Cost-benefit and feasibility analysis for establishing a foot-and-mouth disease free zone in Rukwa region in Tanzania

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Abstract

Tanzania has the second largest livestock population in Africa and livestock keeping is an integral part of most people's livelihoods. Foot-and-mouth disease (FMD) is a transboundary disease, affecting cloven-hoofed animals, that is currently endemic in Tanzania. The Tanzania Development Vision 2025 aspires to make the livestock sector more competitive. Part of this plan foresees establishing a FMD disease free zone in Rukwa region to be able to increase the export of animals and animal products. The aim of this study was to assess the economic efficiency and feasibility of establishing such an FMD-free zone and to advise policy makers on the profitability of the investment.

A stochastic benefit-cost model, set-up in Palisade @Risk for Excel for a time frame of ten years, was developed to assess whether the benefits of establishing a FMD-free zone would outweigh the costs. Data were collated from reviewing literature, government statistics, and key informant interviews with farmers, traders and veterinarians in Tanzania, and complemented by informed assumptions and expert opinion. Moreover, feasibility aspects including underlying infrastructure, market structures and resource availability were discussed based on key informant interviews, literature review and historical analyses. The net present value for the establishment of a FMD-free zone was negative and the benefit-cost ratio was below one (mean 0.09, min 0.05 - max 0.15 in the scenario considering vaccination of all susceptible domestic animals, and mean 0.11; min 0.06 - max 0.20 when considering vaccinating cattle only), excluding potential benefits from trade. The sensitivity analysis showed that variables related to the cost of vaccination had the largest negative impact on the net present value. The proposed FMD-free zone in Rukwa region is unlikely to be cost-effective with the current FMD status and export trade prospects in Tanzania. Interviews with stakeholders revealed that vaccine availability, funding, farmers' willingness to participate and lack of staff continuity in key roles were the main barriers to establish a reliable FMD control programme in the country. Recommendations towards FMD control and potential short and middle term strategies are discussed.

Key words: Foot-and-mouth disease, vaccination, cost-benefit analysis, feasibility analysis, Tanzania, Rukwa region

1. Introduction

Tanzania is located in East Africa and has the second largest livestock population in Africa, with a standing population of 32 million cattle, 20 million goats, 5 million sheep, 2 million pigs, and 42.7 million chickens in 2019 (Anonymous, 2019). Although the livestock sector has grown steadily in the last years, this has been mainly due to an increase in livestock numbers rather than productivity gains. As in other low- and middle-income countries (LMICs), livestock keeping is an important and integral part of many people's livelihoods. Half of the households keep livestock and 70% of poor rural populations depend on livestock for their income and livelihoods (MLFD, 2013).

Foot-and-mouth disease (FMD) is a viral disease affecting cloven-hoofed animals. It has negative impacts for large and small-scale farmers in endemic countries, including direct economic losses, stemming from reduced livestock production due to fever, loss of appetite, drop in milk yield, lameness, and pain (Jemberu et al., 2014; Lyons et al., 2015; Nampanya et al., 2015; Chaters et al., 2018), and indirect economic costs, related to implementation of control measures, such as movement bans, pre-emptive culling or vaccination of animals (Knight-Jones and Rushton, 2013). At the national level, FMD obstructs the possibility of exporting animals and animals' products to FMD-free countries.

In Tanzania specifically, FMD has an important negative impact on milk production and draft power for crop production at the household level, ultimately reducing income generation and compromising children's food and nutrition security, particularly in the north of the country, where children are reliant on milk as a protein source (Queenan et al., 2017; Casey-Bryars et al., 2018). The disease is endemic and widespread across Tanzania, with numerous outbreaks due to serotypes O, A, SAT1 and SAT2 serotypes, occurring every year in different regions

(FAO and OIE, 2018). Currently, the country is on Stage 2 of the Progressive Control Pathway (PCP-FMD) (FAO, 2018), which means that a risk-based control plan has been designed, but there are no official FMD control measures, and animal vaccination is a private business decision.

The Tanzania Development Vision 2025 aspires to make the livestock sector more competitive by producing world class quality animals and products. The Vision is interpreted in the National Livestock Policy (2006), which supports the establishment of an FMD disease free zone in line with international guidelines, and the Sanitary and Phytosanitary Measures (SPS) agreement. Briefly, member countries agree to recognise disease free zones as sources of animals and animal products for international markets, subject to risk assessments. The Ministry of Livestock and Fisheries (MoLF) expects that the establishment and maintenance of a disease-free zone would promote the availability of safe and quality food products (like meat and milk) for local and export markets, ultimately improving earnings of livestock producers and businesses in the value chain, and enhancing the performance and efficiency of the national veterinary services by eventually freeing resources through an improved animal disease status (Ministry of Livestock and Fisheries Development, 2012).

In 2016, the Rukwa region, located in south western Tanzania (Figure 1), was selected by the MoLF to pilot the establishment of an FMD-free zone in Tanzania. Rukwa region was chosen based on its geographical location and natural barriers demarcating the area, as well as its potential for livestock production and infrastructure, given that an established partnership existed between public and private sectors. The proposed FMD control plan aimed to create initially disease-free populations in the ranches (individual-owned commercial ventures that manage large areas of land to produce grazing livestock either on their own or by renting the land to producers) in Rukwa by vaccination, then expand the FMD-free zone to the entire region and establish a supportive surveillance system. It was therefore believed by MoLF that controlling the disease in the region was feasible in principle and could create spill-over benefits to other parts of the country by for example facilitating a steady supply of cattle that would create business opportunities in the national beef value chain. As for any project of this magnitude, a large investment was needed, and external funding would have to be secured. In 2015, it was therefore decided to apply for a project preparation grant from the World Trade Organisation (WTO) to investigate formally whether the investment would be profitable and the intervention feasible. This paper presents the outcomes from this analysis.

Rukwa region is characterised by a predominantly extensive agro-pastoral production system, which keeps indigenous zebu cattle (known as Ufipa zebu), sheep, goats and some other livestock (pigs and chickens). Crop production is the predominant economic activity, with farmers successfully producing maize and rice as the main crops. Cattle have an important role in cultivation as a source of draft power and manure. They depend on communal grazing and there is no common practice to give supplementary feeding, even for large herds. After harvest, some of the cropland and stubble fields are used for livestock grazing based on agreements (and sometimes payments) with the landowners (Anonymous, 2002). In most agro-pastoralist households, cattle off-take rates (i.e., the proportion of cattle sold or slaughtered for consumption in a year) are low, typically less than 10% (Musemwa et al., 2010). Cattle are mainly sold to meet expenses such as school fees, food and clothing purchases, or capital for building. This pattern is also observed in very large herds. Hence, cattle are not seen as a way of wealth creation or economic activity through sales, but rather a store of capital. Only a minority of farmers in the region (less than 1%) keep livestock for commercial purposes, selling up to 300 animals per year, with off-take rates ranging from 14-38% on commercial ranches (Ministry of Livestock and Fisheries Development, 2011). Semi-intensive production systems are found at the large beef ranches of Kalambo, owned by the National Ranching Company (NARCO), and Nkundi, owned by the Sumbawanga Agricultural and Animal Food Industries Limited (SAAFI) ranch. In urban areas of Rukwa region, semi-intensive zero grazing is practised by smallholder dairy farmers that keep on average two to three animals to produce milk for consumption in the household and to sell to the urban population. According to data provided by MALF (personal communication Dr Makungu S. Luka), FMD animal level prevalence in Rukwa region remained largely stable and overall low (3%) between 2013 and 2017; the total number of cases reported over this period were 11,730. The expected between-herd prevalence during the same period was 5%, and the within-herd incidence rate 20%. Consequently, MALF expected that there would be substantial benefits to be gained from the reduction or elimination of the disease in this region.

The objectives of this study were to estimate the costs and benefits of establishing an FMD-free zone in the Rukwa region, Tanzania, to discuss the feasibility of such an intervention, and to formulate recommendations for policy makers based on the outcomes of the analysis.

2. Material and Methods

2.1. Study area

Rukwa region is one of 25 regions in Tanzania, and is located in the south western part of the country. It covers an area of 27,765 km^2, of which 76.2% is land, and the remaining 23.8% is water covered (Anonymous, 2014). The region is well demarcated by natural barriers which are formed by Lake Tanganyika on the south west (border with Democratic Republic of the Congo), Lake Rukwa in the north east, and the Katavi National Park in the north west (Figure 1).

2.2. Study overview and model development

A cost benefit analysis (CBA) was conducted to assess whether the benefits of establishing an intervention of vaccination and surveillance in Rukwa region, to reduce and eventually eliminate FMD, would outweigh the costs. The study, including data collection, model development and analysis, was divided into three chronologic stages:

First stage: Following an initial conceptualisation of the study plan, a scoping visit was held in Tanzania in September 2016 by BH, JMl and JMg. The aim of this first visit was to gain an overview of Rukwa region, including its geography, livestock and human population, socioeconomic activities, animal diseases present in the study area, infrastructure, and services. Statistics and official data were collated when available. Following this visit, the structure of the CBA was refined and data needs for the economic model and feasibility assessment were identified. The authors agreed that it would be informative to conduct a historical analysis to look at lessons learned from past FMD control efforts in Tanzania to inform future control options. Subsequently, a total of 58 stakeholders were interviewed to gather information on past FMD control activities, trade opportunities, and inputs such as types and prices of vaccines and their supply channels (questions presented in the supplementary material). Out of the 58 stakeholders, 49 were public officers (22 ministry officials, five zonal officers working at Zonal Veterinary Laboratories, 11 officers of the Rukwa Regional Office, seven district officials and four from the milk or meat board); six were from the private sector (mainly livestock keepers), and three academics affiliated with the Sokoine University of Agriculture. Stakeholders were selected in a way that would allow good coverage of all topics investigated making use of the professional networks of the Tanzanian co-authors. Because of the nature of the questions asked, such as the structure and processes of FMD control, institutional memory, lessons learned, infrastructure, diagnostics and capacity, most stakeholders were from different parts of the public services.

Second stage: Primary and secondary data collected during the first stage were cleaned and used as inputs in the economic model (a detailed description of the model is provided in section 2.3). The model was simulated for a range of vaccination scenarios as described below. Data gaps were identified, and further literature searches were conducted. Moreover, additional stakeholder interviews (n=10) were conducted in Tanzania by a local researcher (JM). All people interviewed were veterinarians, four were still in service working as field veterinarians, in diagnostic laboratories or vaccine regulation, five were former public employees at director level and one was a private veterinarian. In addition, a narrative analysis of past FMD control efforts in Tanzania was performed.

Third stage: The first author made a second visit to Tanzania in March 2017. During this visit, the progress with the analysis was discussed with representatives from MoLF, and remaining data gaps were addressed by visiting and interviewing further stakeholders (n=6; four were public officials and two were from the private sector). Following this second visit the model was updated, the analyses were completed, and the results interpreted and discussed.

2.3. Economic analysis

Stochastic models were developed in Microsoft Excel with Palisade @Risk software for simulation modelling; they are available on request from the corresponding author. Probability distributions were used when necessary to account for variability in input parameters.

Conceptualisation: Two situations were compared in a cost-benefit analysis, namely 1) a baseline that described an endemic situation with regularly occurring FMD outbreaks that necessitate an outbreak response and cause production losses and expenditures for palliative treatment ; 2) an intervention based on government led mass vaccination and surveillance that would reduce and potentially eliminate FMD in the region. Benefits were expected to result from the avoidance of disease costs and outbreak control costs with the intervention; costs included the expenditures related to interventions. Additional expected revenues from increased trade and in particular export revenue were not estimated as a benefit, but included in the final step (see below). The following items were estimated:

i. Production losses and expenditures for palliative treatment (disease costs)
ii. Costs of outbreak investigation and control
iii. Costs of the intervention, i.e., mass vaccination and surveillance activities to support the vaccination campaign
iv. Comparison of costs and benefits: The question was asked whether the benefits from the avoidance of disease and outbreak response costs would be large enough to cover the costs of the intervention.
v. In case of a negative net value, a calculation was made to estimate what additional income would need to be generated from trade revenue for the programme to break even.

Disease, outbreak and intervention costs were estimated, taking into account existing animal numbers in Rukwa region at the time of the study. Disease costs were estimated by main types of herds found in Rukwa region (Table 1). These included agro-pastoralist and/or pastoralist small, medium, and large herds, and herds on the ranches Nkundi Ranch, Kalambo Ranch and Kalambo Ranch blocks (i.e., grazing land of 13 blocks of an average area of 3,000 hectares hired to farmers for feeding their cattle). The data for small, medium, and large herds were gathered from the Rukwa Livestock Development Annual Report (Anonymous, 2012). The data for the ranches and the Kalambo Ranch blocks were received from ranch managers based on their records when visiting the ranches.

All prices used were in Tanzanian Shillings (TSh); 1 USD = 2,235 TSh at the time of analysis (2017). The time frame chosen for the analysis was 2017 to 2026. All future costs and benefits were translated into present values by multiplying the costs or benefits by the discount factor using Equation 1:

$$1/(1+r)^t \quad \text{Equation 1}$$

Where r = discount rate: 3% was selected in line with other cost-benefit analyses for animal disease in production animals (e.g. Lyons et al., 2021; Hakim et al., 2020) and t = the time in years.

2.3.1. Production losses and expenditures for palliative treatment (disease costs)

Disease costs were estimated for cattle only, and included production losses due to mortality (L_M), losses due to abortion (L_A), losses due to reduced milk yield (L_{RMY}), losses due to reduced weight gain (L_W), losses due to loss of traction in agro-pastoralist systems (L_T) and expenditures for palliative treatment (E_{PT}) (Equations 2 to 7). Following discussions with farmers and veterinary authority staff in Rukwa region, losses due to premature culling of young and adult stock, as well as prolonged calving interval were considered negligible, and therefore not considered in the model.

The number of cattle in each production group (cows, steers, bulls, oxen for draft, steers calves and heifers) was calculated by multiplying the total number of cattle in a herd by the proportion of animals in the respective group stratified by herd size (small 1 to 10; medium 11 to 49 and large ≥50 animals) and ranches (Table 1). This calculation was needed, because there were no data available on the actual numbers of different types of cattle for the different herd sizes. Physical loss coefficients, market prices and production data used in the model to estimate FMD production losses and expenditures and their sources are listed in Table 2.

Losses due to mortality (calves and heifers only, no mortality was reported for adult cattle)

$$L_M = N_{CV} \cdot Mt_{YS} \cdot AV_{CV} + N_H \cdot Mt_{YS} \cdot AV_H \qquad \text{Equation 2}$$

Where

- N_{CV} stands for the number of calves,
- N_H for the number of heifers,
- Mt_{YS} for the extra mortality rate due to FMD in young stock,
- *AV* for live animal value for calves *(CV)* and heifers *(H),* respectively.

The live animal value is approximated as the market price. However, because animals are commonly sold on needs basis and are often a store of capital, the term animal value appears more adequate.

Loses due to abortion

$$L_A = (N_C + N_H) \cdot P_P \cdot Mb \cdot AR \cdot CA \qquad \text{Equation 3}$$

Where

- N_C stands for the number of cows,
- N_H for the number of heifers,
- P_P for proportion of cows and heifers that are pregnant,
- *Mb* for morbidity,
- *AR* for the extra abortion rate due to FMD in clinically ill, pregnant animals, and
- *CA* for costs per abortion.

Because there is a dearth of accurate data on the effect of FMD on abortion, an abortion rate published for a similar context, namely Kenya (Ellis and Putt, 1981), was used as a conservative estimate. The cost of abortion was estimated as the loss of the calf foregone approximated as the value of a calf (AV_{CV}) and the treatment cost for an adult animal ($EV_{A,}$ Table 2).

Losses due to reduced milk yield

$$L_{RMY} = N_C \cdot P_L \cdot Mb \cdot (P_{MLA} \cdot N_{MLA} \cdot RMY_A + P_{MLC} \cdot N_{MLC} \cdot RMY_C) \cdot MY \cdot MP \qquad \text{Equation 4}$$

Where

- N_C stands for the number of cows,
- P_L the proportion of cows in lactation,
- Mb for morbidity,
- P_{MLA} and P_{MLC} for the proportion of cows affected with milk loss during acute *(A)* and chronic *(C)* FMD,
- N_{MLA} and N_{MLC} for the number of days with reduced milk yield,
- RMY for the rate of reduced milk yield,
- MY for average daily milk yield, and
- MP for the market price per litre of milk.

Losses due to reduced weight gain

$$L_W = (N_C + N_B) \cdot Mb \cdot RWL \cdot VM \qquad \text{Equation 5}$$

Where

- N_C stands for the number of cows,
- N_B for the number of bulls,
- Mb for morbidity,
- RWL for the rate of weight loss assuming that the reduced weight gain would only be partly compensated in the long term, and
- VM for the value of the meat lost.

While it can be argued that the weight loss does not matter for producers not operating on a commercial schedule, we decided to incorporate the weight loss for all producers, as producers selling on a need basis may need to sell their animals at a time when they have a loss in condition. Anecdotal evidence from producers in FMD endemic areas suggests that some animals might not fully recover over time; i.e. we are effectively modelling a worst case situation.

Losses due to loss of traction in agro-pastoral systems

$$L_T = (N_O \cdot Mb)/2 \cdot P_{OP} \cdot WTL \cdot RRI \cdot (A_c \cdot V_{ARC} \cdot \mathrm{P_{Land}} + A_c \cdot V_{AMC} \cdot (1\text{-}\mathrm{P_{Land}})) \qquad \text{Equation 6}$$

Where

- N_O stands for the number of oxen,
- *Mb* for morbidity,
- Divided by 2, because the land area is worked by an ox pair
- P_{OP} for the probability of an outbreak during planting season,
- *WTL* for the oxen working time lost in days due to FMD,
- *RRI* for the rate of reduced income per day from crop due to late planting,
- A_C for the land area under crop,
- P_{Land} for proportion of land area used for each crop,
- V_{ARC} for the value of the average rice crop per hectare, and
- V_{AMC} for the value of the average maize crop per hectare.

Expenditure for palliative treatment

$$E_{PT} = N_A \cdot Mb \cdot VTR_A \cdot EV_A + N_Y \cdot Mb \cdot VTR_Y \cdot EV_Y \qquad \text{Equation 7}$$

Where

- *N* stands for the number of adult *(A)* and young *(Y)* cattle,
- *Mb* for morbidity,
- *VTR* for the proportion of clinically ill cattle getting treatment, and

- *EV* for the expenditures for the veterinary palliative treatment.

Farmers and local veterinarians described that preventative vaccination for FMD was not common. Consequently, the costs of preventative vaccination were considered to be negligible and not included.

Total disease cost

The losses and expenditures were added up to estimate the total disease costs per farm type (small, medium, large) or ranch. These figures were then multiplied by the number of households keeping cattle in the area (Table 3), the reported between-herd prevalence (5%), and a correction factor of 2 for underreporting (assumption based on discussions with veterinary authorities in Rukwa region and animal health professionals from MoLF), to estimate the total disease impact for the region.

Costs of outbreak investigation and control

An outbreak investigation is expected to be conducted according to existing regulations (Anonymous, 2003). At the time of the study the existing regulations were as follows. Veterinary field officers, farmers and district veterinary officers (DVOs) were expected to report any FMD suspect case, upon detection, to the local zonal veterinary centre (ZVC). From there, the suspected case would be reported to the central epidemiological unit at MALF. Following reporting, two officers from the local ZVC would go to the farm to undertake further investigation including clinical examination (or post-mortem if animal is dead) and collection of biological samples (blood and tissue from blisters). These samples would be sent to the Tanzania Veterinary Laboratory Authority (TVLA) in Dar es Salaam either directly or through the TVLA in Iringa to the TVLA in Mpwapwa, Dodoma, or occasionally to the laboratory at the Sokoine University of Agriculture. Laboratories would be contacted in advance to prepare staff and to avoid delays in processing of the samples. All laboratories were known to provide results in a reliable manner, between two days to two weeks after submission. The laboratories used antigen ELISA (NSP, solid phase and sandwich ELISA) and PCR tests for antigen identification. Any positive results would be communicated to the Director of Veterinary Services or Directorate of Veterinary Services (DVS) on a weekly basis and sent to the DVO for further action. The information on serotyping provided by the laboratory would allow targeted vaccination using the appropriate serotype.

The following control measures were commonly put in place upon reporting of an outbreak. If an outbreak occurred in a block, all neighbouring blocks would receive vaccination, but there would be no vaccination of the affected block as it was already infected. If an outbreak occurred in an agro-pastoralist village, there would be vaccination in all sub-villages (i.e., hamlets, *vitongoji* in Swahili) in the village (apart from the already infected hamlet). Upon suspicion of FMD in a village, a movement ban would be set at the ward level or, alternatively, if a ward is affected, then a movement ban would be set at the district level. Commonly, the movement ban includes live animals and animal products in a zone of a 10 km radius and lasts until the disease has been controlled, or no more cases have been observed. Throughout the outbreak, DVOs would visit the ward or district regularly to check for clinical signs and to make sure that the movement ban is complied with. During the time of the movement ban, the purchasing power of the affected villages is reduced, because of a disruption of the common market patterns and an associated decrease in income.

To estimate the cost of outbreak response, the number of animals to be vaccinated needed to be estimated. Rukwa region had a total of 318 villages at the time of analysis, with an average of 1,903 FMD susceptible animals (calculation: total FMD susceptible animals from

Table 4 divided by 318), of which 1,222 were cattle (calculation: total cattle from Table 4 divided by 318). These values were used as baseline for the first year and an annual population increase of 3% (based on past data of livestock population growth) was assumed for the following years.

The annual outbreak response costs *(CostOB)* included vaccination costs related to an outbreak *(CostVO)* plus diagnostic costs *(CostD)*. *CostVO* were estimated by summing up the costs for the vaccine, materials used for administration of the vaccine, staff, and transport time. Input variables relevant for these calculations are given in Table 5.

$$Cost_{OB} = N_{OB} \cdot N_s \cdot (P_v + P_M) + C_{EV} + N_{OB} \cdot C_F + N_{OB} \cdot (C_S + C_L) \qquad \text{Equation 8}$$

Where

- N_{OB} is the number of outbreaks per year,
- N_S the number of FMD susceptible animals to be vaccinated,
- P_V the price of the vaccine by susceptible species, namely cattle (P_{VC}), sheep and goats (P_{VSG}) and pigs (P_{VSP}),
- P_M the price of materials per animal vaccinated (syringe [P_S], needle [P_N], water-based special paint to mark vaccinated animals [P_{Mas}]),
- C_{EV} the cost of equipment for the vaccinators (boots, cool box, icepacks and overcoats),
- C_F the cost of fuel for the car estimated by multiplying the litres of fuel needed per day (F_d) by the price of fuel (P_F) and the number of days a car would be used. Local veterinary authorities estimated that 500 animals can be vaccinated per day.
- C_S stands for cost for sampling, which included sampling materials and shipping samples to the laboratory.

- C_L stands for the costs for laboratory testing which includes testing suspected samples by PCR and virus isolation.

Input values were provided by local veterinary authority personnel based on their experience with FMD outbreaks. Because the outbreak response, including enforcement of the animal movement ban, is considered part of regular staff duties, and would not require additional resources, staff costs were not included. While there may be an opportunity cost of having to divert staff from their other duties (e.g., contributing to improving livestock health more generally), it was expected that a quantification of these opportunity costs (e.g., how much higher would livestock productivity have been had staff not been diverted) would not significantly affect the results.

The number of detected (i.e., reported) outbreaks in an endemic situation was considered to be an average of 6 outbreaks per year, with a minimum of 4.8 and a maximum of 7.2 outbreaks, based on a previous study (Allepuz et al., 2015). For the intervention scenario, it was assumed that the number of outbreaks following successful vaccination would be zero in line with studies demonstrating titres of clinical protection under field conditions for polyvalent vaccines (Lyons et al., 2017).

2.3.2. Costs of the intervention (mass vaccination and surveillance activities to support the vaccination campaign)

<u>Mass vaccination costs</u>

To estimate the cost of vaccination, the following parameters were considered: (i) number of vaccines and staff needed for vaccination, (ii) procurement of vaccines and storage, (iii) vaccine prices, (iv) vehicles needed and their maintenance costs, and materials and consumables needed for vaccination and animal identification.

Number of animals to be vaccinated and staff needed

Two vaccination scenarios were considered: (i) vaccinating cattle only and (ii) vaccinating domestic animals from all susceptible species (cattle, sheep, goats, and pigs). The number of animals to be vaccinated, stratified per district, are presented in Table 4. Two datasets on animal numbers were received; one from officers in Rukwa region and one from public statistics for the year 2016. The two datasets differed by about 26%. Inquiries were made to establish which dataset was a better reflection of actual numbers, but it was not possible to establish which dataset was more accurate. Consequently, average values between the two were used. A yearly livestock population increase of between 0 and 6%, with the most likely being 3%, was assumed, taking into account a decrease in mortality and increase in fertility, as a result of the FMD control; this was modelled using a Pert distribution.

It was expected that cattle need two to three vaccine doses per year, because of a relatively short duration of protective immunity. This was modelled using a uniform distribution. Only one vaccine per year was assumed to be needed for sheep, goats and pigs. Based on discussions with local authorities and the head of the regional veterinary services, the vaccination campaign would require teams of five to six people (i.e., a driver, a leader/coordinator and three to four vaccinators), constituted from local government staff, and supervised by the respective District Veterinary Officer (DVO). Local and national veterinary authority representatives communicated that no additional staff costs would accrue, as there was capacity in the system to absorb this extra work and deploy people from other parts of the country. Therefore, salaries for the vaccination team were not considered in the model. Like for the outbreak response, it was expected that a quantification of staff opportunity costs (e.g., how much higher would livestock productivity have been had staff not been diverted) would not significantly affect the results and was therefore not included. However, daily subsistence allowance (DSA) was considered to be an additional cost, namely

TSh 80k for a veterinary officer, TSh 60k for field staff, and TSh 50k for a driver per year. Staffing needs are described in the section on feasibility.

The number of vaccination teams were assumed to be four for Sumbawanga DC, four for Sumbawanga MC, three for Kalambo DC and three for Nkasi DC, equalling to a total of 14 vaccination teams. Local veterinary authorities estimated – based on their experience with the vaccination of animals in the region - that a team can vaccinate 500 animals per day, which gives a maximum of 123,000 livestock heads per year based on regular 246 working days per year in Tanzania.

Vaccine storage costs

To handle the anticipated volume of vaccines, the ZVC in Sumbawanga would need to buy new equipment to maintain cold chains during the mass vaccination programme, namely five deep freezers (258 litres: TSh 750k), five refrigerators (TSh 500k), 28 cool boxes (TSh 100k), and 112 ice packs (TSh 20k) (prices from www.jumia.co.tz).

Estimation of total vaccination costs

The total vaccination costs C_V for each scenario were estimated as follows (inputs in Tables 4, 5 and 6):

$$C_v = \sum[N_S \cdot N_D \cdot (P_{VS} + (P_N / N_{\mathrm{AVN}}) + (P_S / N_{\mathrm{AVS}}) + P_{MAs})] + N_T \cdot (C_{VH} + C_{DSA} + C_E) + C_{CC}$$

Equation 9

Where

- N_S is the number of susceptible species to be vaccinated,
- N_D the number of doses per species,

- P_{VS} the price of the vaccine by susceptible species,
- P_N the price for the needle,
- N_{AVN} the mean number of animals vaccinated per needle,
- P_S the price for the syringe,
- N_{AVS} the expected number of animals vaccinated before the automatic syringe breaks,
- P_{MAs} the price for marking animals after vaccination,
- N_T the number of vaccination teams,
- C_{VH} the cost of a vehicle and
- C_{DSA} the cost for daily subsistence allowance,
- C_E is the cost of equipment per team, and
- C_{CC} the cost of cold chain..

The number of teams needed was estimated by dividing the total number of injections needed by the capacity of vaccination per team (expressed in the number of animals that can be vaccinated). For the automatic syringe it was estimated by local veterinary authority representatives, based on their experience in mass vaccinating animals, that the average number of animals injected before breaking it was 7,500. For the needles, they estimated it to be used for 50 animals before changing.

Cost of vehicles needed for vaccine distribution and sample collection:

The running costs per vehicle *(C_{VH})* was estimated as follows (inputs in Table 5):

$$C_{VH} = N_{LFD} \cdot P_F \cdot N_{DCU} + P_{MS} \cdot 2 + P_T \cdot 3 \qquad \text{Equation 10}$$

Where

- C_{VH} is the cost per vehicle needed for vaccine distribution and sample collection,
- N_{LFD} the litres of fuel needed per day,

- P_F the price of a litre of fuel,
- N_{Dcu} the number of days each car would be used in one year,
- P_{MS} the price of each maintenance service, and
- P_T the price of a set of tires.

It was assumed that existing cars would be used for the mass vaccination campaign and that no additional cars would need to be purchased. Apart from the cars needed for the rolling out of the vaccination, two vehicles would be required for vaccine distribution and progress monitoring; namely one car to ship supplies to ZVC, and subsequent distribution to the districts (including vaccines, cool boxes, ice packs, etc), and a second to coordinate both surveillance and vaccination, and to facilitate communication and training sessions with field staff, livestock keepers and the general public.

Costs of surveillance activities to support the vaccination campaign

It was proposed by a senior officer from MALF that the following surveillance activities would be needed to support the vaccination campaign: (i) sensitise, (ii) create awareness and train livestock value chain actors, (iii) train field veterinary personnel (public and private) on FMD recognition and reporting; (iv) equip veterinary service staff with necessary logistical materials and (v) provide adequate technical support and sanitary measures. The costs for the Livestock Identification and Traceability System (LITS) were not included, as this is a national legal requirement and was expected to be rolled out independently of any disease specific control programmes.

Sensitise, create awareness and train livestock value chain actors

A campaign to raise awareness and train stakeholders in disease recognition and reporting was foreseen with training events for stakeholders (7) at the district headquarters: 80

stakeholders trained per district per year, with four (i.e., quarterly) training events (16 training events for the region). The total amount per training was calculated by multiplying the number of trainees and trainers by the DSA for the days attended (n=2) and travelled (n=1) plus the consumables for each trainee (Table 7) and overhead projector hire. It was assumed that the number of training events would be the same each year to maintain awareness and avoid intervention and surveillance fatigue.

A second activity, to make stakeholders aware of the intervention, raise awareness of FMD impacts and gain their support, would be to use local radio, and to share information through the village extension officer. One team per council would be deployed for this task with one driver and two communications officers (one communications leader and one communications assistant), and two village leaders per village visited (318 villages in total); DSAs are listed in Table 7. The team would spend one day per ward, twice a year. As there are 64 wards in all of Rukwa region, it would require 128 days of work. There would also be 10 information posters per village, to hang up in public places like shops, schools, churches, etc, and 365 short radio messages (one daily of 30 seconds) and 12 long radio messages (one monthly 30 minutes) (Table 7).

Train field veterinary personnel (public and private) on FMD recognition and reporting

To support effective surveillance, training for field veterinary personnel and DVOs would be offered twice per year on reporting, sample collection, data quality and robustness, and disease recognition at the regional level. The training would be conducted centrally in Sumbawanga. Each training event would host up to 15 people to ensure that each officer can attend the training once per year. Trainers would be senior staff (“senior trainers”), namely the regional veterinary officer and three additional relevant staff members from the headquarters and the ZVO.

The total amount per training was calculated by multiplying the number of trainees (n=15) and trainers (n=4) by the DSA for the days attended (n=3) and travelled (n=1), plus the consumables for each trainee and the costs for projector hire (Table 7). It was assumed that the number of training events would be the same each year to maintain and promote surveillance capacity.

Equip veterinary services with necessary logistical materials and provide adequate technical support

Diligent and prompt investigation of reported suspect FMD cases was deemed critical during the vaccination campaign. MALF staff proposed that five surveillance stations needed to be established in Rukwa region to coordinate and conduct relevant surveillance activities, and support vaccination efforts. For these stations, new equipment would be needed as described in Table 8. The total equipment costs were calculated by multiplying the number of items needed over the years by their costs.

For active surveillance, each station would collect 25 blood samples per year from FMD susceptible animals and send them to the laboratory services for testing. It was assumed that all these animals can be sampled in a day with the following costs: fuel for car, a driver, one coordinator, two veterinary field officers, and sample materials (vacutainer tube: TSh 500; plastic holder: TSh 100; needles: TSh 350; vial for serum: TSh 1,000). All samples would be shipped to the Centre for Infectious Diseases and Biotechnology (CIBD) in one delivery at a cost of TSh 1,600,000. The CIBD has capacity for antigen detection and antibody detection based on ELISA for serotypes A, O, and SAT 1, 2 and 3. Five samples from individual animals from the same site would be pooled into one sample (which is common practice in

CIBD) and tested for FMD antigen and antibody, this would cost TSh 44,000 to test. Molecular typing using PCR would be also done, which costs TSh 60,000 per pooled sample. The analysis of the data, risk analysis, and report writing was assumed to be absorbed as part of the regular duties of veterinary service staff and no additional costs were calculated for these services.

Border control

A total of ten check points for movement control were envisaged throughout the duration of the intervention, supported by police patrols to avoid illegal movements of animals, with police officers seconded from the police force. The costs for a checkpoint were estimated as follows: two livestock officers with a salary of TSh 450,000 per month, (i.e., TSh 5.4 m per officer per year), phones, electricity, computer and furniture, all at an estimated cost of TSh 20 m, and DSA cost for police officers and veterinary officers. These DSA costs were estimated as follows: Green border controls twice per week with four people (two police officers TSh 60k for DSA and two livestock officers TSh 60k for DSA) and one driver (TSh 50k DSA) plus the cost of fuel 50l TSh 2,000 per litre.

2.3.3. Estimation of benefits

The benefits were comprised of the disease costs avoided and the outbreak response costs avoided, due to the intervention. To estimate the disease costs avoided, the authors used their expertise and professional judgement, and data from previous vaccination efforts in other countries, to make assumptions on the between herd prevalence: between 3.5 and 4% in the first year of intervention, between 2 and 2.5% in the second year of intervention, between 0.5 and 0.6% in the third year of intervention and 0% from Year 4 onwards.

2.3.4. Comparison of costs and benefits (without considering benefits from trade)

Two measures were used to estimate the profitability of the project: benefit-cost ratio (BCR) and net present value (NPV). The BCR is the ratio between the sum of the present value of benefits and the sum of the present value of costs and was calculated using Equation 11.

$$BCR = \sum \frac{B_t}{(1+r)^t} \Big/ \sum \frac{C_t}{(1+r)^t} \qquad \text{Equation 11}$$

Where B=benefits C=costs; t=time in years; r=discount rate

The NPV represents the difference between the sum of the present value of the benefits (B) and the sum of the present value of costs (C), was calculated using Equation 12:

$$NPV = \sum \frac{B_t}{(1+r)^t} - \sum \frac{C_t}{(1+r)^t} \qquad \text{Equation 12}$$

Where B=benefits C=costs; t=time in years; r=discount rate

2.3.5. Estimation of break-even point

The differences between the cumulative benefits and costs of the FMD intervention over the time frame chosen were used to assess whether a breakeven point would be achieved within the time frame given. If there was no breakeven point, the shortfall in benefits was used to estimate the amount of trade revenue that would need to be generated for the programme to be considered acceptable from an economic point of view. This was calculated by dividing the shortfall in monetary units by ten years to estimate the average annual shortfall and then divide this by the export beef price. Three different export prices were used to model a best case, medium case and worst case scenario based on the export beef prices reported (Selina Wamucii, n.d.). The export prices were TSh 10,505 (USD 4.7) per kg (2016 price, best case), TSh 5,588 (USD 2.5) per kg (average between 2017 and 2018 price of USD 2.9 and 2.1, respectively), and TSh 2,235 (USD 1.0) per kg (2019 price, worst case). The resulting figure was divided by 1000 to estimate the total tons of beef that would need to be exported from Rukwa for the programme to break even in the region. This value was compared to export figures to inform a discussion on the likelihood of increased exports.

2.3.6. Sensitivity analysis

Sensitivity analysis was performed to quantify the impact of uncertainty and variability in the different input variables included in the model on the NPV using the software Palisade @Risk for Excel. The software's in-built sensitivity analysis tool was used, which performed multivariate stepwise regression for values sampled from the defined distributions to calculate beta regression coefficients. In multiple regression, the beta coefficient is the degree of change in the outcome variable for every one-unit of change in the predictor variable. A positive coefficient indicates that this input has a positive impact on the output (i.e., increasing this input will increase the output); a negative coefficient shows that the input affects the output negatively. The larger the coefficient, the bigger the influence on the output. The model was run with 10,000 iterations.

2.3.7. Historical lessons and feasibility considerations

A historical assessment of previous FMD control efforts was conducted based on a review of available information on the topic (e.g., reports, publications) and multiple interviews with different stakeholders to identify valuable lessons from past efforts and inform efforts going forward. The question guide was semi-structured and included questions presented in the supplementary material. Data were analysed in a narrative way by one of the authors (JMl) and the narrative was reviewed by the other authors for a sense check. Moreover, information was collated in interviews with stakeholders, and by using desk reviews for the following feasibility considerations: vaccine supply, staffing, animal traceability, trade benefits, and general implementation risks. This information was collated, discussed by the authors and presented in a descriptive manner.

2.3.8 Ethical approval

The project was initiated by the Tanzanian government with a support grant from the Standards and Trade Facility (STDF). It was a collaboration between the Royal Veterinary College, Sokoine University of Agriculture, and the Ministry for Livestock and Fisheries Development. Effectively, data collection at all levels involved the team being authorized by relevant authorities. Consent was sought from each person interviewed. The methodology was discussed with officials of the Ministry for Livestock and Fisheries Development and their regional staff. Consequently, the work was categorised as an evaluation, i.e., "non-research" appraisal of a potential service activity without requiring ethical approval. In Tanzania, there is no ethical approval process available for this type of work at the national level. To make the study available also to the scientific community, retrospective ethical approval was sought from and granted by the Social Sciences Research Ethical Review Board (SSRERB) of the Royal Veterinary College, UK (number URN SR2020-0251) and the Sokoine University of Agriculture's Ethical Committee of the Directorate of research, technology transfer and consultancy.

3. Results

3.1. Production losses and expenditures for palliative treatment (disease costs)

The total FMD disease costs (losses and expenditures) for each type of cost considered and different types of animal holdings for the baseline (endemic situation) in Rukwa region are presented in Figure 2 and supplementary material Table S3. The major cost was due to mortality of young stock, followed by loss due to reduction of weight gain, loss due to reduction on milk yield (in small farms), and loss due to increase in abortions (in large farms and all ranches). Loss due to impact on traction, only impacted small and medium farms, where mixed crop-livestock production is common practice. The cost per herd was higher in ranches, but the cost per head affected was higher in small farms. The mean total disease costs for the endemic (baseline scenario) was TSh 781 million per year (USD 351,628) and ranged between TSh 511 million (USD 229,945) and TSh 1,182 million (USD 531,806).

3.2. Costs of outbreak investigation and response

The total outbreak control cost was estimated to be TSh 10.2 million (USD 4,563) per outbreak, when all animals are vaccinated, and TSh 6.1 million (USD 2,729) when only cattle are vaccinated. The estimated outbreak response costs considering an average of 6 outbreaks per year was TSh 61 million (USD 27,293) when all animals are vaccinated, and TSh 37 million (USD 16,554) when only cattle are vaccinated. The cost avoided (benefits) following intervention are presented in Table 9.

Costs of intervention (mass vaccination and surveillance activities to support the vaccination campaign)

Table 10 illustrates the total estimated costs for the vaccination campaign in Rukwa region per year for each of the two scenarios (vaccinating all domestic susceptible species and vaccinating domesticated cattle only) and assuming a vaccination coverage of 100%. The cost of vaccines is the main expense in this category in both scenarios followed by the daily subsistence allowance. Data used on staffing at the local government level (district) is given in the supplementary material (Table S2). According to local authorities, the current staffing seems adequate for the vaccination programme, but none of the four district/municipality councils have a district veterinary officer (DVO) in place. Therefore, DVOs would have to be recruited or seconded from other regions to give confidence to the operations of the FMD-free zone.

The total estimated costs for the surveillance activities in Rukwa region for the years 2017 to 2026 are presented in Table 11. Equipment was the main cost in the first year, with training becoming the main expense from the second year. Although only one laboratory (which is in Dar es Salaam, over 1,000 kilometers away and thereby causing transport costs) has a Centre for Infectious Diseases with the biotechnology for diagnosis, the cost of diagnosis was one of the lowest costs in this category, considering the sample size.

3.3. Comparison of costs and benefits

The mean total discounted costs and benefits are presented in Figure 3. Intervention costs were estimated to increase during the first three years of the intervention from TSh 3,020 million (USD 1.35 million) in the first year to TSh 7,581 million (USD 3.39 million) in the third year, if all susceptible animals were vaccinated, and from TSh 2,417 million (USD 1.08 million) to TSh 5,855 million (USD 2.62 million), if only cattle were vaccinated. From the fourth year onwards, the discounted costs plateaud in both scenarios. Similarly, discounted benefits increased from the first to the fourth year, and then plateaud. Benefits were below the intervention costs in the 10 years considered in the analysis. The benefit-cost ratio and net present value are presented in Figure 4. The net present value was negative for both scenarios and the benefit-cost ratio was below one (mean 0.09, min 0.05, max 0.15 when vaccinating all susceptible animals and mean 0.11; min 0.06, max 0.20 when vaccinating cattle only) showing that the intervention costs are larger than the benefits (i.e., the disease costs and outbreak costs avoided).

Sensitivity analysis

Sensitivity analyses showed that variables related to the vaccine (number of doses and price), and the rate of yearly livestock population increase had the largest negative impact on the net present value. The number of cattle per farm, between herd prevalence and the correction factor for underreporting had positive regression coefficients between 0.02 and 0.09 (Figure

5). The effect that stochastic input variables have on the output "Net Present value" expressed as beta regression coefficients is presented in Figure 5. Only variables with a regression coefficient ≥0.02 are presented.

3.4. Estimation of break-even point

For the intervention campaign to be economically acceptable, the trade revenues and intangible benefits (such as reputation and better animal welfare) created from this programme would need to be at least TSh 63,500 m (USD 28.59 m) for the programme to break even. Using the medium scenario export price, an average of 1,311 tonnes of meat would have to be exported every year from Rukwa to break even if vaccinating all susceptible livestock and 853 tonnes if vaccinating cattle only. When considering the export prices for the best and worst case scenarios, an average of 601 tonnes and 2,826 tonnes would have to be exported if all animals were vaccinated and 454 and 2,133 tonnes if only cattle were vaccinated, respectively.

3.5. Historical analysis and feasibility considerations

Since the 1960s there have been three structured plans in Tanzania to control FMD and/or establish a disease-free zone, but none of them was implemented successfully.

First structured effort (1960-1980):

Efforts and activities in this stage were well documented. The aim was to establish a pilot FMD disease Free Zone in South Western Tanzania. Three regions were targeted (Mbeya, Iringa and Rukwa) and the economic rate of return was expected to be high (30%). First, a cost-benefit analysis was conducted in 1972 and a loan application for two combined animal health projects was made to the International Bank for Reconstruction and Development (IBRD) in 1974. Implementation was to be led by the Ministry of Agriculture under the then Director of Livestock Development and implemented by veterinary staff in the regions assisted by additional staff recruited for the purpose. In addition, an export abattoir was going to be built in Mbeya and serve the three regions.

The disease-free zone did not materialise and although none of the former veterinary officers interviewed could mention the exact reason, they recalled that that there was no budget allocation, as another project was prioritised for funding (the Dairy Project) and probably some of the funds were used in capacity development (e.g., training people abroad). Another former regional veterinary officer was certain that the dairy component was funded, but suspected that the animal health component, especially the FMD free zone, was not funded. An internal document of the World Bank revealed that the FMD disease Free Zone pilot, though technically sound, was not funded on two main grounds, 1) the anticipated benefits were unlikely to materialise due to the uncertainty in the timing of the Mbeya slaughterhouse construction, supplies of cattle for export, and the requirement of a disease-free zone by Zambia; and 2) data on impact of FMD in traditional herds was inadequate and the impact of FMD was considered minor by livestock officers and farmers alike (World Bank, 1975). Abattoir construction subsequently stalled.

Second structured effort (1981-82)

Documentation for the second effort could not be retrieved and therefore information presented here is based on interviews conducted. In 1981/82 a separate Ministry of Livestock Development was formed and another structured effort was developed to establish an FMD free zone, which was to be established in the Eastern Zone with the (already built) Tanganyika Packers Abattoir, in Dar es Salaam, serving as the export abattoir. The EU was the target market. The plan was to transport cattle from the Lake Zone by train and hold them in a holding zone in the Coast Region, separated from the disease-free zone by a fence (which was to be constructed). In the holding grounds, animals would be vaccinated, and after six months be moved into the disease-free zone. A full cost-benefit analysis was done and the proposal was submitted to the Ministry of Finance. Although the desk officer was very supportive, he was later transferred to another post and the proposal stalled. The responsible official in the Ministry of Livestock Development was also later transferred to another post and the second structured effort was discontinued.

Third structured effort (from 2000)

Following eradication of Rinderpest in Tanzania with the assistance of the Pan African Control of Epizootics (PACE) programme, the focus of animal health control efforts shifted once again to FMD control in the country and in East Africa. Efforts started in the country in 2000 and are ongoing. By 2000, the use of fencing had lost much favour, and OIE and FAO have since developed other practical control measures such as compartmentalisation, commodity-based trade and Progressive Control Pathways (PCP).

Two consecutive budget reports (2015 and 2016), by the Minister responsible for livestock, mentioned two different approaches. The first focussed on a disease-free zone in Rukwa region (which is the basis of the CBA presented above), while the second one emphasised the FMD Compartments in the former national commercial ranches (NARCO), probably indicating policy shifts.

Feasibility considerations

Table 12 presents the current situation and main challenges for an FMD control programme to be feasible based on interviews with key stakeholders.

4. Discussion

In this study we estimated the costs and benefits of establishing an FMD-free zone in the Rukwa region of Tanzania. The results show that FMD has a continual burden on the livestock sector in the area of between US$351,000 to 531,000 per year with a greater impact per head of cattle in the small-scale systems of US$5.70, versus US$4.50 in larger systems. This impact is largely production loss rather than expenditure on treating sick animals, and therefore will be difficult for producers to see – a burden of what is missing (an opportunity cost), rather than a financial cost. Despite this impact, the analysis clearly shows that the outlined FMD elimination programme is unlikely to be beneficial with the current FMD status. For the programme to be economically justifiable in Rukwa region, substantial benefits from export trade would be needed to cover the costs accruing from the intervention, namely between 454 and 2,826 tonnes of meat, depending on the scenario considered. As a point of comparison, in the last years the amount of beef exported from Tanzania fluctuated with a maximum of 1,115 tonnes in 2017 and a minimum of 14 tonnes in 2019 (Selina Wamucii, n.d.). The only export abattoir in Rukwa region was not operating during that time, i.e., there were no direct beef exports from that region. Without the operation of an export abattoir in the region or trade links to abattoirs in other regions, the export revenue required to break even will be difficult to realise. Existing beef export channels reported by the Tanzanian Meat Board (TMB) include Gulf countries, and Vietnam (boneless beef). Future potential to export beef to higher value markets in the short term is questionable, since a number of factors would have to be improved, including a steady and reliable supply to fulfil contractual quotas, stability in the beef value chain, and reliable and established market structures including functioning facilities for slaughter and transport.

The control of FMD in LMIC is often modelled on success stories from eradication programmes in developed countries, but Rushton (2008) demonstrated that in extensive South American cattle systems FMD control at farm-level is not favourable. For a cost-effective situation there needs to be equal access to markets for farmers supported by investment for export to countries that are sensitive to FMD status and pay a premium for that status. Such investments need to consider development of the value chain from livestock production to processing and marketing, a system that guarantees quality and safety of the product and can negotiate international trade deals. These high-end export markets increasingly impose standards beyond FMD status with requirements and preferences concerning animal welfare, organic production, drug residue testing and food safety, making access to high-end export markets more challenging, even with successful FMD control. Before making control decisions based on a hypothesis of improved market access there is a need to assess the possibilities and the realities of these markets in terms of the requirements to enter them, the competition to supply the markets and the returns on investment for such additional costs. In short it is not enough to say FMD free status will guarantee access to markets that pay better prices. A recent assessment for Uruguay on a change of FMD vaccination policy provides a good example of the types of market assessment require when considering market access (Perry et al, 2020).

Moreover, Zimbabwe and other southern African beef exporters struggle to achieve the stable and steady supply necessary to deliver consistently to more lucrative markets because of disease outbreaks, droughts and local market demands (Perry et al., 2003); this precludes the opportunity to negotiate higher priced forward contracts. Regional trade may both be more feasible and constitute an opportunity to meet African demand for beef. It is critical that the export markets and likely returns are explored before investment is made in control programmes. It is also argued that in LMICs, even if high investment in FMD control is successful, it will ultimately benefit the large companies with limited trickle down of benefits to improve livelihoods of small-scale, subsistence livestock keepers (Mariner, 2009). However, an economic analysis of FMD control in Zimbabwe by Perry et al (2003) showed skewed benefits to the owners of capital, but also that increased economic activity stemming from effective FMD control would benefit low-income households through income. Control programmes for FMD in Africa should be tailored to the individual country or region's specific needs considering their often unique challenges, including the livestock production and marketing systems as well as the epidemiological, ecological, socio-economic and governance issues that challenge effective control of FMD (Maree et al., 2014). Furthermore, marketing systems will have to identify risk sensitive issues and potential new risks, which may affect the stability of the supply chain. Potential issues include price fluctuations (between different markets), droughts and other disease outbreaks affecting off-take rates. In Zambia, an attempt was made at creating a disease-free zone in the Central, Lusaka and Copperbelt provinces in 2009-13. However, an economic analysis conducted during the project, using data from experiences in Namibia, Botswana and South Africa, which rely heavily on heavy duty buffalo fencing, concluded that it was not cost effective and faced technical feasibility challenges (van Lancker, 2012). The latter included unfenced African buffalo populations, uncontrolled movement of people and cattle, and illegal movement of cattle and goats into the disease-free zone to access trade options. Economic costs were therefore heavily affected by the cost of fencing. In addition, if exports markets became accessible, an inadequate supply of beef to meet local demand was envisaged.

In light of these challenges and the outcome of this study, other options might be considered and explored in the case of Tanzania such as the Commodity Based Trade (CBT) and a value chain approach to produce FMD safe deboned beef from an endemic area (Thomson et al., 2013). CBT provides a system to ensure safety of the animal product, irrespective of the disease status of the country of origin, as an alternative to creating a disease-free zone (Rich and Perry, 2011; Thomson and Penrith, 2015). Although this option has similar requirements to the disease free-zone, it is advocated as a more “conservation friendly” approach to FMD control and livestock production, given its removal of the requirement for veterinary cordon fencing and geographical zonation (Ferguson et al., 2013). It also faces less pressure in terms of operational costs, need for region-wide disease awareness and support from the whole farming community. The case of Namibia, which has managed successfully to produce CBT beef for export, based on an OIE endorsed FMD control programme with government subsidised vaccination and a nationwide compulsory livestock identification system, highlights the importance of the underlying infrastructure and capacity needed, but at the same time illustrates that it is feasible in countries with similar production conditions (Naziri et al., 2015).

The main cost of the control programme for a disease-free zone in Rukwa region was the cost of vaccination, and variables related to the vaccination programme were the most influential and had the largest negative impact on the net present value. Although vaccination costs could be partially recovered from farmers, non-commercial farmers may not see the value in vaccination since production losses for them are typically low, as are their chances to access export markets. Interviews with subsistence livestock keepers in Rukwa region revealed that these farmers perceived FMD outbreaks to have less impact than other diseases that had higher mortality and loss of traction, such as Contagious Bovine Pleuropneumonia (CBPP) and East Coast Fever. Although a drop in milk production was noted by these producers, milk was mainly used for household consumption and not for sale, making loss quantification harder for farmers. A recurring theme during interviews with local farmers (excluding ranchers), was that there was a lack of perceived value and incentive to purchase vaccines privately, if the government was not supplying and subsidising them. By contrast, the larger ranches recognised losses in milk production and live weight, and increased calf mortalities, and the financial implications. Yet, they still referred to CBPP as their main concern, and described FMD vaccines as expensive and difficult to access. Co-benefits could be created by using vaccination efforts to target diseases that are perceived as more important by farmers, which would optimise the use of resources, reducing costs and improve acceptance of the vaccination programme.

When interpreting the results of this study, it is important to consider that the costs for the vaccination efforts were based on expert opinion and some assumptions had to be made. Vaccine costs may have been overestimated in the analysis as these are based on 100% coverage. It is possible that a lower coverage rate might be enough to control FMD outbreaks and may be reduced further in time, during the prevention stages. On the other hand, the vaccination costs were estimated for the quadrivalent vaccine on the market. This is not a Differentiating Infected from Vaccinated Animals (DIVA) vaccine and therefore does not allow to differentiate between antibodies resulting from previous infections, and those from vaccination. The use of a DIVA vaccine would allow for such immunological differentiation. The cost of this purified vaccine is three times the price of the standard vaccine and therefore this would increase the costs of the campaign substantially. Finally, the real costs for staffing of the vaccination programme are likely to be even higher than the ones estimated in this analysis, since in some cases it may not be possible that the necessary staff from the veterinary service can be allocated to other tasks in the service, as currently assumed by the authorities and considered in the model, and new people would need to be recruited with an impact on salary costs.

The cost of surveillance was the second most expensive component of the programme. If the programme was to go ahead, further costs for surveillance would accrue once the disease gets reduced in the population and surveillance efforts need to be increased to demonstrate freedom from disease. The current sample size calculation provided by the authorities is based on an endemic situation with a 20% within herd prevalence. This figure likely underestimates the costs, as with decreasing prevalence, more efforts would need to be put into surveillance designs to increase the detection probability. Furthermore, given the epidemiology of FMD and wildlife in Africa, there is a need to consider FMD at the livestock - wildlife interface (Jori et al., 2016), the interaction between species that might influence disease dynamics and the competition for natural resource use. Thus, involvement of the Ministry of Natural Resources and Tourism is encouraged.

Transhumance is recognised as a major driver in the spread of FMD, and the control of livestock movement is debatably the main challenge in FMD eradication programmes (Sinkala et al., 2014). The success of this programme therefore would be heavily dependent on a reliable livestock identification system, which would allow monitoring, control of movement and the enforcement of movement bans during outbreaks. The Rukwa region shares an international border with Zambia, which is not fenced and the capacity to patrol and monitor illegal livestock movement is currently limited. Informal communication showed doubts about the feasibility of vaccination for FMD control without fencing. Any attempts at fencing would increase drastically the investment and operational costs and importantly, fencing is in direct contradiction of the Tanzanian “no-fence” policy. Because of the geographic features of Rukwa region, innovative approaches may be tested here that make use of the natural barriers. For example, given the steep ascent, it appears to be very difficult to trek livestock from the lowlands to the plateau. Studies would need to be conducted to identify which paths were used in (attempted) past crossings and more stringent policing could be used in such areas complemented by border patrols in the lowlands. Besides,

Zambia has two abattoirs close to the border which attract livestock sales from Tanzania. Building a formal abattoir was identified by all stakeholders as an essential part in upgrading the beef value chain in Rukwa region and a potential option for reducing movement of domestic animals in the border area.

A limitation of this study is that the benefits calculated do not include some wider potential benefits such as the capacity of animal health extension services, with resultant improved animal health and welfare that could expand on the back of the FMD related training nor nonmarket benefits such as international reputation. Other benefits not included, would be the reduction in losses from FMD in other livestock species as a result of the control programme in cattle.

Underreporting of FMD cases appeared to be a major issue with anecdotal evidence estimating underreporting at over 50%. As a result, reported data suggested a low incidence of the disease. Farmers perceiving FMD as a low impact disease, due to its low mortality, may be less likely to report cases. This highlights the importance to plan awareness activities and sensitise stakeholders along the production chain - activities (and costs) that are rarely considered in CBA. Indeed, it can be argued from the farmers' perspective, that FMD control measures (such as movement bans) during outbreaks have a greater impact on their livelihoods than the disease itself. Farmers would need positive incentives to report outbreaks, so timeliness can be improved and passive surveillance can be strengthened.

Finally, the issue of limited land availability was a major concern for most farmers. Even though there are policies in place to alleviate land issues, conflicting requests for land for crop production, livestock grazing, hunting, game reserves, conservation and national parks are a frequent problem. Creating stable market opportunities and connect demand and supply across different stakeholders in the system is crucial for further disease control stages. Currently, there seems to be a national level disconnect across stakeholders in the beef food systems with suppliers describing a lack of market opportunities and sellers describing unstable supply chains. Suitable approaches that allow linking the different points in the system should be identified, for example contract systems with immediate mobile phone payments could be a feasible option as it is based on a system already established and widely used across stakeholders for other purposes.

Based on the results and analysis presented in this study, key points to be addressed in the near future were identified. It was recommended to refine and update the existing national FMD control plan based on the latest PCP-FMD (FAO, 2018). For Rukwa region a staged approach for the FMD control was recommended to first tackle the ranches and surroundings and in a second step expand to neighbouring districts and finally the whole region. In the absence of fencing, we advised to explore innovative approaches to reduce the risk of introduction of disease from the outside, such as epidemiological studies to establish where the hotspots are for FMD emergence and introduction and elaboration of a risk-based surveillance and control approach. In addition, further research was recommended to better understand the off-take rates and identify potential incentives and barriers for farmers to report. If off-take rates from herds are to be increased, the implications of potential behaviour on the population, market dynamics and the livelihood of producers and their families need to be researched carefully and understood.

The recommendations from this study have been used by the Department of Veterinary Services in Tanzania to inform the development of a Risk Based Control Plan for FMD assisted by the OIE and FAO FMD technical working group. Briefly, the plan aims to vaccinate animals in the NARCO Ranches and private subleased plot ranches that are linked to export abattoirs. The document is in the final stages of development and the Director of Veterinary Services (DVS) plans to submit it to the Regional Advisory Group for countries of the Southern African Development Community.

5. Conclusions

The study shows that the proposed establishment of an FMD-free zone in Rukwa region is unlikely to be cost-effective with the current FMD status in Tanzania for a number of reasons: lack of high-end export market opportunities, the uncertainty of the future involvement of the livestock farmers in the in-country value addition, the fact that cattle are mainly kept as store of capital to be commercialised based on need resulting in a low off-take, and the perceived low impact of FMD by most farmers in the area. It is therefore recommended to target efforts on the development and implementation of a reliable surveillance and vaccination programme using the PCP guidelines to systematically progress on the control of FMD before considering an investment for an FMD-free zone.

6. Acknowledgments

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7. Declaration of interest

JMg and MM worked for the Tanzanian Ministry of Livestock & Fisheries when the study was conducted. The MoLF had an interest in the study for the purpose of informing the control of FMD in Tanzania. This did not create a conflict, as the study and its design were contracted to and led by BH; JMg and MM provided input and coordinated data collection but did not conduct data analysis. GL works at the Pirbright Institute (that is involved in vaccine development) but does not work on FMD vaccine or test development and declares no conflict of interest. BH, JMl, JR, and KQ declare no conflict of interest.

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Figure captions

Figure 1 (a) The 25 regions in Tanzania and neighbouring countries. Rukwa region is located in the southwest of the country; (b) Map of Rukwa region and its three districts Nkasi, Kalambo and Sumbawanga (NBS, 2012)

Figure 2 Mean (5% and 95% confidence interval) estimated baseline FMD disease cost per annum in Rukwa region, Tanzania for different types of holdings considered (farms on the left graph and ranches on the right graph). L_M= Losses due to mortality; L_A= Losses due to abortion; L_{RMY}= Losses due to reduced milk yield; L_W= Losses due to reduced weight gain; L_T=Losses due to loss of traction in agro-pastoral systems; E_{PT}= Expenditure for palliative treatment.

Figure 3 Mean total discounted intervention costs (black solid lines) and benefits (grey solid lines) in million TSh. Dashed lines represent 5% and 95% confidence intervals following 10,000 iterations.

Figure 4. Boxplots presenting net present value (a) and benefit cost ratio (b) when vaccinating all susceptible animals (light grey) and when vaccinating only cattle (dark grey) following 10,000 iterations.

Figure 5 The effect that selected input variables have on the output “Net Present value” expressed as beta regression coefficients for both scenarios when all animals are vaccinated (a) and when only cattle are vaccinated (b) as part of the control strategy.

Figure 1

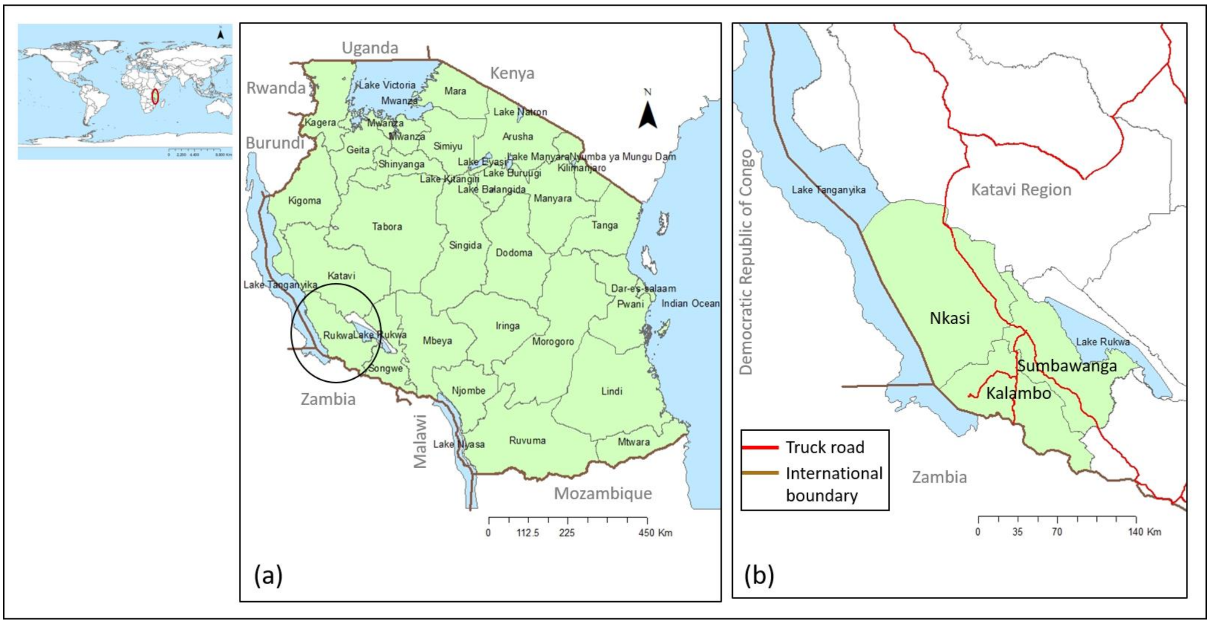


Figure 2

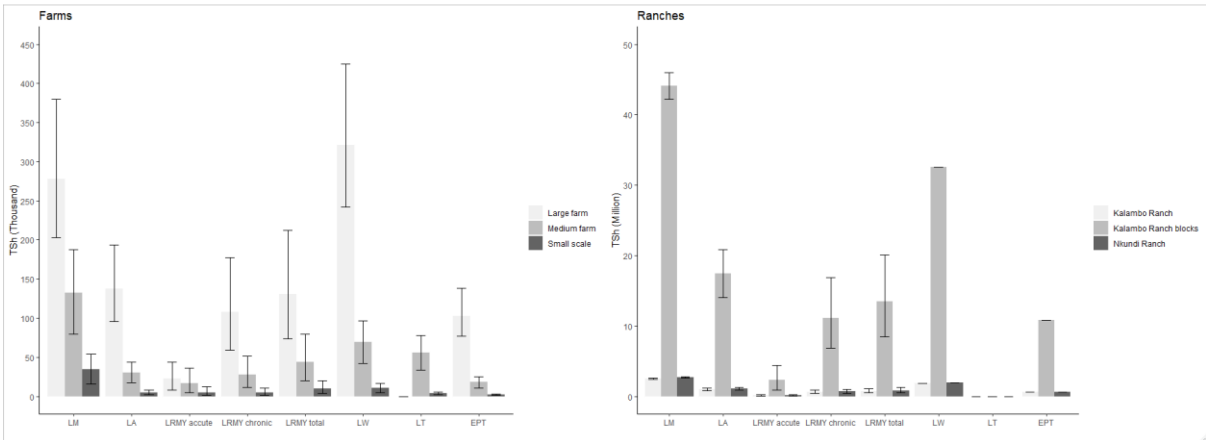


Figure 3

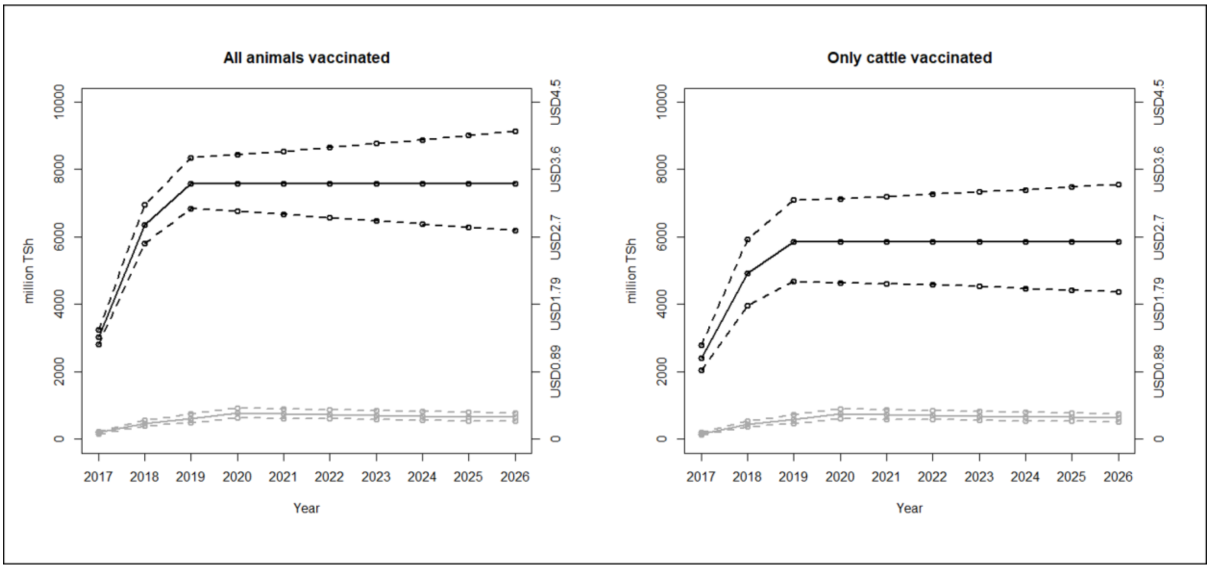


Figure 4

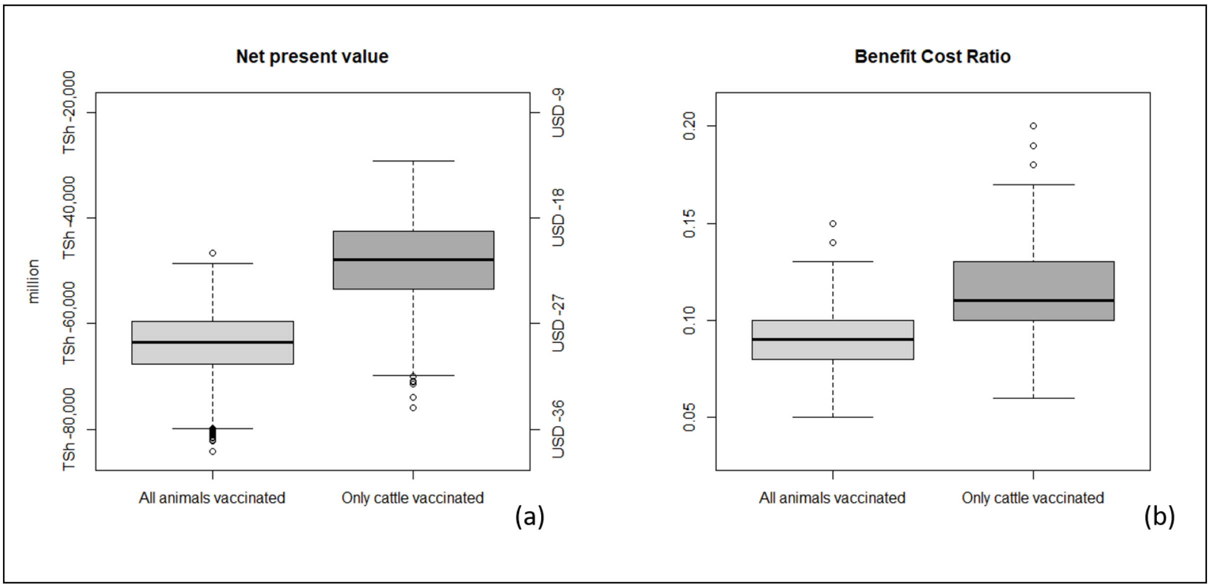
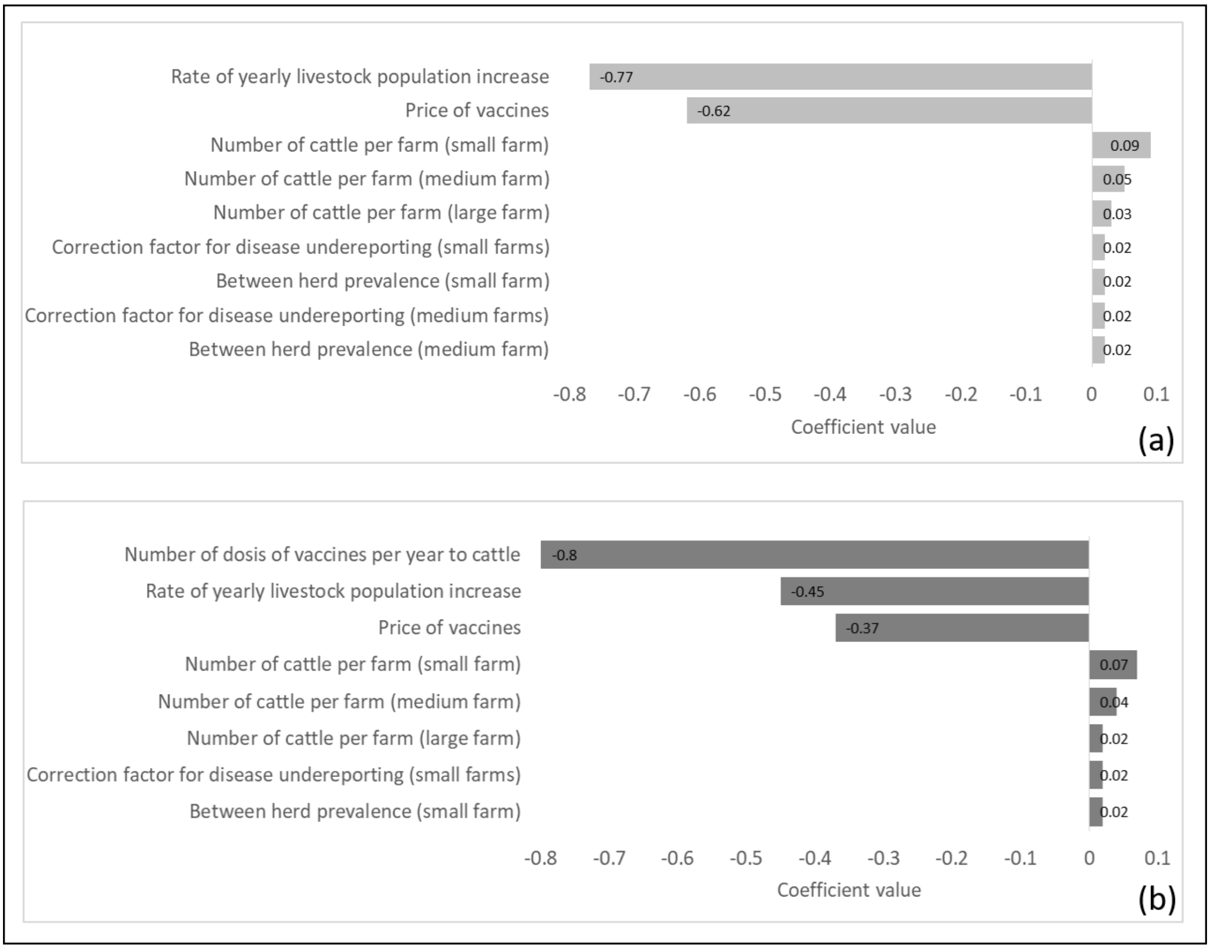


Figure 5



Rate of yearly livestock population increase
Price of vaccines
Number of cattle per farm (small farm)
Number of cattle per farm (medium farm)
Number of cattle per farm (large farm)
Correction factor for disease undereporting (small farms)
Between herd prevalence (small farm)
Correction factor for disease undereporting (medium farms)
Between herd prevalence (medium farm)
-0.77
-0.62
0.09
0.05
0.03
0.02
0.02
0.02
0.02
-0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1
Coefficient value
(a)
Number of dosis of vaccines per year to cattle
Rate of yearly livestock population increase
Price of vaccines
Number of cattle per farm (small farm)
Number of cattle per farm (medium farm)
Number of cattle per farm (large farm)
Correction factor for disease undereporting (small farms)
Between herd prevalence (small farm)
-0.8
-0.45
-0.37
0.07
0.04
0.02
0.02
0.02
-0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1
Coefficient value
(b)