Improving foot-and-mouth disease control through the evaluation of goat movement patterns within the FMD protection zone of South Africa

David Dazhia Lazarus [a,b*], Pamela Anne Opperman [a,c], Mohamed Mahmoud Sirdar [a,c], Tanja Esther Wolf [d], Ilana van Wyk [e], Oupa Boetie Rikhotso [f], Geoffrey Theodore Fosgate [a]

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

[b] National Veterinary Research Institute, Foot-and-Mouth Disease Virus Research Laboratory, Vom, Nigeria

[c] Agricultural Research Council, Onderstepoort Veterinary Research, Transboundary Animal Diseases, Onderstepoort, South Africa

[d] University of Pretoria, Faculty of Natural Sciences, Mammal Research Institute, Pretoria, South Africa

[e] University of Pretoria, Faculty of Veterinary Science, Mnisi Community Programme, South Africa.

[f] Mpumalanga Veterinary Services, Department of Agriculture, Rural Development Land, Administration, South Africa

*Email: lazdav2003@yahoo.co.uk dlazarus@nvri.gov.ng (D.D. Lazarus)

Tel: +27 74 634 7529

Highlights

• Goats are the most common livestock species kept by smallholder farmers in Africa

• They are susceptible to infections with foot-and-mouth disease virus

• Their role in the epidemiology of the disease is poorly studied

• Goats are easily moved out of the FMD protection zone without official movement permits

• Movement of sub-clinically infected livestock poses a risk for the spread of disease

Abstract

Foot-and-mouth disease (FMD) is a transboundary animal disease that has a major impact on livestock production, regional and international trade and livelihoods of smallholder farmers in endemic settings. Many livestock diseases are transmitted through direct contact between animals, and thus between herds and flocks through animal movements. In this study, we described the pattern of goat movements among smallholder farmers within a communal farming area in South Africa. A cross-sectional survey using a semi-structured questionnaire was administered to 116 respondents, and separate 13 focus group discussions employing participatory mapping and semi-structured interviews were conducted among smallholder farmers. Overall, 22% (95% confidence interval [CI]: 16 – 31) of questionnaire respondents indicated moving new animals into their holdings during the previous 12 months while 56% (95% CI: 47 – 65) reported moving animals out of the holdings during the same timeframe. A total of 134 participants attended the focus group discussions with 68% (91/134) being male and 32% (43/134) female. Data from the study reported 37 nodes and 78 ties with an overall network density of 0.059 (SD 0.2) across the study area. Four locations within the (former) FMD-free zone of the country had connections with movement of goats from the study area. Furthermore, 60% (95% CI: 51 – 69) of farmers being ignorant of the need to obtain official veterinary movement permits for goats. These animal movements put the country at risk of future FMD outbreaks within the free zone. We recommend that the relevant authorities implement risk-based control measures to prevent the spread of infectious diseases.

Keywords: FMD, Movement, Network, Risk, Smallholder Farmer, South Africa,

1. Introduction

Foot-and-mouth disease (FMD) is a highly infectious transboundary animal disease that affects cloven-hoofed livestock and wildlife including cattle, buffalo, pigs, sheep, goats, impala, deer and antelope (OIE, 2018; Poolkhet et al., 2019). The disease is caused by infection with foot-and-mouth disease virus (FMDV), a single-stranded RNA virus in the genus *Aphthovirus,* family *Picornaviridae* (Han et al., 2018). Goats are the most common livestock species kept by smallholder communal farmers in South Africa (Braker et al., 2002). However, the clinical signs of FMD in goats can be inapparent or mild with nasal discharge, ulcerative lesions of the oral mucosa and fever occurring in only a proportion of animals experimentally infected with FMD virus Southern African Territories (SAT)1 (Lazarus et al., 2019). Goats affected by FMD also do not show obvious sickness behaviors (Wolf et al., 2020). Thus, goats can be considered "silent shedders" of disease because of the lack of obvious clinical signs of FMD compared to other livestock including cattle and pigs.

FMDV is primarily transmitted through direct contact via inhalation (OIE, 2018; Poolkhet et al., 2019) and can be spread through the movement of infected and susceptible hosts (Brito et al., 2017; Tekleghiorghis et al., 2016). Effective movement controls, such as those implemented during the 2001 FMD epidemic in the United Kingdom, can slow down the spread of disease (Ferguson et al., 2001; Haydon et al., 2004). Risk factors for the occurrence and spread of FMD include poor farm biosecurity practices (Ellis-Iversen et al., 2011; Megersa et al., 2009), presence of infected animals (Gibbens et al., 2001), presence of wildlife reservoirs (Molla et al., 2010; Vosloo et al., 1996), exposure to secretions or products derived from infected animals (Elnekave et al., 2016), exposure to contaminated fomites (Alexandersen et al., 2003), poor vaccination coverage (Jori et al., 2009; Nyaguthii et al., 2019), longer vaccination intervals (Lazarus et al., 2017), poor livestock inspection (Jori et al., 2009) and unvaccinated animal populations (Bravo de Rueda et al., 2014).

Livestock movement is one of the most important ways of spreading infectious diseases between holdings (Nremark et al., 2011). Many livestock diseases are transmitted through direct contact between animals, and thus between herds and flocks through animal movements. This has led many countries of the developed world to register livestock movements using national databases (Barcos, 2001). Information generated from such databases could be used for surveillance and planning disease control programmes.

The application of social network analysis within the livestock industry has improved our knowledge of livestock movement patterns and has informed risk-based surveillance systems (Dubé et al., 2008; Poolkhet et al., 2019). Social network analysis has been used extensively to analyse livestock movements (Aznar et al., 2011; Green et al., 2008; Kao et al., 2006; Kiss et al., 2008; Mweu et al., 2013; Nremark et al., 2011; Robinson et al., 2007; Webb, 2006) and can help identify targets for surveillance, intervention and control (Bajardi et al., 2012; Christley et al., 2005; Kiss et al., 2006; Natale et al., 2009). A network analysis study of the 2001 UK FMD outbreak (Shirley and Rushton, 2005), identified livestock markets and dealers as the hubs for disease spread. Certain nodes (units of interests) including certain farms, animal markets and dealers were key players in the early spread of FMD during the outbreak (Ortiz-Pelaez et al., 2006). All nodes had a high betweenness centrality, a measure of how frequent a node is located between each pair of node connections. The transportation of infected livestock is known to be responsible for disease transmission (Dubé et al., 2008) and the out-degree centrality, a quantification of the number of outgoing ties (links between nodes) from the node, is useful for estimating the resulting size of the outbreak. The control of infectious livestock diseases such as FMD should focus on livestock movements within the livestock trade network (Natale et al., 2009).

FMD is still one of the most important livestock diseases that threatens livestock production in South Africa, with outbreaks reported outside the FMD control zone of the country. Between January and November 2019, two FMD serotype SAT2 outbreaks were reported in the formerly FMD free zone of Limpopo Province, (DAFF 2019a; DAFF 2019b). These outbreaks caused South Africa to lose the World Organisation for Animal Health (OIE) certified free zone status without vaccination.

The aim of this study was to investigate the magnitude of goat movements within an area of the FMD protection zone of South Africa as a proof-of-concept and to identify high-risk locations for implementation of improved surveillance and strategic vaccination programmes.

2. Materials and methods

2.1. Study area

This study was conducted in a communal farming area within the FMD protection zone with vaccination in the Mnisi Tribal Authority (MTA), Bushbuckridge Local Municipality, Mpumalanga Province, South Africa. The MTA is divided into three animal health wards (Bushbuckridge East, Animal Health Wards I-III) and totals 16 communal dip tanks (livestock inspection points). The communal dip tanks are animal holding facilities where cattle are routinely treated against ectoparasites using acaricide dips. They are also used for the routine livestock FMD inspection and vaccination campaigns. Communal farmers within this area are involved mostly in livestock rearing. The proximity to the Kruger National Park (KNP) poses a threat to livestock production due to infectious diseases and the surrounding areas have poor market access as they are located within the FMD protection zone with vaccination (Lazarus et al., 2018).

FMD control measures in South Africa include the separation of wildlife and livestock using fences, clinical surveillance, routine vaccination of cattle and movement control of susceptible livestock, wildlife and their products (DAFF 2014). According to the South African veterinary legislation, three zones exist for the control of FMD (DAFF 2014). The three zones classify the country into: a) FMD infected zone b) FMD protection zone (with or without vaccination) and c) formerly FMD free zone (majority of the country). The FMD protection zone was established to protect the status of animals in the FMD free zone and movement of livestock into the free zone is restricted using a permit system after the animal has been examined and certified to be free from FMD.

Farmers within the protection zones are mostly engaged in communal farming activities, which are considered to be cost-effective farming system (Dovie et al., 2006). However, it is a high-risk husbandry system due to poor biosecurity practices that might lead to the occurrence and spread of diseases including FMD. As a control measure for FMD and other infectious diseases, movement of cattle out of this zone of the country is only allowed if the animal originates from a herd that has evidence of previous FMD vaccination and has a movement permit issued by the official veterinary service. Thus, FMD vaccinated animals can only move to other vaccination areas or a designated abattoir for direct slaughter.

2.2. Target population and sample size calculations

The target population was smallholder farmers who kept goats within the three animal health wards of the MTA. The required sample size was calculated based on the desire to estimate the proportion of respondents that reported goat movements (in and out) of their flock at least once during a one-year period (July 2017 –June 2018). Given the lack of knowledge of goat movements in the area, the proportion was assumed to be 50% and calculations were based on a desired confidence level of 95% and absolute error of ±10%. The sample size was estimated to be 97 respondents (Thrusfied, 2005) but increased by 5% to account for non-response and the possibility of data exclusions. Participants were selected proportional to the total number of registered livestock owners (stratified by small stock) per communal dip tank (Supplemental Table 1).

2.3. Ethical considerations

The study was approved by the University of Pretoria, Faculty of Veterinary Science, Animal Ethics Committee (Project Number V022-17) and the Faculty of Humanities, Ethics Committee (Project Number GW20170623HS). Participants were presented with a consent form before the commencement of interviews or focus group discussions and their identity was coded to ensure confidentiality. Verbal consent was obtained from illiterate respondents.

2.4. Data collection

2.4.1. Questionnaire development and administration

The questionnaire was pilot tested among 12 smallholder farmers from a community in Northwest Province, South Africa prior to finalization and administration in this study. The final questionnaire comprised a total of 21 questions divided into the following four sections: owner demographics, herd demographics, animal management and animal movement and losses. A combination of open and closed questions was used. For some questions, respondents were asked to choose only the most applicable answer, while for others they could select all appropriate options.

A semi-structured interview was administered in Xitsonga language using a trained interviewer. Smallholder goat farmers were individually recruited on a voluntary basis as they appeared for the routine livestock inspection at the dip tanks. Respondents were enrolled after being informed of the study purpose. The interview session lasted approximately 30 minutes with each respondent.

Interviews were conducted at the communal dip tanks, which is the usual meeting point for all farmers during the routine livestock inspections. Global positioning system (GPS) coordinates for all study locations were captured using a handheld device (Garmin eTrex® 10, USA) at the time of the interview.

2.4.2. Focus group discussions and participatory mapping

For the focus group discussion and the participatory mapping, an independent semi-structured interview was conducted with separate groups at the communal dip tanks. Participants were recruited on a voluntary basis after being informed of the study purpose. Sessions were split into multiple groups with a maximum of 11 participants when group sizes were large. Respondents were requested to identify origins and destinations of goat movements on a sketch map display of the MTA using laminated pictures of goats. Participants were further asked to list the origin and destinations of animal movements outside the three animal health wards. Questions were also asked concerning reasons for buying and selling animals and challenges faced in goat production. The local animal health technicians also participated in a group session to validate collected data and remove uncertain ties (origin and destination pairs) from the network.

2.4.3 Network properties

The network of goat movements in the three animal health wards of the MTA were analysed using directed and symmetrized methods (Borgatti et al., 2013). Nodes were the communities within the wards and the ties were live goat movements between communities. A descriptive statistical analysis was performed and network analysis was calculated on a directed binary network using UCINet6.66.4 (Analytical Technologies, USA) (Borgatti et al., 2013). The following indices were used for the calculation of the network centrality measures.

The degree centrality is the sum of all actors who are directly connected to the focal actor. The node with a high value reflects a high number of ties or the channel of node connection. Directed networks are networks that have in and out degree centrality measures available for analysis.

The betweenness centrality is the number of times an actor connects pairs of other actors, who otherwise would not be able to reach one another. The node with a high value indicated a high frequency of animal movements through the node.

The closeness centrality is a value based on the notion of distance and considered the geodesic distance from one node to all remaining nodes of the network. The geodesic distance is one of several techniques for evaluating closeness in network analysis. A node with a high value indicated that it is easy to move animals to the linking node.

The clustering coefficient is calculated from three connected nodes forming a triangular shape (transitivity) in the network. A network with a high clustering coefficient means that many node triangles are present.

The network density is the proportion of actual ties that are present in the network out of all possible ties.

2.4.4. Data analysis

Descriptive statistics were presented as frequencies and percentages with 95% confidence intervals (95%CI). Continuous data were described either using mean ± standard deviation (SD) or medians and interquartile ranges (IQR). The normality assumption for quantitative variables was assessed by calculating descriptive statistics, plotting histograms and performing the Anderson-Darling test for normality within MINITAB Statistical Software, Release 16 (Minitab Inc., USA). Normally distributed variables were presented as means ± SD and comparisons performed using one-way

ANOVA. Kruskal-Wallis tests were used to compare centrality measures across the three animal health wards of the study area. Statistical analyses were performed in commercially available software (IBM SPSS Statistics Version 24, International Business Machines Corp., Armonk, New York, USA) and significance was set at $P<0.05$. Mapping of the study area displaying the distribution of dip tanks was performed using ArcGIS 10.2.3 (ESRI, USA), and the sociogram of the movements network was performed using the UCINet6.66.4 programme (Analytical Technologies, USA) (Borgatti et al., 2013). Nodes were projected using their GPS coordinates estimated using Google Earth (https://www.google.com/earth/) when outside the study area.

3. Results

3.1. Demographic and husbandry findings

A total of 116 smallholder goat farmers were interviewed during June-July 2018 with 36, 35 and 45 respondents from Wards I-III, respectively. The median (IQR) age of respondents for the three wards was 62 (53 – 75), 65 (52 – 79) and 66 (55 – 74) years for Wards I-III, respectively. The major occupation of respondents was livestock farming with some also involved in private or government employment (Table 1). In addition to rearing goats, some respondents also reared cattle, pigs and chickens. The median (IQR) experience in farming was 27 (14 – 38), 28 (11 – 28) and 19 (10 – 27) years for Wards I-III, respectively. Eighty-three percent (30/36), 86% (30/35) and 80% (36/45) of respondents kept cattle in addition to goats in Wards I-III, respectively. Respondents from Ward I indicated that their motivation for farming included love for animals (31%), subsistence (22%), business (19%), draught power (6%), ceremonial and cultural purpose (31%) and long-term savings and investment (3%). For the respondents in Ward II, these included subsistence (51%), love for animals (20%), draught power (11%), business (9%) and long-term savings and investment (6%). Motivating factors for respondents in Ward III included subsistence

(42%), business (22%), love for animals (13%), long terms savings and investment (11%), ceremonial and cultural purposes (7%) and draught power (2%).

Age of respondents, level of education, farming experience and number of goats owned were not different among the three animal health wards (Table 2). A total of 134 participants attended the focus group discussions from across the three animal health wards, with 68% (91/134) male and 32% (43/134) female.

3.2. Animal movements

There were less reported movements into holdings based on questionnaire responses relative to movement out of the holdings during the previous 12 months (Table 3). Reported movement into holdings were 5 goats in Ward I, 17 goats in Ward II and 11 goats in Ward III. Respondents from Ward I indicated the most recent time of animal movement into the holdings to be median 6 (1 – 30) months. The most recent time for animal movement into the holdings for respondents in Ward II was median 6 (4 – 12) months. Respondents in Ward III indicated a median time of 5 (3 – 12) months. Livestock movement out of the flock for the previous 12 months preceding the study was 45 goats in Ward I, 38 goats in Ward II and 36 goats in Ward III. The most recent reported time of animal movement out of the holdings was median 6 (2 – 11) months in Ward I, median 2 (1 – 8) months in Ward II, and median 4 (1 – 6) months in Ward III. Most of the respondents, 60% (95%CI: 51 – 69) in all the study indicated their ignorance on the need to obtain official veterinary movement permits to move goats from their holdings within this protection zone (Table 3).

3.3. Network analysis of goat movements

Data from 116 questionnaires and 13 independent focused group discussions reported 37 nodes and 78 ties with an overall network density of 0.059 (SD = 0.2) across the study area (Figure 1). Most of the nodes had connections with each other, with extension to nodes outside the study area

(Figure 2). Village A in Ward I and Village F in Ward II had the largest in-degree centrality values of 9 and 7 respectively. Moreover, the first five nodes with the highest values for out-degree centrality were Village F (12), Village G (11), Village E (7), Village H (7), and Village I (7). Ten nodes had links with communities outside the study area and animals were routinely moved to these outside communities either for consumption or husbandry purposes. On average, the actors (respective nodes of the study network) had a degree of 2 for both in-degree and out-degree, which was quite low given that there were 37 actors in the network. Overall, the network had 15 nodes within the study area and 21 nodes outside the study area. Four locations within the formerly FMD free zone of the country (Nelspruit, Tzaneen, Barberton and Leboeng) had links with the movement of goats from the study area. The range of out-degree was slightly higher (minimum – maximum: 0 – 12) than that of the in-degree (0 – 9) with more variability across actors in the out-degree than the in-degree (standard deviation and variance). The network had an out-degree coefficient of variation of 154 and in-degree coefficient of variation of 89. In this network, the out-degree graph centralization was 28% and the in-degree graph centralization was 20% of the theoretical maximums.

Closeness centrality measures indicated Villages F and G, both in Ward II to be the nodes with the highest out-degree closeness values followed by Village M in Ward III and Village E in Ward I. There was more variation in the out-closeness value relative to the in-closeness (minimum – maximum: 0 – 20).

Villages F and H both in Ward II, Village E (Ward I) and Village O (Ward III) had the largest betweenness measures. There was a lot of variation in actor betweenness (range 0 – 175; standard deviation = 37 relative to a mean betweenness value of 17). Despite this, the overall network centralization was relatively low (13%) with an overall graph clustering coefficient of 0.24.

However, there were no significant differences of movement centrality measures among areas (Table 4).

4. Discussion

The primary aim of this study was to evaluate the role that movement of goats might play in the spread of FMD within a disease control area and identify high-risk disease locations for improved surveillance and strategic vaccination programmes. In this paper, the patterns of goat movement networks were investigated because of our desire to improve FMD control in the country. It is expected that the results of this study will be useful for disease control through the implementation of risk-based surveillance and strategic vaccination in disease endemic countries prioritizing FMD protection zones and high-risk production sectors within their regions.

The number of goats kept by respondents in this study were similar to a smallholder study conducted in another part of the country (Braker et al., 2002). In addition to keeping goats, communal farmers also kept cattle and pigs, which are also susceptible hosts for FMD. Most communal farmers within the study area reported that they do not require livestock movement permits to move goats to neighboring and distant locations. This suggests a need to educate farmers concerning the risk of livestock movement out of disease control areas. Most goats are bred and consumed locally within the communities with some reported movements outside the study area.

Livestock movement contributes to the spread of infectious diseases from endemic to free zones (Nremark et al., 2011). In South Africa, the majority of the country was previously classified as FMD free (DAFF, 2014). However, the KNP and adjoining nature reserves were classified as part of the FMD infected zone due to the existence of wildlife reservoirs including the African buffalo (*Syncerus caffer*) (DAFF, 2014). Communal farming areas surrounding the KNP were classified as the FMD protection zone with vaccination, where cattle are routinely inspected and vaccinated against FMD (Lazarus et al., 2018). Movement of livestock from the FMD protection zone to any other part of the country requires inspection and a movement permit (DAFF, 2014). In this study, respondents reported more movement of animals out of their holdings relative to movement into their holdings during the previous 12 months. The most influential nodes in the network were communities F and G, which were closer to urban settlements with accessible roads network. They had the highest out-degree centrality measures, and thus were the most influential communities for the possible spread of diseases. Goat movement out of the holdings was independent of each other to reach everyone in the network as demonstrated by high out-closeness centrality measures.

Village A had the highest in-degree centrality measure followed by Villages F and O, which suggests high-risk nodes for disease outbreak occurrence. Therefore, more FMD surveillance should be focused on these nodes as they tend to receive more inward animal movements relative to all other nodes. Village F had a relatively high centrality measure, and this might be due to its location and accessible road network compared to the more remote settings. Farmers in Village F tended to source goats from nearby nodes and then export them to distant locations. A similar movement pattern was previously described in the study of a traditional cattle trade network in Tak Province, Thailand (Khengwa et al., 2017). In the current network, the out-degree graph centralization is much greater than the in-degree graph centralization, and this suggests that there is proportionally more out-degree movement in this network. These communities require additional education on disease prevention and control, improved surveillance and inspection before animal movements. In terms of the network analysis, such communities could be described as the disease spreaders. Therefore, in the event of an FMD outbreak within the country, the relevant authorities should focus their disease control measures on nodes with higher out-degree centrality measures and middlemen involved in livestock movements.

The betweenness centrality was high for two nodes in Ward II and one node each in Wards I and III, reflecting the high frequency of goat movements between nodes. Villages F and H both in Ward II, Village E in Ward I and Village O in Ward III, appear to be more important than the other nodes by this measure. This suggests that more animals pass through these nodes relative to the other nodes of the network. Interestingly, in 2017, a SAT2 FMD outbreak was reported in Village E (Ward I), one of the communities with a high betweenness centrality measure (OIE-WAHID, 2017).

In 2019, two SAT2 FMD outbreaks (DAFF, 2019a; DAFF, 2019b) were reported in the FMD free zone of Limpopo Province, which were linked to animal movements but not associated with the study area. However, on the 3rd of March 2020, a SAT2 FMD outbreak was reported at Villages J, M and K (Ward III) which subsequently spread to Villages E and A (Ward I) by the second week of April, 2020 (Mr Solly Mokone, Animal Health Technician, personal communication). From our study, Villages J and M were the most influential nodes in cattle movements as demonstrated by their out-degree centrality measures (data not presented). The rapid spread from the three initial villages is therefore consistent with the expectations based on the network analysis findings.

Goats have been described as "silent shedders" of FMD without showing obvious clinical signs and sickness behaviors. These facts make it very difficult to identify infected goats that might pose a threat for the spread of disease through animal movements. The results of this study indicate that goats are moved by communal farmers out of the study area without official movement permits, although the absolute number of movements appears to be low. The study also identified communities at high risk of disease occurrence and communities that might play important roles in subsequent disease spread. Four locations in the (former) FMD free zone of the country (Nelspruit, Tzaneen, Barberton and Leboeng) were identified as having connections with movement of goats from the study area and this calls for careful monitoring to mitigate the potential spread of FMD from the protection zone.

The results of this study should be interpreted considering several limitations. A goat identification system and an organized database are not in use within the study area, even though each ward has a small stock register. Therefore, it was not possible to verify the movement of individual animals. Animal movement data derived in this study were solely based on interviews and subject to recall bias and purposeful misinformation. We were unable to verify each origin and destination reported by the respondents outside of the study area due to limited budgets and resources. Other limitations to the study include the limited study area and the lack of production records for the verification of herd additions and subtractions.

The results of this study suggest the need to improve control measures within FMD protection zones and high-risk production sectors in disease endemic countries. We recommend the following: control goat movements via official movement permit systems, establish organized goat auction points or markets to control trader activities, initiate traceable livestock identification systems, develop databases for livestock movements and improve surveillance and inspection of FMD in goats within FMD protection zones and regions with high-risk production sectors such as dairy industries. Presented information could be used to improve FMD control within the study area and adoption in other rural settings of southern Africa could improve the progressive control of FMD in general.

Author contributions

David D. Lazarus: Conceptualisation, Investigation, Data Curation, Writing- original draft manuscript, Pamela A. Opperman: Supervision, Reviewing and Editing, Mohamed M. Sirdar:

Methodology, Reviewing and Editing, Tanja E. Wolf: Methodology, Reviewing and Editing, Ilana van Wyk: Project administration, Investigation, Reviewing and Editing, Oupa B. Rikhotso: Project administration, Reviewing and Editing, Geoffrey T. Fosgate: Conceptualisation, Funding acquisition, Project administration, Supervision, Writing, Reviewing and Editing.

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Declaration of competing interest

None of the authors has financial or personal relationship that could influence or bias the content of the paper.

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Table 1. General demographic data of respondents for the three Bushbuckridge Animal Health wards in Mnisi Tribal Authority, Bushbuckridge, Mpumalanga Province, South Africa during June 2018 (n=116).

Table 2. The association between the three animal health wards with potential continuous predictors in 116 respondents sampled within the Mnisi Tribal Authority, Bushbuckridge, Mpumalanga Province, South Africa during June 2018.

Table 3. Responses of respondents to attitude questions towards animal management, animal movements and animal losses within the three animal health wards of Mnisi Tribal Authority, Bushbuckridge, Mpumalanga Province, South Africa during June 2018.

Table 4. Goat movement network centrality measures in the three animal health wards of Mnisi Tribal Authority, Bushbuckridge, Mpumalanga Province, South Africa during June 2018.

Figure 1. Map of the study area showing the distribution of communal dip tanks where the survey was conducted during June to July 2018.

Figure 2. Goat movement patterns in three animal health wards of Mnisi Tribal Authority, Bushbuckridge, Mpumalanga Province, South Africa. Node shapes and colours indicate locations; green circle = Ward I, blue box = Ward II, colourless triangle = Ward III and red boxes are nodes outside of the study area.

Supplemental Table 1. Relationship between the total population of goat owners within the study area and sample selection for interview during June 2018.

Table 1. General demographic data of respondents for the three Bushbuckridge Animal Health wards in Mnisi Tribal Authority, Bushbuckridge, Mpumalanga Province, South Africa during June 2018 (n=116).

Variable	Number of respondents (%)		
	Ward 1 (n = 36) n % (95%CI)	Ward 2 (n = 35) n % (95%CI)	Ward 3 (n = 45) n % (95%CI)
Sex			
Male	24 67 (50 – 81)	28 80 (64 – 91)	28 62 (47 – 75)
Female	12 33 (19 – 50)	7 20 (9 – 36)	17 38 (25 – 53)
Age			
<20 years	0 0 (0 – 8)	1 3 (0 – 13)	0 0 (0 – 6)
20 – 40 years	6 17 (7 – 31)	1 3 (0 – 13)	4 9 (3 – 20)
41 – 60 years	12 33 (19 – 50)	14 40 (25 – 57)	21 47 (33 – 61)
61 – 80 years	10 28 (15 – 44)	7 20 (9 – 36)	13 29 (17 – 43)
>80 years	6 17 (7 – 31)	5 14 (5 – 29)	5 11 (4 – 23)
No response	1 3 (0 – 13)	7 20 (9 – 36)	2 4 (1 – 14)
Marital status			
Single	2 6 (1 – 17)	2 6 (1 – 18)	6 13 (6 – 26)
Married	25 69 (53 – 83)	21 60 (43 – 75)	25 56 (4 – 70)
Divorced	0 0 (0 – 8)	0 0 (0 – 13)	0 0 (0 – 6)
Widowed	9 25 (13 – 41)	12 34 (20 – 51)	14 31 (19 – 46)
Education			
Non formal	11 31 (17 – 47)	16 46 (30 – 62)	22 48 (35 – 63)
Primary school	5 14 (5 – 28)	5 14 (5 – 29)	11 24 (14 – 39)
Secondary school	15 42 (27 – 58)	11 31 (18 – 48)	9 20 (10 -34)
Tertiary	0 0 (0 – 8)	0 0 (0 – 8)	1 2 (0 – 10)
No response	5 14 (5 – 28)	3 9 (2 – 22)	2 4 (1 – 14)
Main occupation			
Livestock	20 56 (39 – 71)	17 49 (32 – 65)	33 73 (59 – 85)
Crops	0 0 (0 – 8)	0 0 (0 – 8)	1 2 (0 – 10)
Government employee	1 3 (0 – 13)	3 9 (2 – 22)	3 7 (2 – 17)
Private sector	3 8 (2 – 21)	2 6 (1 – 18)	5 11 (4 – 23)
Own business	9 25 (13 – 41)	8 23 (11 – 39)	0 0 (0 – 6)
General employee	0 0 (0 – 8)	3 9 (2 – 22)	2 4 (1 – 14)
House keeping	1 3 (0 – 13)	1 3 (0 – 13)	0 0 (0 – 6)
No response	0 0 (0 – 8)	1 3 (0 – 13)	0 0 (0 – 6)
Goat rearing experience			
<10 years	5 14 (5 – 28)	6 17 (7 – 32)	8 18 (9 – 31)
10 – 20 years	5 14 (5 – 28)	4 11 (4 – 25)	12 27 (15 – 41)
21 – 30 years	5 14 (5 – 28)	4 11 (4 – 25)	7 16 (7 – 28)
>31 years	14 39 (24 – 55)	19 54 (38 – 70)	18 40 (27 – 55)

Table 2. The association between the three animal health wards with potential continuous predictors in 116 respondents sampled within the Mnisi Tribal Authority, Bushbuckridge, Mpumalanga Province, South Africa during June 2018.

Variable	Ward I		Ward II		Ward III		
	n	Median (IQR)	n	Median (IQR)	n	Median (IQR)	P – value*
Age of respondents (years)	23	62 (51 – 80)	18	68 (66 – 70)	24	65 (56 – 71)	0.371
Level of education (years)	19	7 (0 – 12)	14	4 (0 – 11)	24	2 (0 – 6)	0.135
Farming experience (years)	14	31 (18 – 54)	13	27 (16 – 39)	16	20 (13 – 28)	0.198
Number of goats owned	23	11 (6 – 15)	18	8 (6 – 13)	24	10 (5 -12)	0.591

IQR = Interquartile range. *Based on Kruskal-Wallis tests comparing variables among the three animal health wards. Age of respondents H statistic is 1.985 (2, N = 65), Level of education H statistic is 4.000 (2, N = 57), Farming experience H statistic is 3.236 (2, N = 43) and Number of goats owned by respondents H statistic is 1.047 (2, N = 65).

Table 3. Responses of respondents to questions towards animal movements within the three animal health wards of Mnisi Tribal Authority, Bushbuckridge, Mpumalanga Province, South Africa during June 2018.

Variable	Ward I (n = 36) Frequency		Ward II (n = 35) Frequency		Ward III (n = 45) Frequency	
	n	% (95%CI)	n	% (95%CI)	n	% (95%CI)
Livestock movement "into" the holdings in previous 12 months						
Yes	9	25 (13 – 41)	9	26 (13 – 42)	8	18 (8 – 31)
No	27	75 (59 – 87)	25	71 (55 – 84)	36	80 (66 – 90)
Reasons for moving in animals						
Farming	6	17 (7 – 31)	6	17 (7 – 32)	5	11 (4 – 23)
Business	0	0 (0 – 8)	3	9 (2 – 22)	0	0 (0 – 6)
Rituals	0	0 (0 – 8)	0	0 (0 – 8)	1	2 (0 – 10)
Gift/inheritance	2	6 (1 – 17)	0	0 (0 – 8)	2	4 (1 – 14)
Separating new animals from the herd/flock						
Yes	6	17 (7 – 31)	9	26 (13 – 42)	2	4 (1 – 14)
No	26	72 (56 – 85)	23	66 (49 – 80)	38	84 (72 – 93)
Livestock movement "out" of holdings in the previous 12 months						
Yes	23	64 (47 – 78)	18	51 (35 – 66)	24	53 (39 – 67)
No	12	33 (19 – 50)	17	49 (32 – 65)	21	47 (33 – 61)
Reasons for moving and selling animals						
Emergency needs of funds	3	8 (2 – 21)	0	0 (0 – 8)	0	0 (0 – 6)
Daily expenses	2	6 (1 – 17)	3	9 (2 – 22)	0	0 (0 – 6)
Consumption	4	11 (4 – 25)	4	11 (4 – 25)	6	13 (6 – 26)
Injury/illness	0	0 (0 – 8)	1	3 (0 – 13)	0	0 (0 – 6)
Culling	2	6 (1 – 17)	1	3 (0 – 13)	3	7 (2 – 17)
Pay medical bills/school fees	4	11 (4 – 25)	9	26 (13 – 42)	14	31 (19 – 46)
Rituals/social events	7	19 (9 – 35)	0	0 (0 – 8)	1	2 (0 – 6)
Requirement for a permit to move goats from holdings						
Yes	13	36 (22 – 53)	5	14 (5 – 29)	6	13 (6 – 26)
No	23	63 (47 – 78)	26	74 (58 – 87)	21	47 (33 – 61)
Requirement for a permit to move pigs from holdings						
Yes	7	19 (9 – 35)	1	3 (0 – 13)	2	4 (1 – 14)
No	8	22 (11 – 38)	9	26 (13 – 42)	7	16 (7 – 28)
Selling sick goats from the flock						
Yes	7	19 (9 – 35)	1	3 (0 – 13)	0	0 (0 – 6)
No	29	81 (65 – 91)	31	89 (75 – 96)	44	98 (90 – 100)
Livestock sales (goats)						
Butchers	0	0 (0 – 8)	0	0 (0 – 8)	3	7 (2 – 17)
Middlemen	33	92 (79 – 98)	31	89 (75 – 96)	36	80 (66 – 90)
Auction	1	3 (0 – 13)	0	0 (0 – 8)	2	4 (1 – 14)
Traditional healers	1	3 (0 – 13)	1	3 (0 – 13)	3	7 (2 – 17)
Middlemen/traditional healers	1	3 (0 – 13)	0	0 (0 – 8)	0	0 (0 – 6)

Table 4. Goat movement network centrality measures in the three animal health wards of Mnisi Tribal Authority, Bushbuckridge, Mpumalanga Province, South Africa during June 2018.

Variable	Animal Health Ward			
	Ward I Median (IQR)	Ward II Median (IQR)	Ward III Median (IQR)	P – value*
In-degree	4 (2 – 7)	3 (2 – 6)	1 (0 – 4)	0.612
Normalised In-degree	11 (6 – 18)	8 (6 – 16)	1 (0 – 12)	0.547
Out-degree	4 (3 – 6)	9 (7 – 12)	3 (1 – 5)	0.513
Normalised Out-degree	11 (3 – 6)	25 (19 – 33)	8 (3 – 15)	0.513
In-Closeness	8 (6 – 10)	8 (7 – 10)	0 (0 – 8)	0.579
Normalised In-Closeness	23 (18 – 27)	22 (19 – 26)	0 (0 – 25)	0.579
Out-Closeness	14 (13 – 16)	18 (17 – 20)	14 (12 – 16)	0.699
Normalised Out-Closeness	38 (35 – 46)	51 (47 – 56)	38 (33 – 44)	0.699
Between-ness	16 (9 – 75)	70 (32 – 156)	0 (0 – 52)	0.346
Normalised Betweenness	1 (1 – 6)	6 (2 – 12)	0 (0 – 4)	0.346

*Based on Kruskal-Wallis tests comparing variables among the three animal health wards. IQR – Interquartile range.

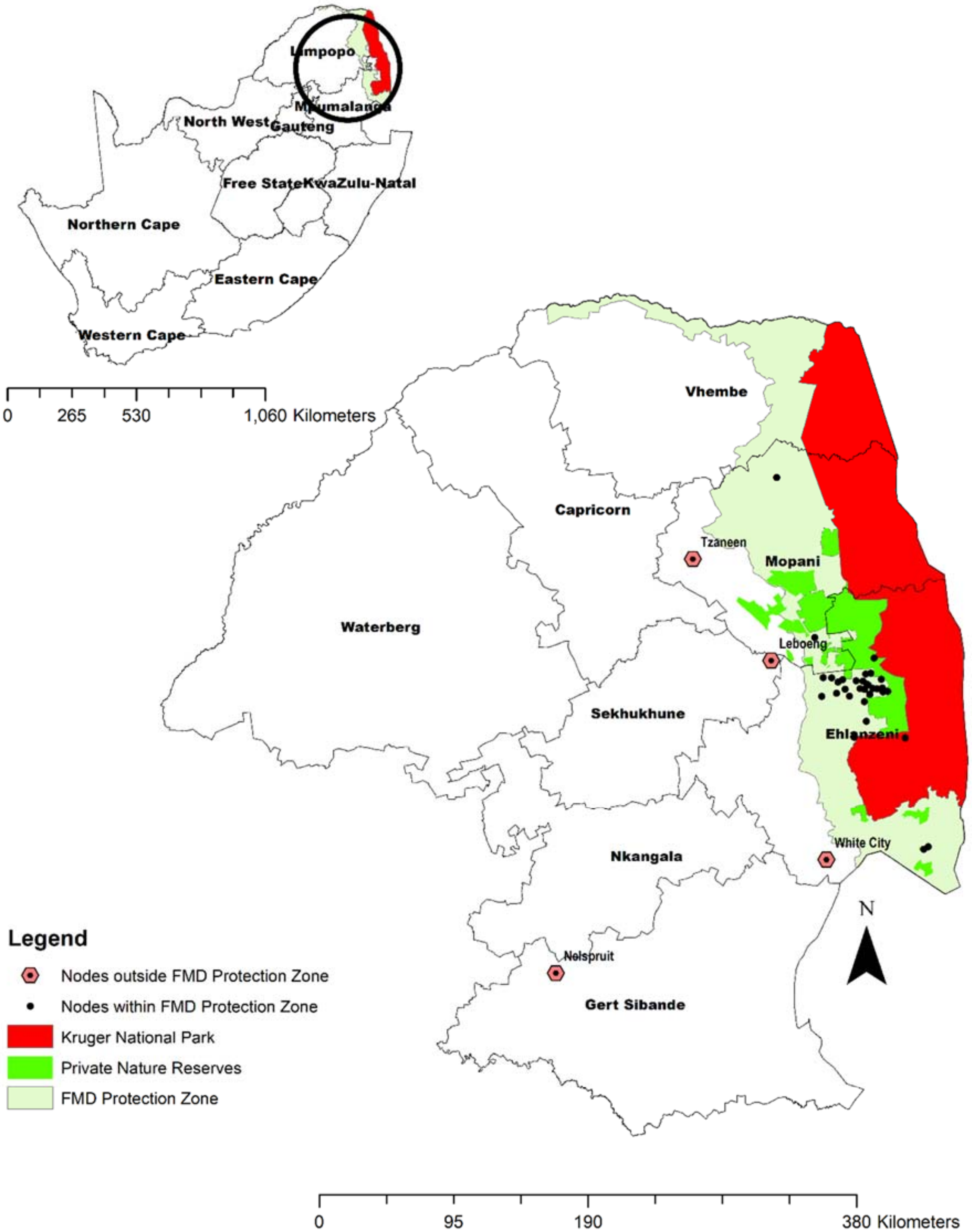

Figure 2. Map of the study area showing the distribution of communal dip tanks (nodes) where the survey was conducted during June to July 2018.

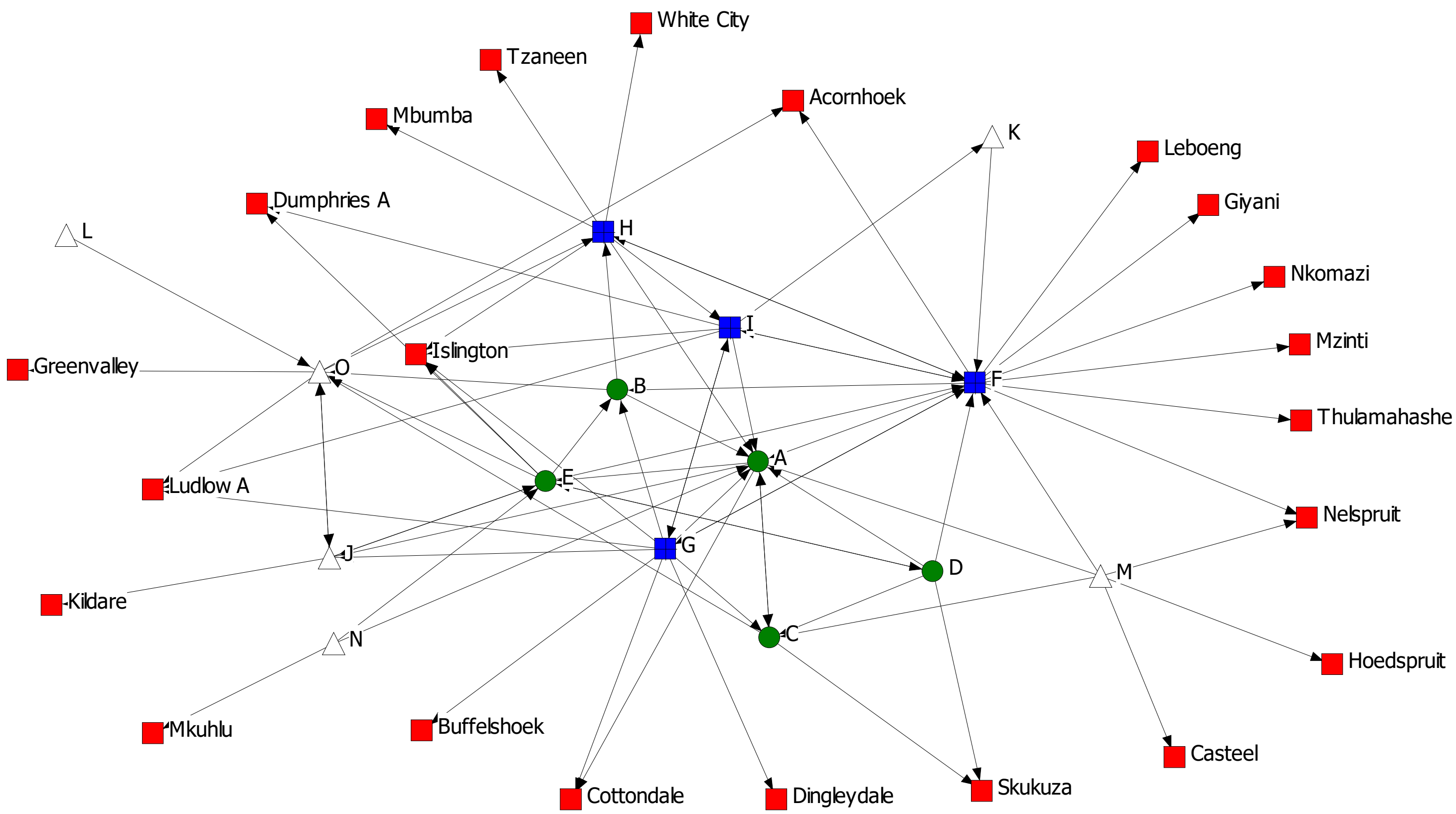

Figure 2. Goat movement patterns in three animal health wards of Mnisi Tribal Authority, Bushbuckridge, Mpumalanga Province, South Africa. Node shapes and colours indicate locations; green circle = Ward I, blue box = Ward II, colourless triangle = Ward III and red boxes are nodes outside of the study area.

SUPPLEMENTAL MATERIALS

Supplemental Table 1. Relationship between the total population of goat owners within the study area and sample selection for interview during June 2018.

Dip tank/Village	Number of goat owners	Goat population	Dip tank average flock size	Sample interviewed
A	31	358	12	6
B	29	219	8	5
C	8	94	12	6
D	26	314	12	6
E	56	575	10	13
F	65	398	6	15
G	39	320	8	8
H	32	310	10	6
I	31	370	12	6
J	46	261	6	11
K	48	273	6	9
L	3	24	8	2
M	54	327	6	11
N	24	201	9	4
O	34	213	6	8