Transboundary and Emerging Diseases

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ORIGINAL ARTICLE

Foot-and-Mouth Disease in Tanzania from 2001 to 2006

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Summary

Foot-and-mouth disease (FMD) is endemic in Tanzania, with outbreaks occurring almost each year in different parts of the country. There is now a strong political desire to control animal diseases as part of national poverty alleviation strategies. However, FMD control requires improving the current knowledge on the disease dynamics and factors related to FMD occurrence so control measures can be implemented more efficiently. The objectives of this study were to describe the FMD dynamics in Tanzania from 2001 to 2006 and investigate the spatiotemporal patterns of transmission. Extraction maps, the space-time K-function and space-time permutation models based on scan statistics were calculated for each year to evaluate the spatial distribution, the spatiotemporal interaction and the spatiotemporal clustering of FMD-affected villages. From 2001 to 2006, 878 FMD outbreaks were reported in 605 different villages of 5815 populated places included in the database. The spatial distribution of FMD outbreaks was concentrated along the Tanzania-Kenya, Tanzania-Zambia borders, and the Kagera basin bordering Uganda, Rwanda and Tanzania. The spatiotemporal interaction among FMD-affected villages was statistically significant ($P \leq 0.01$) and 12 local spatiotemporal clusters were detected; however, the extent and intensity varied across the study period. Dividing the country in zones according to their epidemiological status will allow improving the control of FMD and delimiting potential FMD-free areas.

Introduction

Foot-and-mouth disease (FMD) is, according to the World Organisation for animal health (OIE), the most important animal disease because of its economic, commercial and social impact. FMD is caused by highly contagious RNA virus (*Aphthovirus, Picornaviridae*) affecting even-toed ungulates (*Artiodactyla*). There are seven FMD virus (FMDV) serotypes (O, A, C, SAT1-3 and Asia1) with limited cross-protection between them (Paton et al., 2009). The distribution of serotypes and FMD-affected countries is uneven across the globe: A and O are reported in South America, Asia and Africa, Asia1 is found in Asia and the Middle East and SAT serotypes are generally restricted to Africa (Paton et al., 2009). FMDV circulate between countries in endemic regions and periodically cause outbreaks in countries free of disease. The FMD status, given by the presence of disease and the control methods applied, influence the trade between countries according to OIE regulations. Today in Africa, only three countries are considered completely free of FMD (Lesotho, Madagascar and Swaziland), thus free to trade, and three countries (Botswana, Namibia and South Africa) have FMD-free zones and can therefore export (with restriction) part of their livestock products (OIE, 2010).

In Tanzania, FMD is endemic and the continuous transmission of FMDV causes a number of outbreaks

every year. The persistence of the disease is because of the movement of livestock within and across international borders (Kivaria, 2003). The presence of four serotypes (SAT 1, 2, O and A) and large number of wildlife reserves with susceptible species, especially African buffalo, complicates the control of FMD. To date, vaccination and movement restrictions have not been able to control the disease and are basically implemented to limit its economic impact (Kivaria, 2003). FMD surveillance is based on passive case detection and reporting by veterinary officers in the field. FMD diagnosis is based on clinical signs. A limited number of samples are submitted to laboratory for confirmation and even less samples are submitted for serotyping (Swai et al., 2009).

FMD has a great impact on Tanzania's livestock sector, one of the main economic activities in the country with over 16 million heads of cattle in 2002–2003 (FAO, 2003). FMD control, which should help reducing poverty in Tanzania (Perry and Rich, 2007), requires improving the current knowledge on the disease dynamics and factors related to FMD occurrence so control measures can be implemented more efficiently. The objectives of this paper were to describe the FMD dynamics in Tanzania from 2001 to 2006 and investigate the spatiotemporal pattern of transmission.

Materials and Methods

Study site

Tanzania is a sub-Saharan country in East Africa bordered by eight countries and the Indian Ocean (Fig. 1). It covers around 945 000 km^2 and its climate varies from tropical to temperate. Tanzania's economy is mainly based on agriculture, a sector that employs about 85% of its population. Livestock production, which has been increasing in the past years, is limited by disease occurrence (e.g. FMD) and the presence of tsetse flies and wildlife protected zones in large areas of the country. Although FMD is a multi-species disease, cattle, which constitute the main livestock sector, will be the only species considered in this study.

Data

A database with the total number of cattle FMD outbreaks in Tanzania from 1 January 2001 to 31 December 2006 was provided by the Epidemiology Section of the Ministry of Livestock Development and Fisheries. The FMD cases were clinically diagnosed at village level by district veterinary officials. Information on the number of cattle with FMD signs (cases) as well as the number of cattle at risk, deaths, vaccinated and treated collected in the field by veterinary officials were entered into the

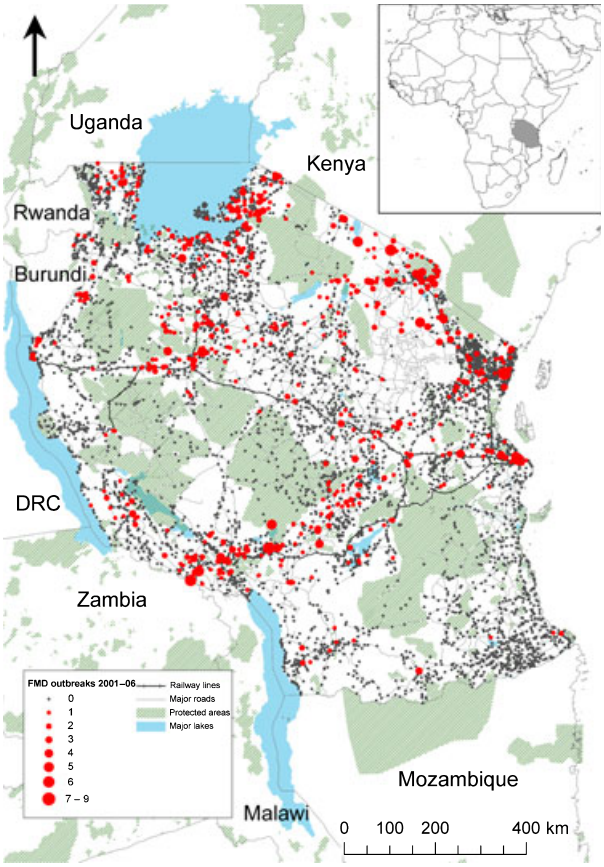

Fig. 1. Map of Tanzania with the locations where Foot-and-Mouth Disease (FMD) outbreaks were notified from 2001 to 2006 plotted as graduated red circles. The locations where no FMD outbreaks were notified are represented as black dots. The main roads, major railway lines, water bodies in Tanzania as well as the protected areas in the region are also represented.

Trans-boundary Animal Diseases Information (TADInfo) system at the Ministry. The locations of the outbreaks were geo-referenced by GPS in the field. A FMD outbreak was defined by the presence of one or more animals from a single cattle herd with clinical FMD. For each FMD outbreak, the village name, geographical position and the date when the FMD clinical signs were reported were available.

The database was cleaned and merged to the list of all villages in Tanzania obtained from GEOnet Names Server (http://earth-info.nga.mil/gns/html/namefiles.htm). Further geographical data were obtained from the Food and Agriculture Organization (FAO) (http://www.fao.org/geonetwork/srv/en/main.home) and the World Database on Protected Areas (http://www.wdpa.org/). Villages in mainland Tanzania were the unit of analysis. All geographical data were projected to UTM Zone 36S coordinate system (datum WGS84) and represented using ArcGIS 9.2 (ESRI, Redlands, CA, USA).

Analyses

Descriptive analyses

The total number of outbreaks per week and a 5-week rolling mean were represented to evaluate the temporal evolution of the FMD occurrence. To explore the spatial distribution of FMD outbreaks, extraction maps were used to determine high density areas (Lawson and Williams, 1993). For each year, an extraction map was obtained by dividing the edge-corrected kernel densities of FMD locations and total population at risk (i.e. all villages in the country) (Bailey and Gatrell, 1995). The bandwidth (or smoothing parameter) was determined by the normal optimal method (Bowman and Azzalini, 1997; Stevenson et al., 2000). The same bandwidth was used for the numerator and denominator as suggested by Kelsall and Diggle (1995). Similarly, weekly extraction maps were obtained to create an animation showing the temporal evolution of the FMD outbreaks in Tanzania from 2001 to 2006 (Video Clip S1). The analyses were conducted using the packages zoo, sm and spatstat in R 2.10.1 software (http://www.R-project.org).

Spatiotemporal analyses

The spatiotemporal pattern of FMD virus transmission among villages in Tanzania was assessed by two complementary methods. First, a global measure – the space-time K-function – was calculated for each year to evaluate the spatiotemporal interaction among FMD-affected villages (Wilesmith et al., 2003). The space-time K-function represents the cumulative number of FMD-affected villages during the study period within a given distance (s) and time (t) from a randomly chosen FMD-affected village divided by the expected number of FMD-affected villages in a spatiotemporal window (or intensity λ) (1).

$$K(s,t) = \lambda^{-1}\mathrm{E}\,[\text{number of further events occurring within distance (s) and time(t) of a random event}] \quad (1)$$

To interpret the results, $D(s,t)$ (2) with $K(t)$ and $K(s)$ the time and space K-functions, respectively, and $D_0(s,t)$ (3), a relative measure representing the excess risk attributable to the space–time interaction, were calculated (Diggle et al., 1995).

$$D(s,t) = K(s,t) - K(t)K(s) \quad (2)$$

$$D0(s,t) = D(s,t)/[K(t)K(s)] \quad (3)$$

The space-time K-function was estimated using maximum separations of 110 days and 325 km for t and s dimensions, respectively. Monte Carlo random label permutations ($n = 999$) were used to determine the P-value (Diggle et al., 1995). $D_0(s,t)$ results were plotted in 3-dimension graphs to facilitate comparisons across years. Spatiotemporal coordinates where the FMD-affected villages doubled, at least, the expected number ($D_0(s,t) > 1$) (Sanchez et al., 2005) were highlighted in red. Excess risk in temporal and spatial dimensions can be related to infectiousness and local spread, respectively (Wilesmith et al., 2003). The splancs package in R was used to calculate the space-time K-functions.

Secondly, local spatiotemporal clusters were determined by a space-time permutation model based on scan statistics (Kulldorff et al., 2005). FMD-affected villages in each year were scanned using a cylinder window to evaluate the number of observed and expected FMD outbreaks in spatial (base) and temporal (height) dimensions. By varying the cylinder size and applying maximum likelihood methods, the scan statistics allow determining the location, size, relative risk (RR) and statistical significance of spatiotemporal clusters. The maximum spatial and temporal window sizes were set up at 50% as recommended by Kulldorff (2009). An elliptic spatial window was used and only non-overlapping clusters with at P-value <0.05, based on 999 Monte Carlo replications, were considered. The analyses were implemented using SatScan 8.2.1 software (Information Management Services, Inc, Boston, MA, USA).

Results

From 2001 to 2006, 878 FMD outbreaks were reported in mainland Tanzania in 605 different locations (villages) of 5815 populated places included in the database. The number of outbreaks per location ranged from 0 to 9, and the FMD-affected villages were mainly located on the borders and northern and central areas of Tanzania. Not many outbreaks were reported in the south or inside protected areas (Fig. 1).

The number of reported outbreaks varied over the study period (Fig. 2). During 2001 and 2002, the number of outbreaks remained low ($n = 52$ and 62, respectively) compared to 2003 ($n = 160$) and especially 2004 ($n = 410$). The number of FMD episodes went down in 2005 ($n = 59$) and increased again in 2006 ($n = 135$), mainly because of a peak of outbreaks in the second trimester of the year (Fig. 2). Similarly, the spatial distribution of FMD-affected villages was uneven as shown by the extraction maps (Fig. 3) and the animation (Video Clip S1). The highest densities of FMD-affected villages were recorded in 2003 and 2004. From 2001 to 2003, high density areas were mainly located in the border area with Kenya. In 2004, that zone was still predominant but there were high density areas in centre of the Tanzania and close to the border with Zambia. In 2005, the densities were low but FMD-affected villages were distributed along

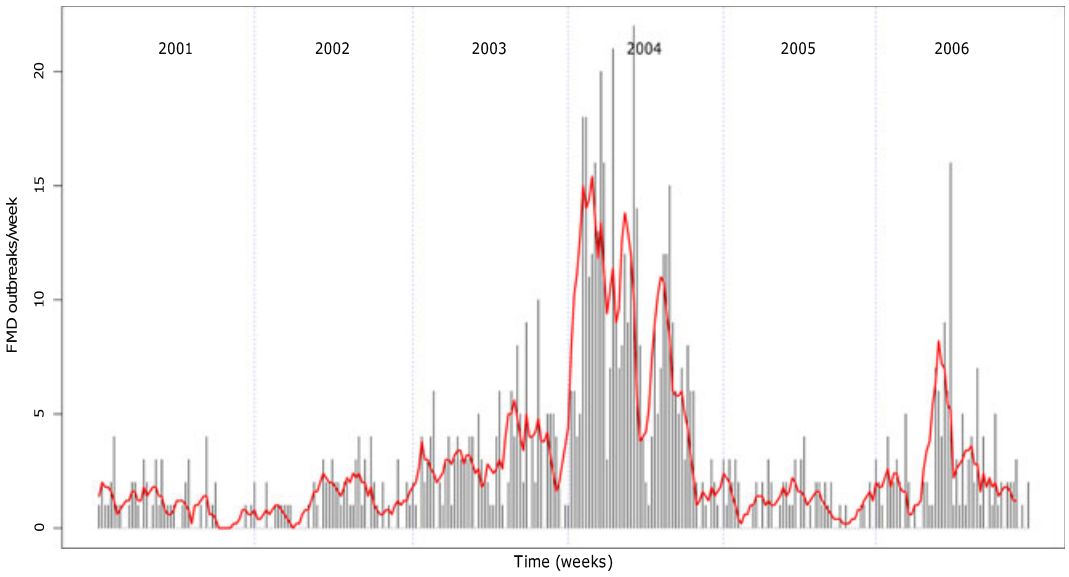

Fig. 2. Graph representing the number of Foot-and-Mouth Disease (FMD) outbreaks (histogram) and the 5-week rolling mean of FMD outbreaks (line) per week from 2001 to 2006.

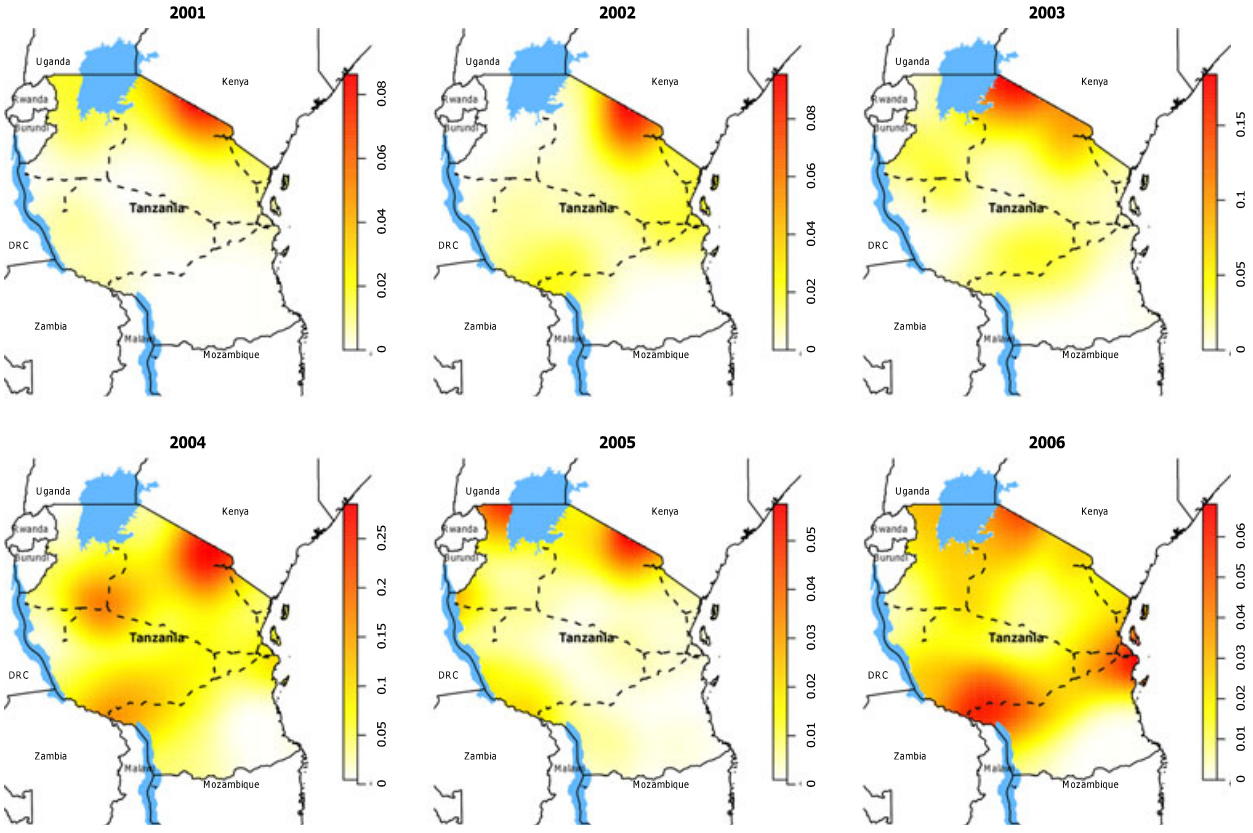

Fig. 3. Yearly edge-corrected extraction maps representing the areas with excess risk of Foot-and-Mouth Disease outbreaks in Tanzania from 2001 to 2006. The major railway lines (dashed line) were added as spatial reference.

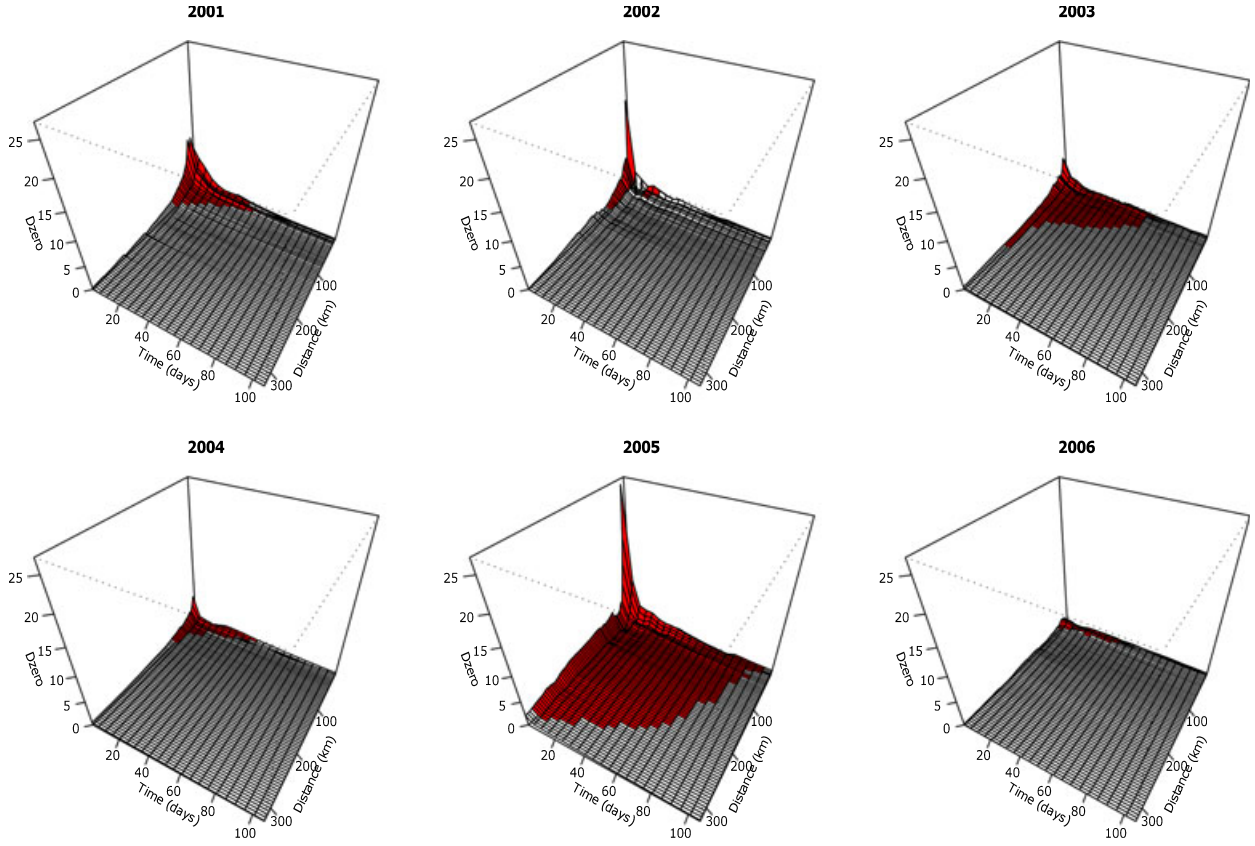

Fig. 4. Yearly space-time K-function representing the spatiotemporal interaction among Foot-and-Mouth Disease outbreaks in Tanzania from 2001 to 2006.

the borders with the neighbouring countries. In 2006, there was a generalized distribution of FMD-affected villages over the country with the highest densities in the area bordering Zambia and the coast.

The spatiotemporal interaction among FMD-affected villages was statistically significant (P-value <0.01) each year; however, the extent and intensity varied over the study period (Fig. 4). FMD-affected villages were clustered at 80–100 km in 2001 and 2002 but 2001 had a larger temporal component (50 days approximately). In 2003, there was an increase of the clustering in both dimensions which would indicate an increase of the infectiousness in time (65 days) and space (200 km). In 2004, the clustering of reported FMD outbreaks was limited and similar to 2001. In 2005, the space-time K-function showed an intense clustering at shorter distances (30 km) and time window (5 days) ($D_0(s,t) > 25$). The clustering persisted, with a lower intensity though, up to 300 km and 100 days spatiotemporal window. Finally, in 2006, clustering of FMD outbreaks was not readily apparent and it was limited in time (45 days) and space (20 km).

The scan statistic detected 12 statistically significant spatiotemporal clusters: three in 2003, two in 2004, four in 2005 and three in 2006 (Table 1 and Fig. 5). No clusters were detected in 2001 or 2002.

Discussion

There are numerous papers reviewing the epidemiological situation of FMD in Africa (Vosloo et al., 2002; Rweyemamu et al., 2008b; Paton et al., 2009) and Tanzania in particular (Kivaria, 2003) but the number of studies analysing field data are scarce. Gathering and analysing information on disease dynamics in sub-Saharan Africa has been pointed out as one of the priorities in FMD control in the region (Kivaria and Kapaga, 2002; Rweyemamu et al., 2008a). The government of Tanzania is planning to establish FMD-free zones that would allow exporting livestock products. The results from this study should help delimiting the most suitable regions and identifying the areas that require special attention. This task however will need strong political commitment and technical input as the heterogeneity observed on the spatial and temporal

Table 1 Information on the local Foot-and-Mouth Disease (FMD) spatiotemporal clusters detected per year in Tanzania from 2003 to 2006 (no clusters were detected in 2001 or 2002). SatScan spatiotemporal clusters

Cluster Num.	Dates	No. of cases	Expected cases	Relative risk	*P*-value
2003					
1	20/02/2003 to 09/04/2003	10	1.31	1.31	0.001
2	05/06/2003 to 09/07/2003	9	1.06	8.52	0.002
3	11/09/2003 to 31/12/2003	45	18.38	2.45	0.001
2004					
4	17/01/2004 to 02/04/2004	107	49.09	2.18	0.001
5	08/05/2004 to 17/09/2004	134	74.26	1.80	0.001
2005					
6	02/01/2005 to 19/03/2005	14	4.07	3.44	0.002
7	20/03/2005 to 09/04/2005	4	0.27	14.75	0.008
8	29/05/2005 to 16/07/2005	11	2.85	3.86	0.003
9	20/11/2005 to 31/12/2005	5	0.42	11.8	0.002
2006					
10	09/01/2006 to 19/02/2006	7	0.57	12.27	0.001
11	28/08/2006 to 17/09/2006	6	0.49	12.27	0.004
12	23/10/2006 to 31/12/2006	8	1.14	7.01	0.017

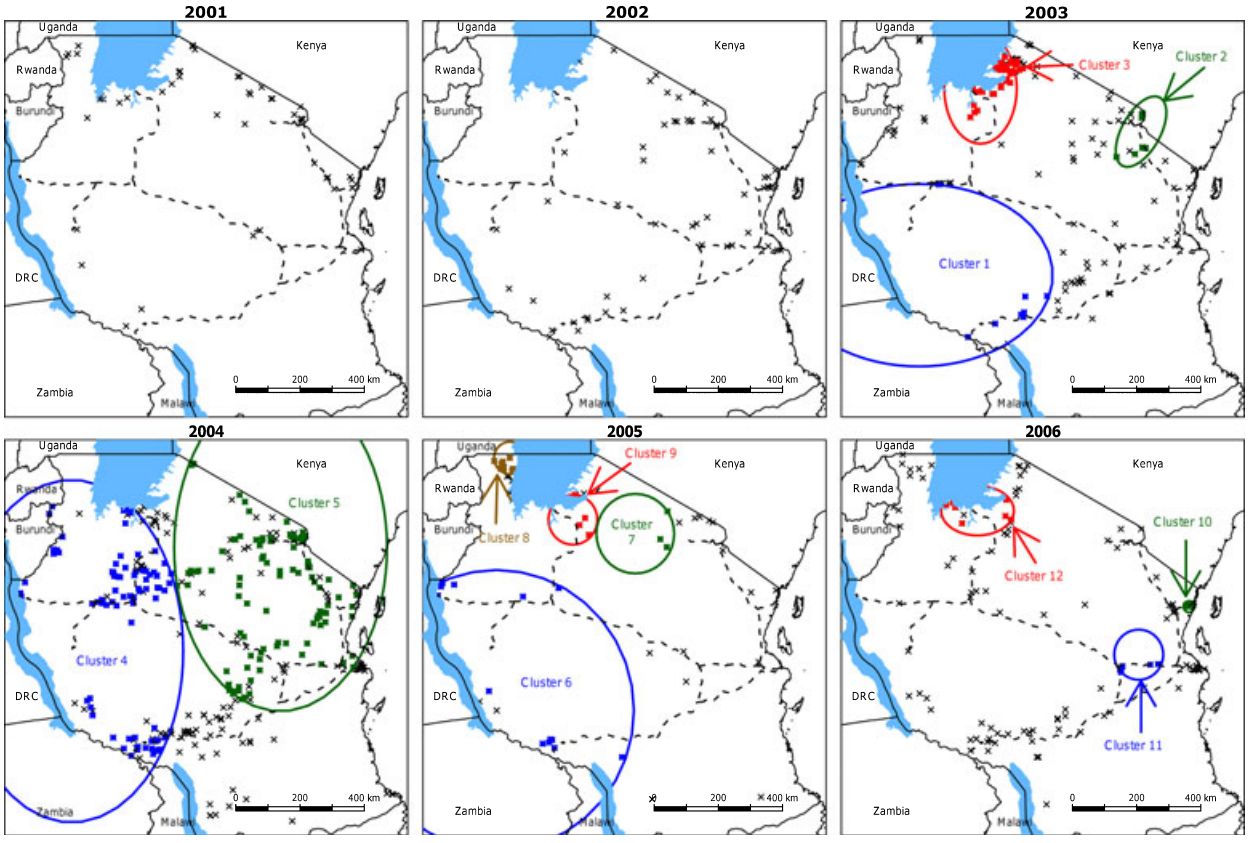

Fig. 5. Map of Tanzania where the Foot-and-Mouth Disease (FMD)-affected villages (squares) in the statistically significant spatiotemporal clusters detected by the space-time permutation scan statistic model are represented in different colours per year. The spatial limits and the cluster numbers are also indicated. The FMD-affected villages reported on the same year but not included in any of the spatiotemporal clusters are represented as black crosses. The major railway lines (dashed line) were added as spatial reference.

distribution of FMD outbreaks highlight the difficulty to implement control measures which have been, at least during the study period, inefficient to limit the FMDV transmission.

In 2001 and 2002, the spatiotemporal patterns observed corresponded to an endemic situation: there was a moderate FMDV transmission (Fig. 4) that was homogeneous in the affected area as no local clusters were detected during that period (Fig. 5). The area with the highest density of cases (Kenya-Tanzania border – Fig. 3) is known as the Maasai ecosystem; and because of the high concentration of wildlife, extensive livestock movement and the pastoral mode of livestock farming, the area has been described as a hot-spot for maintenance and transmission of FMDV and other trans-boundary animal diseases (FAO, 2006, Sangula, 2006).

Both the K-function and the scan statistic space-time permutation models applied only take into account the FMD-affected villages and the area delimited by them each year. The results should be interpreted considering this limitation as well as the parameters set in the analyses (i.e. maximum temporal window of 178 days and non-overlapping clusters for the scan statistic). The use of such methods was deemed appropriate to study the FMDV transmission (Picado et al., 2007) taking into account the origin of the data: reported cases. Passive surveillance makes impossible to ascertain the status of villages where FMD was not reported. Nevertheless, analogous results were obtained when the spatial clustering of FMD outbreaks was assessed using the space K-function. This method ignores the time component but incorporates the underlying distribution of villages at risk. Details on the space K-function methodology and results are available in Data S1.

The increase on the number of reported outbreaks in 2003 and especially 2004 may correspond to an epidemic phase possibly because of the expansion of existing FMDV or the introduction of a new FMDV serotype in the area (Thomson et al., 2003; Balinda et al., 2009; Paton et al., 2009). The global and local spatiotemporal clustering (Figs 4 and 5) observed in 2003 would support this statement. Interestingly, the spatiotemporal interaction at a country level in 2004 was moderate (Fig. 4). This pattern would correspond to a random distribution of reported outbreaks at a global scale as shown by the enlarged area with high density of FMD-affected villages over the country, masking the local transmission in different areas detected by the scan statistic (Fig. 5 and Table 1). The situation observed in 2004 may be because of a combination of factors: trans-boundary or interspecies transmission, use of poorly inactivated vaccines (FAO, 2006; Balinda et al., 2009) or introduction of 'new' FMDV serotypes. Those factors may occur simultaneously, at variable intensity, in different areas (Rweyemamu et al., 2008b; Swai et al., 2009). Molecular epidemiological tools may have provided a better description of the FMDV transmission in 2004 (Kivaria and Kapaga, 2002), although an increase of report submission during the implementation of the Pan Africa Control of Epizootics (PACE) could also explain this observation.

The number of FMD outbreaks reported in 2005 was similar to the endemic phase (2001–2002) but a 'new' pastoralist area (cluster eight in Fig. 5 and Table 1) was affected: the Kagera basin bordering Uganda, Rwanda and Tanzania (FAO, 2006; Balinda et al., 2009; Ayebazibwe et al., 2010). The high degree of spatiotemporal interaction and the number of local clusters detected (Figs 4 and 5) could be compatible with the introduction of a new FMDV serotype in a relatively naive population. Finally, in 2006, the increase in the number of outbreaks, mainly located around the Tanzania-Zambia railway line (Fig. 3), was related to a low spatiotemporal interaction (Fig. 4) but to three small local clusters in the first and last trimesters (Fig. 5 and Table 1). A type O outbreak was reported in the area in 2006 (FAO, 2006) but, as in 2004, the pattern observed seems to correspond to a series of non-related local clusters of FMD transmission throughout the country occurring simultaneously.

As already described by Rweyemamu et al., (2008b), the FMD epidemiological situation in East Africa is the most complicated in the world. In Tanzania, the endemic phases seem to be mainly related to the transmission in pastoralist areas in the North, and epidemic periods tend to affect most of the country. As risk factors and transmission characteristics differ in each region (Swai et al., 2009), surveillance and control measures should be implemented at regional level. Zoning should allow improving surveillance and control of FMD as well as establishing FMD-free zones. Using the major railway lines as reference, three major zones could be delimited in mainland Tanzania: (i) FMD endemic area, north of the central railway line which includes the Maasai ecosystem and the Lake Victoria area. FMD control in this area is challenging and efforts should be made to improve the knowledge on the factors contributing to the persistence of FMD in the pastoralist communities. (ii) FMD epidemic area, between central and Tanzania-Zambia railway lines, where the number of cases increase during epidemic phases. Surveillance need to be improved to detect the disease at early stages and control propagation along the international borders and communication networks. (iii) Low-density FMD area, south of the Tanzania-Zambia railway line, is a potential FMD-free zone, precisely the Mtwara corridor in the south-eastern corner of the country. Strict surveillance and control methods as well as vaccination of

all FMD susceptible livestock in the area should be implemented.

Wildlife may play a role in maintaining and spreading the disease in the region but the fact that FMD outbreaks in Tanzania were mainly clustered in bordering areas and communication networks would indicate that FMDV transmission was primarily related to human activity. This hypothesis is supported by recent observations in Uganda (Ayebazibwe et al., 2010).

The analyses presented here are based on reported FMD outbreaks at a village level. The data may not be complete and the temporal and spatial locations may not be totally accurate (i.e. location of the villages may not correspond to the place where the animals got infected). However, despite the limitations, it was possible to clearly differentiate various epidemiological scenarios in Tanzania. The results presented in this paper shows that (i) spatiotemporal analyses can help understanding the FMD dynamics even with limited data and (ii) routinely collected data could be used to set up FMD risk-based surveillance. To be effective, any control or surveillance programme must involve all the countries in the region.

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Supporting information

Additional supporting information may be found in the online version of this article:

Video Clip S1. Weekly extraction maps: animation showing the weekly evolution of the Foot-and-Mouth Disease outbreaks in Tanzania from 2001 to 2006.

Data S1. Global spatial clustering of Foot-and-Mouth Disease outbreaks per year assessed using the space K-function.

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