Chapter 1
The Science of Wildlife Disease Management

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1.1 What is Disease?

In its widest sense disease can be regarded as any impairment of normal functions. However, for the purposes of this book we will mostly restrict our discussion to infectious diseases, the agents of which are often described as parasites or pathogens. For convenience, these organisms are often split into two categories that reflect their broad characteristics, and their relative size. The macroparasites are multi-cellular organisms that live in or on the host, such as helminths and arthropods, while microparasites include viruses, bacteria, fungi and protozoa. The main functional differences between the two relate to their generation times, with microparasites exhibiting relatively higher within-host reproductive rates and shorter generation times than macroparasites. As a result microparasites are frequently associated with acute disease, although they can induce long-lived immunity to re-infection in recovered hosts. Macroparasites by contrast are more likely to produce chronic infections often characterised by short-lived immunity in heavily infected hosts, and re-infection. Macroparasites may also have distinct life stages that can survive outside the host (e.g. eggs or larvae) and sometimes require other host species to complete their life cycle. Two important groups of pathogens fall outside this classification: rogue proteins (prions) implicated in transmissible spongiform encephalopathies (TSEs) and infectious cancers, of which Tasmanian devil facial tumour disease is a well known example. However, in broad respects these are most usefully considered as microparasites, often producing acute clinical signs without host immunity.

Disease can affect individual hosts by reducing growth rates or fecundity, increasing metabolic requirements, changing patterns of behaviour and ultimately may cause death. Sub-lethal effects of pathogens may also enhance mortality rates by for example, increasing the susceptibility of the infected host to predation. However,

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the intimate relationships between hosts and parasites have in many instances evolved over time into subtle and potentially complex interactions, such that infection does not in itself necessarily lead to disease. Many parasites have little detrimental effect on their hosts for most of the time, only causing pathological damage if this delicate balance is upset, for example when the parasites become too numerous or when the immunological capability of the host is impaired. This balance could be influenced by many factors including nutrition, concomitant infections and a variety of physiological stressors.

Parasites are natural components of ecosystems. They influence the structure of ecological communities (Wood et al. 2007) and are important agents of evolutionary change (Clayton and Moore 1997; Little 2002). Hosts and their parasites are locked in an evolutionary arms race, an endless game of ‘hide and seek’, which finds its ultimate expression in the complex immune systems of mammals. So fundamental is the role of parasitism in the development of biological systems that the imperative to avoid disease may have been an important driver for the evolution of sexual reproduction, which provides a means for recombination of genetic material and the inheritance of protective genes.

Disease is a ubiquitous characteristic of ecosystems. In humans (the most comprehensively studied mammal) over 1,400 diseases have been identified, in our livestock we know of over 600 and in domestic carnivores nearly 400 have been recorded (Cleaveland et al. 2001). Over 60% of human diseases are zoonotic, and for those considered to be of emerging importance, the figure rises to 75% (Taylor et al. 2001). By inference alone there are likely to be many thousands of diseases affecting the 5,400 or so mammal species in the world. Nevertheless, despite the clear implication that they are likely to play an important role in the epidemiology of some diseases of importance to human health and livestock, information on the pathogens of wild mammals is relatively poor.

1.2 The Significance of Wildlife Diseases

There is no doubt that recent years have seen a growing recognition of the potential importance of wild mammals in the epidemiology of diseases that impact on global human health, agriculture and biodiversity. In terms of public health, this has been manifest in high profile reports of hanta virus, Lyme disease and SARS-associated coronavirus in humans, and their links to wild mammals. In some countries, wild mammals are implicated in the persistence of bovine tuberculosis and brucellosis infection in cattle, which have impacted severely on the welfare and productivity of domestic animals and imposed high costs on stakeholders. Some such diseases are the subject of eradication programmes as their potential impact on human activities is so acute. But wildlife populations themselves may also be threatened by disease, particularly if they are already fragmented, and vulnerable to extinction from stochastic events. This is illustrated by examples such as the impact of rabies on populations of the endangered African wild dog (*Lycaon pictus*) and Ethiopian wolf (*Canis simensis*), and of facial tumour disease in Tasmanian devils (*Sarcophilus harrisii).*

In this book we focus on the management of disease in wild mammals, although many of the issues and approaches discussed here will apply to other wildlife. Wild mammals are of particular interest because they share so many common pathogens with domestic livestock and humans, and consequently play a prominent role in the dynamics of diseases of public health and agricultural concern. Most known zoonotic diseases infect carnivores, livestock and commensal rodents, probably as a result of the historical and evolutionary associations with humans. Mammals are also of particular value as sensitive barometers of ecosystem health, sitting as they do at, or near the top of, trophic food chains. For this reason they have often served as key species for conservation initiatives, under the, often unstated, assumption that their protection will safeguard the habitats that they and many other species inhabit.

The growing importance of diseases in wild mammals to a range of human activities has occurred against the background of a rapidly changing world, in which the interface between human and wildlife populations has been profoundly modified by urbanisation, agricultural intensification, climate change and habitat degradation. Some wild mammals have proven extremely adaptable in the face of anthropogenic changes to the environment. The most adaptive species tend to be those with generalist diets and opportunistic habits. Some have increased in abundance and distribution, as they have become habituated to agricultural and urban environments. Examples include red foxes (*Vulpes vulpes*) and Eurasian badgers (*Meles meles*) in the UK, both of which have successfully adapted to life in highly urbanised environments. Furthermore, the high densities of badgers observed in some rural areas of the UK are in no small part due to the abundance of food afforded them by the modern pastoral farming landscape. In several instances the direct management of wild mammals for hunting or game farming has resulted in localised concentrations of unsustainably high density. Wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*) in parts of Central and Western Europe, and white-tailed deer (*Odocoileus virginianus*) in some regions of the North-Eastern USA are notable examples. But the wild mammals with which we have the longest standing and most intimate relationships are undoubtedly the commensal rodents with whom we share our homes and farmland across the globe. Within modified environments, these adaptive species may frequently live in close proximity to humans and our domesticated animals, thus enhancing opportunities for inter-specific transmission of pathogens. For most wild mammals however, human activities have had a devastating impact, largely through the destruction and degradation of their habitat, but also through direct exploitation and pollution. The result is that many species of wild mammal survive in diminished and fragmented populations that are vulnerable to the effects of disease (Chapter 11). Out of 5,416 species of wild mammal, 1,094 were regarded as 'threatened' (i.e. vulnerable, endangered or critically endangered) with extinction by the International Union for Conservation of Nature (IUCN 2007).

In recent decades there has been an unprecedented increase in the global transport of people, animals and animal-derived products. International air travel now provides the opportunities for a disease that would once have taken many months or years to traverse a single continent, to be carried to the far corners of the globe within a matter of hours. Live wild animals are translocated in the interests of the pet trade, game management and conservation, and their products are distributed in the form of, often illegal, bushmeat, 'medicines', trophies and other merchandise. The associated risks of introducing new diseases to previously isolated and naïve populations can have potentially catastrophic consequences. Nearly 38 million live wild vertebrates were legally imported into the USA between 2000 and 2004 (Marano et al. 2007), including 23,000 mammals and at least 263 non-native species. One widely reported consequence of these imports was the 2003 outbreak of the zoonotic monkeypox virus which was initiated by infection in exotic African rodents imported for the pet trade (Guarner et al. 2004). Such events emphasise the need to develop contingency plans to ensure some level of preparedness to deal with disease introductions that could establish in endemic wildlife populations (Chapter 9).

The perpetual movement of people, animals and products around the world is not the only anthropogenic process that creates opportunities for enhanced disease transmission. Environmental degradation in a wide variety of guises may also be a driving factor in the emergence of wildlife diseases. Airborne pollution, habitat fragmentation and the eutrophication of aquatic ecosystems have for example all been linked to disease outbreaks in wildlife (Dobson and Foufopoulos 2001). But, the most pervasive and potentially damaging environmental impact to arise from human activity is undoubtedly global climate change. The consequences for global ecosystems will clearly have significant implications for the ecology of wild mammals and their pathogens (Epstein 2001), as well as presenting major challenges to human activities. Changes in global weather patterns are likely to be accompanied by an increasing tendency for the emergence (and re-emergence) of pathogens and their vectors in new geographic areas and in novel hosts. The development of methods to predict such events and of co-ordinated systems to provide appropriate responses, are major challenges for the international community.

1.3 Managing Disease in Wild Mammals

It is important to consider the question of when disease in a wildlife population requires management intervention. After all, diseases are natural components of ecosystems, although it is often a moot point as to whether a particular pathogen would have existed in a wild population in the absence of its purported introduction by humans or livestock. Human modification of the environment has been so substantial and widespread that the question often arises as to what constitutes a natural ecosystem and, perhaps more importantly, what we can consider to be a natural disease event. The question of when and when not to manage, essentially rests on the extent to which the disease endangers human health, wealth, welfare or conservation aspirations, and the likelihood that intervention will have a beneficial effect. Opinions on the point at which a line is crossed and management becomes necessary, may vary widely between stakeholders of differing perspectives, and the search for ‘common ground’ is a continuing challenge for policy makers and politicians. However, even when a problem is identified as sufficient to warrant management, this may not necessarily mean that intervention is best directed at the wildlife population or the pathogen. In many cases changes to other components of the system (e.g. human behaviour) may be more effective. This may be particularly true when such approaches are targeted at the more tractable elements of the system (e.g. livestock husbandry), which can be managed using the existing socio-economic and legislative framework.

Once the decision to intervene has been reached then the objective of management will need to be determined. This may be prevention or control of disease, or even local or global eradication of the pathogen. The appropriate approach will depend on the characteristics of the problem and in particular on the correct identification of reservoirs of infection (see below). Inevitably, prevention and control are generally more easily achieved than eradication, not least because the latter requires the accurate identification of all reservoirs of infection. The appropriate target of disease management may be the pathogen itself (Chapter 6), one or more host populations (Chapter 7), or some element of the environment that influences transmission (Chapter 8). In this book we will discuss each in turn, although in practice a combination of approaches may be most successful.

Despite the clear requirement to develop effective means of dealing with wildlife disease issues, advances in practical management have lagged far behind the development of disease ecology theory. In particular, managers have been slow to respond to the need to understand and accommodate the ecological complexities of wild mammal populations in intervention plans. And yet, understanding wildlife disease problems is invariably as much an ecological as it is a veterinary challenge. This is elegantly illustrated by an example from the UK where in 1997 the Government convened an Independent Scientific Group (ISG) of experts in veterinary science, ecology, epidemiology, statistics and economics, to investigate the effects of badger culling on bovine tuberculosis in cattle. The results of the large scale field experiment and related research they initiated, showed that attempts to reduce disease in cattle by culling badgers caused changes in the behaviour of the wild host that under certain circumstances were counter-productive for disease control (Independent Scientific Group 2007). Their findings illustrate the fundamental importance of understanding host ecology and social behaviour (Chapter 2) for the development of disease control strategies, and the clear need to identify, characterise and quantify the key ecological processes that drive disease transmission and persistence (Chapter 3) in wildlife populations. Hence we need to look critically at existing assumptions of disease control and management, particularly where they are underpinned by experience in dealing with disease in domestic animals. The development of successful approaches to the management of disease in wild populations will require careful consideration of the entire host community, of the economic dimensions, and of the practical challenges of successfully implementing any intervention. Where management of disease involving wildlife was once the almost exclusive domain of veterinarians, it is now increasingly recognised that it requires a multi-disciplinary approach involving ecologists, epidemiologists, experts in public health, mathematical modellers, geographic information specialists, statisticians and economists. Such an approach is essential if we are to further our understanding of the dynamics of disease in wildlife and to develop sustainable strategies for their management.

The key to developing effective tools for the management of disease involving wildlife is a sufficient understanding of the conditions required for the persistence of pathogens. Many important diseases infect multiple hosts, some of which will constitute persistent sources of infection for other species, whilst others will not. Unfortunately, many past attempts to manage disease in wildlife populations have failed to recognise this distinction and have instead been rooted in a poor or even misguided understanding of the host community and the likely impact of intervention on disease dynamics. Central to our understanding of any disease system is the concept of the reservoir host. An over-abundance of definitions of disease reservoirs can be found in the literature, each emphasising different aspects, and together leading to no small amount of confusion. A clearer conceptual framework may be achieved by taking an ecological community-based approach which defines a reservoir as "*one or more epidemiologically connected populations or environments in which the pathogen can be permanently maintained, and from which infection is transmitted to the defined target population*" (Haydon et al. 2002b). Past attempts to manage disease involving wildlife have all too often been aimed at 'suspected' reservoirs with little hard evidence that they represented the most important source of infection. That said, it can be difficult to unequivocally identify a reservoir host population. Although correlative and risk-based associations can provide strong circumstantial evidence, only interventions that can isolate target populations can produce experimental evidence, and these are rarely possible.

Effective management of wildlife diseases needs to be based on sound science and developed on the basis of the objective review of previous evidence. This evidence-based approach has led to a radical change in the way human medicine is influenced by previous experience. Systematic review of the effectiveness of previous practices is now widely accepted as standard practice in public health and has been advocated for conservation management (Sutherland et al. 2004). There is a clear need to develop and maintain systems to support evidence-based practice in wildlife disease management. This implies a fundamental change from what has been common practice in the past, such that in the future the outcomes of disease management interventions should be systematically monitored, collated and made available to others. Inevitably however, even with unfettered access to evidence from past experiences of dealing with disease in wildlife, many unanswered questions regarding the potential impact of management interventions will remain. Some important areas of data shortfall may be addressed through systematic scientific investigations and experimentation, although in some cases this may be practically difficult, prohibitively expensive, or there may be insufficient time given the magnitude of the problem. As a consequence, the reality is that we will often be required to make decisions in the face of substantial uncertainty. In such circumstances mathematical modelling can provide a powerful tool, both for increasing our understanding and for generating predictions of the likely outcome of interventions (Chapter 4). Mathematical simulations provide the opportunity to play out various scenarios under different conditions and to incorporate the known uncertainties of the system under investigation. If the modelled outcome of management decisions is robust to different underlying assumptions, then we can be more confident of its utility. If management decisions rely heavily on assumptions, then we have to make a decision based on the relative risk, and cost of each potential outcome. With sufficient understanding of the underlying assumptions, the limitations and levels of uncertainty associated with outputs, then the results of mathematical models of disease dynamics and management interventions can make valuable contributions to the decision-making process.

Modelling can therefore be used to help define interventions that are likely to give a positive benefit, in terms of reducing disease prevalence. However, the most effective techniques to reduce the burden of disease will likely require the most effort, and so be more costly. As resources are always limited, a balance needs to be struck between desired outcomes and their financial costs. This is where the application of economic analyses can help (Chapter 5). The costs and benefits of each potential strategy can be compared in terms of cost-effectiveness or the cost–benefit ratio, and so help to identify an 'optimum' strategy.

In the world of commerce it is widely recognised that you cannot manage what you do not measure. This is equally relevant to disease management. Unless we are able to identify changes in disease occurrence in wildlife populations through monitoring and surveillance (Chapter 10), we will not be able to identify situations that require action, and if we cannot monitor the impact of interventions, then we will not know whether they are working. This seems obvious enough, but in practice surveillance for diseases of wildlife is poorly developed in most countries. Also, past endeavours to control disease in wildlife have often been characterised by a failure to adequately monitor progress, describe the baseline pre-intervention situation against which to measure progress, or indeed to clearly state the objectives of the intervention. An appropriate programme of monitoring should therefore always accompany any wildlife disease management intervention, and should be designed so as to assess its effectiveness in achieving the stated objectives. Further development of methods for the surveillance and monitoring of pathogens and hosts is intrinsic to the future successful management of diseases in wildlife.

1.4 Conclusions

Management of disease in wild mammals should be sustainable, based on sound epidemiological and ecological knowledge, and must balance the requirements for preserving biodiversity, and protecting human health and economic well-being. Striking the appropriate balance between these interests will be a major challenge for the development of future national and international policies. The magnitude of this task grows as the unrelenting processes of globalisation gradually move us in the direction of a free mixing population in which the opportunities for disease transmission and persistence are profoundly enhanced. At the same time, environmental degradation and habitat loss continue to reduce global biodiversity, and themselves contribute to the emergence of pathogens in wildlife. In the face of this growing threat to the health of humans, domestic animals and wildlife, there is an increasing awareness amongst many researchers, managers and stakeholders of the need to change the way we deal with these problems. All too often the management of wildlife diseases has in the past been characterised by reactive, unsustainable and ill-informed interventions that have ignored the fundamental importance of the ecology of hosts, pathogens and vectors, and have been out of step with the global imperative to conserve biodiversity. The conservation of species and preservation of healthy ecosystems are inextricably linked to sustained human well-being. Consequently the retention of biodiversity and the potential for adverse ecological impacts must become material considerations when choosing how we manage disease in wildlife. We need to start treating wildlife diseases as wildlife management issues, and to develop a greater capacity to predict and prepare for potential problems. To these ends we must ensure that we employ the appropriate contemporary tools such as mathematical modelling, risk assessment, economic analysis and GIS. And perhaps most importantly, we need to recognise the role that human activities play in perpetuating disease in wildlife, and the potential for changes in human attitudes and behaviour to reduce opportunities for disease emergence. The world has changed immeasurably in recent decades and so our approaches to managing disease in wildlife must change too.

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