Modeling Foot and Mouth Disease risk factors in Botswana

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Abstract

Various factors may contribute to the spread of an infectious transboundary disease such as FMD. Careful assessment of the risk of importing the virus in an area may help focus preventative measures. In the case of FMD two modes of transmission *i.e.* airborne and contact should be considered. To determine the likelihood of contact or airborne transmission of FMD into herds kept under communal livestock management practices in Botswana two models were developed. The outcome of the models showed that contact transmission is the most likely way of disease introduction and spread in the livestock herds of the communal areas of Botswana. Conditions favouring airborne transmission are not present.

Keywords: Livestock, Foot and Mouth Disease, Southern Africa, Modelling, Risk factors

Résumé

Différents facteurs peuvent contribuer à la diffusion d'une maladie infectieuse transfrontalière telle que la fièvre aphteuse (FMD). L'évaluation précise du risque d'importation du virus dans une zone peut aider à mettre au point les mesures préventives. Dans le cas de la fièvre aphteuse, deux modes de transmission sont à considérer: celle par voie aérienne et celle par contact. Pour déterminer la probabilité de contact ou de transmission par voie aérienne de la fièvre aphteuse dans des troupeaux de bétail gérés communautairement au Botswana, deux modèles ont été développés. Le résultat des modèles a montré que la transmission par contact est la voie la plus probable d'introduction et de diffusion de la maladie dans les troupeaux de bétail des zones communautaires du Botswana. Les conditions favorisant la transmission par voie aérienne n'y sont pas présentes.

Mots-clés : Bétail, Fièvre aphteuse, Afrique australe, Modélisation, Facteurs de risque, Elevage communautaire

Resumo

Vários fatores podem contribuir para disseminar uma doença contagiosa sem fronteiras como a febre aftosa (FMD). A avaliação cuidadosa do risco de importação do vírus em uma área pode ajudar no foco de medidas preventivas. No caso da febre aftosa dois modos de transmissão - pelo ar e por contato - devem ser considerados. Para determinar a probabilidade de transmissão da febre aftosa por contato ou pelo ar dentro de rebanhos mantidos sob práticas de manejo comunal em Botsuana dois modelos foram desenvolvidos. O resultado dos modelos mostrou que a transmissão por contato é a via mais provável de introdução e disseminação da doença nos rebanhos das áreas comunais de Botsuana. Condições que favoreçam a transmissão pelo ar não estão presentes.

Palavras-chave: Gado, Febre aftosa, Sul da África, Modelizando, Fatores de risco

Introduction

Effective control and prevention of a transboundary infectious disease such as Foot and Mouth Disease (FMD) relies largely on the careful assessment of the risk of introducing the virus in an area. Various factors may contribute to the spread of the virus. In the Matsiloje and Matopi areas of Botswana, for example, illegal transboundary movements of infected livestock from a neigbouring country resulted in a disease outbreak. Further transmission of the virus into the susceptible herd can be the result of contact or can occur via the air. To determine the likelihood of contact or airborne transmission of FMD in Botswana into herds kept under communal livestock management practices two models were developed. The likelihood of each mode of transmission in the circumstances prevailing in Botswana was determined.

Material and methods

Model parameters for contact transmission

To develop the model for contact transmission of FMD virus, certain assumptions had to be made. First, it was assumed that 10 cattle per month entered into Botswana from a neigbouring country. This figure can be considered a reasonable estimate and was based on estimates made by the Botswana Department of Animal Health and Production. Furthermore, it was assumed that FMD was present in the neigbouring source population at a prevalence of 0.1 and that on average 1 infected animal was smuggled into Botswana per month. Once the infected animal was introduced into the susceptible population, the number of infective animals that this animal produced during its entire infective period was defined as R_0.

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Under communal grazing practices in Botswana, the following factors were considered to determine the level of contact between the infected animal and the susceptible population:

- An infected animal will be kept within the susceptible herd and graze in a small cluster. However, it will share pasture as well as water sources with other herds in the communal area and hence mix temporarily with animals from other susceptible herds.
- Close contact between infected and not-infected animals is more likely to occur overnight when animals are kraaled, at watering points or when animals are packed into crush races during routine vaccinations.

Based on the above factors and review of the literature (Ferguson *et al.*, 2001) an average R_0-value of 1.3 was used.

Model parameters for airborne transmission
The main factor determining the level of airborne transmission of FMD virus is the maximum distance over which a plume containing infective virus produced by an infected cattle herd on one side of a cordon fence can travel and successfully infect susceptible animals on the other side of the fence. Due to lack of field data, a lot of assumptions had to be made to simplify the model and yet obtain an appreciation of the likelihood of airborne transmission. Values for the parameters of the model were derived from published data (Table 1).

To allow for a comparison between the airborne and the animal contact model, the same prevalence in the source population (P = 0.1) was assumed.

Based on meteorological data from the region, an average wind speed of 2 m/s was used in the model. It was also assumed that the susceptible animals were located downwind from the infected herds.

Under an extensive husbandry system, cattle graze over extensive areas and therefore are seldom stationary in one area for a long period of time. For the purposes of the model, 6 hours was assumed to be a reasonable upper limit for the length of time that the susceptible herd had to graze in one area in order to receive the plume of virus from the infected herd. The infected animals also have to be at the appropriate place at the exact time and graze there for the same period of time.

The quantity of virus excreted by a certain number of infected animals over a certain time period is given by:

$$Q_t = \log(N_a \bullet 10^q \bullet \frac{t}{24})$$

Where Q_t is the quantity of virus excreted over a time period
N_a is the number of infected animals excreting virus
q is the quantity of virus produced per 24 hours per animal
t is the time period the infected animal(s) stays and excretes virus

To simplify the model, the total amount of virus (Q_t) was assumed to be released all at once. Furthermore, it was assumed that the plume underwent biological decay at the two given decay rates (Table 1) until reaching the susceptible animal(s).

The time (T) that the plume would take to reach the target population was calculated by using the “IF” command of Microsoft excel as presented in the following formula:

$$= IF\left\{\left[\frac{(1-Q_t)}{-decay_1}\right] \le 10, \frac{(1-Q_t)}{-decay_1}, \frac{[1-(Q_t - 10 \bullet decay_1)]}{(-decay_2)} + 10\right\}$$

Where Q_t is the quantity of virus excreted over a time period
$decay_1$ is the virus decay per minute up to 10 minutes
$decay_2$ is the virus decay per minute after 10 minutes

Table 1: Parameters used to model the airborne transmission of FMD

Parameter	*Value*
Quantity of virus excreted per 24 hrs per animal (log $TCID_{50}$)*	3.5[a]
Virus decay per minute up to 10 minutes (log) at 55% RH	2.5[b]
Virus decay per minute after 10 minutes (log) at 55% RH	0.044[b]
Minimum dose of airborne FMD virus infection for cattle (log $TCID_{50}$)	1[a]
Wind speed (m/s)	2
Hours animal stays in one place	6

[a] Based on data from Sørensen *et al*. (2000).
[b] Based on data from Donaldson (1972).
* $TCID_{50}$ is the 50% tissue culture infectious dose (The dilution of material which would infect 50% of inoculated cell cultures).

The maximum distance was calculated using the following formula:

$$d = s \times T$$

Where: d is the maximum distance
s is the wind speed

For successful transmission to occur, the minimum dose of virus that must be inhaled by the target animal was 10 $TCID_{50}$ (Table 1). In this study case a plume containing

$$\frac{10^{3.5} \times 6}{24} = \frac{10^{3.5}}{4}$$

virus was assumed to be excreted by an infected animal and inhaled by a single animal after being subjected to decay. The decay is a function of *i.a.* time and thus distance. The distance at which the viral dose reaches $10^{1.0}$ was thus the maximum distance over which an animal could become infected. This maximum distance determined the area in which the susceptible animal had to move during a period of six hours for transmission to occur. This parameter was used to judge the likelihood of airborne transmission.

Results

Contact transmission model
Since it was assumed that one infected animal (P = 0.1) entered into Botswana per month and with an estimated R_0-value of 1.3 the infection will spread into a susceptible herd.

Airborne model
According to the airborne transmission model and assuming one infected animal excreted a plume of virus for 6 hours, a maximum distance of 91 meters between the source and the target will allow for effective airborne transmission of the virus (Table 2).

Discussion

It is a widely accepted that the most common mechanism of FMD transmission is through physical or close contact between infected and susceptible animals, often as a result of movement of infected animals (Pharo, 2002; Cleland *et al*, 1995). Graves *et al*. (1971) demonstrated transmission of FMD virus from an experimentally infected steer to susceptible steers through moderate physical contact. Their observations indicate that transmission occurred on the first day after a contact period of at least 21 hours. The animal could transmit the virus for 7 – 8 days with the most infectious period on the third day after infection. This observation was supported by the work of Scott *et al*. (1966) who could not demonstrate transmission after day 8. These findings indicate that although contact transmission is the most efficient mode of FMD dissemination, introduction of an infected animal does not necessarily imply that every susceptible contact animal will become infected. The cattle stocking density in Matsiloje/Matopi area is around 6 – 10 animals per square kilometer. This is relatively low and as a consequence very low contact rates between herds can be expected within the communal pastures. This and the fact that animals are likely to be kraaled longer during the rainy season may explain why the observed outbreaks were restricted to a few kraals and did not spread from herd to herd. James & Rossiter (1989) indicated that chance was a very important aspect in the establishment and spread of a disease, particularly when the number of infected individuals in the populations is low.

The indication from our airborne model is that increasing the prevalence increases the likelihood of airborne transmission (by increasing the maximum distance within which a susceptible animal has to graze around for six hours). However, an increase in the prevalence also implies an increase in the number of infected animals smuggled across the cordon fence and thus an increase in the number of susceptible animals infected through contact transmission. Furthermore, under the communal grazing system it is highly unlikely for animals to graze in one area for a continuous period of six hours. In our model we assumed the source of airborne virus to be cattle. This was based on the fact that in the area surrounding Matsiloje there are no intensive pig farms that could have provided a source of virus for airborne transmission. Gloster *et al.* (1981) and Donaldson *et al.* (1982) indicated that in most outbreaks where airborne infection has been implicated, pigs have been identified as the source of infection and cattle as the species most likely to be affected downwind. Sørensen *et al.* (2000) were able to show through computer-simulated studies that the single most important factor in airborne transmission was the species of origin of airborne virus. Only when pigs were affected did transmission of airborne

Table 2: The estimated maximum distance over which successful transmission of FMD virus occurs given that an infected animal excretes virus for 6 hours.

Hours animal stays (t)	Quantity of virus excreted (Q_t)	Time to log 1 (T)	Distance (d)
	Log $TCID_{50}$	Minutes	Meters
6	2.8979	0.76	91.10

virus occur over distances of 3 kilometers. The non-involvement of pigs in the two outbreaks would thus serve to further support the suspicion of introduction and spread of disease through animal contact rather than airborne.

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