission between domestic animals and wild carnivores could lead to the spreading of a disease to endangered carnivores back inside a protected area.

Where ranges of target and reservoir hosts overlap, measures can still be taken to reduce disease transmission. Controlling the ranging of domestic dogs, for example, by keeping them confined at the household by fencing or tying, could be useful and would reduce the chance of wildlife/dog contact. However, cultural obstacles may prevent this, for example, because of the role of dogs as guards or cleaners of the human environment. In other situations, cultural taboos prohibit close contact with dogs, and owners may be reluctant to handle dogs to tie them up. In addition, where dogs are not adequately fed by their owners, they have to range to find food. For several years, the Ethiopian Wolf Conservation

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Table 1. Management options for disease control for wild canids (adapted from Laurenson et al. 2004)

General approach	Options	Advantages	Disadvantages	Assumptions	Likely benefits/chance of success
Do nothing		Cheap, easy, may evade controversy	Population viability not guaranteed		Depends on degree of threat
Reduce disease incidence in reservoir species	<ol style="list-style-type: none"> 1. Vaccination 2. Culling 3. Limit reproduction 4. Treatment 	<p>No intervention with target. Public health and economic advantages to communities (zoonoses)</p> <ol style="list-style-type: none"> 1. Effective vaccines available 3. Can be very effective 4. Therapy availability depends on pathogen 	<p>No guarantee of protection in target</p> <ol style="list-style-type: none"> 1. Expensive, logistics, large area 2. Cost, welfare, cultural attitudes, limited effectiveness 3. Effective methods not yet available over large areas 4. Limited effectiveness 	Know reservoir	<ol style="list-style-type: none"> 1. May be high if wide <i>cordon sanitaire</i>, and properly managed 2. Not sustainable 3. High in theory, but may not be practicable 4. Poor
Reduce disease in target species	<ol style="list-style-type: none"> 1. Vaccination 2. Treatment 	<ol style="list-style-type: none"> 1. Direct protection 	<ol style="list-style-type: none"> 1. Effective vaccines not always available 2. Often not feasible, no therapeutic agent available 		<p>Variable: may be high as short-term emergency plan or in specific situations if feasible and cost-effective</p> <p>1 and 2. Last chance in emergency situation</p>
Reduce transmission between reservoir and target species	<ol style="list-style-type: none"> 1. Fencing/physical barrier 2. Restraining domestic animal reservoir 3. Buffer zone 	No intervention with target	<ol style="list-style-type: none"> 1. Often not feasible 2. Cultural constraints/conflict with dog function in long term 3. Feasibility 	Know reservoir	<p>Medium on continental situation</p> <p>High on islands</p>

Programme carried out an education programme that encouraged dog owners living in Ethiopian wolf habitat to own fewer dogs and to tie them up. The programme also provided owners with collars and chains (Sillero-Zubiri and Laurenson 2001). Although dog owners listened to and discussed these issues with the education officer, few if any dogs were subsequently tied up. In some cases when dog owners did attempt to tie up their dogs, adult dogs that had never previously been tied up simply escaped. In other cases, the collars and chains had been used for tying up livestock, such as calves. Overall, the success of this approach may be limited and it must be recognised that cultural change occurs slowly in terms of the generational time of both people and dogs.

Reduce disease incidence in reservoir population

The second general approach to controlling canid disease in wild carnivores involves reducing or preferably eliminating disease in the reservoir population and thus reducing the chance of the disease being transmitted to the target host.

Clearly, this approach depends on determining the reservoir of infection. In many circumstances, this is the domestic dog, but wild reservoirs have also been implicated in a number of situations. For example red foxes (Europe), yellow mongooses (South Africa), and raccoons and skunks (North America) are examples of wild reservoirs for rabies, whereas a suite of wild carnivores may be involved in sustaining endemic canine distemper infection in Europe and North America.

Disease incidence in a reservoir is reduced by reducing the number of susceptible hosts in the reservoir population, and thus reducing R_0 , the measure of how rapidly a disease can spread in a population. R_0 is the basic reproductive rate of the disease (Anderson and May 1991) and is defined as the number of secondary cases arising from a primary case. If R_0 can be reduced to below 1, then the disease will not persist in the reservoir because each case will result in less than one new infection on average, and the infection will disappear. Even if the disease is not eliminated, any reduction in R_0 will decrease the chance of transmission to the target species.

In general, there are three methods of reducing R_0 : reduce the population density (assuming density-dependent transmission), reduce the number of susceptible hosts through vaccination, and reduce transmission between hosts.

This approach to disease control directly parallels the control of diseases of public health concern such as rabies and visceral leishmaniasis in domestic dogs and abundant wild canids. Therefore, the successes and failures of this approach, for example through the culling and vaccination of reservoir hosts, provide important lessons for the conservation of rare canids threatened by infectious disease.

Limit host density

Dog density might be reduced by controlling fertility, by culling, or by changing human attitudes so that fewer dogs are owned. Fertility control, which reduces the number of susceptible hosts being introduced into the population and thus eventually total population size, shows some theoretical promise (Barlow 1996). In practice, given that surgical sterilisation of female dogs is expensive, as well as being culturally and logistically difficult, and that dog populations are rarely closed, this approach may also be limited in its success. Fertility control would be even more difficult to achieve among wild canids, although initial investigations of immunocontraceptive vaccines that target the release of reproductive hormones have shown encouraging results for red foxes in France and Australia. Oral contraceptives are available for use in wildlife (Tuytens and Macdonald 1998), but their use in areas occupied by threatened populations would be inappropriate (as would the use of poisons for reservoir control). Despite these concerns, immunocontraception, especially if it could be combined with vaccination, may hold some promise for the future management of disease reservoirs.

Culling reservoir domestic dog populations is a superficially attractive means of controlling dog population sizes. Where wildlife is a reservoir, culling wild canids such as foxes to control rabies, while sometimes successful in the short term in a limited area, has otherwise met with failure due to the rapid recovery of fox populations and thus the continued (expensive) culling effort required (Macdonald 1980). In addition, changing moral attitudes towards wildlife culling potentially render this approach obsolete. Humane culling of domestic dogs, although occasionally a potentially useful short-term adjunct in urban areas where stray dogs may subsist on human rubbish, also does not address the root issue: dog populations are actually usually limited by humans (Perry 1993). Where dogs have a role in human society as guards or cleaners, people will keep dogs to fulfil this role until a better option is available. Thus, cultural attitudes towards dog ownership and the optimal number of dogs must change before dog populations can be reduced. This is clearly a considerable challenge, particularly where human populations are expanding. Moreover, dog populations in rural areas of developing countries are generally growing faster than the human population. The reasons for this are not well understood, but reduced household sizes or an increased perception

of security problems may be involved. Finally, where human densities are high, even comparatively low dog:human ratios may generate dog populations large enough to represent a disease risk to local wildlife. Overall, these factors mean that this approach entails considerable challenges, and indeed we know of no successful programme.

Reduce the number of susceptible reservoir hosts through vaccination

Vaccination of reservoir hosts, which essentially reduces the susceptible population size for the pathogen, is a common approach to disease control in both human and domestic animal populations. For example, experience from the rabies control programmes suggests that vaccination of both reservoir domestic dogs and wild canids may be powerful tools for wildlife managers. In North America and Europe, rabies control programmes for public health have successfully controlled or eradicated rabies in extremely large areas. (Aubert *et al.* 1994, Mackowiak *et al.* 1999). This approach is increasingly being incorporated into disease control for wild canids in a number of countries, particularly where safe and effective vaccines are available, as is the case for many viral diseases of dogs.

In rural Tanzania, results demonstrate that a simple central-point vaccination strategy, resulting in vaccination of 60%–65% of dogs adjacent to Serengeti National Park, significantly reduced the incidence of rabies in dogs and risk of exposure to people, with opportunities for transmission to wildlife also decreasing (Cleaveland *et al.* 2003). Dog vaccination campaigns have also been conducted around other national parks such as Ruaha, Arusha, and Tarangire. In Ethiopia, no cases of rabies or canine distemper were reported within wolf range within the Bale Mountains National Park between 1998 and August 2003, when a dog vaccination campaign was being conducted both inside the Park and, where resources allowed, in neighbouring communities outside the Park. Cases of rabies in dogs and other species still occurred at the edge of vaccination zones, although the overall incidence in dogs and people was very much reduced (Ethiopian Wolf Conservation Programme, unpublished data). However, in September 2003, rabies broke out in Ethiopian wolves in one area of the park, thought to have been brought in by an immigrant domestic dog (Randall *et al.* 2004). A wide “cordon sanitaire” is clearly required, particularly where transhumance of people and their domestic animals occurs. This has illustrated the disadvantage of this approach: there is no direct protection of the target species, and success cannot be guaranteed if intervention is carried out on too small a scale. Clearly, the area to be covered would be vastly bigger for the same size population of African wild dogs (home range 400–1,200 km² per pack) (Woodroffe and Ginsberg 1998) than of Ethiopian wolves (home range 6–11 km² per pack) (Sillero-Zubiri and Macdonald 1997), although this will also vary with the shape of the habitat patches (Laurenson *et al.* 2001). As both these species remain surrounded by landscapes that have been altered by people and

that are inhabited by domestic dogs, regional eradication is nearly impossible without a widescale coordinated rabies control programme. In addition, such vaccination programmes would have to be maintained in perpetuity to control the disease threat. As was the case in Ethiopia, inadequate resources to cover such areas may result in failure of this approach. Furthermore, where payment for vaccination is expected, or where dogs are used for illegal hunting and are not presented for vaccination, the success of this approach may also be curtailed.

Concern has been expressed that vaccination of disease reservoirs – especially domestic dogs – could remove an agent of population limitation and thus lead to increased host density (Moutou 1997). This could be potentially damaging, especially if vaccine cover were to be halted. However, preliminary studies indicate that while dog vaccination in northern Tanzania has led to a significant decline in disease-related mortality rates, population growth rates have not increased. This has been attributed to a reduced demand for puppies, and thus a lowering of recruitment rates, and a dog population that is generally more stable (Cleaveland, unpublished data). However, this effect may only be temporary and research is still required to assess longer-term demographic impacts, as well as to assess the demographic impact of mass vaccination in other types of settings.

Coordinated rabies control programmes involving both public health and livestock authorities could reduce the cost borne by the conservation community, and both financial (primarily from a reduction in livestock losses) and public health benefits would accrue to local populations. Vaccination of domestic dogs by wildlife managers also provides additional nonfinancial benefits that may improve relationships between protected areas and local communities. This is an example of an outreach activity in which both parties may cooperate in a mutually beneficial activity (Sillero-Zubiri and Laurenson 2001). As such, it can be a powerful tool that is underutilised by protected area managers who are looking for opportunities to improve communication with local communities.

Decrease susceptibility or spread in target population

The third general approach to improving the control of canid diseases in wild carnivores is to reduce the susceptibility or rate of spread of disease in the target population. This approach may work even when the reservoir species is unknown or when a relatively intractable wild reservoir population is involved. This approach, whilst reducing the mortality of individuals, may also limit transmission within the host population.

Target hosts can sometimes be directly treated, for example, against mange in arctic foxes (Goltsman *et al.* 1996). However, vaccination of threatened hosts is a more common conservation tool (Hall and Harwood 1990, Woodroffe 2001). To date, demonstration of the effectiveness of this approach has been limited (but see Hofmeyr *et al.* 2000, in

which vaccinated wild dogs survived a rabies outbreak that killed other members of the pack), not least because most cases have been crisis interventions dealing with acute disease risks where unvaccinated controls have not been left. However, if vaccines are safe, effective, and require relatively little disturbance to the subject animals to administer, they can potentially improve the viability of canid populations severely threatened by infectious disease.

The approach has been used in African wild dogs, Channel Island foxes, and Ethiopian wolves. For African wild dogs in which rabies and, to a lesser extent, canine distemper represent acute threats to the persistence of small populations, direct vaccination has met with mixed success. The issues and controversy surrounding these attempts in wild dogs have been extensively reviewed (Woodroffe *et al.* 1997, Woodroffe 2001). In summary, the efficacy of killed rabies vaccines in wild dogs, particularly after a single dose, is questionable and is the subject of further research. However, the feasibility and efficacy of using oral vaccines warrants further investigation. Preliminary trials suggest that an effective baiting system can be designed (Knobel *et al.* 2002).

In southern Africa, vaccination of jackals and captive-bred African wild dogs using live oral rabies vaccines (SAG strains) demonstrated the safety and potential efficacy of oral vaccination, with high rates of seroconversion in both species (Knobel *et al.* 2003, Bingham *et al.* 1999). However, no field trials have yet been conducted. Nevertheless, recombinant rabies vaccines, which incorporate only part of the rabies virus genome and cannot induce rabies in target or nontarget species, are a safer alternative from a vaccination perspective (Kieny *et al.* 1984, Blancou *et al.* 1986), but have yet to be tested in these African species. Potential environmental impacts in terms of local nontarget species must of course be evaluated as approaches involving various types of recombinant vaccines continue to be developed and explored.

Direct vaccination has also been used to protect Channel Island foxes from canine distemper. A new recombinant distemper vaccine, using a canarypox virus vector, was first tested on six captive foxes and shown to elicit seroconversion with no observed ill effects (Timm *et al.* 2000). Vaccination protocols were then conducted on the western part of Santa Catalina island. The epidemic had, however, by then faded (S. Timm, personal communication). Unfortunately, in the absence of challenge experiments, it is impossible to be certain that vaccination confers protection from canine distemper. However, the existence of a distemper vaccination protocol known to be safe and likely effective in free-ranging island foxes is a valuable tool for conservation of this critically endangered species (Woodroffe *et al.* 2004).

Most recently, in late 2003, an emergency trial parenteral vaccination campaign was carried out to control an outbreak of rabies in Ethiopian wolves in the Bale Mountains (Randall *et al.* 2004). As permission had not been granted to test the efficacy of oral vaccines, wolves were trapped and vaccinated by injection with an inactivated rabies vaccine. Preliminary results suggest good seroconversion rates, but the trial is still ongoing. Only extensive monitoring work will enable the success or failure of this approach to be assessed, although

again it is impossible to be certain that wolves are protected in the absence of challenge experiments.

Overall, although this approach has some clear advantages (Table 1), vaccine availability is a severe constraint, because few vaccines have been tested for safety and efficacy in wildlife. In addition, in the absence of challenge experiments in captivity, only situations in which target hosts are challenged will ultimately enable the efficacy of vaccines to be assessed. Nevertheless, in a crisis situation, as for the Channel Island foxes and Ethiopian wolves, this may be the conservation manager's only intervention option in the face of an outbreak. Developing such potential tools in advance of a crisis situation is clearly desirable.

Which approach is best?

This paper has attempted to outline the general approaches available to wildlife managers for carnivore disease control, illustrating these approaches with some specific examples and

pointing out the general advantages and disadvantages of each approach. It is clear that conservationists are ill equipped to manage the threat of infectious disease to wild canids. Lack of information hinders management of this newly recognised threat. There are no established models to follow, and some early and unsurprising failures have attracted damaging controversy (Woodroffe 2001). This makes it difficult to assess which approach is most likely to meet with success. However, it is also important to recognise that the decision not to intervene must in itself be a conscious choice that reflects a consideration of all options. Where intervention is warranted, vaccination either directly of endangered wildlife hosts or of the domestic animal reservoir hosts are our most feasible disease management options. This approach may be effective if safe, effective, and practical vaccination protocols are available, depending on the local epidemiological circumstances. Vaccination of wildlife reservoirs is, however, more problematic. In all situations, the specific conditions in the area will determine what actions can be taken by local wildlife managers.

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