Chapter 1

What is this Infamous "Wildlife/Livestock Disease Interface?" A Review of Current Knowledge for the African Continent[1]

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Introduction

The wildlife/livestock interface means different things to different people. Impressions vary from images of wild bird contact with intensive pig operations along the avian migration routes of North America to dusty scenes of thirsty and hungry cattle trudging through protected areas of Africa in search of drought-depleted resources. The many facets to the interface, such as health, conservation, environment, culture, and economics, have been issues since livestock became an integral part of the landscape. There are positive and negative aspects to the interface and it has been a source of conflict in many areas, often as a result of misunderstanding and polarisation of opinion between ecocentric and anthropocentric forces in society. To review all aspects of the interface is beyond the scope of this article, and other texts provide useful data (Boyd *et al.* 1999) for those wishing a more comprehensive view. Attention here is given to those elements relevant to the health of the large-mammal communities and is focused on Africa, where currently there is an urgent need to find solutions to the problems of abject poverty, poor health status for people and animals, and threats to the environment and biodiversity.

The African rural context

Africa is a continent with great natural richness, particularly in terms of human culture and natural resources. This is especially so in dry-land pastoral systems, where livestock and people share resources with the most diverse array of wild ungulates on earth (R. Kock *et al.* 2002). With improvements in human health care, the population is growing exponentially but the economies of most countries are not growing correspondingly. Poverty is widespread, with significant portions of the continent's people living on less than US$1 per day (FAO/UNEP/CGIAR 2004). Communities are often food insecure, especially where land degradation is prevalent and social systems have broken down, which often happens during times of war or other unrest. Consequently, there is considerable international pressure to accelerate development and alleviate poverty (Thrupp and Megateli 1999). With rapid economic development, environmental change and loss of biodiversity can be expected; indeed, this has been the experience in many countries. One form of poverty is thus replaced by another.

Eighty percent of the population is rural, and the majority of these people are dependent on livestock; 70 million people are wholly dependent with no alternative source of food or wealth (AU/IBAR 2002). Yet, Africa accounts for only 2% of the total value of world trade in livestock and livestock products and imports twice as much as it exports with the net imports increasing at 4% per year (Thambi 2003). Taking this into account, one way to alleviate poverty in Africa is through improved livestock (and agricultural) economics, as well as through the development of alternative rural livelihoods based on natural resources. Urbanisation and industrialisation are not an answer as the energy, human resources, skills, and infrastructure needed to compete globally are lacking. Since the first warnings of a need for a shift in wealth distribution from the North to the South (Brandt 1980), there has been no sign that this will occur. Developed nations continue to unsustainably utilise dwindling resources, which they control and need in order to maintain their own positive economic growth (Pyle 2003). Under these conditions, Africa has little choice but to concentrate on utilising its natural resources and exploiting the agricultural potential of the land.

Health constraints and the market

The single most important constraint on the African livestock export trade is the "Sanitary and Phytosanitary Measures" of the World Trade Organisation (WTO) (OIE 2003); i.e., the status of endemic disease(s) in many African countries is a barrier to trade and this is a key concern of policymakers. This is despite the fact that the impact of these trade-sensitive diseases is minimal within Africa, especially amongst pastoral livestock and poor farmers (Perry *et al.* 2002). As the maintenance of these extensive livestock systems, and to some extent the close association between wildlife and livestock, is the main reason for the current disease status, pressure is building amongst certain political elements in Africa for change and this is threatening the existence of traditional pastoral society and also wildlife resources (R. Kock *et al.* 2002). These WTO rules are set up by the developed nations, essentially in their own self-interest, and African nations have not been able to influence

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[1] See abstract on p.xix.

changes in these regulations to their own advantage (Thambi 2003). This barrier to Africa's entry into lucrative markets is ironic, given the rhetoric from the developed world on achieving poverty reduction in Africa.

However, the situation is not simple because, even if changes were possible, under current conditions the resulting trade is likely to directly benefit only a small sector of people – those running commercial enterprises – so its relevance to many of the poor people on the continent is questionable. In Kenya, for example, only 3% of the meat trade is supplied by the commercial livestock ranching sector, a likely beneficiary of the export trade, whilst 67% of the available meat is from pastoral communities, which could not easily benefit (EU 2003). There are examples of African livestock export success stories, such as in Botswana, where cooperative systems and well-developed livestock movement procedures and other disease control measures ensure a profitable trade and benefits to livestock keepers, although the role of government support (subsidies) and the sustainability thereof cannot be ignored. In most African countries, measures taken at the international level will need to be matched at the local level with initiatives that more obviously connect pastoralists with the global economy before the export trade can benefit the majority of livestock owners. Nevertheless, as long as this disease "pariah" status exists, it will be an incentive for countries to seek ways to comply rather than seek changes to the rules, which will continue to isolate remote and politically disenfranchised pastoral communities, which suffer endemic diseases that cannot easily be controlled.

Misconceptions at the wildlife/ livestock interface

There is a perception amongst African intellectuals and others that there is a link between the desire of the international community to conserve Africa's wildlife as a world heritage and a reluctance to support livestock development and people (Bourn and Blench 1999). This comes from the idea, still commonly held outside of Africa, that livestock is a major factor in land degradation and loss of wildlife. This view has been shown to be overly simplistic; positive environmental benefits can be attributed to livestock systems as much as "overstocking" can lead to soil impaction and loss of vegetation (Mace 1991). There is also a tendency for livestock-induced degradation to be associated with subhumid and humid zones, especially at the periphery of agricultural areas. Even here, livestock are only part of the picture in terms of the trend towards a general fragmentation of habitats and disruption of the natural ecology, including the disappearance of large mammal wildlife across much of its historic range. The arid and semi-arid lands do not fall so neatly into this category.

Contemporary studies have shown that pastoralists' strategies are optimal for sustaining the communities and the resources and that they are a force, as well, in conserving the environment to the benefit of wild species (Roth 1996, Scoones 1994). The most compelling evidence for this is the fact that the last significant, unrestricted, wild ungulate populations surviving in Africa (East 1999) are associated with pastoral systems. Improvements in livestock production systems, health, and marketing in pastoral society, along with sustainable exploitation of wildlife resources, are likely to lead to a *reduction in domestic animal herd sizes,* which are currently high primarily to insure against drought and disease. This improvement will lead to healthier ecosystems.

Parallel to the improved understanding of the role of livestock in dry lands, there is an increasing awareness of a new potential value of the wildlife resource through community-based ecotourism and other forms of utilisation, with wildlife industries becoming increasingly important in the economics of African countries (Chardonnet *et al*. 2002, Jansen *et al*. 1992, Cumming and Bond 1991). To further support this, studies of mixed systems indicate considerable environmental benefit as well as economic ones (Western 1994). It can be argued that one of Africa's main advantages (perhaps the only one in economic terms) over the rest of the world is its extensive and diverse wildlife resource, which is so attractive to tourism. This is not to say that livestock are not important on the continent but, to put it into context, Chile and Argentina taken together currently have a larger livestock industry than all the countries of Africa put together (FAO 2003). So to sacrifice wildlife in favour of developing a competitive commercial livestock sector has little justification, but to develop both wildlife and commercial livestock concerns mutually (not defaulting to one or the other exclusively) is a key to utilisation of available resources.

Given the increasing economic benefits from wildlife, health issues are an increasing concern in this field especially where epidemics and chronic disease problems occur as a result of introduced disease. A review of the coexistence of livestock and wildlife (Bourn and Blench 1999) concluded that wildlife disease was not a constraint, but lack of information on diseases in the field make this a risky assumption. Disease can adversely affect animal population dynamics in the short and long term (Hudson and Dobson 1989, Rodwell *et al*. 2001, Jolles 2003, Lankester 2003, Hwang 2003) and increases the risk of the extinction of rare species (Andanje 2002). The initial impacts of exotic disease can be devastating and depress population growth for decades (Mack 1970, Plowright 1982, Kock *et al*. 1999); conversely, control or eradication of these pathogens can lead to dramatic recovery of populations (Sinclair 1970). The more subtle effects of disease are to make the population more susceptible to other impacts, such as predation, and effectively depress the numbers well below the limitations of the food resource available (Joly 2003). The decision on what to accept as a natural or an acceptable disease dynamic within a biological system may well in the end be a value judgement, but in terms of resource use, consumptive or otherwise, depressed populations will limit the options.

With this background, the important reasons for enhancing understanding of the wildlife/livestock interface in terms of disease are clear: to alleviate fears or concerns about the impact of disease at the interface and ensure that appropriate policies and control measures are implemented. This will improve livestock production and support healthy ecosystems.

Veterinary intervention at the interface

Policy and practice in Africa on interface disease issues have often been controversial. Examples are the wildlife eradication policies for the control of tsetse fly and trypanosomiasis (Austen 1907, Sidney 1965), some approaches to buffalo management and control of foot and mouth disease (FMD) (R. Kock *et al.* 2002, M. Kock *et al.* 2002), and contagious bovine pleuropneumonia control using fencing (Owen and Owen 1980, Taylor and Martin 1987, Scott Wilson 2000). With wildlife abundant during the earlier part of the last century, it is perhaps understandable that farming communities and veterinarians attempted broad-brush approaches on the path to establishing a livestock economy. The natural resources seemed endless and wild animals were considered to some degree to be pests. The concerns over wildlife as a source of infection were sometimes justified as efforts to establish commercial livestock industries were frequently failing or constrained as a result of disease outbreaks, some of which could be attributed to contact with wildlife. FMD was a good example of this. In fact, strict land-use policies, animal movement controls, and fencing largely resolved the problem of FMD in southern Africa (Thomson 1995). The impact of wildlife disease has also been a concern to traditional livestock keepers, e.g., the Maasai communities of the greater Serengeti ecosystem, where malignant catarrhal fever (MCF) causes significant cattle mortality and reduces the ability of livestock to exploit pasture resources (CSU 1999, Rwambo *et al.* 1999).

The understanding of wildlife/livestock diseases globally is improving and better tools for researching health issues now exist, mainly due to the progression in the science of molecular biology. This, coupled with improved techniques of monitoring the environment with remote sensing and the application of easily comprehended reporting systems using GIS, make it theoretically possible for decisionmakers to promote better policies for sustainable resource use and animal health management. Unfortunately, even though the technology makes it easier to interpret information, it has the disadvantage that unless data are scientifically sound and balanced a false picture can be made entirely believable.

One problem in Africa is a lack of basic field data on the interactions at the wildlife/livestock/environment interface in relation to disease. There are some data from southern Africa, but here the interface is much more limited than elsewhere due to fencing and landscaping. Historical data on wildlife disease in eastern Africa have been mainly from laboratory-based activities with few epidemiological studies. The outputs of wildlife disease research in the region have been reviewed (Grootenhuis 1999). Attempts were made more recently to gather information in pastoral systems such as the Greater Serengeti ecosystem (CSU 1999, Rwambo *et al.* 1999) to fill this gap but sufficient hard data are still lacking, with relatively superficial results based mainly on questionnaire surveys from relatively few areas. The emphasis was on livestock diseases, of which East Coast fever (ECF), MCF, anthrax, and anaplasmosis were reported as priorities. Buffalo were not associated by the Maasai with ECF outbreaks, and the recent die-off in the Ngorongoro crater of buffalo (25%), lion (50%), and rhinoceros (40%) associated with increases in ticks, biting flies, and blood parasites (R. Kock, personal observation 2001) was not predicted by this assessment. It may well be that there are numerous disease associations in this region at the interface but that they have been overlooked.

A fundamental issue in this field in Africa is a lack of effective institutions to do field research and act on any information. Even with the current knowledge of what matters and on what interventions are needed to maintain healthy ecosystems, few countries are currently able to do anything meaningful to stop the decline in animal populations and parallel degradation of land and other natural resources.

One certainty is the increasing need for veterinary input in the fields of wildlife disease and human public health, in recognition of the growing intensity of the human/wildlife/livestock interface and the emergence of diseases that either originate in wildlife or have wildlife reservoirs. An example is the recent global phenomenon of severe acute respiratory syndrome (SARS), a well-documented threat to public health believed to have originated in captive wildlife. This human-infective coronavirus disease emerged most probably from a species of civet cat after a massive mixing of indigenous and exotic animals with people in crowded urban markets in China. Human immunodeficiency virus (HIV), Ebola virus, West Nile virus, and monkey pox are all documented to have emerged in humans through an association with wildlife, with pathogens' species-jumping being associated with, for example, bush meat consumption or the exotic pet trade or insect vectors, with these viruses achieving notoriety due to their association with human mortality within Africa and beyond (WCS 2003). There has also been an increasing incidence of wildlife/livestock interface diseases reported over the last decade (bovine tuberculosis [BTB], rinderpest, anthrax, FMD) (Bengis *et al.* 2002).

This apparent emergence of disease is partly a result of the expansion of human and livestock populations into wildlife areas, with dramatically disturbed habitats and novel interactions, but also a result simply of increased awareness. Ironically, there is also now a belief in some philosophical circles that human and natural landscapes should not be separated (Paquet, personal communication 2003). Much of this is based on the thought that packaging nature (e.g., in National Parks and Reserves) separate from man will not maintain biodiversity and associated essential ecological and evolutionary processes. In some parts of the world, this concept has led to reduced persecution and the recovery of wildlife populations in some agricultural, urban, and suburban environments with dramatic results. For example, in North America there are now an estimated 39 million deer living in a highly modified environment, some restricted in farms and fed artificial diets but the majority free ranging. Interestingly, chronic wasting disease appears to have emerged under these conditions (Williams and Miller 2002, Powers 2003).

This trend towards establishing larger more integrated wildlife systems is also occurring in Africa, e.g., through

Table 1. African wildlife species associated with diseases of economic importance in wildlife/livestock systems and their epidemiological role

Wild Animals Concerned	Diseases	Epidemiological Role	Predicted Mortality (wildlife)
Ungulates (notable species)			
Kudu, impala	Anthrax	Multiplier epidemic hosts	High
Buffalo	Brucellosis	Epidemic host	Low
Buffalo, kudu	BTB	Epidemic hosts	Moderate
Eland, buffalo, impala	Ticks and TBDs	Multiplier endemic hosts	Low
Grazing ungulates	Internal parasites	Multiplier endemic hosts	Low
Gerenuk, others	Rift Valley fever	Multiplier epidemic hosts	High in epidemics
Buffalo, impala, kudu, wildebeest, sable	FMD	Epidemic hosts	Low
Eland, kudu, giraffe, impala, bushbuck, buffalo	Rinderpest	Epidemic hosts	High
Wild bovine, hippotragine, caprine species	MCF	Epidemic hosts	Negligible
Kudu	Rabies	Epidemic host	High
Eland, springbuck, lechwe, sitatunga	Heartwater	Endemic hosts	None
Bushbuck and others	Trypanosomiasis	Multiplier endemic hosts	None
Gazelles, oryx, ibex	PPR	Epidemic hosts	Moderate
Important species-specific associations			
Buffalo	BTB	Maintenance host	Moderate
	Rinderpest	Multiplier epidemic host	High
	FMD	Maintenance host	Negligible
	Corridor disease	Endemic host	None
Bushbuck	Bovine petechial fever	Endemic host	None
Warthog	ASF	Endemic host	None
Wildebeest	MCF	Endemic host	None

transfrontier parks (Gelderblom *et al*. 1996): extension of wildlife management areas into communities, conservancies, and wildlife corridors (IIED 1994, Hulme and Murphree 1999). Clearly, to conserve wildlife there is a need to find a more integrated approach and yet we cannot recreate Eden; there will be costs. These initiatives will inevitably be a compromise with other land-use practices and will result in complex disease phenomena (Rosenzweig 2003) that will need novel solutions and interventions. This is the contemporary challenge to the veterinary community, disease biologists, and wildlife managers alike.

Definition of the wildlife/livestock interface

Here, an attempt is made to define this interface in Africa, in relation to pathogenic infections and economically important diseases and the species that, based on current knowledge, have some epidemiological significance to these infections (Table 1), as well as to illustrate what the interface amounts to, in a physical sense, and how this relates to transmission of the concerned diseases.

Contact – The physical interface and disease transmission

Defining the interface in a physical sense, which is critical to understanding transmission dynamics, is complicated by an almost total lack of published observations of contact between livestock and wildlife species. This is more the realm of experience of the goat herder than of the scientist. Some published studies (Dobson 1995, Kock *et al*. 1999) and ethological texts (Kingdon 1997, Estes 1991) on wildlife across the African continent allow for some generalisations, but there are remarkably few studies that relate to observations of diseased populations.

The species most often reported in wildlife/livestock disease outbreaks come from the ungulate group and are mainly from the family Bovidae, of which the buffalo and bovine antelope are most prominent. This is perhaps not surprising given their relatively close phylogenetic relationship to ancestral (wild) cattle. These species live in spatially discrete small family groups or in larger herds (up to many thousands), with intraspecific fusion-fission herd dynamics (Prins 1987). Herds are usually made up of related animals, which maintain close contact with each other but occasionally split or come together according to social or environmental factors (e.g., rain, drought, formation of bachelor groups, breeding, migration), which clearly have epidemiological implications; i.e., opportunities for contact and transmission of infection are frequent but variable, within and between herds of a given species. Mixing, or contact, between animals or herds of different species occur but are less often observed. It is more common in open habitats and with plains species, e.g., during mass migrations of wildebeest, topi, zebra, and gazelles in the greater Serengeti system of East Africa. Bush, woodland, or forest species are usually more cryptic and even less likely to come into direct contact with other species. In all cases and especially under conditions of drought, contact increases at watering points or locations with key forage resources. When wild species mix, the separation distance can be a matter of a few feet, certainly close enough for transmission of most aerosol-borne infections, for pathogen transmission through contamination of grazing, or via water/bodily fluids. However, the typical and predictable behaviour of species can be disrupted by disease and ill health, e.g., rinderpest, in which the animal can exhibit bizarre behaviour such as losing fear of man, chasing other species aggressively, or seeking contact with other animals, having been rejected by its own herd members (Kock *et al*. 1999, Rossiter 2001).

The behaviour between wildlife and livestock is somewhat different. Wildlife usually avoids livestock and human contact spatially and temporally unless habituated. Whether this is instinct or learned behaviour is not clear. An example of this is seen at shared water points or grazing areas. Buffalo and other wildlife will be seen at night and early in the morning watering and grazing at these locations, purposively moving off sometimes only minutes before livestock arrive from their night bomas (secure pens constructed of brush or thornbush adjacent to temporary human shelter). The daily distance moved by wildlife to and from these key resources can be less than 100m if thick protective vegetation is adjacent to the point, or many kilometres to safe havens when there is regular aggressive contact with livestock owners or hunters. So the disease interface between wildlife and livestock is not usually a direct physical interaction or even sharing of the same space at the same time but an indirect contact; through the soil, forage, and water with which another animal has recently been in contact and has left bodily discharges, such as faeces, urine, saliva, or ocular or nasal discharge, or through shared insect vectors or intermediate hosts (Fenner 1982).

Infective agents survive for different periods in the environment depending on a number of factors, both intrinsic (e.g., cell structure of the organism, adaptation to vectors or intermediate hosts) and extrinsic (climate and season, temperature and humidity), surviving for a period of seconds or minutes (many viruses) to up to 200 years (some bacteria, such as anthrax) (Hugh-Jones and de Vos 2002). This in part explains why major wildlife/livestock disease epidemics that have been observed (Kock *et al*. 1999) are associated with drought, when the contact rate between animals, a fundamental driver, particularly for epidemics from microparasitic infections, increases (Anderson 1982). As much as animal disease can vary with seasonally determined environmental factors, temporally distinct animal cycles such as seasonal calving can have an important role in disease transmission, e.g., MCF in wildebeest (Rossiter 1983).

Another basic concept in transmission dynamics is the immune status of the population to a particular disease agent at the time of the epidemic. This can be described as the number of animals in a population that are susceptible to disease and indicates the likelihood that contact between infected animals and unexposed animals will lead to further multiplication of the organism and transmission (greater than 20% susceptible in a population are considered necessary for an epidemic of an infectious disease to occur [Thrusfield 1997]). In a stable biological system, the disease dynamic tends towards endemism with little or no clinical manifestation, and the host and parasite are described to be in balance (Allison 1982). There is a coevolution of host and parasite. This concept has also tended to convince many wildlife managers to consider all disease(s) in the protected areas as natural, and this historically has discouraged interest or intervention in parks and reserves in relation to disease outbreaks. This would be valid in “Eden,” perhaps, or in a truly natural ecosystem, but this state is historical, if it ever existed.

The situation has changed significantly over the past century, with many examples of transcontinental disease introductions (rinderpest, BTB) causing persistent problems in wildlife and livestock populations. The wild species were never exposed to these agents over millennia, there had been no coevolution, and the consequences were serious and persistent (Bengis *et al*. 2002, de Lisle *et al*. 2002). Besides these initial introductions of major diseases through importation of livestock to the continent, the coexistence of humans and their livestock with wildlife is still not governed by natural mechanisms; at best they are only partially integrated, especially in pastoral systems when contact may occur seasonally or only in drought years. Thus, endemism is disturbed and this is another reason the interface deserves close attention.

Diseases at the interface

Trade-sensitive diseases

The main diseases of concern to trade in Africa are FMD, Rift Valley fever (RVF), rinderpest (eastern Africa), peste des petits ruminants (PPR) (western Africa), and African swine fever (ASF).

Foot and mouth disease

FMD is the single most important disease influencing global livestock trade. The role of wildlife species in FMD was extensively reviewed (Thomson *et al.* 2003), but there are a number of important points in relation to the interface that are highlighted here. African buffalo are the only wildlife species confirmed to be a long-term maintenance host and this is exclusively for South African Territories (SAT) types of the virus (Condy *et al.* 1985). Natural infection has been reported in a wide host range but appears to be self limiting, and in most areas where FMD has been controlled the disease has disappeared in wildlife. Buffalo herds act as a reservoir for future outbreaks, transmitting infection to cattle directly or through other species, which have contracted the infection from the buffalo (Sutmoller *et al.* 2000, Bastos *et al.* 2000). As FMD is a highly infectious virus, transmitted in most instances by aerosol over short distances, it requires a relatively close contact situation between buffalo, other wildlife species, and cattle herds for interspecific transmission. In fact, how the transmission occurred in historical outbreaks is still uncertain, but it has been possible to confirm the connection through genetic sequencing and comparison of virus isolated from cattle and buffalo during outbreaks. Transmission is likely through mechanisms discussed above and may even involve venereal transmission, as virus has been isolated from semen and sheath washings and buffalo-cow mating has been observed in the field.

So the interface becomes an issue only when the disease is controlled in livestock, which is the case in a number of southern African countries. It is also becoming a concern in other regions as commercialisation of the livestock sector is planned and wildlife and particularly buffalo populations exist. Countries reporting FMD currently are Ethiopia, Kenya, Uganda, Tanzania, Zimbabwe, Mozambique, Chad, Niger, Burkina Faso, Senegal, Ghana, Togo, Benin, and Mali, all supporting buffalo populations except Niger and Mali (AU/IBAR 2003). Probably many more outbreaks in other countries have gone unreported. The only effective control measure at the interface where there are infected buffalo herds has been separation of this species from cattle and, in the case of South Africa, this includes vaccination of buffer livestock populations around the source of virus. There have also been some initiatives involving the establishment of disease-free buffalo herds, allowing for integration of this species into game-ranching enterprises in FMD-free areas (Foggin and Taylor 1996).

In countries where the extensive wildlife populations are integrated with pastoral systems, there is no possibility of effective separation. In these locations, the proposed solution is the creation of small export zones from which wildlife is excluded. Effectively, this means the creation of "protected areas" for livestock. This approach could resolve the conflict and provide the opportunity for commercial livestock development without much affecting the important wildlife resources in these parts of Africa. This would also support the culture and traditions of the pastoral peoples. The concept does not exclude the opportunity for links between the pastoral communities and the export zones, although a system of quarantine and mechanisms for this will need to be explored. As the loss of key grazing resources has been a factor in the decline of pastoralism, this potential reconnection with what would amount to fattening areas could strengthen the overall livestock economy and reduce pressure on national parks, which are frequently used for this purpose. This will also enable traditional peoples to benefit from a mixed-species system and develop wildlife-related livelihoods in addition to their livestock, while bypassing the veterinary restrictions, which have been a constraint on local trade.

Rift Valley fever

In the case of RVF, wildlife and livestock are epidemic hosts, whilst the mosquito is the maintenance host that also acts as the vector for virus infection in mammals (Swanepoel and Coetzer 1994, Garcan *et al*. 1988). Epidemics occur when conditions of high rainfall lead to extension of the range of infected mosquitoes, and nonimmune animals become exposed. Wildlife plays a role in the epidemiology through general amplification of virus in the environment, but the interface is not important to the trade or human/livestock health issues. RVF outbreaks are highly sporadic spatially and temporally, and the main emphasis for disease control is on early warning and timely vaccination of livestock. From this perspective, there is a possible sentinel role for wildlife, which, if monitored, may show signs well before the epidemics reach human and livestock concentration areas, allowing for more timely and effective control measures to be put in place. In northern Kenya, for example, the first species affected during the last major epidemic in 1997 after an El Niño event were gerenuk followed by small livestock (R. Kock, personal observation 1997).

Rinderpest

Rinderpest is the focus of a global eradication campaign and, after over a century of applying control measures, the virus is currently restricted to one last focus, in the so-called Somali ecosystem of Kenya and Somalia, where a single strain persists. The presence of the virus was confirmed through virus isolation techniques or by reverse transcription polymerase chain reaction (RT-PCR) from buffalo, eland, and kudu (Barrett *et al.* 1998). The process of verification of the absence of rinderpest virus from most countries in Africa (OIE 1998) will take some years, but the most important contemporary issue is the presumed persistence of a mild form of rinderpest in cattle. Although a cattle syndrome has been reported and confirmed by agar-gel immunodiffusion (AGID) during wildlife outbreaks (Rossiter 1997), no virus has yet been isolated from cattle to confirm its association with the wildlife disease. Experimental infection with wildlife virus isolates produces a very mild syndrome in indigenous cattle, although quite severe disease was reported in exotic breeds. This finding supports the hypothesis that the virus is circulating cryptically in livestock. The current thinking is that the virus occasionally "spills" from cattle herds, causing sporadic outbreaks amongst mainly buffalo and other susceptible wildlife species, with disease of varying severity (Kock *et al.* 1999).

With this last pocket of infection, the threat remains of recurrence and spread of this potentially devastating disease back to currently free areas in the region and to other continents worldwide. There is also the threat that the virus will revert to virulence given changing epidemiological conditions, and this is now a major risk given the cessation of vaccination in all cattle populations in Africa by the end of 2003. The current economic impact is minimal in livestock, but regular outbreaks in wildlife in Kenya have had an inevitable cost. The last major epizootic in 1994–1997 caused over 60% mortality in buffalo in Tsavo and mortality was estimated to be even higher in kudu (approximately 90%), with two further smaller epidemics occurring since then in the region. The depressive effect on these populations is both dramatic and persistent. In the two largest protected area systems in Kenya, Tsavo and Meru National Parks, the loss of visible wildlife species such as buffalo has contributed to a significant decline in visitors and related income.

In all the epidemics reported, there was circumstantial evidence that the origin of virus was cattle (Kock *et al.* 1999, R. Kock 2002), but in no instance was this proved. There is evidence from buffalo epidemics that the virus spreads to virtually all members of a contiguous population after the index case in the species, and the infection might or might not subsequently transmit interspecifically (R. Kock 2002, Rossiter 2001). Where there is multiple species involvement, these seem to be separate independent epidemics, which may occur simultaneously from similar or different point origins and with different rates of spread.

In all wildlife species there is evidence that the disease does not persist at a herd or population level. Interspecific transmission of infection is probably a rare event, dependent on chance contact, which is therefore increased where there are large numbers of infected wild animals present in the ecosystem, with seasonally determined contact patterns playing a role. Should the transmission dynamic have been more fluid between species, wildlife might have played a more significant role in maintenance of the virus, but fortunately this appears not to be the case. The infection in buffalo herds of approximately 300 animals lasts 2–3 months and in an ecosystem of approximately 50,000km^2 can persist for 3–4 years and can affect all animals. Reinfection of partially immune populations leads to focal epidemics, which can be very localised and the disease may not affect all animals, although in any single infected herd (of buffalo) all eligible animals will be involved.

The significance of the interface for rinderpest is that since the disease does not persist in wildlife, its existence in cattle is essential for recurrence of wildlife epidemics. The chance of transmission from wildlife back to cattle is proved experimentally but not reported under natural conditions. In theory, transmission from wildlife back to cattle can occur and this would mean wildlife could have a greater role in the epidemiology (and not just as a dead-end host). This role is perhaps best described as that of a vector, multiplying the virus in the environment and spreading it spatially for a limited period of time. During the extensive blanket vaccination campaigns of cattle in the region over recent years, this aspect may have been underestimated as a contribution to persistence. Virus may have remained in the environment (in wildlife) for a period of years with reinfection of young cattle a possibility, although the epidemiological data available do not suggest this is in fact the case. The fact that this persisting virus appears to be of low virulence in cattle and may be reaching some sort of host-parasite equilibrium is a major concern to the eradication strategy, as this creates considerable obstacles to surveillance and application of control measures.

The clinical expression in wildlife provides a sentinel but, unless improved techniques are determined for identifying the virus in cattle populations, the ultimate goal may remain elusive. The fact that the virus still appears capable of high virulence in wildlife is also of concern as this indicates a different trend to that seen in cattle after a century of exposure to the virus. If eradication is not achieved, this will create a considerable problem for the region in relation to trade, which is already restricted in a number of countries due to common borders with infected countries. The means of spread of the disease between cattle and buffalo (or other species) in nature is not known for certain but probably is through aerosol and contamination of pasture and water points. As sick buffalo, with profuse diarrhoea and ocular and nasal discharges, frequently remain and die around water points, this is probably the area where transmission takes place, intra- and interspecifically. Whilst this disease persists, development of commercial export livestock systems will be constrained in affected regions, and unless rinderpest is eradicated it might become necessary to isolate cattle from wildlife in a similar manner as for FMD.

Peste des petits ruminants

The epidemiology and clinical picture of PPR, another morbillivirus, is similar to that of rinderpest but it affects (clinically) only small ruminants. The incidence and role of PPR in free-ranging wildlife is not known, as epidemics have not been reported except in captive or semi-captive conditions. The severity of the disease in wildlife, with up to 95% mortality in gazelles (Mwanzia 2002), suggests it may well have been a problem and have affected natural populations, although there is no proof for this. Since the virus appears restricted to West and central Africa and Ethiopia, it is interesting to correlate the presence of the virus over the last 40 years with the decline and even extinction of gazelle from many areas within this zone, with robust populations surviving in the rest of East Africa, where the virus is absent. Other wildlife species can provide a sentinel role through serology for the presence of this virus, and antibody has been detected in a number of species, such as buffalo.

African swine fever

Another disease of importance to trade of pigs and pig products is ASF. Currently it is a problem in West Africa and parts of East and southern Africa (AU/IBAR 2003). Wildlife does not appear to be involved in the epidemiology of the disease in West Africa, with the viral transmission cycle occurring within the free-ranging (village) pig population, which is difficult to control by conventional methods. In East Africa, in contrast, the disease is often associated with warthog, in which the disease is endemic and associated with the maintenance host, an ornithodorus tick (Plowright *et al*. 1969, Plowright *et al*. 1974). This tick lives in warthog burrows and feeds on warthog, infecting young pigs as they are born (Thomson 1985). This interface issue has been a factor in preventing the development of pig farming in the East African region.

Summary

There are relatively few diseases of concern to international trade associated with the interface, and few species of epidemiological significance (primarily buffalo). If commercial export systems for livestock are to be developed under the current trade rules, in countries where presently trade is only local or at best regional, the exclusion of buffalo and pastoral livestock will be necessary to control the important diseases (e.g., through export zones). This approach will reduce the burden on government veterinary departments, ensuring realisable targets in epizootic disease control, and allow for the development of improved animal health services in the pastoral communities which are more relevant to the local disease concerns.

Non-trade-sensitive high-impact diseases at the interface

Of the trade-sensitive diseases mentioned above, only rinderpest currently impacts wildlife population dynamics, and this is only in certain wildlife species, in relatively few locations. There are more widespread infections that can cause high mortalities, and these are discussed in this section.

Anthrax

Anthrax is considered natural to the African continent, and epidemics in wildlife are probably as old as the origin of the species themselves (Hugh-Jones and de Vos 2002). Certain species have been more associated with outbreaks and these include kudu, wildebeest, buffalo, and impala, probably more a result of their relative abundance than any species-specific susceptibility. The manner in which anthrax survives is highly effective, which is why this ancient disease has not changed much over generations. After entering a host it multiplies, usually killing the animal and, after exposure to air, produces billions of spores. These are released into the environment, where they persist for years – under ideal conditions, for hundreds of years.

Infection is dose dependent and occurs at the soil level in most instances, although leaf contamination from vulture faeces has been associated with disease in browsers, particularly kudu (Lindeque and Turnbull 1994). Certain ecological and geographical conditions favour the persistence of the bacteria, and these have been documented for some wildlife populations (de Vos and Bryden 1996). In these cases, the presence or absence of cattle does not necessarily affect the cycle of disease. Nevertheless there have been associations of anthrax epidemics in wildlife with cattle infections, and no doubt this association can work in both directions. Once an epidemic reaches areas where livestock and cattle mix, the chance of crossover between domestic animals and wildlife increases. If there are high concentrations of cattle on the periphery of wildlife concentration areas and there is a general water run-off from one area to the other, transmission can occur through indirect exposure mechanisms. Essentially, the water carries the spores to a water sink and there concentration takes place, leading to an increased probability of infection of the animals feeding or watering at that point.

The main implications of this disease to the wildlife/livestock interface are that control measures may necessarily include certain restrictions involving the extent of the interface to reduce contamination levels at key points. Vaccination is also possible for livestock and this can help to reduce the overall environmental load. At the time of epidemics, further measures can be taken and these ideally involve burning of the intact carcass (with coal as fuel if possible) to reduce spread of the bacteria by scavengers and local contamination (Nishi 2003, Hugh-Jones and de Vos 2002).

Tuberculosis

Tuberculosis, for the purposes of considering its impact at the interface, is considered to mean bovine tuberculosis (BTB). This infection was introduced to the continent, arriving with imported livestock and subsequently spilling into wildlife populations in southern and eastern Africa in particular. BTB is not only a concern to the African wildlife/livestock interface but is also a particular problem in the United Kingdom (badger–cattle), New Zealand (opossum–cattle/deer), and North America (deer/bison-cattle). It has been prominent in Africa in the higher-density wildlife systems in South Africa, Uganda (Woodford 1982a, 1982b), and Tanzania.

The disease is chronic, and transmission between livestock and wildlife probably occurs sporadically through direct contact, but the organism is able to establish in some species, which then become a maintenance host. This is the case with buffalo, and once this has occurred the disease can spill back into cattle as well as to a number of other species including kudu, lion, and baboon, to mention a few (Keet *et al*. 1996). In low-density ecological systems (often pastoral arid systems), despite the considerable mixing of wildlife and livestock, the disease is rarely observed and probably here does not play an important role. However, in the sites with higher densities of wildlife, the disease does appear to depress population growth rates and make species more vulnerable to other regulating factors such as predation; its net effect will depend on the extent of environmental variation the population is exposed to (Jolles 2003). Since BTB is difficult to control in free-ranging populations, once it is established in wildlife and wildlife becomes a potential source, this is likely to lead to the need for separation of wildlife and livestock by fencing to ensure that control measures in cattle are not frustrated. The approach to or need for or indeed feasibility of controlling BTB in wildlife systems remains a current debate and focus of research (de Vos *et al*. 2001).

Brucellosis

Brucellosis, although present in livestock, has been demonstrated as a clinical entity only rarely in wildlife in Africa (Gradwell *et al*. 1977) and the evidence is mainly serological (Grootenhuis 1999, de Vos and van Niekerk 1969). The significance of African wildlife in the epidemiology of brucellosis is not well understood and appears minimal, which is likely to remain the case until perhaps the disease is controlled in livestock.

Malignant catarrhal fever

MCF virus is of considerable concern to pastoral livestock keepers as it is usually fatal in cattle. This herpes virus (Alcelaphine herpes virus 1) is maintained in wildebeest and transmitted to cattle by the young calves (2–4 months of age) through contamination of pasture from nasal secretions (Mushi *et al*. 1980). Generally, the livestock keepers will avoid calving grounds, but when they have no choice the grazing strategy of the pastoralists shows considerable understanding of the epidemiology of the disease. The virus is highly sensitive to drying, heat, and ultraviolet light, so under natural conditions the pastoralists have learned that since wildebeest calve at night, by 10:00 a.m. the pasture is sterile (in terms of MCF) and infection can be avoided.

Rabies

Rabies virus infection in livestock is rarely contracted from wildlife, through bites from sylvatic hosts (mongoose, foxes, jackals). This is a sporadic and dispersed problem through Africa and is not necessarily associated with the more intensive interface areas. Since the domestic dog plays the more significant role in the maintenance of this infection, it will not be considered in more detail here.

Macroparasites and the interface

Internal and external parasites can play a significant disease role in wildlife and livestock populations, and there are certain infections that are particularly important at the interface. The most significant of these is trypanosomiasis (Morrison *et al*. 1981). This blood parasite is maintained in a variety of wildlife species and has led to the virtual exclusion of cattle from large tracts of African bush. Due to the susceptibility of cattle to infection, with high morbidity and mortality, considerable investment has been made to control the disease through eradication or control of the tsetse fly, which acts as the vector. Few of these efforts have been sustained, and the disease remains a significant moderator of the interface between wildlife and livestock in many areas of Africa. The other major impact of this disease at the interface is in the negative attitude of livestock communities to wildlife and their natural habitat that harbours the fly. Some approaches such as the use of drugs and field insecticide targets and traps have helped to reduce the impact but it remains a problem. In these areas, more diverse livelihood approaches are needed to mitigate the problem; otherwise, destruction of wildlife and their habitat is likely.

The other broad disease grouping, which is important at the community level, is tick-borne diseases (TBDs), which perhaps are more important to the ordinary African livestock keeper than any other. Here, the interface is important due to the reservoir status and the multiplier effects of numerous host species. Normally a problem of livestock, with wildlife showing tolerance, TBDs can under certain conditions be a problem to both, e.g., with wildlife translocation, which leads to novel exposure of source or recipient populations of wildlife/livestock to new parasites for which there is no immunity. Losses can be high.

One of the most important TBDs is theileriosis, which causes corridor disease in cattle (Neitz 1955). Buffalo carry the parasite *Theileria parva (lawrencei)* and only in the presence of a particular tick, *Rhipicephalus appendiculatus*, does one see cattle mortalities. The parasite is not able to survive in cattle, which act as a dead-end host, literally, as cattle die before the piroplasm stage develops (Grootenhuis 1999). As with the other vector-borne infections, direct contact is not necessary and sharing the range is all that is required for transmission of the parasite between wildlife and livestock through the tick. There is growing molecular-based evidence that the buffalo-derived parasite is indeed different from the cattle parasite *T. parva*, with which it can be confused. The cattle *T. parva* also causes disease, namely East Coast fever, which occurs when nonimmune cattle are exposed, again with a tick vector. *T. parva* from cattle will not infect buffalo. Another parasite found in livestock and wildlife species, often confused with *T. parva*, is *T. taurotragi,* which occasionally causes clinical disease in eland.

Heartwater caused by the rickettsial parasite *Cowdria ruminantium* is another important TBD of livestock, with at least three species of *Ambylomma* tick involved. There are many possible wildlife reservoir hosts, the most important of which are probably buffalo, giraffe, and eland.

Helminth parasites (nematodes, cestodes) are numerous and can locally be of considerable importance to both livestock and wildlife, but there is little or no evidence that wildlife acts as a true reservoir for livestock or vice versa even though some helminth species have multiple hosts and each can act as amplifiers. Haemonchosis is the most important nematode disease of small livestock; gazelle can be carriers (Grootenhuis 1999). The pathogenicity of the parasite usually depends on whether the individual has had prior exposure and on its nutritional state. Seasonal factors can be important including heavy rain, which supports egg survival and increases challenge from infective larvae on the pasture, and drought, during which animals suffer malnutrition and show poor resistance. These organisms have coevolved with the host, so under natural conditions there is a balance (Fowler 2001). Seasonal movements and sporadic contact at the interface between livestock and wildlife can be a source of novel parasite infestations and disease.

The most important external parasite in wildlife is sarcoptic mange, caused by *Sarcoptes scabiei*. Although the disease can cause devastating short-term mortality in African species of great ape, cat, and antelope, an epizootic does not generally affect long-term population dynamics, although endangered or threatened species are vulnerable to its effects (Pence and Ueckermann 2002). The origin of the parasite in wildlife populations is thought to be man and his domestic animals, and interspecies infection appears to occur.

Conclusions

There are many situations when protected-area managers and communities have come to tolerate the problems of disease at the livestock/wildlife interface, usually where the impacts are cryptic or difficult to quantify. A number of superficial reviews of the interface were carried out in the 1990s, and no new disease issues could be identified. However, the situation is rapidly changing as land becomes more developed and the interface more intense. There is already some indication of re-emergence of serious infectious diseases and emergence of new diseases on or from the continent. As this process of change continues, the situation will need to be addressed. When high-impact diseases occur, the implications are not only devastating to communities, but the financial implications can be disastrous, particularly for developing nations but also for the economies of developed nations.

Disease is becoming an important issue in conflicts between national parks authorities and adjacent communities. These frequently poor interface communities increasingly perceive wildlife negatively, especially when they have no stake in the management or use of that wildlife resource. Under these circumstances, disease outbreaks can be the trigger to conflict, and politics dictate that interventions by public health and (agriculturally oriented) state veterinary services take priority: this usually impacts negatively on the wildlife resource. On the other hand, those same poor communities and livestock are seen as a threat to many protected areas as they compete with wildlife for resources and also because of a history of disease introductions. This situation is counterproductive for all concerned and cannot lead to better decisions being made for healthier ecosystems or human environments. To reduce the conflict, the risks and impacts of disease, in particular at the interface between wildlife and livestock but also at the interface with people, will need to be better understood amongst all the stakeholders. More research is needed, as are new philosophies and attitudes, and new approaches to livelihoods and resource use. New practical measures must be introduced in order to improve animal and human health. This will be beneficial to community development and biodiversity conservation alike. The lack of investment and of trained personnel in this field in Africa are major constraints that, if not addressed, will affect overall development and conservation goals for the continent.

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