Stakeholder perceptions of foot-and-mouth disease control in South Africa

Laura C. Roberts [a,b], Geoffrey T. Fosgate [a,*]

[a]University of Pretoria, Faculty of Veterinary Science, Department of Production Animal Studies, Onderstepoort, 0110, South Africa

[b]Western Cape Department of Agriculture, Elsenburg 7607, South Africa

*Corresponding author at: University of Pretoria, Faculty of Veterinary Science, Department of Production Animal Studies, Private Bag X04, Onderstepoort, 0110, South Africa

Tel: +27 12 529 8257

Fax: +27 12 529 8315

E-mail address: geoffrey.fosgate@up.ac.za (G.T. Fosgate).

Abstract

Foot-and-mouth disease (FMD) prevention and control is a challenge worldwide but the situation in southern Africa is particularly complex because the virus is endemic in wild African buffalo (*Syncerus caffer)*. The objective of this study was to compare stakeholder perceptions of the FMD control methods employed to restrict FMD virus to the infected zone of South Africa. Data collection was performed using an online questionnaire distributed to FMD experts, government veterinarians, private livestock veterinarians, people involved within the wildlife sector, and "other" occupation groups including the general public. Data were also collected using semi-structured participatory group discussions with government animal health technicians (AHT) and communal cattle owners directly affected by FMD control measures. Evaluated control methods were the disease control fence bordering the western boundary of the Greater Limpopo Transfrontier Conservation Area, clinical surveillance of livestock, movement control of cloven-hoofed animals and products, and routine FMD vaccination of cattle. These management procedures were scored according to a set of technical, economic, and ethical criteria by stakeholders, who also weighted the criteria according to their perceived importance. Scores and weights were aggregated using an additive linear model to rank control methods. Sensitivity analysis was performed using a stochastic model to explore the effects of varying inputs and the exclusion of scores from randomly selected respondent groups on the ranking of control methods. The deterministic analysis assigned the highest ranking to the disease control fence and the lowest to routine vaccination of cattle. The fence had the highest ranking in 40% of the stochastic iterations, and second, third and fourth in 26%, 20% and 14% of iterations, respectively. The inputs from the AHT and people involved in the wildlife sector were the most influential for ranking the fence as the preferred control option. The most influential criteria were the feasibility of the fence as a control option and its influence on the economics of the communal cattle owners, livestock industry in the FMD free zone, and the government. The disease control fence was the highest ranking control option but further investigations are necessary to understand the reasons for stakeholder perceptions.

Keywords: Multiple criteria decision analysis, Foot-and-mouth disease, Disease control fencing, Livestock, Participatory epidemiology

1. Introduction

Wildlife conservation and commercialization of livestock production are both fundamental to rural development in southern Africa but the socio-economic advancement of local communities can be hindered by the incompatibility between these activities (Thomson et al., 2013). Wildlife species are reservoirs for diseases that affect livestock (Bengis et al., 2004) and this is a cause of the incompatibility. Most important in this respect is foot-and-mouth disease (FMD), a globally important transboundary animal disease (TAD) (Ferguson et al., 2013; Tekleghiorghis et al., 2016). Unfortunately, FMD management strategies in southern Africa have had unintended environmental and socio-economic consequences through the construction of disease control fencing (Woodroffe et al., 2014). These fences are designed to preclude contact between cattle and wild African buffalo (*Syncerus caffer*), the wildlife reservoir for the Southern African Territories serotypes of the FMD virus (SAT1, SAT2 and SAT3) (Thomson et al., 2003).

Foot-and-mouth disease control in southern Africa combines disease control fencing, vaccination of cattle, movement control of cloven-hoofed animals and products, and surveillance activities (DAFF, 2014). South Africa is classified as having an FMD free zone where vaccination is not practiced (OIE, 2017). The Kruger National Park (KNP) in South Africa is one of Africa's largest wildlife reserves. Foot-and-mouth disease is endemic in KNP and African buffalo are believed to be the major source of FMD virus transmission to domestic livestock in the surrounding areas (Bastos et al., 2003). Cattle owners on the border of the KNP, within the FMD control zone with vaccination, must present their cattle at government inspection points every week for examination by government veterinary technicians. Cattle in this zone are vaccinated every four months using an inactivated trivalent product containing antigens for SAT1, SAT2, and SAT3 (Lazarus et al., 2017).

The successful control of FMD depends on the co-operation of multiple stakeholder groups. Decisions with regard to animal disease control are often made at a regional or national level, but the most directly-affected people are the livestock owners and the government personnel implementing control strategies. The input of all stakeholder groups can be accommodated within a multiple criteria decision analysis (MCDA) framework, which is a set of techniques developed to facilitate well-informed and transparent decision making (Belton and Stewart, 2002). This approach enables the synthesis of potentially conflicting data in an effort to identify a preferred option, to rank available options, to shortlist options, or simply to distinguish acceptable from unacceptable options (Dodgson et al., 2009). An MCDA can incorporate stakeholder involvement at each step of the decision making process. The objective of the current study was to compare the perceptions of stakeholder groups concerning FMD control methods employed to restrict FMD virus to the infected zone of South Africa within a modified MCDA framework. Investigated stakeholder groups included communal cattle owners, veterinary animal health technicians, FMD experts, government veterinarians, private livestock veterinarians, people involved in the wildlife sector, and other occupation groups including commercial farmers in the FMD free zone and the general public.

2. Materials and methods

2.1 Study location

South Africa is classified as free of foot-and-mouth disease (FMD) without vaccination but with the presence of infected zones (DAFF, 2014). The primary infected zone is the Greater Kruger National Park (KNP), which comprises the KNP and adjoining nature reserves (Figure 1). The KNP and adjoining nature reserves form part of the Greater Limpopo Transfrontier Conservation Area. Thembe Elephant Park and Ndumo Game Reserve in

Figure 1. The foot-and-mouth disease infected zone includes the Greater Kruger National Park (KNP), which is in the northeast region of South Africa and is comprises the KNP and the adjoining wildlife reserves.

northern KwaZulu-Natal Province, bordering Mozambique and Swaziland, are also classified as FMD infected. South Africa experienced an FMD outbreak in 2011 within the FMD free zone of the KwaZulu-Natal Province and subsequently did not regain OIE recognition of the FMD free zone status until February 2014 (Zokwana, 2015). There are four primary methods of FMD control performed within South Africa: 1) Clinical surveillance of livestock, 2) Disease control fencing, 3) Movement control of cloven-hoofed animals and products, and 4) Prophylactic vaccination of cattle. Cattle within the FMD control zone with vaccination are inspected weekly for clinical signs suggestive of FMD. Disease control game-proof fencing (Supplemental Figure 1) separates FMD virus infected wildlife in the infected zone from domestic livestock in the surrounding areas. Movement control procedures (permit system) restrict the transport of FMD susceptible animals and their products within and between FMD control zones. Movements from higher to lower FMD risk areas are discouraged. Cattle within the FMD control zone with vaccination are prescribed to be vaccinated every four months using a trivalent inactivated-vaccine (containing SAT1, SAT2 and SAT3) by veterinary animal health technicians (AHT) working under the supervision of provincial government veterinarians (DAFF, 2014).

2.2 Study design

A multiple criteria decision analysis (MCDA) framework was modified to assess perceptions of control methods aimed at preventing outbreaks of FMD in the FMD-free zone of South Africa that originate from the infected zone. The FMD control zone with vaccination is situated between the infected and free zones. Stakeholders included cattle owners living on communal land in the FMD protection zone with vaccination (along the western boundary of the Greater Limpopo Transfrontier Conservation Area), veterinary AHT working in the protection zone with vaccination, FMD experts and researchers, South African provincial government veterinarians, national government veterinary personnel of the South African Department of Agriculture, Forestry and Fisheries (DAFF) Directorate for Animal Health, South African private livestock veterinarians, participants in the game industry and game reserve staff (wildlife sector), and other occupations within the FMD free zone including commercial cattle farmers and the general public. Private wildlife ranches and public reserves commonly have FMD susceptible wildlife species including African buffaloes and impala (*Aepyceros melampus*).

The sample size for the group discussion of communal farmers was calculated to estimate the proportion that was satisfied with the current FMD control policies. It was assumed that 75% of farmer groups were satisfied (Lazarus et al., 2017) and it was desired to estimate this proportion with 25% allowable error and at the 95% level of confidence (Fosgate, 2009). Farmers were sampled using the government FMD inspection points (dip tanks) because individual list frames were not available prior to the study and farmers in the FMD protection zone with vaccination present their cattle for inspection every week. The total number of dip tanks in the protection zone was 203 and the calculated sample size was 11 farmer groups (dip tanks to be sampled). Dip tanks were first stratified by province (Limpopo or Mpumalanga Province) and randomly selected proportional to the total number of dip tanks per province using inspection records obtained from provincial veterinarians. A committee of experienced farmers (typically 2-3 individuals per village) is responsible for maintaining the appropriate dip concentration and for providing representation for the other farmers in nearby villages. These Dip Tank Committees were contacted by the area AHT to participate in the group discussions and other farmers were also invited upon completion of the dipping session. All AHT working in the government veterinary area of the randomly sampled dip tanks were also selected for study. FMD experts were identified based on the publication of three or more peer-reviewed articles identified through an English language literature review and were contacted via email. South African government veterinarians were contacted via email using addresses obtained from the DAFF website and from the organizers of the South African Society for Veterinary Epidemiology and Preventive Medicine conference. South African private livestock veterinarians were contacted via the local rural veterinarian email listserv, which had 491 members at the time of the study. Participants in the game industry and game reserve staff (wildlife sector group) were contacted via email using the Wildlife Ranching South Africa mailing list of 1970 people. Employees of the KNP were also contacted via email using information available from the South African National Parks Veterinary Wildlife & Services office at Skukuza, Mpumalanga Province. Commercial cattle farmers were contacted through two industry magazines using the magazines' social media web pages and by publishing letters to the editor. The general South African public was contacted through a social networking site. The link to the questionnaire was posted on a page created by the first author and advertised to her contacts. Viewers of the webpage were requested to complete the questionnaire and encouraged to share the link with their own contact lists. The study was reviewed and approved by the Research Ethics Committee of the Faculty of Humanities, University of Pretoria (Reference number 26217369).

2.3 MCDA framework development

The usual steps of a MCDA have been described as: 1) define the decision problem, 2) identify stakeholders, 3) identify alternatives, 4) identify criteria for assessing alternatives, 5) evaluate alternatives according to criteria and weight criteria to indicate their relative importance to stakeholders, 6) aggregate information and 7) evaluate sensitivity (Dodgson et al., 2009; Mourits et al., 2010; Aenishaenslin et al., 2013; Brookes et al., 2014a). Stakeholders can be involved in any one or more of the first to fifth steps. Stakeholder perceptions were incorporated in this study by asking representatives of stakeholder groups to evaluate the alternatives according to the criteria chosen by the researchers and to weight the criteria. The problem that was addressed with the development of the modified MCDA in this study was an apparently increasing frequency of outbreaks of FMD in vaccinated cattle within the protection zone of South Africa. The typical approach of an MCDA is to specify measurable (quantitative) outcomes as a consequence of performing an evaluated action (e.g., effect of a FMD control method). This approach was modified to account for stakeholder perceptions and to alleviate concerns related to the appropriate method to quantify the effects of the control methods, such as decreasing the number of FMD outbreaks. For example, the number of outbreaks in the FMD protection zone currently varies from year to year and the number of independent outbreaks is only a single possible method of quantification. Outbreaks could also be quantified by the number of affected dip tanks, the time duration of the outbreak (total amount of time necessary to resolve), the total number of cattle in affected dip tanks, and the number of clinical cases observed. It was desired to identify the perceptions of all stakeholder groups within their own framework of judgement rather than attempting to be precise with a defined magnitude of effect. All individuals have different perceptions of acceptable and unacceptable (or substantial versus negligible) risk and we desired to measure individual perceptions. The questionnaire was designed to measure these perceptions using a sliding scale, usually from extremely negative to extremely positive effects. For example, perceptions of the effectiveness of a control method were elicited in response to the question: How could this affect the annual number of outbreaks in the protection zone (there were 7 outbreaks in 2012)?

The typical approach to performing an MCDA is to request the respondent to consider trade-offs between one criterion and another, when assigned weights to criteria. An example would be to compare a defined increase in required government spending versus the desirable effect of a defined improvement in communal cattle owner livelihoods. A trade-off approach in the contextual framework of the present study would have required a long and complicated survey instrument because of the number of evaluated criteria and the differing scales of measurement for each evaluated criteria. The MCDA framework was therefore modified to score each criterion independently in an effort to collect data concerning stakeholder perceptions within their own contextual framework rather than rigidly defined magnitudes of effects.

2.4 Modified MCDA design

The four FMD control methods assessed were identified from the Veterinary Procedural Notice (VPN) for Foot and Mouth Disease Control in South Africa (DAFF, 2014). These were: clinical surveillance of livestock, the disease control fence erected between wildlife and livestock areas, movement control (permit system) of live animals and all products derived from cloven-hoofed species (domestic and wild), and routine vaccination of cattle against FMD virus. The three groups of criteria employed for the modified MCDA (Table 1) were Technical, Economic and Socio-political (Aylward et al., 2000; Aylward and Birmingham, 2005). The Technical group included the criteria “Effectiveness” to measure the effect of the control method on the number of FMD outbreaks. “Feasibility” was included to measure the likelihood of the control measure being administered as intended. The Economic group of criteria was approached from the aspect of stakeholders and included three criteria measuring the financial effect of a control method on local communal cattle owners (“Cattle owner economics”), commercial cattle farmers in the FMD free zone (“Industry economics”) and the government (“Government economics”). The Socio-political group included effects of the control measure on the welfare of cattle owners in the vaccination zone (“Human

Table 1. Definitions of criteria and their measurement scales for a modified multiple criteria decision analysis (MCDA) of foot-and-mouth disease (FMD) control methods performed in South Africa.

Criterion group	Criterion	Criterion name	Criterion description	Measurement scale
Technical	1	Effectiveness	Effectiveness	"Substantial increase" (-100) to "substantial decrease" (100), through "no effect" (zero) *†
	2	Feasibility	Feasibility	Easy (0) to Impossible (100)
Economic	3	Cattle owner economics	Financial effect on the local cattle owners	Substantial loss (-100) to substantial profit (100) through no effect (0) †
	4	Industry economics	Financial effect on the cattle industry	Substantial loss (-100) to substantial profit (100) through no effect (0) †
	5	Government economics	Financial effect on the government	Substantial loss (-100) to substantial profit (100) through no effect (0) †
Ethical	6	Human welfare	Effect on the quality of life of local cattle owners	Extremely negative (-100) to extremely positive (100) through no effect (0) †
	7	Cattle welfare	Effect on the welfare of local cattle	Extremely negative (-100) to extremely positive (100) through no effect (0) †
	8	Environmental welfare	Effect on ecosystem health (includes wildlife)	Extremely negative (-100) to extremely positive (100) through no effect (0) †

*Measured indirectly by estimating the effect of removing the control measure from the control programme on the number of outbreaks in the protection zone with vaccination.

†Scores were converted to a scale of 0 – 100 by the addition of 100 and division by two, to eliminate the distortion of criterion scores when a negative standardized weight is multiplied by a negative criterion score

welfare"), domestic animals ("Cattle welfare") and the environment and wildlife ("Environmental welfare"). The criterion, "Feasibility" and the economic and ethical criteria were designed to measure impacts of the control measure that occur through mechanisms independent of increased or decreased FMD outbreaks.

Criteria effects were measured using a score of -100 (extremely negative) to 100 (extremely positive) with zero indicating no effect. Economic criteria were phrased to range from "substantial loss" to "substantial profit". Effectiveness was measured indirectly, by asking respondents about the effect of removing a control method on the current number of FMD outbreaks in the protection zone. Feasibility was measured from 0 (easy) to 100 (difficult). Brookes et al. (2014b) described (but did not employ) a direct method to obtain weights for each criterion and this approach was implemented using a sliding scale of 1 (not important) to 100 (very important).

All questions related to the weighting and scoring of a criterion were followed by questions concerning the level of confidence that respondents had in the previously provided responses. Questions related to the level of confidence were included in the questionnaire based on previous experience suggesting that respondents are more likely to answer questions if they are also allowed to note that they have low confidence in provided responses. These questions were therefore included to reduce the amount of missing data for the responses of interest.

The feasibility of additional hypothetical control methods was also investigated. Evaluated control methods included the culling of wildlife infected with FMD virus, the selective decrease in susceptible wildlife populations irrespective of FMD prevalence, depopulation of

FMD infected cattle herds within the protection zone with vaccination, construction of a double fence around the FMD infected areas of South Africa, routine serological surveillance in addition to the current clinical surveillance, active supervision of cattle during grazing to prevent contacts between cattle and wildlife, and the vaccination of wildlife against FMD. Feasibility was the only criterion scored for these additional control methods and it was not possible to incorporate these data into the MCDA.

2.5 Questionnaire development and administration

Scores for the FMD control methods and weights for criteria on which the control methods were scored were obtained using an online questionnaire (Supplemental Material Questionnaire) and via face-to-face semi-structured interviews. Interviews were conducted with AHT and communal cattle owners and all other stakeholder groups were asked to complete the online questionnaire.

The online questionnaire was constructed and administered using SurveyGizmo (www.surveygizmo.com). A test questionnaire was distributed to staff and students of the University of Pretoria's Faculty of Veterinary Science and changes made according to received comments. The hyperlink to the questionnaire was distributed via email and magazine social media pages, websites, and letters to the editor of trade magazines. People involved within the wildlife sector and other occupation groups answered a questionnaire containing questions including only a single randomly-selected control method while the FMD expert and veterinarian groups answered questions on three randomly-selected control methods (three out of four). The questionnaire evaluating only a single control method was designed to be completed within 15 minutes and the longer questionnaire was expected to take 20 minutes to complete. The online questionnaire was available for the 3-month period from 20 July to 20 October 2014 and a lucky draw for an online store voucher was used as an incentive for participation in the study.

A paper-based questionnaire, identical to the online questionnaire, was initially planned for eliciting scores and weights from communal cattle owners and AHT. However, a pilot study involving three interviews with cattle owners indicated that the questions were not understood by these stakeholders. Therefore, scores and weights from communal cattle owners and AHT were obtained using a semi-structured, participatory, group discussion approach (Catley et al., 2012). Questions were translated from English into the local language for participatory interviews with cattle owners. The translator varied because of the variety of languages and the requirement for a person familiar to the cattle owners of the area. Livestock owners and AHT received a pair of rubber boots as an incentive for participating in the research. Interviews were performed during May 2014.

At the start of each discussion, the aim of the study was explained and confidentiality of information assured. The clinical signs and effects of FMD, as well as the control zones, were explained. Laminated cards with images were used to indicate the control method or criterion for discussion. The first part of the discussion involved questions concerning the technical, economic and ethical aspects of the four evaluated control methods and encouraged discussion among the participants. An interactive, participatory approach was used to weight the technical, economic and ethical criteria and to assess the feasibility of the four control options. The interactive questions involved portioning of dried beans to represent relative criterion weighting ("proportional piling"). Laminated cards were ordered from least to most preferred when groups were reluctant to use the beans. Control methods were numbered and the order in which they were discussed was randomly selected for each group.

Table 2. Example decision matrix for a modified multiple criteria decision analysis (MCDA) of foot-and-mouth disease (FMD) control methods performed in South Africa.

	Criteria scores								Weighted criteria scores*								
Control methods	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
FMD vaccination	S_{V1}	S_{V2}	S_{V3}	S_{V4}	S_{V5}	S_{V6}	S_{V7}	S_{V8}	W_1S_{V1}	W_1S_{V1}	W_1S_{V1}	W_1S_{V1}	W_1S_{V1}	W_1S_{V1}	W_1S_{V1}	W_1S_{V1}	$\sum WS_V$
Disease control fence	S_{F1}	S_{F2}	S_{F3}	S_{F4}	S_{F5}	S_{F6}	S_{F7}	S_{F8}	W_1S_{F1}	W_1S_{F1}	W_1S_{F1}	W_1S_{F1}	W_1S_{F1}	W_1S_{F1}	W_1S_{F1}	W_1S_{F1}	$\sum WS_F$
Movement control	S_{M1}	S_{M2}	S_{M3}	S_{M4}	S_{M5}	S_{M6}	S_{M7}	S_{M8}	W_1S_{M1}	W_1S_{M1}	W_1S_{M1}	W_1S_{M1}	W_1S_{M1}	W_1S_{M1}	W_1S_{M1}	W_1S_{M1}	$\sum WS_M$
Clinical surveillance	S_{S1}	S_{S2}	S_{S3}	S_{S4}	S_{S5}	S_{S6}	S_{S7}	S_{S8}	W_1S_{S1}	W_1S_{S1}	W_1S_{S1}	W_1S_{S1}	W_1S_{S1}	W_1S_{S1}	W_1S_{S1}	W_1S_{S1}	$\sum WS_S$
Criteria weights	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8									

*Employed MCDA standardized the weights by subtracting the mean and dividing by the standard deviation of the weights within each individual respondent prior to multiplication with the corresponding scores from the same individual.

Notes taken during the interviews with communal cattle owners and AHT were transcribed and summarized. Data obtained via the interviews were recorded numerically on the same scales as the online questionnaires and a decision matrix (Table 2) was completed for each group. Criterion scores were recorded as zero (no effect) when not mentioned by the interviewed group. Each dip tank or AHT group was analyzed as a single respondent.

2.6 Descriptive analysis

Data were described by calculating the median and range and via boxplots created using the ggplot2 package (Wickham, 2009) within R (R Development Core Team, 2017). Scores and weights were compared among respondent groups using Kruskal-Wallis tests followed by pairwise Mann-Whitney U tests with Bonferroni adjustment of P values for multiple post-hoc tests. Descriptive data analysis was performed using commercial software (IBM SPSS Statistics for Windows, Version 23, IBM Corp, Armonk, NY, USA) and results interpreted at $P<0.05$.

2.7 Modified MCDA implementation

Criterion weights – the relative importance of each criterion for the evaluation of continued FMD outbreaks in cattle of the protection zone with vaccination.

Standardized criterion weights – the relative importance of each criterion after subtracting the mean and dividing by the standard deviation of the criterion weights. Standardization was performed within each individual respondent to ensure that some individuals did not influence results more than others.

Criterion scores – the perceived performance of each control method against each criterion.

Weighted scores – the product of criterion scores and standardized criterion weights.

Sum of weighted scores – sum of weighted scores for each control method. This is the outcome used to rank the acceptability of the four evaluated control methods.

Missing values for criterion scores were imputed by calculating the mean value for each criterion within the respondent group. Criterion scores for Effectiveness and Feasibility were transformed to be comparable with the criterion scores for the other criteria. To eliminate the distortion of criterion scores when a negative standardized weight is multiplied by a negative criterion score, the criterion scores on a scale of -100 to 100 were converted to a scale of 0 – 100 by the addition of 100 and division by two.

Criteria weights and criteria scores for each respondent were aggregated using a simple linear additive model. The overall weighted score for an option was calculated as:

$$V(a) = \sum_{i=1}^{m} w_i v_i(a)$$

where $V(a)$ is the overall value of alternative a, $v_i(a)$ is the value score reflecting alternative a's performance on criterion i, m is the total number of criteria and w_i is the weight assigned to reflect the importance of criterion i (Belton and Stewart, 2002).

The weighted scores ($w_i v_i(a)$) and summed weighted scores ($V(a)$) for each respondent were calculated. The mean sum of weighted scores for each control method was calculated for each stakeholder group, and the mean of these means was used to rank the control methods overall.

The impacts of potentially influential responses from a small number of individuals (robustness of results) and methods employed to impute missing data were evaluated using

Monte Carlo simulation. Inputs of the model were elicited using only collected data based on triangular or uniform distributions fit based on the distributions of group responses (Supplemental Material Distributions). Distributions were fit using the minimum, median and maximum, for triangular distributions, and the minimum and maximum for uniform distributions. Inferences were based on 10,000 iterations performed using commercial software (@Risk 6.3.1 Risk Analysis add-in for Microsoft Excel, Palisade Corporation, Ithaca, NY, USA).

2.8 Sensitivity analysis

The impact of including the 10 commercial cattle farmers in the FMD free zone within the other occupation group was assessed by creating a new commercial farmer group within the deterministic MCDA. The overall ranking of control methods was assessed in addition to the rankings of the new farmer group versus the remainder of the respondents in the other occupation group.

The stochastic MCDA model was modified to randomly exclude one stakeholder group during each iteration. Sensitivity analysis was based on 10,000 additional iterations performed using the commercial software (@Risk 6.3.1 Risk Analysis add-in for Microsoft Excel, Palisade Corporation, Ithaca, NY, USA). The correlation between inputs and the outputs of control measure weighted scores and rankings were evaluated using Spearman's rho. Binary logistic regression was used to estimate the association between inputs with Spearman's rho >0.05 and the ranking of the preferred control method. The dependent variable for the logistic regression analysis was whether or not the control method was ranked first.

3. Results

3.1 Questionnaire response proportions

Two hundred and nine people opened the online questionnaire and 145 (69%) provided usable data for analysis. Among the usable responses, 18 respondents were FMD experts (18/38 contacted; 47% response proportion), 37 were government veterinarians (37/156 emailed; 24%), 25 were livestock veterinarians (25/491; 5%), 33 respondents were members of the other occupation group (unknown denominator), and 32 respondents were people involved within the wildlife sector (32/1970; 1.6%). This wildlife sector group included 13 game farmers/ranchers/breeders/farm owners, eight "game reserve staff", three game translocator/capturer/specialists, one staff member of the Wildlife Ranching South Africa organization, one game reserve owner, and one hotel manager. Only 10 usable responses were obtained from cattle farmers within the other occupation group (three representing mixed farmers of game and cattle).

3.2 Qualitative interview responses

Eleven meetings with communal cattle owners were arranged but only 10 were conducted with an average of 12 people attending (range, six to 23). The government veterinarian was present at five of the meetings and also acted as the translator on three of these occasions. The area AHT was translator for six dip tanks and a University of Pretoria research assistant translated at the other. Seven interviews were conducted with AHT and between one and five people were present at each meeting.

Seven of the communal cattle owner groups (70%) stated that the disease control fence provided an economic benefit through predator control. Interviewed groups identified problems related to the fence due to feasibility with the perception that the fence is poorly maintained. Three of the AHT groups (50%) also stated that compensation is not provided for predated livestock. The fence was also stated to restrict access to natural resources (e.g., grazing, timber, game) by three of the AHT groups (50%) compared to only one communal cattle owner group (10%). In general, perceptions of the disease control fence by AHT groups were more negative than communal cattle owner groups concerning restriction of natural resources, damage caused by people, and the problems related to fences crossing rivers and ditches. There was also confusion concerning the agency responsible for fence repair. Four of six AHT groups believed that the current FMD vaccine was inferior and a cause of economic loss to the government.

3.3 Descriptive comparisons and deterministic MCDA

The disease control fence was the highest ranked control method overall and responses from five of the eight (63%) stakeholder groups rated the fence as being the preferred control method (Table 3). The four currently employed FMD control methods in addition to serological surveillance of cattle were perceived to be the most feasible options based on respondent criterion scores (Figure 2). The sums of weighted scores obtained from the AHT group for the disease control fence had the lowest median score (Figure 3). The wildlife sector group gave high scores for the fence with a more narrow distribution than reported for other control options. Government veterinarians provided higher scores for the effectiveness of the disease control fence compared to AHT and communal cattle owners (Table 4). The other occupation group (10 of the 33 respondents were commercial cattle owners within the FMD free zone) provided higher scores for the disease control fence's effect on cattle welfare compared to FMD experts. The weighted scores that the FMD experts assigned to the fence, movement control and vaccination were descriptively high relative to other groups. Sums of weighted scores for movement control varied among stakeholder groups ($P = 0.027$) with

Table 3. Mean sum of weighted scores evaluating four foot-and-mouth disease (FMD) control methods for a modified multiple criteria decision analysis performed in South Africa where missing values were imputed. Scores in bold indicate the most highly ranked control method for each respondent group.

	Clinical surveillance		**Disease control fence**		**Movement control**		**FMD vaccination**	
Respondent group	**Mean**	**Median (range)**	**Mean**	**Median (range)**	**Mean**	**Median (range)**	**Mean**	**Median (range)**
FMD experts	26.2	27.6 (-62, 182)	**75.5**	82.7 (-35, 165)	73.1	96.3 (-76, 165)	52.9	64.0 (-22, 147)
Government veterinarians	27.9	21.3 (-148, 193)	**40.6**	28.9 (-122, 185)	34.2	47.5 (-97, 169)	36.9	49.8 (-165, 163)
Livestock veterinarians	20.6	6.4 (-65, 154)	32.3	45.1 (-63, 173)	**39.2**	31.3 (-36, 159)	31.7	38.7 (-169, 116)
Wildlife sector group	38.9	67.7 (-23, 175)	**46.6**	91.3 (81, 131)	36.3	60.1 (-17, 90)	30.0	38.4 (-9 138)
Animal health technicians	**1.6**	-12.4 (-67, 65)	-9.7	-22.6 (-91, 46)	0.2	-7.5 (-32, 15)	-6.8	2.1 (-71, 54)
Communal cattle owners	21.8	37.2 (24, 51)	**22.5**	14.0 (-26, 22)	13.1	20.3 (-8, 25)	8.4	22.2 (-10, 35)
Other occupation	**24.1**	23.1 (-112, 180)	15.8	8.2 (-95, 118)	4.0	-33.9 (-77, 87)	6.9	13.7 (-123, 65)
Overall*	23.0	23.1 (-148, 193)	**31.9**	28.9 (-131, 185)	28.6	31.3 (-101, 169)	22.8	38.4 (-169, 163)

*Mean of group mean sums of weighted scores

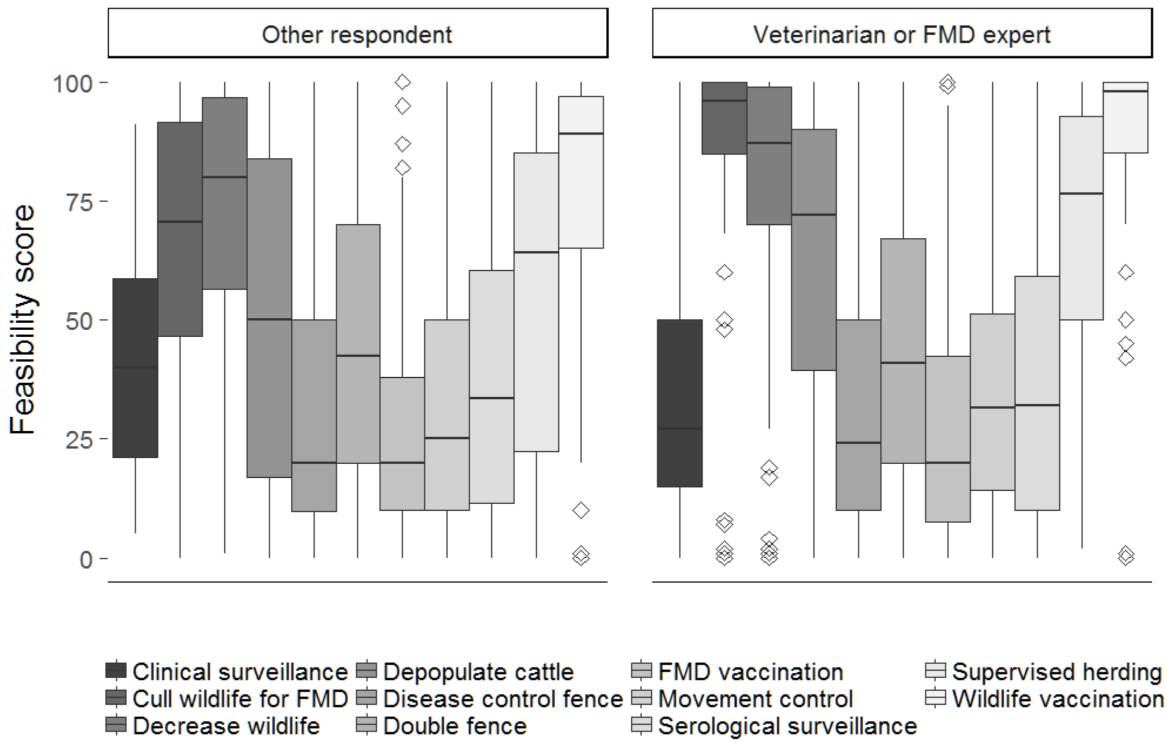

Figure 2. Feasibility data from 81 Veterinarians and FMD experts and 55 other respondents collected for a modified multiple criteria decision analysis (MCDA) of foot-and-mouth disease (FMD) control methods performed in South Africa. Larger values represent less feasible control options and outliers are represented by diamonds.

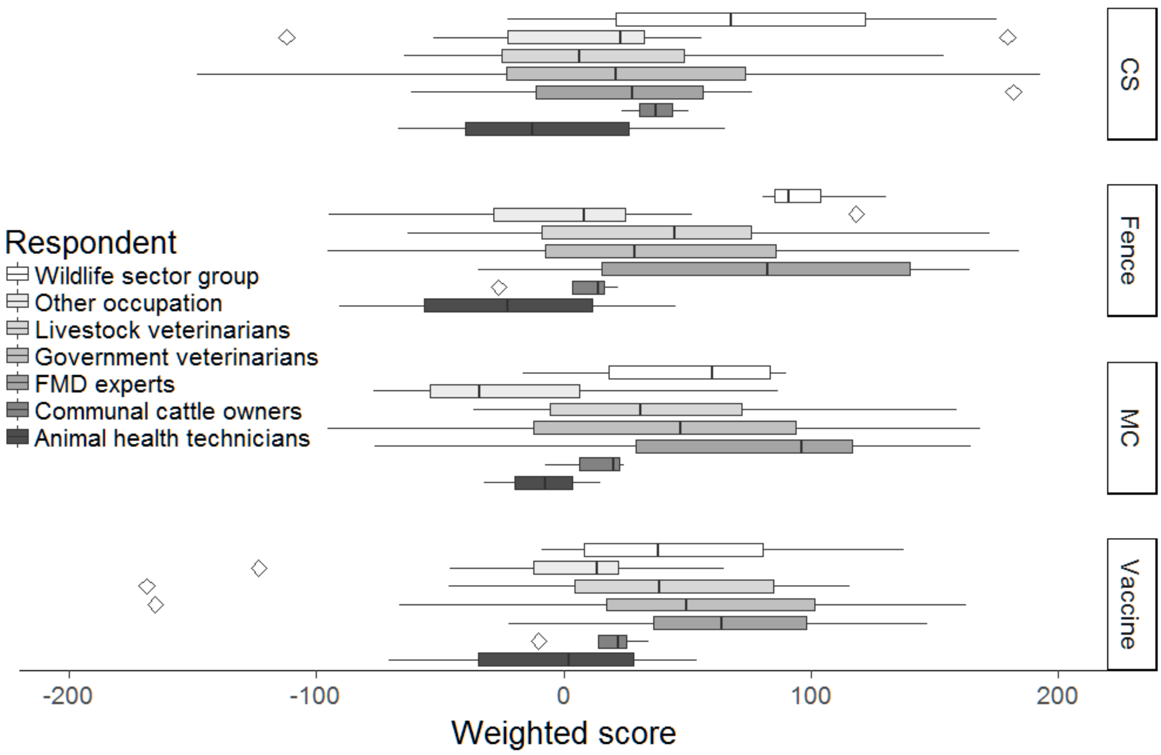

Figure 3. Sums of weighted scores assigned to foot-and-mouth disease control methods by stakeholder groups for a modified multiple criteria decision analysis (MCDA) of foot-and-mouth disease (FMD) control methods performed in South Africa. Control methods include routine vaccination of cattle against FMD virus (Vaccine), movement control between disease control areas of differing FMD risk (MC), clinical surveillance (CS) and the fence between wildlife and livestock areas. Outliers are represented by diamonds.

Table 4. Median (minimum, maximum) criteria scores for the disease control fence as a foot-and-mouth (FMD) control method compared among stakeholder groups based on a modified multiple criteria decision analysis performed in South Africa.

Criterion	**FMD experts**	**Government veterinarians**	**Livestock veterinarians**	**Wildlife sector group**	**Animal health technicians**	**Communal cattle owners**	**Other occupation**	**P value***
Cattle owner economics	50 (10, 80)	50 (10, 100)	50 (30, 100)	76 (25, 95)	70 (35, 90)	65 (50, 75)	61 (29, 88)	0.215
Government economics	24 (10, 94)	26 (0, 99)	32 (15, 100)	45 (13.5;91)	50 (40, 50)	50 (50, 50)	50 (13, 80)	0.067
Industry economics	50[a] (32, 96)	75[a] (4, 100)	50[a] (26, 100)	77[a] (55, 94)	50[a] (50, 50)	50[a] (50, 50)	76[a] (30, 88)	0.022
Effectiveness	89[a,b] (14, 100)	99[a] (1, 100)	81[a,b] (40, 100)	80[a,b] (18, 100)	48[b] (20, 60)	63[b] (50, 90)	76[a,b] (65, 100)	0.001
Cattle welfare	50[a] (25, 80)	73[a,b] (7, 100)	50[a,b] (26, 100)	56[a,b] (43, 77)	40[a,b] (40, 90)	55[a,b] (40, 75)	74[b] (50, 93)	0.012
Environmental welfare	29[a] (8, 95)	46[a] (10, 100)	29[a] (0, 100)	25[a] (0, 75)	50[a] (50, 100)	50[a] (50, 85)	36[a] (15, 88)	0.011
Human welfare	50 (13, 84)	60 (1, 100)	50 (24, 100)	47 (18, 60)	40 (30, 80)	58 (50, 75)	50 (27, 96)	0.466

Medians without superscripts in common are significantly different after Bonferroni correction of P values for multiple post-hoc comparisons.

*Based on Kruskal-Wallis tests comparing distributions among stakeholder groups.

FMD experts providing higher weighted scores than the other occupation group (P = 0.015).

The creation of the FMD free-zone commercial cattle farmer group (n = 10) did not change the overall ranking of the four control methods. The ranking within this group of clinical surveillance and the disease control fence as methods ranked 1 and 2 respectively also did not change. The only recognized difference was the farmer group ranked movement control as the third option with FMD vaccination last whereas the remainder of the other occupation group ranked FMD vaccination third and movement control last.

The standardized weights assigned to the criterion Government economics were the lowest (Figure 4). The AHTs assigned descriptively lower weights to Effectiveness and Industry economics compared to other groups and higher weights for Government economics, Cattle welfare, and Human welfare. Cattle owners also gave relatively low weights to Effectiveness and Industry economics and relatively high weights for Cattle welfare. Government veterinarians assigned relatively high weights to Government economics and, along with the FMD experts, descriptively lower weights for Environmental welfare. Standardized weights for Effectiveness (P = 0.047), Government economics (P < 0.001), Cattle welfare (P = 0.013), and Environmental welfare (P < 0.001) all varied among stakeholder groups. Weights that the AHT group assigned for Effectiveness were lower than the weights provided by FMD experts (P = 0.038). Weights that the government veterinarians assigned to Government economics were higher than responses from the wildlife sector (P < 0.001) and other occupation groups (P = 0.027). Weights provided by the government veterinarian group concerning Environmental welfare were lower than responses from both the livestock veterinarian (P = 0.036) and wildlife sector (P = 0.001) groups.

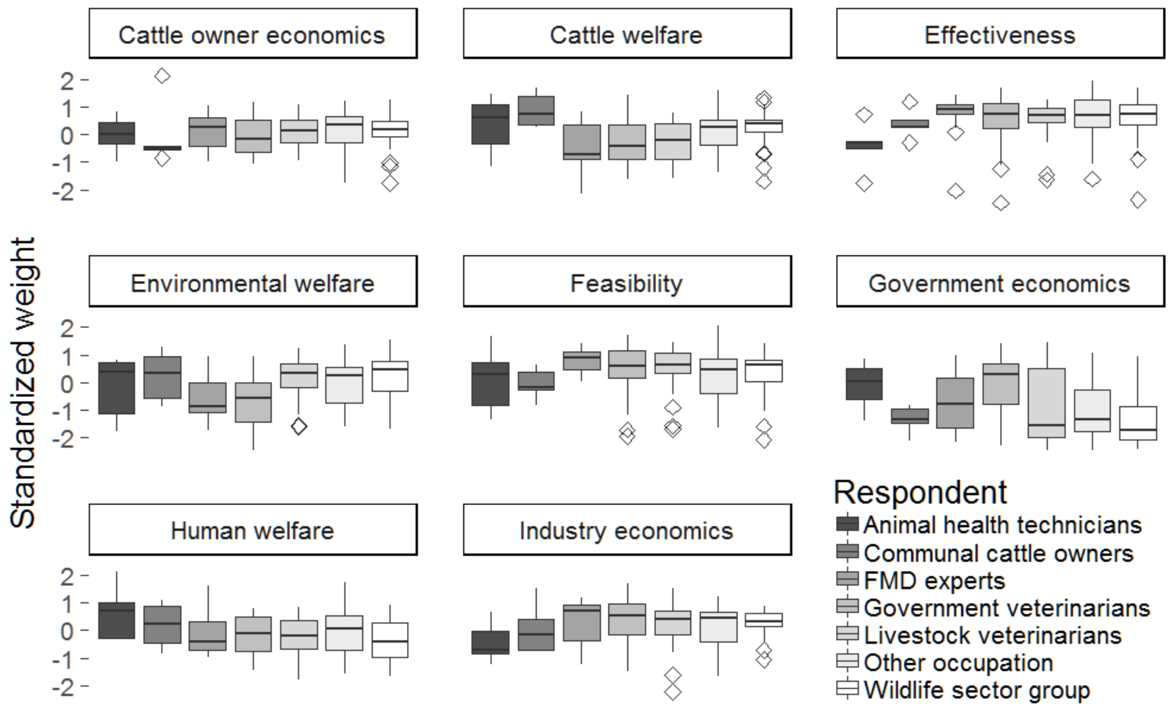

Figure 4. Standardized criteria weights assigned by stakeholders to criteria used to assess foot-and-mouth disease control methods for a modified multiple criteria decision analysis (MCDA) of foot-and-mouth disease (FMD) control performed in South Africa. Outliers are represented by diamonds.

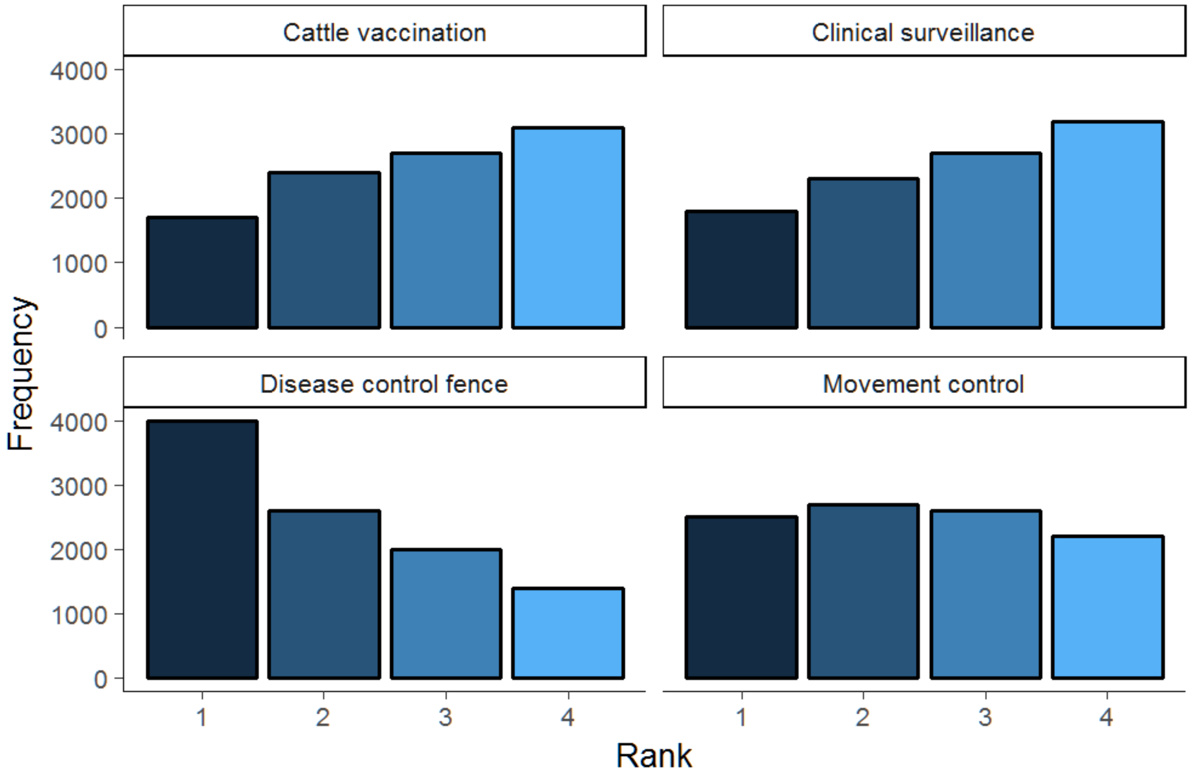

Figure 5. Rankings of foot-and-mouth disease control methods over 10,000 iterations of a modified multiple criteria decision analysis performed for stakeholders in South Africa. The model incorporated stochastic inputs and headings relate to the control option being ranked while the x-axis denotes the number of rankings in which each control measure was first through last (1-4).

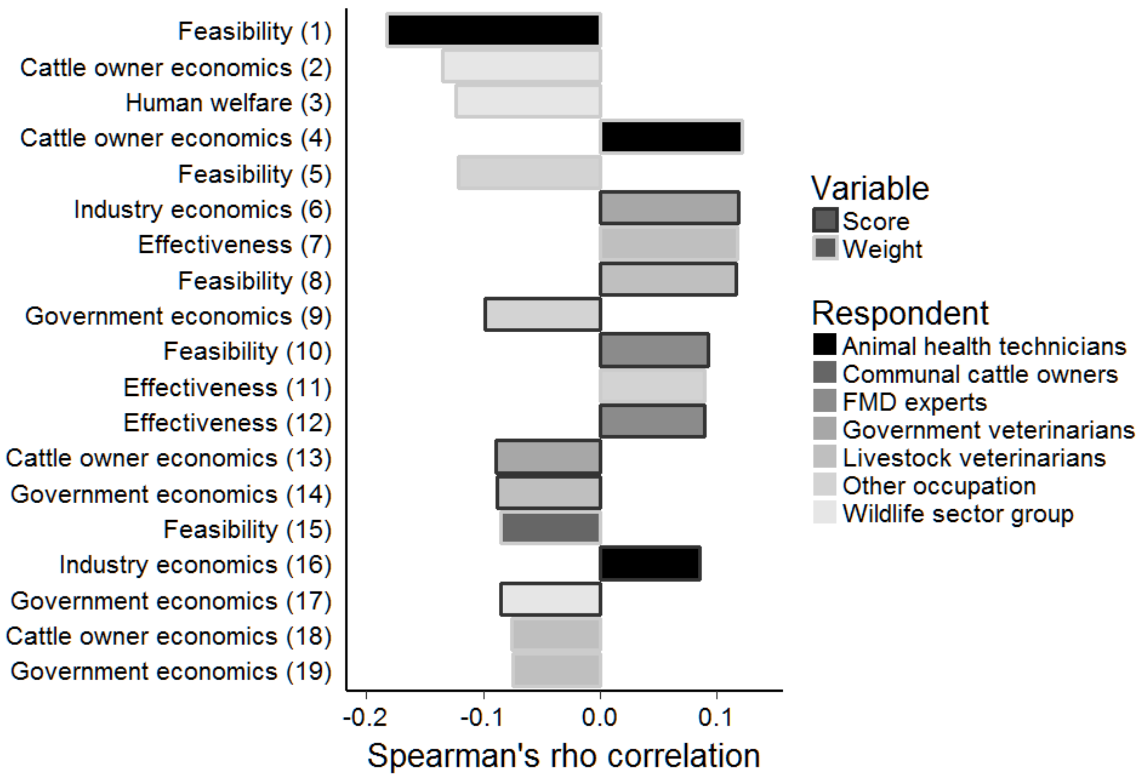

Figure 6. Sensitivity analysis for the MCDA inputs most strongly related to the weighted sum for the fence as a FMD control. The border outline corresponds to whether the input was a measured weight or score and the fill color corresponds to the respondent group.

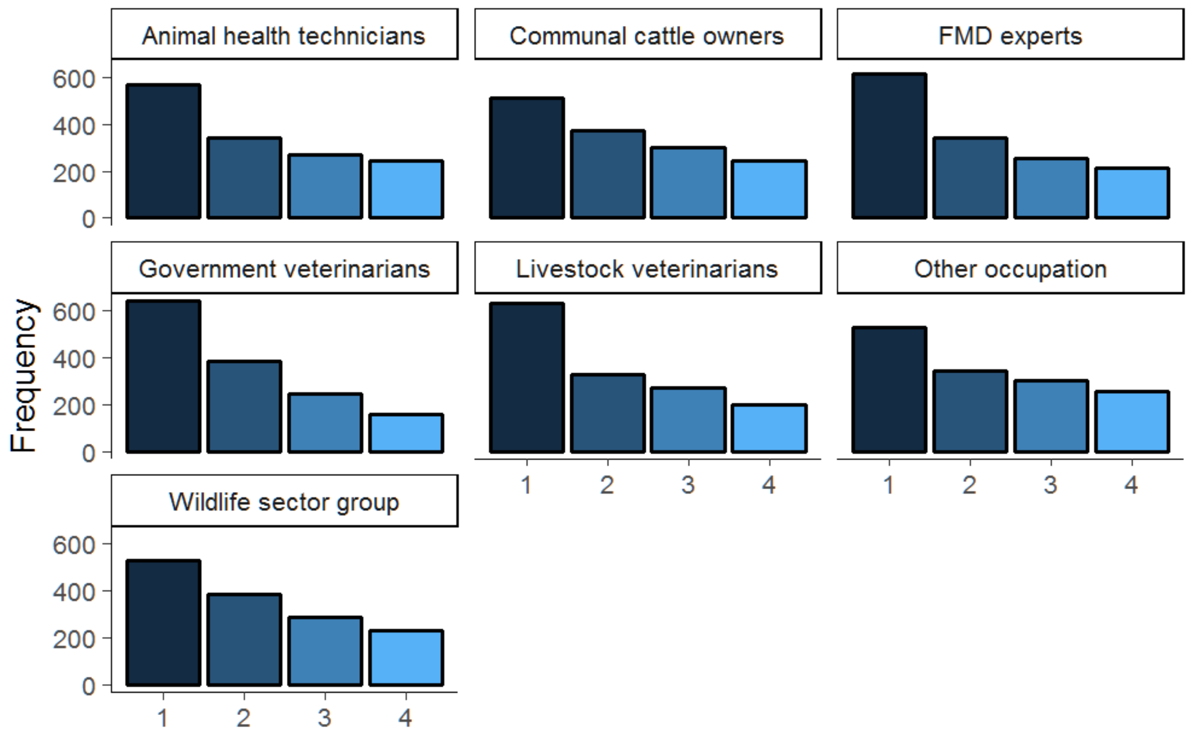

Figure 7. Rankings of the fence as a foot-and-mouth disease (FMD) control method evaluated over 10,000 iterations of a modified multiple criteria decision analysis performed for stakeholders in South Africa where one random stakeholder group was excluded from the model at each iteration. The model incorporated stochastic inputs and the panel heading identifies the group excluded for those data while the x axis relates to the number of iterations in which the fence ranked first through last (1-4).

3.4 Stochastic MCDA results

The fence was ranked first on 40% of the stochastic simulations (Figure 5). Movement control was ranked first for 25% of the simulations whereas clinical surveillance (18%) and vaccination (17%) were similar in the frequency of first rankings. Vaccination was ranked as the least acceptable option (fourth) for 31% of the iterations. No stochastic inputs were strongly correlated with the mean weighted score for the fence based on Spearman's rho (Figure 6). The feasibility weighting provided by the AHT group had the strongest negative correlation (ρ = -0.183). This group also had the largest positive influence through the weights provided for Cattle owner economics (ρ = 0.122). All individual inputs had very little practical influence on the likelihood that the fence would be ranked first (odds ratios obtained from the logistic regression analysis ranged between 0.979 and 1.036).

The mean weighted scores calculated through the random exclusion of the communal cattle owner, wildlife sector, and other occupation groups reduced the proportion of iterations (36-37%) in which the fence ranked as the preferred control option (Figure 7). Random removal of the responses from the government veterinarian, livestock veterinarian, and FMD expert groups caused the fence to rank first slightly more frequently (43-45%). The rankings for movement control were more susceptible to the removal of stakeholder groups (data not shown). Individual exclusion of the cattle owner, other occupation and livestock veterinarian groups caused a higher proportion of first rankings for movement control.

4. Discussion

There is a global drive to improve FMD control and the Progressive Control Pathway was launched by the World Organisation for Animal Health (OIE) and Food and Agriculture Organisation of the United Nations (FAO) to encourage countries to determine the most suitable way forward (OIE, 2012). Livestock owners and the government personnel implementing the control strategies are directly affected by FMD control options, though they might not be consulted when these important decisions are considered. The input of all stakeholder groups should be obtained prior to implementing FMD control initiatives and MCDA is a process that is suited to such situations. MCDA has been used extensively in the fields of environmental management, industry and business management (Aenishaenslin et al., 2013) but few studies have used MCDA to assess animal disease control options (Mourits et al., 2010; Cassidy et al., 2013; Brosig et al., 2016). However, MCDA have been used to prioritise animal diseases (Humblet et al., 2012; Maino et al., 2012; Del Rio Vilas et al., 2013; Brookes et al., 2014a) and to perform spatial risk assessments (Clements et al., 2006; Hongoh et al., 2011; East et al., 2013; Stevens et al., 2013).

The modified MCDA reported here was performed to investigate the perceptions of a wide range of stakeholders concerning FMD control strategies and identified the disease control fence as the most acceptable method. This result was somewhat surprising considering that the fence prevents communal livestock herders from accessing protected areas. Communal areas often have substantially less grass available during the dry season compared to adjacent protected areas behind disease control fences. Damage to the disease control fence is not uncommon and there is evidence that farmers will enter protected areas to graze their livestock (Jori et al., 2009; Brahmbhatt et al., 2012).

The preference for the disease control fence is also surprising considering the concern about the harmful effect of fences in conservation, for example, in terms of large mammal migrations (Ferguson et al., 2013; Woodroffe et al., 2014). However, in this analysis, the effect on the environment and wildlife was only evaluated as one of eight criteria and overall was not an especially influential criterion (did not reach the threshold for inclusion in Figure 7). MCDA results (Table 3, Figure 3) suggested that individual stakeholder groups ranked control methods differently. The potential environmental consequences in conjunction with the effect on grazing opportunities for communal livestock farmers were reasons why it was expected for the fence to rank lower as an acceptable FMD control option. The secondary functions of the fence are likely perceived as bigger benefits to the affected stakeholders compared to the perceived negative influences. Potential secondary benefits include the exclusion of elephants (Van Eden et al., 2016) and predators from entering village areas. Fence breakage and buffalo escapes are also common explanations for FMD outbreaks in the communal livestock areas surrounding the KNP (van Schalkwyk et al., 2016).

Veterinary AHT have exposure mostly to the fence on the western boundary of the Greater Limpopo Transfrontier Conservation Area. This fence is maintained by the government and the negative opinion of AHT (Table 3) might be related to first-hand experience with the frequency and consequences of fence damage. The opinions expressed by this group tended to be more negative towards the fence in general. Sums of the weighted scores provided by the FMD expert group (Figure 3) tended to be higher than other groups while the same scores from the AHT group tended to be the lowest. This indicates diverging opinions between those involved in the more theoretical study of FMD control from those responsible for enforcing control on the ground. However, the different data collection methods might also have contributed to these divergent results.

The ranking of vaccination as the least preferable FMD control option (Figure 5) was also somewhat surprising. The cross-sectional design of the study did not allow for in-depth analysis of the reason for this finding and therefore explanations can only be speculative. We considered this result surprising because vaccination of susceptible cattle was the primary reason for the successful eradication of Rinderpest (Roeder et al., 2013) and vaccination is typically considered a beneficial component of control strategies for transboundary diseases (Lubroth et al., 2007). It was expected that FMD experts would rank vaccination lower since there is extensive antigenic variability of SAT viruses (Maree et al., 2011) potentially limiting the efficacy of routine vaccination. A recent study conducted in a section of South Africa's FMD protection zone with vaccination (Lazarus et al., 2017), documented relatively high satisfaction levels with government disease control efforts and it was therefore surprising that communal farmers contributed low weighted scores to the use of vaccine for the control of FMD (Table 3, Figure 3). The relatively low scores contributed by the AHT group (Table 3, Figure 3) were also unexpected and could indicate problems with the design or implementation of the FMD vaccination strategy. South Africa was utilizing an FMD vaccine produced in another southern African country at the time of this study and some AHT groups expressed an opinion that this vaccine was not locally effective and therefore vaccination represented a net economic loss to the government. The AHT in the FMD protection zone also have first-hand experience with the practical difficulty in maintaining the vaccine cold chain. The weighted scores from both AHT and communal cattle owner groups were descriptively lower than the FMD experts and other stakeholder groups (Figure 3).

The results of the stochastic model corroborated the finding that the disease control fence was the preferable FMD control option. However, the distributions of the rankings for FMD vaccination and clinical surveillance were almost identical. Their rankings as third and fourth can be considered interchangeable despite the fact that the deterministic model ranked vaccination as fourth. The distribution of ranks for movement control was relatively uniform indicating no clear preference for, or against, this method of FMD control.

There was no single model input or respondent group that was strongly associated with the ranking of the fence as the most preferred FMD control option (Figures 6 and 7). The most influential inputs did not have a practically important effect on the ranking of the fence (the point estimates for all OR within the sensitivity analysis were between 0.98 and 1.04). The feasibility of using the fence as a FMD control option was the most influential factor in the mean weighted scores (Figure 6). The strongest negative correlation was observed in the responses from the AHT group. These individuals live and work in the communal areas surrounding the KNP and it is possible that they have first-hand experience with fence damage and the escape of wildlife into the surrounding villages. The private veterinarians and FMD experts scoring of the feasibility was positively correlated with ranking the disease control fence indicating a possible disconnect between the theoretical and practical knowledge of maintaining disease control fencing.

The economics criteria appeared most frequently in the list of influential fence scores within the sensitivity analysis (Figure 6). Government economics contributed to 4 of the 19 most influential inputs and was negatively associated with the mean weighted score for the fence. This criterion and the criterion Environmental welfare tended to have the lowest scores reported for the disease control fence (Table 4). The fence could theoretically be improved by addressing these concerns, but in reality it would be difficult if not impossible. It is necessary to investigate these perceptions closely if it is desired to more completely understand the perceptions of the disease control fence as a practical FMD control method.

The distribution of ranks in the sensitivity analysis was very similar irrespective of the excluded respondent group (Figure 7). This suggests some agreement among stakeholders.

It appears that communal cattle owners had the strongest preference for the fence since the removal of this group caused the greatest decline in the proportion of iterations in which the fence was ranked as the number one (first) option. Conversely, it appears that government veterinarians had the lowest opinion of the fence since the removal of their responses caused the fence to be ranked number one more frequently. The rankings for movement control were more susceptible to the removal of stakeholder groups. This result suggested that movement control is more controversial than the other control methods. This was further evidenced by the results from comparing the sums of weighted scores, where there were significant differences among the scores assigned by the different stakeholder groups.

The study reported here was designed to follow a modified MCDA framework and limitations and potential sources of bias are important to consider when interpreting the presented results. The potential for selection bias is an important consideration since all respondents were volunteers and the online questionnaire limited respondents to those comfortable using computers and the internet. Under-coverage could also have been an issue due to the fact that people involved within the wildlife sector who were not members of Wildlife Ranching South Africa and livestock veterinarians not on the contacted listserv were excluded by design. There were also no responses from DAFF veterinarians and very few commercial farmers participated in the research. The resultant small sample size is a potential reason for the relatively few significant differences that were obtained. A greater incentive or a more user-friendly questionnaire might have helped to improve the representativeness of all target groups, especially the general public or other occupation group.

The modified MCDA was not developed from the perspective of the decision makers involved with FMD control (DAFF veterinarians). The approach was designed to incorporate the perceptions of all stakeholders and an independent approach to collected data related to weights was implemented for this reason. The weighted sum aggregation method assumes weights represent how much a stakeholder is willing to sacrifice in terms of one criterion in order to gain in terms of another (Belton and Stewart, 2002; Keeney, 2002; del Rio Vilas et al., 2011). The criteria in this modified MCDA were weighted simultaneously but the respondents were not required to consider trade-offs. The usual trade-off approach was not employed since it was not considered feasible to implement for the AHT and communal farmer groups. The nine evaluated criteria created 72 pairwise trade-offs (9 criteria * 8 comparisons for each) and this approach was not considered feasible to request of volunteer participants. It might also be questionable to request respondent groups (e.g., cattle farmers) that are directly affected by the control methods to consider trade-offs involving themselves with an independent third party (e.g., South African government). Furthermore, it is preferable to phrase MCDA questions in a quantitative manner related to the expected impact of the control method on the number of FMD outbreaks. An example would be to rather phrase the question about the effectiveness of the fence as: "If the fence is removed, there could be a maximum of 10 FMD outbreaks next year, a minimum of 0 outbreaks, but how many outbreaks would be most likely?" The most likely number of outbreaks would be chosen on a slider with a maximum of 10 and a minimum of zero. This approach was rejected at the time of designing the questionnaire since we felt that only FMD experts (and some veterinarians) would be able to estimate the effects of control measures in a quantitative manner. For example, the extent of an outbreak varies tremendously and some stakeholder groups would not be expected to know that the number of outbreaks varies from year to year independent of the control measures. Our research therefore represents a more qualitative investigation of the perceptions of stakeholder groups.

The wildlife sector and other occupation groups answered a questionnaire containing questions concerning only a single control method in effort to create a shorter instrument and increase the number of responses. However, the missing values for these respondents had to be imputed for the calculation of weighted scores in the modified MCDA model. These respondents therefore contributed less to the overall model result than the veterinarian and FMD expert groups (who scored three of the four methods). Group means were used in place of the missing values as it was believed that this would have the least influence on the MCDA. This imputation did not appear to unduly influence results since the deterministic MCDA findings were consistent with the findings of the stochastic analysis in which distributions were elicited excluding imputed data (Figure 5). However, a larger sample size would have reduced the potential impact of this imputation and provided more statistical power for the comparison of weights and scores among stakeholder groups. It was also necessary to convert the information obtained from the semi-structured interviews into numerical weights and scores on the same scales as the data from the online questionnaire. All weights were standardized in an attempt to make the weighted scores comparable, but the accuracy of the conversion cannot be guaranteed.

A strength of this study was that communal farmers and veterinary AHT within the FMD protection zone with vaccination were included as stakeholder groups. However, the inclusion of these groups also caused potential limitations. Data collection required modification in effort to incorporate the perceptions of these groups into the investigation. This modification created difficulties because there is the possibility that farmers and AHT might not have given their honest opinions when the provincial veterinarian was present at the meetings. It is also possible that the recorded perceptions were representative of the dominant individuals present at the group discussions rather than the opinion of the majority of participants. The variability in responses might have therefore been less than what would have been observed had data been collected on an individual level. The responses from these groups did not have an unusually large influence on the MCDA findings suggesting that the potential biases were likely towards the null; the exclusion of these data did not change the overall findings of the model.

The current study represents a cross-sectional evaluation of the perceptions of stakeholder groups concerning methods for FMD control. The reported weights and scores were compared among groups but the cross-sectional design did not include a follow-up investigation to identify the reasons for the observed differences between groups. The current study therefore represents a preliminary investigation into the perceptions of various stakeholder groups in South Africa concerning FMD control. Explanations for observed differences can only be speculative at the present time. It is therefore necessary for future studies to implement the appropriate methods to test hypotheses related to perceived differences in the costs and benefits of FMD control methods.

Despite the study limitations, results indicate that a modified MCDA can be used to compare the perceptions of different stakeholder groups with regard to animal disease control. The opinions of stakeholders are expected to be influenced by their knowledge and level of involvement in FMD control. The identification of groups with conflicting opinions could indicate where additional discussion, and possibly more planning, might be required. It is important to include all stakeholders, as those with technical knowledge are unlikely to be the individuals directly affected by the control methods. MCDA is an inclusive decision support tool that can identify the weaknesses of the assessed options and even indicate where the most preferred option could be improved.

5. Conclusions

The disease control fence was the preferred FMD control method for South Africa. The preference for the fence was stable among investigated stakeholder groups and no single input had undue influence on this ranking. Vaccination was the lowest ranking control option and this suggests that improvements might be necessary when using this option for the control of FMD in southern Africa. Results of this study cannot be used to suggest modifications to FMD control in South Africa because of the study limitations and international requirements for maintenance of the FMD free zone in the country. The control of FMD in southern Africa is complicated by the presence of wildlife reservoirs and further investigations are required to identify the reasons for differing perceptions of FMD control among stakeholder groups in effort to reduce FMD outbreaks in the region.

Conflicts of interest:

None of the authors has financial or personal relationships that could influence or bias the content of the paper. The funding agency did not influence the design, conduct, analysis, or reporting of the study.

Acknowledgements

The authors thank the provincial veterinarians Drs Ayanda Mpehle and Jonathan Wright for logistical help concerning data collection from communal livestock farmers and veterinary animal health technicians. The authors would also like to thank all respondents for contributing their time for the successful completion of this project. The research was funded by the National Research Foundation (NRF), South Africa (Grant Numbers 90578 and

76734). The first author was funded for an MSc by the NRF Scarce Skills bursary.

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