

Review Article

A Review of Bovine Tuberculosis in the Kafue Basin Ecosystem

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The Kafue basin ecosystem is the only remaining natural habitat for the endangered Kafue lechwe antelope (*Kobus leche Kafuensis*). However, hydroelectricity power production, large-scale sugar plantations, commercial fishing and increasing livestock production are threatening its natural existence and sustainability. Further, increasing human settlements within and around the Kafue basin have resulted in decreased grazing grounds for the Kafue lechwe antelopes despite a corresponding increase in cattle population sharing the same pasture. Baseline epidemiological data have persistently reported findings of bovine tuberculosis (BTB) in both wild and domestic animals, although these have been deficient in terms of describing direct evidence in the role of either lechwe antelopes or cattle in the reported observations. Despite the current literature being deficient in establishing the casual role and transmission patterns of BTB, a bimodal route of infection at the livestock/wildlife interface has been postulated. Likewise, it is not known how much of (BTB) has the potential of causing disease in humans. This paper, seeks to underline those aspects that need further research and update available data on BTB in the Kafue basin with regards to the prevalence, distribution, risk factors, threats on wildlife conservation, livestock production, public health implications, and possible mitigatory measures.

1. Introduction

The origins of mycobacterial infections despite being age-old diseases have been a subject of much debate [1–4]. However, through the works of Brosch and coworkers, they have been able to demonstrate that the genome of *M. bovis* is smaller than that of *M. tuberculosis* and that *M. bovis* has undergone numerous deletions compared to *M. tuberculosis* implying that the origin of *M. bovis* is *M. tuberculosis* [4]. It has been demonstrated that the first six ancestral *M. tuberculosis* strains that resemble the last common ancestor before the separation of *M. tuberculosis* and *M. africanum* are all human pathogens with *M. bovis* being the final member of a separate lineage that branched from the progenitor of *M. tuberculosis* isolates [4]. Further, other molecular biological studies involving DNA typing have shown that *M. tuberculosis* has been present longer than *M. bovis* [5]. Similarly, Rothschild and coworkers successfully applied spoligotyping to a 17,000-year-old skeletal specimen of an extinct North American bison and the pattern revealed

that the respective bacteria were probably not related to *M. bovis* or *M. microti*, but best fitted *M. africanum* and *M. tuberculosis* patterns [6].

Although members of the *Mycobacterium tuberculosis* complex (MTC) are responsible for the majority of mycobacterial infections worldwide, nontuberculous mycobacteria (NTM) a group of atypical mycobacteria or mycobacteria other than tuberculosis (MOTT) are increasingly becoming more of a public health significance [1, 4]. The *Mycobacterium tuberculosis* complex includes very closely related species of mycobacteria among them: *Mycobacterium tuberculosis*, *Mycobacterium africanum*, *Mycobacterium microti*, *Mycobacterium bovis*, *Mycobacterium caprae*, and *Mycobacterium pinnipedii* [4]. Nontuberculous mycobacteria (NTM) include both slow growing mycobacteria (SGM) where colony formation requires at least seven days and rapid growing mycobacteria (RGM) forming colonies in less than seven days [1].

Bovine tuberculosis (BTB), caused by *Mycobacterium bovis* (*M. bovis*), a member of the MTC [1, 4], has been

shown to have a very wide host range with a potential to cause zoonotic tuberculosis [7–9]. In Zambia, BTB was reported in cattle as far back as 1947, when the Veterinary Department diagnosed the disease in cows at Nega Nega, Kabwe, and Mazabuka [10]. The veterinary annual report of 1956, highlighted a number of areas where the disease was diagnosed; Abercorn (now Mbala), Broken Hill (now Kabwe), Mazabuka, Monze, Namwala, and Kalomo [10]. The abattoir compilation done by the Veterinary Department in the same report indicated that 1.6% of cattle slaughtered at an abattoir in Lusaka had tuberculous lesions; 2% at an abattoir in Livingstone; 5.2% Mazabuka and 16.8% of slaughtered animals from Namwala [10].

Studies on the epidemiology of BTB in Zambia have indicated that the disease is not homogeneously distributed, however, high prevalence rates have been recorded within and around the Kafue basin an area with extensive overlap in terms of grazing land from wild and domestic animals [11–13]. Additionally, the lechwe antelopes have been described as feral reservoirs of BTB in Zambia [14, 15]. The disease has a historical presence in the Kafue basin that predates the identification of the area as a protected ecosystem and Ramsar Site no.530 [16]. Despite the continued reduction in annual rainfall figures, the Kafue basin still remains as one of the few lacustrine wetland ecosystems in Zambia supporting a surging cattle population estimated at 300,000 animals [17] at a carrying density of 50 animals per square kilometre and approximately 38,000 lechwe antelopes [16] on a 6,000 square kilometre wetland [18]. The basin has further been identified as an important livestock production zone, a recognition that is threatened by the sustained and high BTB prevalence in both wild and domestic animals [19–23]. It is to a greater extent characterised by high cattle BTB herd level prevalence of around 50%, whereas a comparatively lower herd prevalence averaging 5.6% has been determined in areas outside the basin [11, 19]. Likewise, the corresponding Kafue lechwe antelopes have been shown to have a higher prevalence rate [15, 22], raising questions on a possible interspecies transmission of the disease between cattle and Kafue lechwe antelopes, however hampered by the lack of direct evidence to conclusively ascertain this assertion. Notwithstanding the elaboration of risk factors associated with BTB in the Kafue basin [11, 19], the genetic diversity and/or relatedness of lechwe and cattle BTB needs molecular epidemiological studies to elaborate on this relationship.

2. Bovine Tuberculosis in Kafue Lechwe Antelopes (*Kobus leche kafuensis*)

It has been reported that in the last 75 years, the Kafue lechwe population has declined by 85% from 250,000 animals in 1931 to 38,000 in 2005 (Table 1) [16]. The Kafue lechwe antelope, which is endemic only to the Kafue basin of Zambia, is particularly vulnerable given the persistent reports of high tuberculosis prevalence, high poaching rates, and high human settlement pressure coupled with increasing grazing pressure on few available pasturelands

TABLE 1: Population of the Kafue lechwe (*Kobus leche kafuensis*) between 1970 and 2005.

Year	No. animals	Reference
1970	94,075	Bell et al., 1973
1971	93,215	Bell et al., 1973
1972	93,158	Bell et al., 1973
1973	109,612	Osborne et al., 1975
1975	80,774	Osborne et al., 1975
1981	45,867	Howard et al., 1983
1983	41,155	Howard et al., 1983
1987	50,715	Howard et al., 1987
1988	65,018	Howard et al., 1988
1989	47,145	Jeffrey et al., 1991
1990	44,538	Jeffrey et al., 1991
1991	68,872	Jeffrey et al., 1991
1993	64,940	Kapungwe, 1993
1994	50,000	Jeffrey, 1994
1999	45,000	Kampamba et al., 1999
2001	42,119	Kamweneshe et al., 2002
2005	38,000	Chansa and Kapamba, 2010

from resurging cattle herds among other biological and anthropological factors (Table 2). The situation is further compounded by the reduction in suitable habitat through the rapid encroachment by the invasive alien mimosa weed (*Mimosa pigra*) and the disruption of the flooding cycle by the damming of the Kafue River upstream at Itezhi-tezhi [24].

Bovine tuberculosis in the Kafue basin has persisted since 1969 during which after a cropping exercise, it was realized that 14.0% of the lechwe antelopes had BTB [25]. The disease was only confined to lechwe antelopes. These findings prompted the Zambian government at that time to embark on building an abattoir specifically for screening wild animals at Lochinvar National Park. By 1971 Gallagher and coworkers through this facility had examined 125 lechwe antelopes slaughtered under a cropping exercise and recorded a prevalence of 36% (45/125) [25]. In 1972, they examined a total of 86 animals and recorded a prevalence of 33.7% (29/86) (Table 3) [25]. Between 1973 and 1974, they recorded a prevalence rate of 49% [25].

Of the other species examined by Rottcher [26, 27], BTB was only detected in an adult eland (*Taurotragus oryx*) that had generalized lesions involving the lungs, pleural, and mediastinal lymph nodes [26, 27]. This was one of the first reports that indicated the possibility of a spillover effect to other animals. More recent studies by Pandey [13] showed a prevalence rate of 19.2% ($n = 177$) in the Lochinvar NP, while Munyeme and coworkers [15] recorded a prevalence of 24.3% ($n = 119$) for the period from 2004 to 2008 across the North and South banks of the Kafue flats, indicating the continued existence of BTB in the Kafue lechwe (Table 3).

TABLE 2: Factors influencing BTB in the livestock/wildlife interface areas of the Kafue basin.

Host Factors	Environmental factors	Pathogen
High Cattle densities	Swampy/Marshy environments	Showed maintenance in lechwe antelopes for a very long time establishing reservoir host potential
High Lechwe densities	Moist pastures for most parts of the year	Shown potential for interspecies and intraspecies spread
High Cattle/lechwe interaction heightening potential of aerosol route of infection	Moist soil conditions	
Lechwe lekking behavior	Shrinking grazing grounds Alien invasive weeds (<i>Mimosa pigra</i>) spreading on already shrinking pastures Overlapping grazing grounds for lechwe antelopes and cattle	

3. Bovine Tuberculosis in Cattle of the Kafue Basin

In the Kafue basin, cattle ownership is a symbol of status and wealth (Figure 1). In this very complex social system of mutual obligation, cattle are often used as a medium of exchange in place of money. As a result there is a lot of exchange of cattle between families and villages implying that cattle are neither kept in closed nor stable populations due to these movements within and between herds and kraals. Still, cattle from different villages and families can be kept together in one large herd especially during transhumance and those which become permanently resident in the interface areas away from the villages more for security reasons. In short, cattle are central to the economic and social activities among the indigenous communities of the basin [28, 29].

Three types of cattle enterprises according to grazing strategy and herd size exist in the Kafue basin. The village resident herds (VRH) are small herds kept within the confines of the villages all year round. As herd sizes increase, most cattle owners start taking their animals to the wetlands (deep into the wildlife grazing zones) in search of pasture during the drier months (May to October) where grazing land is abundant. These herds return to the villages during the rainy season (November to April). This practice of taking animals to the flood plains in dry months is known as transhumance, and the cattle herds that practice this type of grazing strategy are known as transhumant herds (TH). However, some transhumant herds become very large to be supported around villages, such herds resort to be permanently resident within the wetlands drawing back to higher grounds when there are floods, but without going back to the villages. Such herds are known as interface herds (IFH). When these different types of enterprises were studied in detail, it was found that their BTB prevalence varied among them [19]. In IFH, BTB prevalence was found to be high [19]. Epidemiological studies on risk factors of BTB in the Kafue basin indicate geographical differences based on the type of cattle enterprise [11, 19]. However, the reasons for the observed spatial variations in BTB prevalence in Zambia need further elaboration to be able to conclusively ascertain

TABLE 3: Bovine tuberculosis in the Kafue lechwe of the Kafue basin.

Year	Total animals examined	Number infected	Percent affected	Reference
1956	2	2*	100%	Leroux, 1956
1962	—	—	14.0%	Anonymous, 1962
1971	125	45	36.0%	Gallagher et al., 1972
1972	86	29	33.7%	Gallagher et al., 1972
1973–1976	300	90	30.0%	Dillman, 1976
1976–1977	141	46	32.6%	Rottcher, 1978
1976–1977	38	33	23.4%	Rottcher, 1978
1976–1977	147	5	3.4%	Rottcher, 1978
1977	7	7*	100%	Clancey, 1977
1977	63	33	52.4%	Clancey, 1977
1986	41	33*	80.5%	Krauss et al., 1986
1990	92	15	16.3%	Stafford, 1991
1998	177	34	19.2%	Pandey, 1998
2004–2008	119	29	24.3%	Munyeme et al., 2010

* Samples from cachectic/and or dead animals collected from the Kafue flats.

the deterministic factors of BTB occurrence and sustenance in the basin. In combination to geographical and biological factors, studies have also intimated to a greater extent significant anthropological determinants for the observed differences within and outside the Kafue Basin [12, 13, 28]. Other, studies in more or less similar ecosystems, have also indicated that the type of cattle management becomes a significant risk factor for BTB transmission given the type of existing risk factors in that particular ecosystem [30, 31]. This becomes more elaborate when the likelihood of cattle movement in that enterprise is high [32], an important point for consideration in the Kafue basin given the high

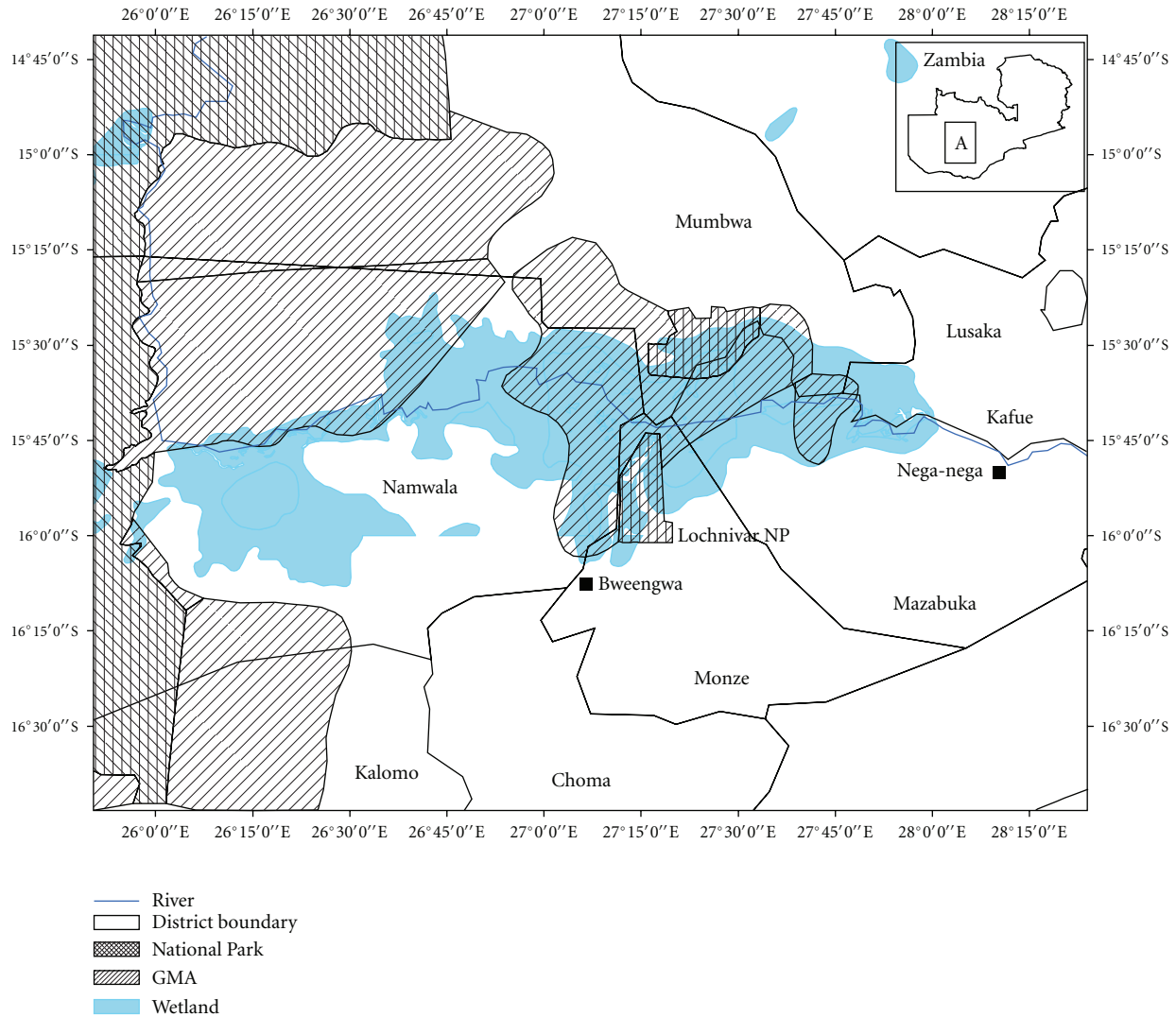


FIGURE 1: Map of the Kafue basin, insert Map of Zambia showing the location of the basin.

interaction patterns between different cattle herds and wild animal populations.

4. Conservation Implications

Due to the population decline in the Kafue lechwe (Table 1), the Zambia Wildlife Authority (ZAWA) has embarked on conservation strategies aimed at saving the remaining population from possible extinction [16]. Lack of empirical evidence on the factors contributing to the significant decline of the Kafue lechwe population has various scholars to postulate different causal factors [13, 22, 23, 33]. However, what is common amongst all the scholars is that they point out likelihood of BTB playing either a primary significant immunosuppressant role due to its chronic nature or a proxy role for other coinfections such as parasites and possible nutritional and other related stress factors [13, 22, 23, 33].

As a response to ZAWA's call to conserve the remaining lechwe antelopes, *ex-situ* conservancies have started rearing

the Kafue lechwe outside government protected areas on private-public partnerships (PPPs) where the conserved animals are kept on private game ranches but still considered government property. Thus far, approximately 700 Kafue lechwe antelopes have been translocated from the Kafue basin into game ranches. In order to promote the successful rearing of these animals on game ranches, it is imperative that a "BTB free breeding stock" is raised for translocation purposes to game ranches. The danger of translocating BTB infected animals is that they could serve as a source of new infection in new naïve areas subsequently introducing the disease to other animal species in *ex situ* conservancies which would end up reaching the human food chain. Inadvertently, BTB has since been detected from Kafue lechwe on game ranches [34]. Given that all Kafue lechwe antelopes currently reared on game ranches in Zambia originate from the Kafue basin particularly from Lochinvar NP, it is likely that the disease was introduced from lechwe that were translocated from the Kafue basin. The translocation of the Kafue lechwe

to game ranches was carried out without prescreening for BTB. Hence, it is imperative that a “BTB free herd” of Kafue lechwe is generated as breeding stock for translocating to game ranches and for further conservation purposes.

5. Economic Implications

Unlike the developed world that recognised the importance of eradicating the disease from cattle, most African countries, Zambia inclusive, argue that BTB is not a disease of national economic importance and as such, there is lack of both political will and intervention measures from respective governments. However, these arguments that BTB in cattle and wildlife in African countries does not need intervention based on economical reasoning may not be entirely justifiable. It can be argued that western-based methods of cost-benefit analysis may underestimate the value of a loss of a cow through abattoir condemnation of a carcass as a result of generalised BTB, without mentioning the threat posed to abattoir workers [7, 8]. However, the real value of an animal in a Zambian pastoral community is not only based on commercial value at the point of sale. This is so because the majority of the benefits obtained from traditional animals in rural Zambian pastoral communities are intangible and incommensurable such as social security, social status, transportation means, and credit worthiness among others. Thus to assess the real economic impact of BTB in the traditional livestock sector of Zambia, there is need for reliable and accurate epidemiological and socioeconomic information regarding the exact impact of the disease, thus its spread, maintenance, prevalence, socioperturbations, abattoir condemnations, and so forth.

Diagnosis of tuberculosis in wildlife has far reaching and serious consequences both nationally, and internationally. The current creation of Transfrontier Conservation Areas (TFCA) in Southern African countries with the translocation of wild animals across borders cannot be done with infected wildlife populations. Thus despite the perceived low returns in controlling BTB by many African countries, the accompanying benefits from eradication of the problem are incomparable. Further, a BTB free state will mean that certain sanitary mandates will have been achieved and can foster a country to enter certain highly lucrative and competitive dairy product and beef markets at a global stage, a direct economic benefit that most policy makers in African countries are oblivious of. Further benefits are through increased production efficiency to subsistence farming with majority of resource poor traditional farmers entirely dependent on livestock as the only source of livelihood. The lack of infectious communicable diseases in wildlife populations may mean increased ecotourism which is a direct source of much needed foreign revenue in Zambia and other developing countries alike. The net results of these economic benefits from disease-free livestock and wildlife may have a substantial boost and trickle-down effect to the country's Gross Domestic Product (GDP).

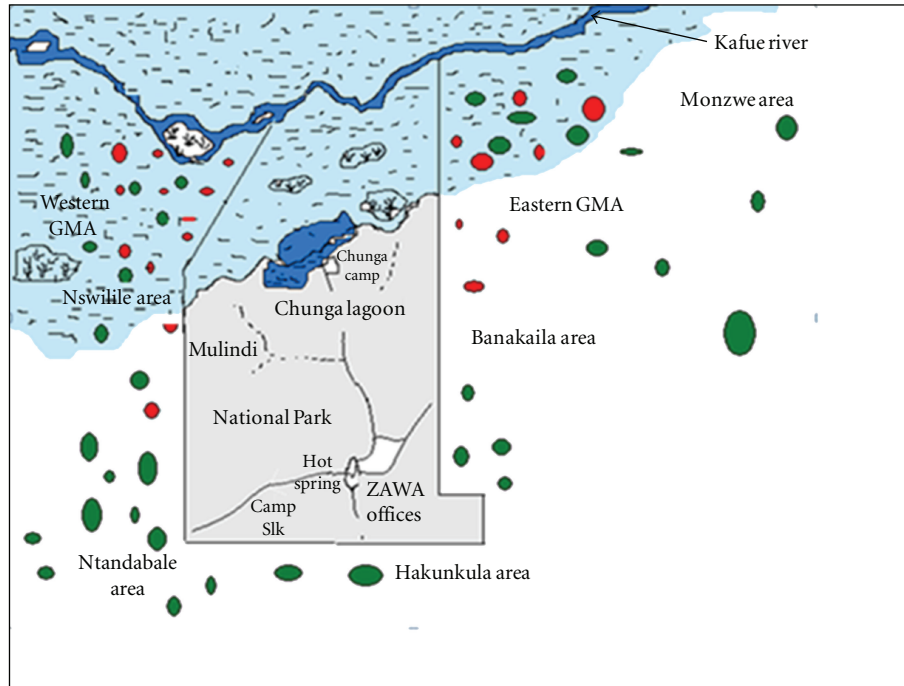
This BTB free state can be achieved by developing rational and realistic strategies capable of controlling *M. bovis*

infection in wild and domestic animal populations. However, eradication of BTB at the livestock/wildlife interface area is costly considering the need for sustained and long-term intensive surveillance. In addition, each ecosystem has its unique challenges, just like in the Kafue basin where control strategies must take into consideration the complex nature of cattle ownership and other local practices of the cattle owners [35]. Factors relating to interaction patterns within and between herds of cattle and wildlife must be analyzed and possible transmission routes identified before any intervention strategies are proposed [35]. Control measures should be applied both for wild and domestic animal hosts simultaneously. In wildlife hosts, the identification and removal of infected animals and the creation of *ex situ* disease-free populations for future restocking into depleted National Parks is one of the most viable control options. However, with wildlife, the detection of infected animals is made difficult by the mode of restraint which is prohibitively expensive as it is based on delivering chemicals through darts (projectiles) fired from special guns. Limiting interaction between domestic and wild animals with simultaneous application of control strategies across species is recommended. Eradication campaigns in cattle such as test and slaughter schemes, despite having been shown as unsuitable for Africa [7], can still be applied together with other surveillance systems. These control measures must be backed by an animal disease control fund for the indemnification of cattle owners. Unfortunately, due to cost implications, such a scheme in most African countries still faces serious challenges.

6. Public Health Implications

In Zambia, the burden of *M. bovis* infection in humans is still unknown more so that the disease is clinically indistinguishable from that caused by *M. tuberculosis* [7, 12]. To a greater extent, such information still remains unavailable in most developing countries [7]. However, epidemiological studies conducted in high cattle rearing areas within Zambia have intimated possible BTB association between cattle and human populations although these studies have not been conclusive enough [12]. However, risks of disease especially those of zoonotic nature such as BTB remain a major threat to pastoral communities although the real extent of this threat is yet to be elucidated [12]. It is likely that despite the paucity of information in this region, coupled by the nonpasteurisation of milk, cattle is predisposed as a likely source of zoonotic TB for man [36]. Studies have indicated a high proportion of pastoral communities within the Kafue basin not pasteurizing their milk as they want to consume it in a soured form as relish or local traditional yoghurt [28, 37]. The lack of regular testing of cattle herds compounded by the lack of funds to indemnify affected farmers means the problem of BTB is likely to be widespread as it still remains without mechanisms of detection and control in place.

The relatively low incidence of development of open (infectious) pulmonary tuberculosis due to *M. bovis* in man is almost certainly due to immunological factors which



- Lechwe sampling sites
- Cattle sampling sites
- ▨ Swamps and dambos

FIGURE 2: Map of Lochinvar indicating interacting sites of lechwe and cattle of the Kafue basin.

can be abrogated in HIV/AIDS. This should be cause of concern given the impact of the HIV/AIDS pandemic in resource poor countries such as Zambia with high prevalent BTB in livestock. Given the lack of diagnostic services in most rural settings where BTB prevalence is high in cattle populations, possible cases of BTB may actually go undetected [12]. With *M. bovis* being naturally resistant to a first line antituberculosis drug (pyrazinamide) and a threat of its possible circulation in humans may cause concern despite the probability being remote. In Zambia, the general lack of knowledge on zoonotic tuberculosis [37] poses another risk factor for the ease of contracting the disease [37]. Observations like these are very important in the establishment of viable workable control programs in future when public awareness campaigns and education will be sought.

7. Transmission

In the Kafue basin, *M. bovis* infection has persisted in both lechwe and cattle for a very long time without understanding the conditions the causal relationship between cattle and lechwe antelopes [15]. It has however been observed by various scholars that disease is well maintained in both cattle and lechwe antelopes and that both species have subsequently become effective disseminators [15, 20, 22]. However, up to

now, intra- and interspecies transmission routes of infection between cattle and lechwe herds are yet to be illustrated. Thus there is need for further research to understand the transmission dynamics of the disease between lechwe antelopes and cattle. However, the gregarious nature of lechwe antelopes with higher herd densities obtained in drier seasons is thought to facilitate intraspecies transmission of *M. bovis* within the lechwe antelopes themselves [22, 29, 38]. Yearly seasonal floods are also thought to play a role in the propagation and dissemination of micro-organisms in the environment (a point which needs further study and elaboration), while overcrowding of animals during lekking (mating season) with extralarge assemblages at watering points enhances the direct animal to animal transmission due to the contagious nature of the disease [39]. Available literature on gross pathological distribution of tuberculous lesions in both cattle and lechwe antelopes intimate a respiratory route of infection [13, 15, 22] with over 60% of tuberculous lesions in both cattle (Figure 3) and lechwe antelopes (Figure 4) being confined to the lungs (Figures 3 and 4). This figure may be higher considering that abattoir-based meat inspection relies heavily on visible gross lesions which may be missed if such lesions are discrete and small. Such findings indicate that environmental contamination of pasture may be a less effective method of interspecies transmission between lechwe and cattle in the Kafue basin. Biological plausibility of disease transmission of *M. bovis*



FIGURE 3: Caseous granulomatous material in the Lung and draining lymph nodes of a cow during routine abattoir surveillance in Namwala District close to the Kafue basin.

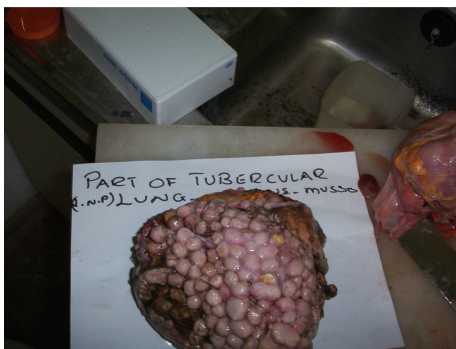


FIGURE 4: Severe Caseous granulomatous lung from a sick lechwe antelope that was seen lagging behind a large herd from the Lochinvar Game Management Area of the Kafue basin.

dictates that both environmental, host and agent attributes be optimal for transmission [34, 39], a feature which a few studies have remotely elaborated are reminiscent in the Kafue basin region [19]. Our previous work has indicated that grazing strategy apart from being a major predictor variable for BTB status in cattle, was also found to act as a proxy variable for other risk factors considered pivotal in both the maintenance and transmission of BTB between cattle and lechwe antelopes [35].

Epidemiological studies have shown that the grazing range of Kafue lechwe and cattle extensively overlap with the density of interaction increasing extensively during the dry season when transhumant herds (TH) migrate deep into the lechwe grazing grounds with further reductions of watering points coupled by few remaining good pastures [40]. Studies have shown high cattle and lechwe interaction points during the drier months (Figure 2) [40]. Lechwe antelopes and cattle are usually seen grazing together during this period (Figure 5). The absence of predators in the Kafue basin areas limits the transmission BTB to nonbovid species unlike the Kruger NP where the disease has been reported to cross into nonbovid species such as lions, cheetahs, and hyenas [41, 42]. Hence, tuberculous animals live longer and have a long period to transmit the disease to other animals.



(a)



(b)

FIGURE 5: Lechwe antelopes and cattle grazing together in the Game Management Areas of Lochinvar National Park of the Kafue basin (left picture indicates the Eastern Game Management Area, whilst the right picture indicates the Western Game Management Area).

8. Control

It has been observed that once BTB establishes itself in feral reservoirs the likelihood of eradication becomes complicated [42]. Additionally, the existence of a livestock/wildlife population further complicates the situation due to the likelihood of a bidirectional mode of transmission with possible contamination of the environment [43].

When control measures are envisaged, it is important to consider factors at play in the epidemiology of the disease. Further, the choice of workable control measures and strategies should take into account all key factors unique to each different ecosystem. A number of factors have been observed to be associated with BTB in cattle herds [44]. Oloya and coworkers observed that BTB was associated with different types of drinking water sources [45]. The same study also indicated that BTB is linked to specific geographical regions of production although they did not conclusively state the factors responsible for this observation [45]. BTB has also been shown to be associated with communal grazing, animal breed type and husbandry practices [44]. Studies have also shown that herd size has an influence on the prevalence of BTB [12, 30, 31, 46, 47]. Taken together, these factors are vital in formulating workable control strategies for cattle BTB. However, in free living wildlife populations, control measures such as test and slaughter schemes applicable to cattle are impractical.

Nevertheless, at the livestock/wildlife interface areas, more detailed studies are needed to understand factors related to the maintenance, spread, and transmission of the disease. Owing to impracticability of other control measures, the key factor at the livestock/wildlife interface area is to reduce or to completely remove interspecies contact. Selective cropping of old debilitated animals can also be used to remove would-be chronic shedders of the disease. Given the resource position of most developing countries, the use of vaccines at the moment is still impracticable.

9. Conclusion

Once policies to control bovine tuberculosis at the livestock/wildlife interface areas has been envisaged, the determination of the role of wildlife, domestic animals, and the environment in the maintenance and spread of mycobacterial pathogens is important. This requires further research on the ecological and biological disease determinants of mycobacterial infections at the livestock/wildlife interface. In summation, it is important to base control policies on objective and empirical evidence that have taken into account critical deterministic factors of disease maintenance, dissemination, occurrence, and susceptibility.

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