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Transmission of foot and mouth disease at the wildlife/livestock interface of the Kruger National Park, South Africa: Can the risk be mitigated?

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ABSTRACT

In Southern Africa, the African buffalo (*Syncerus caffer*) is the natural reservoir of foot and mouth disease (FMD). Contacts between this species and cattle are responsible for most of the FMD outbreaks in cattle at the edge of protected areas, which generate huge economic losses. During the late 1980's and 90's, the erection of veterinary cordon fences and the regular vaccination of cattle exposed to buffalo contact at the interface of the Kruger National Park (KNP), proved to be efficient to control and prevent FMD outbreaks in South Africa. However, since 2000, the efficiency of those measures has deteriorated, resulting in an increased rate of FMD outbreaks in cattle outside KNP, currently occurring more than once a year.

Based on retrospective ecological and epidemiological data, we developed a stochastic quantitative model to assess the annual risk of FMD virus (FMDV) transmission from buffalo to cattle herds present at the KNP interface. The model suggests that good immunization of approximately 75% of the cattle population combined with a reduction of buffalo/cattle contacts is an efficient combination to reduce FMDV transmission to one infective event every 5.5 years, emulating the epidemiological situation observed at the end of the 20th century, before current failure of control measures. The model also indicates that an increasing number of buffalo present in the KNP and crossing its boundaries, combined with a reduction in the vaccination coverage of cattle herds at the interface, increases 3-fold the risk of transmission (one infective event per year).The model proposed makes biological sense and provides a good representation of current knowledge of FMD ecology and epidemiology in Southern Africa which can be used to discuss with stakeholders on different management options to control FMD at the wildlife livestock interface and updated if new information becomes available. It also suggests that the control of FMD at the KNP interface is becoming increasingly challenging and will probably require alternative approaches to control this disease and its economic impact.

1. Introduction

Foot and mouth disease (FMD) is considered one of the most important infectious animal diseases in the world, mainly because it inflicts severe economic losses due to the restrictions in trade of livestock and its products within infected countries (Thompson et al., 2002). In southern Africa, the epidemiology of this disease is substantially different than in other regions, mainly due to specific circulating strains (SAT1, SAT2 and SAT3) and the role of reservoir played by African buffalo (*Syncerus caffer*) populations (Vosloo et al., 2002; Vosloo and Thomson, 2004). This wild bovid is widespread in southern Africa's protected areas and represents a serious challenge for the control of FMD, particularly among cattle living in close proximity to natural habitats of buffalo. During the last decades of the 20th century, the implementation of specific control measures in exporting countries in the region, such as veterinary cordon fences and regular vaccination of cattle herds exposed to buffalo contacts, has managed to limit the occurrence of the disease in the region to less than one outbreak per decade. However, since 2000, the region has been experiencing a serious re-emergence of the dis-

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ease (Baipoledi et al., 2004; Jori et al., 2009; Thomson et al., 2013a), with a frequency of at least one outbreak per year in areas where the disease was previously under control.

Epidemiological models are tools that provide useful insights into complex situations associated with the management of animal diseases at the wildlife/livestock interface (Miller et al., 2013) and are developed to improve our understanding on the effect of external inputs, through representation of the interactions between components of a complex system. Such tools can be helpful in discussions with (domestic and wild) animal health authorities and managers about the critical pathways of transmission and the assessment of different scenarios on disease outcomes in order to guide decisions. In that context, the development of stochastic epidemiological models that take into account the complex dynamics of FMDV have been modelled in the past, to estimate the risk of FMD transmission posed by different wildlife species in Zimbabwe and more recently, to take into account landscape heterogeneity, and climatic variability in the transmission of FMDV at the wildlife–livestock interface of Kruger National Park (KNP), (Dion and Lambin, 2012). In our study, we used a stochastic approach with the goal of integrating quantitative information of cattle and buffalo movement across the veterinary cordon fence surrounding the KNP, and using available data accumulated by the animal health and wildlife authorities working at the interface of the KNP during the last two decades to measure the risk of FMD transmission in that area. The goal of the model was to estimate the annual probability of cattle becoming infected with FMDV at the interface of the KNP and to compare the impact of several mitigation measures on the annual occurrence of the disease during recent years.

2. Methods

2.1. Study area

The study area is the KNP wildlife/livestock interface, described in detail by Jori et al. (2009) and other authors (Van Schalkwyk et al., 2014). The KNP and adjacent private wildlife areas, inhabited by free-ranging buffalo populations, are recognised as the FMD-infected zones of the country (Fig. 1). Adjacent to these fenced borders lies the buffer zone, mostly comprising communal farming areas, where rural communities graze their cattle and which is divided in two sections: (i) a portion directly adjacent to the FMD infected zone, where cattle are vaccinated three times a year, referred to as the buffer zone with vaccination (BZV), and (ii) a second portion adjacent to the BZV, where animals are not vaccinated but where increased livestock surveillance and movement control are implemented, known as the buffer zone without vaccination (BZNV). Adjacent to the latter is an inspection zone, where increased surveillance is implemented through the inspection of domestic livestock every 28 days. In the infected zone, BZV and BZNV, restrictions on animal movement are also enforced to prevent the occurrence and spread of outbreaks among cattle herds, while in the FMD-free zone (rest of South Africa), no restrictions are applied.

2.2. Definition of the risk and model formulation

Since long distance air-borne transmission is extremely unlikely to occur in southern Africa (Sutmoller et al., 2000), we considered direct transmission as the main route of FMDV transmission between an infected and a susceptible animal.

The quantified risk (output of the model) was defined as the annual probability for at least one bovine from the BZV becoming infected with FMDV as a result of a contact with an infected wild buffalo from the KNP. This probability $P(I_{\text{cbz}})$, was modelled as follows:

$$P(I_{\text{cbz}}) = 1 - (1 - P_{\text{cbz}})^{n_{\text{cbz}}}$$

where n_{cbz} is the number of cattle in the BZV and P_{cbz} the probability that one cattle head of this population becoming infected with FMDV from a buffalo transmitting virus.

Since this event can happen through two independent and compatible events, I_{cbz} will be the result of the union of two probabilities: the probability (P_{A}) that a bovine gets infected by a buffalo escaping from the KNP into the communal grazing areas of the BZV and, the probability (P_{B}) that a bovine enters the KNP and becomes infected through contacts with buffalo in the park. According to probability laws, the union of P_{A} and P_{B} is equal to the sum of both probabilities minus the product of those probabilities (Saporta, 2006). Therefore, $I_{\text{cbz}} = (P_{\text{A}} + P_{\text{B}}) - (P_{\text{A}} \times P_{\text{B}})$.

The pathway of events considered in the model is based on a preliminary qualitative risk assessment (Jori et al., 2009) illustrated in Fig. 2.

The release assessment considered the annual probability for a buffalo to excrete FMDV. Most young buffalo, which are usually born during midsummer (November–February), become infected between 3 and 6 months of age (Thomson and Bastos, 2004), when maternal antibodies wane (Bengis et al., 1986). By the time they reach one year of age, almost 90% have been infected and show circulating antibodies to the three SAT type viruses (Thomson et al., 1992), and most surveys of buffalo in KNP and surrounding protected areas show FMD seroprevalence values that range between 80 and 90% (Jori et al., 2014). In the acute stages of infection, young buffalo excrete FMDV in roughly the same quantities and by the same routes as infected cattle and become highly contagious (Gainaru et al., 1986). Within 15 days of infection, the virus can no longer be recovered from the tissues, secretions or excretions, with the exception of cells in the pharyngeal mucosa, where the virus may persist for extended periods of time, resulting in carrier buffalos (Condy et al., 1985).

Therefore, the annual probability for a buffalo becoming infected, and excreting FMDV (P_{i} in Fig. 2) can occur as the result of 3 event probabilities:

i) A young weaned buffalo younger than one year is infected and becomes viraemic ($P1.1$).
ii) A young weaned buffalo younger than one year has become infected and becomes a carrier, after this period of viraemia ($P1.2.$).
iii) A buffalo older than one year has become a carrier, after becoming infected during the first year of his life ($P1.3.$).

As a result of the two different scenarios proposed, P_{A} and P_{B} were assessed on the basis of historical data collected by wildlife management authorities and the Veterinary Services from the study area as well as from recent published literature (Table 1).

The exposure assessment focused on the probability of livestock becoming infected as a result of infectious contacts with excreting buffaloes. Potential scenarios of transmission involving other wildlife (antelope) species or small ruminants were not considered in our study since the transmission of FMDV from buffalo to cattle is the most common scenario (Jori et al., 2009; Tekleghiorghis et al., 2014) in the Southern African context, the other domestic and wild species playing a minor role in FMD transmission (Jori et al., 2009; Weaver et al., 2013).