The value of livestock abortion surveillance in Tanzania: identifying disease priorities and informing interventions

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Abstract

Background: Lack of reliable data on the aetiology of livestock diseases, especially in Africa, is a major factor constraining the design of effective livestock health interventions to improve livelihoods, food security and public health.

Rationale: Livestock abortion is an important disease syndrome that affects productivity and livestock economies, and poses risks to public health. Worldwide, several pathogens are associated with livestock abortions but across Africa livestock disease surveillance data rarely include information from abortion events, little is known about the aetiology and impacts of livestock abortions, and data are not available to inform prioritisation of disease interventions.

Methods: This paper describes outcomes from a surveillance platform that was set up in 15 wards in northern Tanzania spanning pastoral, agropastoral and smallholder agro-ecological systems to investigate the causes and impacts of livestock abortion. Abortion cases were reported by farmers to Ministry of Livestock and Fisheries livestock field officers and on to investigation teams. The abortion was eligible for inclusion if the research field team or livestock field officer could attend within 72 hours of the event occurring. If so, a field investigation was carried out to collect diagnostic samples from aborted materials and aborting dams and questionnaire data on herd/flock management. Laboratory diagnostic tests were carried out for a range of abortigenic pathogens, and laboratory and questionnaire data analysed to investigate a) determinants of attribution; b) patterns of investigated events, including species and breed affected, history of previous abortion and recent stressful events, and the seasonality of cases; c) determinants of reporting, investigation and attribution; (d) cases in which zoonotic pathogens were detection.

Results: Over a two-year period (2017-2019), 215 abortion events in cattle (n=71), sheep (n=44) and goats (n=100) were investigated from 13 of the 15 wards. The number of investigated cases varied widely across wards, with three of the 15 field officers (20%) reporting 70% of investigated cases. Aetiological attribution, achieved for 19.5% of cases through PCR-based diagnostics, was significantly affected by delays in field investigation. Histopathology proved less useful than PCR diagnostics due to rapid deterioration of field samples. Vaginal swabs from aborting dams provided a practical and sensitive source of diagnostic material for pathogen detection.

Discussion / Conclusion: Livestock abortion surveillance, even at a small scale and when capturing only a small proportion of events, can generate valuable information on causes of zoonotic disease outbreaks, livestock reproductive losses and can identify important pathogens that are not easily captured through other forms of livestock disease surveillance. The study demonstrated the feasibility of establishing an effective reporting and investigation system that could be implemented across a range of settings, including remote rural areas, with engagement of community-based field officers, and establishment of practical sample collection protocols and molecular diagnostic platforms all being important elements of effectiveness.

Introduction

Livestock reproductive losses, including spontaneous abortion, are a major concern for the livestock industry worldwide, resulting in significant economic loss and posing a threat to public health. The impacts of livestock abortion on the world's poorest livestock-keepers, who are heavily dependent on livestock for food security and livelihoods (Food and Agriculture Organization 2011), is likely to be substantial. For these families, the loss of a livestock foetus and a subsequent decline in milk production reduces the availability of a high-quality food source (milk) that can be essential for childhood growth and cognitive development (Neumann et al. 2003). In addition, livestock reproductive losses reduce income (from sales of meat and milk), and results in a loss of livestock assets that are a critical store of wealth, collateral or a safety net in times of need (The World Bank 2021). Recent analyses have shown that because of the need for increased spending on animal management, livestock abortions can also have indirect negative impacts on household expenditure and education (Ahmed et al. 2019). Livestock abortion can also pose a direct threat to human health because many abortigenic agents are also zoonotic (Givens and Marley 2008; Thomas et al. 2022).

Surveillance is defined as the real-time (or near real-time) collection, analysis, interpretation, and dissemination of health-related data to enable the early identification of the impact (or absence of impact) of potential health threats, which require effective action (Hulth 2014). Effective livestock health surveillance provides critical data for evidence-based approaches to livestock disease control and management but this requires reliable, high-quality, and timely data that can be drawn from multiple sources (George et al. 2021). Over the past decade, increasing attention has been given to animal health syndromic surveillance (Dórea and Vial 2016), which relies on detection of health indicators, such as livestock abortion, that are discernible before a confirmed diagnosis is made. However, systematic reviews of the literature that collectively cover a period from 2000 to 2016 indicate that syndromic surveillance programmes have mostly been implemented in Europe, North America or Australasia with only a single pilot project identified in Africa (Dórea and Vial 2016; Dorea, Sanchez, and Revie 2011).

In public health, event-based surveillance has also been gaining attention for the early detection of unusual events that might signal acute and emerging human health risks (World

Health Organization 2008; Africa Centres for Disease Control and Prevention 2018). This involves the collection, analysis and interpretation of information through both formal and informal channels to rapidly identify unusual or unexpected health events, such as disease outbreaks, emerging infectious diseases, or other public health threats. Although the WHO guidelines for event-based surveillance (World Health Organization 2008) make explicit reference to the capture of information around unusual disease events in animals, the development of integrated early-warning systems involving animal disease events is still very limited. Livestock surveillance has a clear potential for identifying and preventing outbreaks of zoonotic and emerging diseases; a substantial proportion (39.4%) of livestock pathogens infect humans (Cleaveland et al. 2001), and ungulates harbour more zoonotic pathogens than any other taxonomic group (Woolhouse and Gowtage-Sequeria 2005). With several abortigenic agents also causing emerging livestock diseases, for example those caused by Schmallenberg virus, bluetongue virus and porcine reproductive and respiratory syndrome virus, livestock abortion may represent a particularly important syndromic target for zoonotic and emerging disease surveillance. However, there is limited information available on current practices, effectiveness, and challenges of livestock abortion surveillance, particularly in low- and middle-income countries.

Livestock abortion has many causes, including infectious, nutritional, physical and genetic factors and the diversity of agents makes abortion diagnosis complex and challenging (Wolf-Jäckel et al. 2020). Challenges relate to timely collection of diagnostic samples, sample availability and deterioration, biases in detectability of agents, as well as complexities around establishment of a causal aetiology, particularly for pathogens such as *Coxiella burnetii* and *Escherichia coli*, which are commonly present in livestock samples (Thomas et al. 2022; Wolf-Jäckel et al. 2020). As a result, aetiological attribution of livestock abortion rarely exceeds 35%, even in well-resourced industrialised livestock systems (Cabell 2007; Wolf-Jäckel et al. 2020) and data are particularly sparse in African livestock systems.

A recent prospective study of the aetiologies of livestock abortion, carried out in northern Tanzania (Thomas et al. 2022), investigated 215 cases of livestock abortion of which an attribution was made in 41 cases (19%). The infectious causes of abortion were identified as Rift Valley fever virus (RVFV) in 14 cases (6.6%), followed by *Neospora caninum* in ten (4.7%),

pestiviruses in nine (4.2%), *Coxiella burnetii* in six (2.8%), and *Brucella* sp., and *Toxoplasma gondii* each in one case (0.5%). Our study draws on the operational data generated from the Thomas et al. (2022) aetiological study to examine characteristics of reporting and investigation of cases of livestock abortion. While this study was not designed as a systematic or comprehensive evaluation of a surveillance system, we present data on several key attributes (ECDC 2014) of the platform, including simplicity, data quality, representativeness, timeliness and usefulness. We discuss our findings in relation to the feasibility, practicality, and value of establishing a livestock abortion surveillance framework to support evidence-based interventions to improve livestock development, livelihoods, and human health in Africa.

Methods

Logic model

A logic model was created to provide a conceptual framework that described the logical links between the main activities, outputs, and outcomes that were expected from the programme (Figure 1). The model depicts the overarching assumption that building better livestock abortion surveillance systems and strong community partnerships will lead to data-driven prevention actions and changes in knowledge, attitudes, behaviours, or practices that could improve livestock productivity, livelihoods, and health.

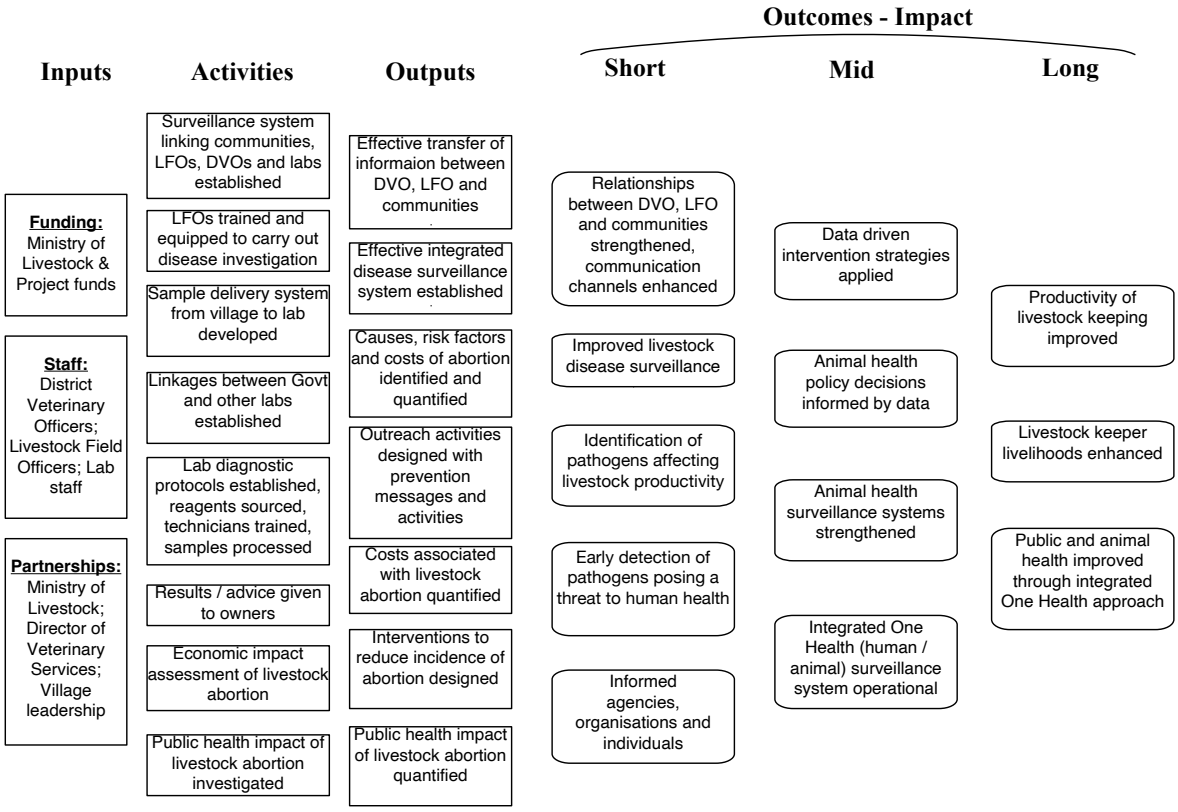


Figure 1. A logic model illustrating the conceptual links between the inputs, activities, outputs, and short to long term impacts expected from effective livestock health surveillance with a particular focus on abortion.

Abortion surveillance platform

The abortion surveillance platform was set up in northern Tanzania through a collaboration between the Ministry of Livestock and Fisheries, local government authorities, and the research team. The study was undertaken from October 2017 through September 2019 in 15 wards of five districts of Arusha, Kilimanjaro, and Manyara Regions in northern Tanzania (Figure 2). These study wards were selected from randomly selected wards included in earlier cross-sectional exposure studies (Bodenham et al. 2021). Seventeen wards were selected at random and two additional wards were selected purposively because of strong existing relationships with the livestock-keeping community (Thomas et al. 2022). These 15 wards comprised five wards that were expected to be predominantly pastoral, three were expected to be predominantly agropastoral and seven expected to predominantly smallholder, with categories assigned by the research team following discussion with local experts (typically the district level veterinary officer) (Bodenham et al. 2021). Following recruitment into the study,

livestock field officers (LFOs) associated with each target ward received training on the causes and safe investigation of livestock abortion. Livestock field officers are government employees that are equivalent to para-veterinarians in other settings. They were requested to ask livestock owners to report any incidents of livestock abortion, stillbirths, and peri-natal death (hereafter referred to as abortion cases).

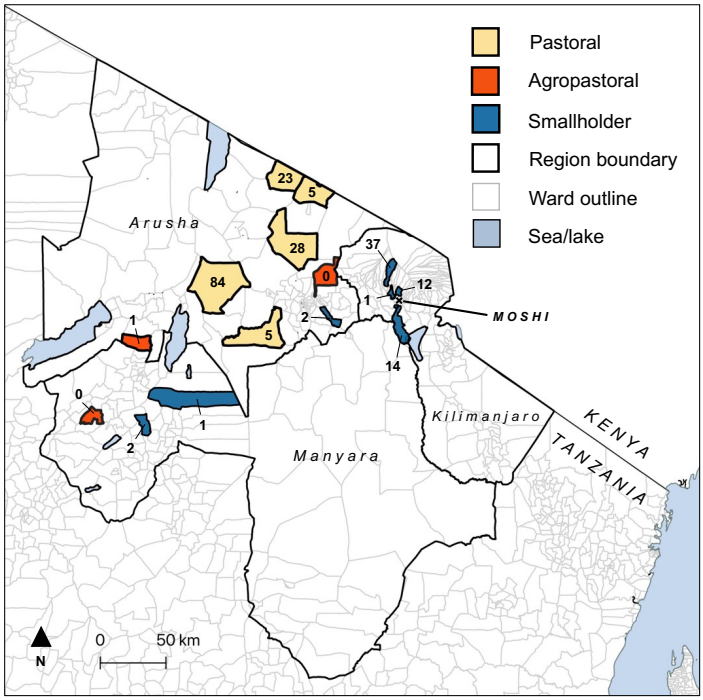


Figure 2: Map of the study area in northern Tanzania showing selected pastoral, agropastoral and smallholder wards in Kilimanjaro, Arusha and Manyara Regions. The number of investigated cases per ward are shown and the study base (Moshi) is shown.

Investigation of cases

Cases were investigated if, following a report from the LFO, the event could be followed up within 72 hours of the abortion occurring. Full details of sample collection are provided in Thomas et al. (2022). Briefly, where available, blood, milk and vaginal swabs were collected from the aborting dam and tissue and swab samples collected from the foetus and placental membranes. Information was collected about the abortion event and a household questionnaire conducted to collect information on livestock demographics, livestock abortion history, the aborting dam (age, breed), household livestock parturition practices and household socio-economic data (Supplementary Material 1). Questionnaire data were used

189 to investigate underlying patterns of abortion, risks associated with abortion cases, and
190 operational aspects of the surveillance platform. These data were not collected from abortion
191 cases that were not investigated by the research team.
192
193 LFOs were instructed to provide farmers with advice as to locally appropriate preventive
194 measures that could be taken to reduce transmission or contamination risks associated with
195 abortion cases, which included safe removal of abortion tissues from livestock-occupied areas
196 (e.g. burning, burying or covering the tissues in thorny branches) (Supplementary Materials
197 2). Diagnostic results were reported back to LFOs and livestock owners within 10 days of the
198 investigation and, where pathogens were detected, more specific advice provided as to
199 management strategies that could minimise further transmission to livestock and people.
200
201 Event data were collected using a paper-based Cardiff Teleform system (Cardiff Inc., Vista,
202 Ca., USA) into an Access database (Microsoft Corp, Va., USA). Household questionnaire data
203 were collected using handheld digital devices programmed with the Open Data Kit™ survey
204 tool. Data were imported into R (R Core Team 2023) for cleaning, coding and analysis. The
205 survey instruments were pre-tested in wards that were not targets for this study. Geographic
206 co-ordinates from a central point within the household were collected with a handheld GPS
207 (Garmin eTrex™).
208
209 **Sample analysis**
210 Laboratory diagnostic analyses have previously been described in detail (Thomas et al. 2022).
211 Briefly, samples were tested for: (a) *Brucella* spp., *Coxiella burnetii*, *Chlamydia* spp., and
212 *Leptospira* spp. using quantitative polymerase chain reaction (qPCR) assays: (b) *Neospora* spp.
213 and *Toxoplasma gondii* using conventional nested PCR assays; (c) Bluetongue virus (BTV),
214 bovine viral diarrhoea virus / border disease virus (BVDV/BDV), and Rift Valley fever virus
215 (RVFV) using quantitative reverse transcriptase PCR (RT-qPCR); and (d) additional tests for *C.*
216 *burnetii* and *Neospora* spp. using immunohistochemistry. Additionally, serum was tested for
217 antibodies to *Brucella* spp., bovine herpesvirus (BHV-1), BVDV, *C. burnetii, Leptospira hardjo*,
218 and RVFV.
219
220

Summarising the investigated cases and description of the livestock study population

The number of abortion cases was recorded for each agro-ecological zone (pastoral, agro-pastoral and small holder) and study ward, together with the number of households that had an abortion event, the composition of the livestock herds (cattle, goats and sheep) kept at each household, and the number of previous abortion cases in each household that had an event.

The sensitivity of the platform was examined by dividing the number of investigated abortion cases by the *expected* number of abortions for the livestock population of the study wards over the study period. The expected number of abortions was estimated by multiplying (a) the number of abortion cases per head of livestock reported over a 12 month period obtained through a previous randomized cross-sectional study (described in de Glanville et al. 2022) by (b) the number of livestock in the ward reported by surveys conducted by LFOs from the Tanzania Ministry of Livestock and Fisheries covering a period from 2011 to 2016 (E. Swai, *unpublished data*). This figure was multiplied by two to account for the 24-month duration of the study. Where data were not available for a specific ward, figures were estimated from the average of other wards in the same division (Rau) or by current estimates provided by the LFO (Machame Mashariki) (Supplementary Materials 3).

Determinants of investigation

The determinants of event investigation were analysed to determine: first, the number of cases that each LFO investigated; second, the distribution of time taken between the report and the subsequent investigation by the research team; and third, using a Pearson correlation analysis, the relationship between the time taken between a report and its subsequent investigation and the distance (km) of the ward from the research team headquarters (in the town of Moshi) (Figure 2).

Sample collection data

Data were recorded and summarized for: (a) the types of samples collected for each event; (b) the availability of placental and foetal materials and, when not available, the reasons why these materials were not available; and c) the relationship between sample types and pathogen detection and pathogen attribution.

Observed patterns in investigated abortions

The distribution of investigated abortion cases was examined in relation to a) livestock species and breed in which they occurred, b) history of previous abortion cases in the aborting dams, c) a history of recent stressful events affecting the pregnant dam, and d) seasonality of the cases.

a) Breeds were recorded as indigenous (local) and non-indigenous (cross-bred and exotic). We used the breed distribution in the investigated herds to estimate the expected number of abortions if breed type did not affect the likelihood of abortion. Using an exact binomial test, we compared the expected with the observed number of cases.

b) Data on the occurrence of previous abortion cases and recent stressful incidents were obtained from the questionnaire data collected at the time of the investigation.

c) Stressful incidents were recorded as open-ended questions but were prompted by asking about events such as being chased by predators, drought, unusual handling or recent change in diet or grazing.

d) Seasonality was investigated in relation to typical 'dry' and 'wet' seasons and in relation to monthly rainfall in the Arusha region during the project period. Mean monthly rainfall was calculated from daily rainfall data, which was obtained across the Arusha Region (Ashouri et al. 2015; Sorooshian et al. 2019) and plotted alongside the temporal pattern of reported cases. The relationship between mean monthly rainfall and the number of reported abortions was investigated using linear regression.

All processing and analysis of data was carried out in R.

Determinants of attribution

World Organization for Animal Health (WOAH – previously OIE) guidelines and case definitions, in conjunction with recommendations from specialist/reference laboratories and

285 peer-reviewed literature, were used to inform diagnosis and attribution of infectious causes
286 of abortion (described in detail in Thomas et al. 2022). Binomial logistic regression analysis
287 was carried out with attribution (yes or no) as the dependent variable. Potential independent
288 explanatory variables, including the delay between the event and its investigation, species,
289 and livestock management system, were selected for inclusion in the model through
290 univariable analysis (with all variables with p value < 0.25 selected for inclusion). Potential
291 independent explanatory variables were retained or de-selected through a stepwise
292 approach using Akaike Information Criterion (AIC) as an indicator for model efficiency to
293 achieve a final model.
294
295 **Exposure to zoonotic pathogens**
296 The percentage of cases in which zoonotic pathogens (*Brucella* spp., *C. burnetii*, *T. gondii* and
297 RVFV) were detected, and the percentage of these cases in which someone assisted with the
298 delivery, was calculated. The age and sex of the persons assisting with delivery was also
299 collected.
300
301 **Ethical Approval**
302 Ethics approval for this research was granted by Kilimanjaro Christian Medical Centre (KCMC)
303 Ethics Committee (No, 535 and No. 832); National Institute of Medical Research (NIMR),
304 Tanzania (NIMR/HQ/R8a/Vol IX/1522 & NIMR/HQ/R.8a/Vol IX.2028); Research Ethics
305 Coordination Committee and the Institutional Review Board for Clinical Investigations of Duke
306 University Health System in the United States (Pr00037356); University of Otago Ethics
307 Committee (H15/069 & H17/069); University of Glasgow College of Medical Veterinary and
308 Life Sciences Ethics Committee (200140152 & 200170006).
309
310 **Results**
311 **Descriptive Statistics**
312 Between October 2017 and September 2019, 215 abortion cases were reported from 150
313 households in 13 of the 15 target wards (Fig. 2). The distribution of investigated cases in
314 relation to agro-ecological system and herd/flock composition is shown in Table 1. Of the 150
315 households investigated, most (n=115) had only one event investigated. Of the remaining
316 households, 21 had two cases investigated, eight had three, two had four, three had five and

one household had 11 cases investigated. Herd level summary statistics have been provided in Supplementary Material 4.

The sensitivity of the platform (the percentage of expected abortion cases that were investigated) ranged from 0%-12.4% for cattle, 0-1.2% for goats and 0-0.3% for sheep. A higher percentage of expected abortions in cattle were reported in smallholder wards (2.7%) than in other wards (0% for agropastoral and 0.31% for pastoral wards), with particularly high reporting in one smallholder ward, Machame Mashariki, close to Moshi town, where 12.4% of expected cattle abortions were investigated.

Over the 12 months preceding a reported abortion event, abortions, peri-natal mortalities, or stillbirths occurred in 52 of 184 (28.3%) cattle herds, 98 of 168 (58.3%) goat herds and 93 of 140 (66.4%) sheep herds that had at least one adult female. Of herds that had at least one abortion case, the mean (median, range) number of cases of abortion per herd in the past 12 months was 3.7 (3, 1 – 12) for cattle, 9.0 (6, 1 – 70) for goats and 6.7 (4, 1 – 67) for sheep.

Determinants of investigation

The number of cases reported to the research team by each LFO varied considerably (median = 5, range 0 – 84). Of the 215 cases, 70% were reported by three (20%) of the LFOs, with one reporting 84 cases (39.1%). Two LFOs did not report a single case (Figure 3a). The range in the interval between the report and the subsequent investigation by the research team was zero to four days with a median of one day (Figure 4).

From the Pearson correlation analysis, no significant association was found between the interval between reporting and investigation and the direct distance between the centroid of the ward in which the LFO worked and the research team headquarters (R^2 = -0.07, t = -0.32, p = 0.75) (Figure 3b).

Event	Category	Number (%)
Number of abortion cases	All species	215
	Cattle	71 (33%)
	Goats	100 (46.5%)
	Sheep	44 (20.5%)
Number of abortion cases in each agricultural ecological zone	Pastoral	144 (67.0%)
	Agro-pastoral	1 (0.5%)
	Peri-urban	70 (32.5%)
Number of households that had an abortion event	Households	150
Number of households in each agricultural ecological zone	Pastoral	84 (56.0%)
	Agro-pastoral	1 (0.7%)
	Peri-urban	65 (43.3%)
Composition of the 150 herds	Cattle, goats and sheep	77 (51.3%)
	Cattle and goats	17 (11.3%)
	Goats and sheep	7 (4.7%)
	Cattle and sheep	1 (0.7%)
	Cattle only	40 (26.6%)
	Goats only	8 (5.3%)

Table 1: The number (and percentage) of abortion cases by species and agro-ecological zone and the composition of the livestock herds (and percentage) in investigated households

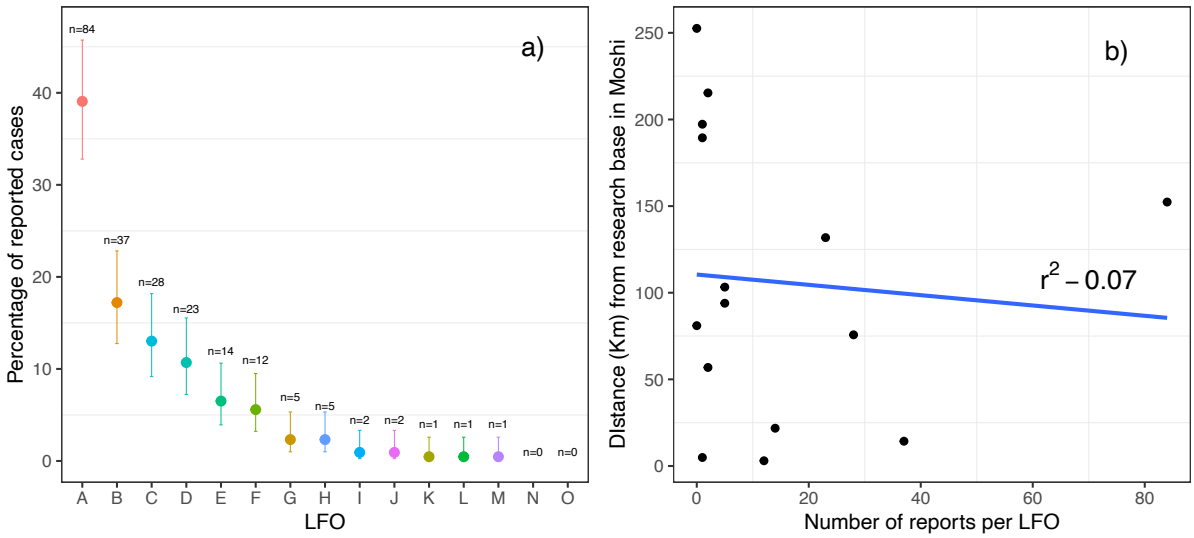


Figure 3: a) The number and percentage of abortion cases reported by each LFO. b) The relationship between the number of reports per LFO and the distance to the research based in the town of Moshi.

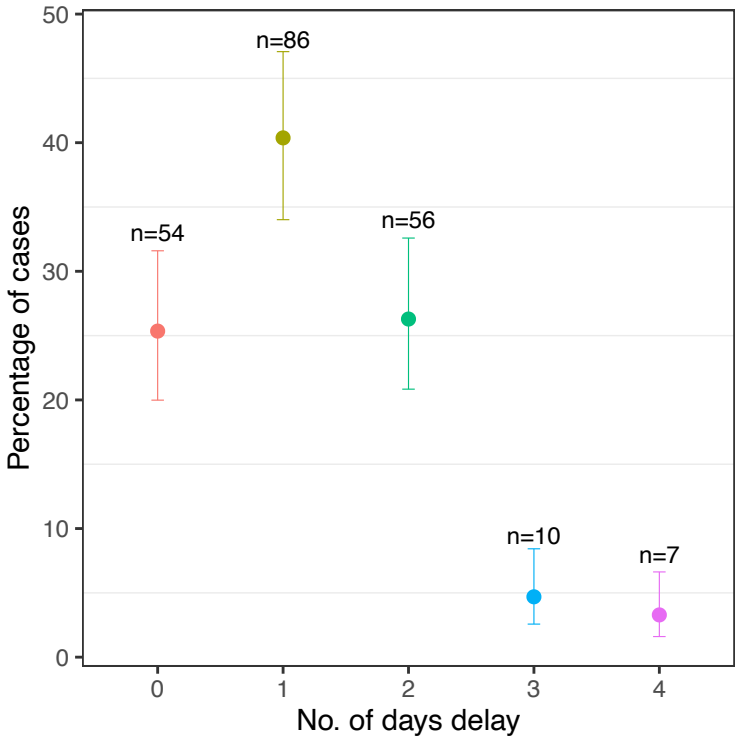


Figure 4: The number of days between abortion and the investigation. No cases were investigated more than after four days after the abortion.

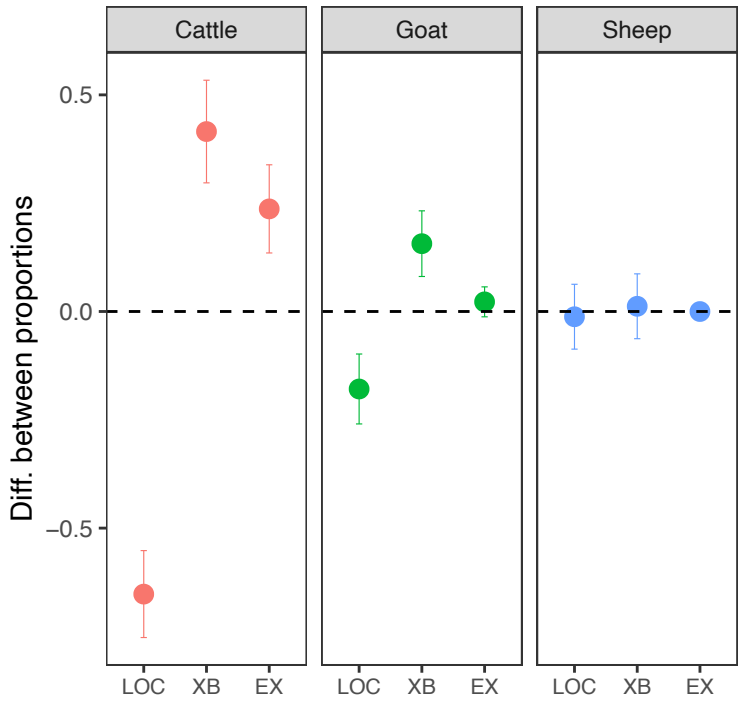
Sample collection data

Out of the 215 cases, placental and foetal tissues were collected in 116 (24.0%) and 141 (34.1%), respectively. The reasons given for failure to collect placental and foetal tissues included: a) the tissues not being seen by owners (for example if the animal aborted while away grazing); b) the tissues being burned by the owner; and c) the tissues being consumed by dogs or other animals. Vaginal and milk samples from aborting dams were collected in 213 (99.1%) and 167 (77.7%) cases, respectively.

Observed patterns in investigated abortions

a) **Pattern of abortions in species and breeds**

In cattle, reported abortions occurred significantly more often than expected in non-indigenous cross-bred animals (expected proportion = 0.11, actual proportion = 0.52, 95% CI: 0.42 – 1.00, $p < 0.001$) and non-indigenous exotic animals (expected proportion = 0.01, actual proportion = 0.25, 95% CI: 0.16 – 1.00, $p < 0.001$). In goats, reported abortions occurred significantly more often than expected in non-indigenous cross-bred animals (expected proportion = 0.02, actual proportion = 0.18, 95% CI: 0.11 – 1.00, $p < 0.001$) and more often than expected in non-indigenous exotic animals, although this difference was not significant (expected proportion = 0.01, actual proportion = 0.03, 95% CI: 0.01 – 1.00, $p = 0.053$) (Figure 5 and Supplementary Materials 5). There was no significant difference in the distribution of abortions in different breeds of sheep.



387

388 **Figure 5.** The difference between the expected and actual proportion of abortion cases in
389 each species and breed. Value of 0 = the expected number of cases occurred, > 0 more than
390 expected, < 0 less than expected (LOC= indigenous (local), XB= non-indigenous cross-bred,
391 EX= non-indigenous exotic breed).

392

393 b) **History of previous abortion cases in the aborting dams**
394

395 Of the cattle, goat and sheep dams that were investigated in this study (and that had had
396 previous pregnancies), 33.3% (n=12), 29.8% (n=17) and 16.7% (n=5), respectively, were
397 reported by the owner to have experienced a previous abortion event. Of these cattle and
398 goats, 41.7% (n=5) and 47.1% (n=8), respectively, had suffered multiple previous abortions.
399 One cow had experienced four previous abortion cases and one goat had experienced seven.

400

401 c) **History of recent stressful events**

402 Of dams that aborted, 16 of 71 cattle (22.5%), 37 of 98 goats (37.7%) and 15 of 43 sheep
403 (34.9%) were reported to have experienced recent stress. Dams for which an aetiological
404 attribution was not made were no more or less likely to have experienced a stressful event
405 than dams that aborted for which an attribution was made. Regarding recent illnesses over
406 the previous four weeks (diagnosed by the farmer), cattle were reported to have suffered

from a range of conditions including anaplasmosis, diarrhoea, lumpy skin disease, and trypanosomiasis, whilst goats were reported to have suffered predominantly from respiratory disease.

d) **Seasonality of cases**

Cases of abortion were reported in every month of the 24-month study period, and although these fluctuated over time, with more cases reported during the drier periods (Figure 6), there was no significant effect of mean monthly rainfall on the number of cases (correlation coefficient = -0.005. t = -0.25, p = 0.8).

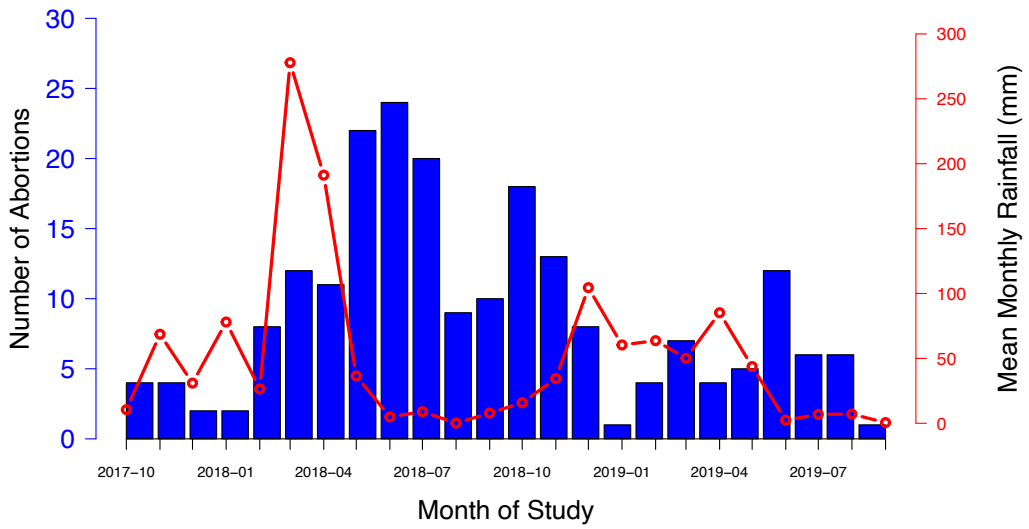


Figure 6. The number of abortion cases investigated per month (blue columns) shown against mean rainfall recorded in the Arusha region over each month of the study period (red line).

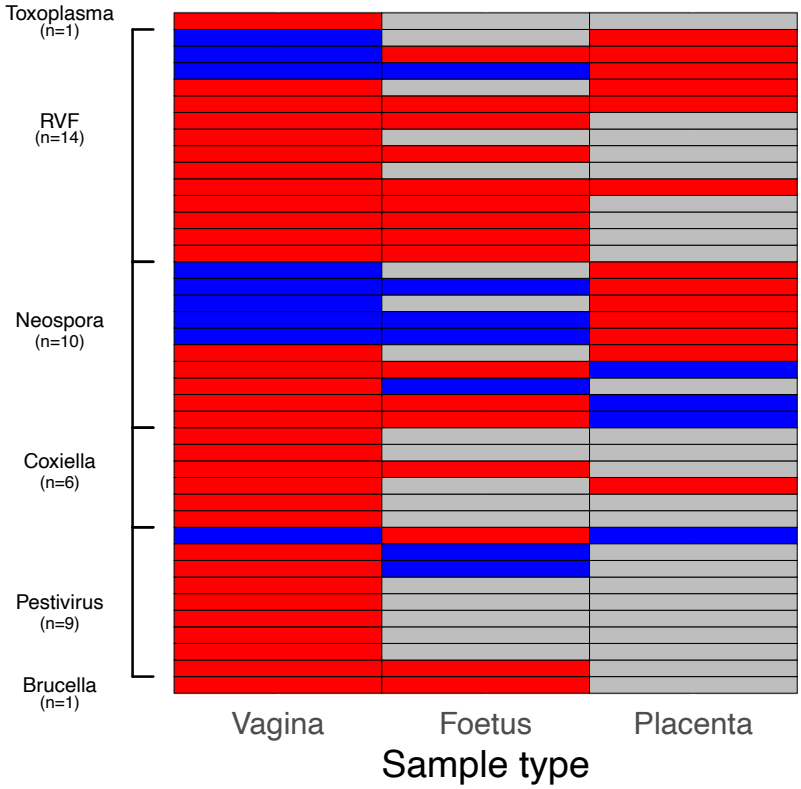


Figure 7: The type of samples in which pathogens were detected in the 41 abortion cases for which an attribution was made using PCR are shown. Each row represents one abortion event. Red - sample type returned a positive result; blue - sample type returned a negative result; grey - sample type was not collected.

Determinants of Attribution

As described in Thomas et al. (2022), the number of cases for which an abortigenic agent was attributed was 42 out of 215 (19.5%). Of these, an attribution was made using PCR in 41 cases. One event in a cow met the case definition for two pathogens (both BHV-1 through seroconversion and *Neospora* through PCR) and in this event both pathogens were attributed. The attribution of the single case that was not determined using PCR (BHV-1) was made by serology alone. The sample types that were collected in each of these 41 cases for which an attribution was made using PCR, and whether the samples returned a positive or negative result, are shown in Figure 7. The time period between the abortion incident and the investigation (*Delay*) had a negative impact on attribution ($z = -2.1$, $p = 0.03$), with each daily increase in the delay corresponding to a decrease in the odds of an attribution being made

by 46.1% (i.e. 1 - 0.539) (Table 2 and Figure 8). Additionally, when the abortion occurred in goats (*Goat*) an attribution was significantly less likely than when it occurred in cattle. Finally, the odds of achieving an attribution were not affected by the availability of the placenta (*Placenta present*), foetus (*Foetus present*) or milk (*Milk collected*) for sampling.

	Odds Ratio	2.5%	97.5%	z value	*p*
(Intercept)	0.353	0.053	2.361	-1.074	0.283
Delay	0.539	0.306	0.95	-2.139	0.032
Goat	0.195	0.058	0.653	-2.651	0.008
Sheep	0.615	0.142	2.664	-0.65	0.516
Foetus present	0.936	0.345	2.544	-0.129	0.897
Placental present	1.779	0.621	5.094	1.074	0.283
Milk collected	2.405	0.639	9.055	1.297	0.195

Table 2: Output of final regression model investigating determinants of attribution

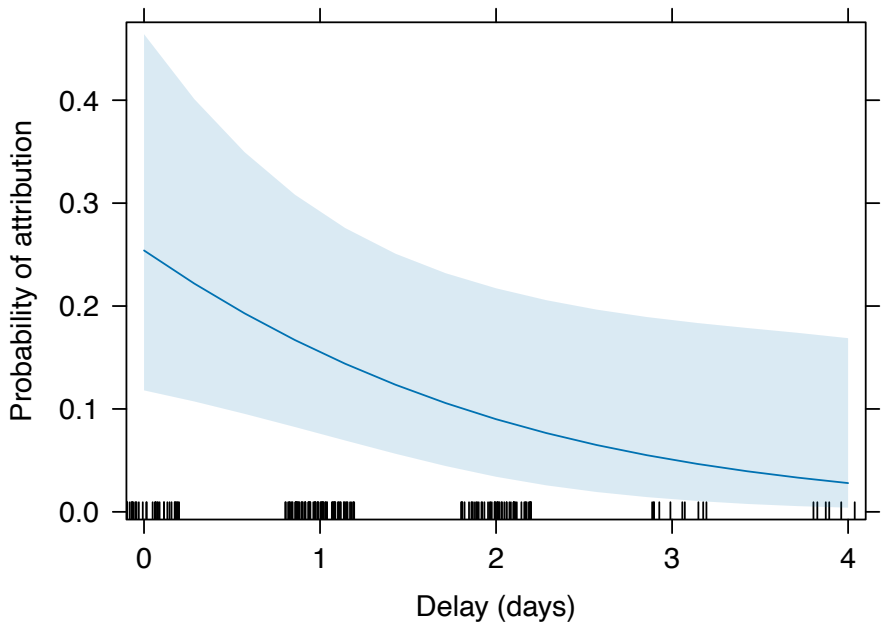


Figure 8. Predicted probability of attribution being made as a function of increasing delay between abortion and case investigation, as determined by the regression model output. The blue line indicates the regression line with the 95% confidence interval shaded blue.

452 **Exposure to zoonotic pathogens**

453 Zoonotic pathogens (*Brucella* spp., *Coxiella burnetii*, *Toxoplasma gondii*. and RVFV) were
454 detected in 61 of the 77 (79.2%) abortion cases where a pathogen was detected. Respondents
455 reported that someone had assisted with the delivery in 13 (21.3%) of these cases, similar to
456 the proportion of assisted deliveries across all abortion cases (40 out of 215, 23.5%). Of those
457 assisting with delivery, the median age was 37, the youngest was seven, the eldest 84, and
458 20% were female.

459

460 **Discussion**

461 This study demonstrated the feasibility of establishing a surveillance platform for reporting
462 and diagnosing cases of livestock abortion and that these investigations, even at small scale,
463 have generated important information on livestock diseases, and their investigation, in
464 Tanzania. This included information that, to our knowledge, has not been captured or
465 reported through existing surveillance systems.

466

467 Key findings were that: i) livestock abortion can be a target for syndromic and/or event-based
468 surveillance, with abortion incidents sufficiently distinctive and noteworthy to be reported by
469 farmers to livestock field officers for investigation; ii) pragmatic and robust protocols for
470 sample collection and laboratory diagnosis can be established, even in resource-limited
471 settings, to generate important etiological and epidemiological data; iii) the likelihood of
472 obtaining an etiological diagnosis depended on the timeliness of reporting and sample
473 collection; iv) there was wide variation in reporting and investigation of cases by different
474 LFOs and this did not appear to be associated with the distance between the ward and the
475 investigation center; v) in many herds prior livestock abortions were reported to have
476 occurred in the 12 months preceding the investigated abortion event; vi) abortions and repeat
477 abortions reported disproportionately more frequently in non-indigenous breeds (cross-bred
478 and exotic) than local breeds; and vii) abortion cases were reported and investigated more
479 frequently during drier periods, although there was no evidence of a relationship with
480 monthly rainfall.

481

482 This study suggests that livestock abortion cases are sufficiently distinctive and observable to
483 be reported by farmers to LFOs, would have widespread acceptability as a target for

484 syndromic or event-based surveillance and would have considerable utility for farmers as well
485 as for the livestock and public health sectors. The platform demonstrated the potential for
486 generating high-quality aetiological data on previously relatively unrecognised livestock
487 disease problems in Tanzania, such as *Neospora caninum* and novel pestiviruses, as well as
488 data on endemic zoonoses, such as Q fever, brucellosis and toxoplasmosis (Thomas et al.
489 2022). Reports of unusual livestock abortion cases also provided an early warning of acute
490 human health risks, as shown in this study area by the detection of an outbreak of RVF in
491 livestock in peri-urban smallholder cattle (de Glanville et al. 2022) and which was
492 subsequently linked with human RVF cases and deaths (Madut et al., n.d.).
493
494 An attempt was made to gauge the sensitivity of the surveillance platform by estimating the
495 percentage of expected abortions that the investigated cases represented. This was carried
496 out using data on ward-level livestock numbers drawn from Ministry of Livestock and
497 Fisheries records. However, given the dynamic nature of livestock populations in the study
498 area and shifts in ward configurations, these estimates should be considered approximate
499 figures only. Overall the sensitivity of this platform was low, with the highest ward level
500 sensitivity (12.4%) below a mean sensitivity of 34% reported for bovine abortion surveillance
501 systems in France (Bronner et al. 2015). Nonetheless, given that this was the first time that
502 an abortion surveillance platform of this kind had been introduced, and the logistic and
503 communication challenges inherent to this type of low income setting, our study gives
504 confidence of the feasibility and potential utility of this approach. Despite the limitations of
505 the data, our conclusion that there is wide variation in the sensitivity of the surveillance
506 platform across wards is likely to be robust. This finding, together with the ability of the
507 platform to investigate only a very small proportion of expected abortion cases overall, has
508 implications for the representativeness of data generated, which needs to be considered
509 when interpreting the results reported here.
510
511 Contrary to expectations, the location and distance of the ward and the type of farming
512 system was not associated with the probability of cases being investigated. Relatively few
513 cases were reported and investigated in agropastoral systems but both high and low rates of
514 reporting occurred in smallholder and pastoral systems. This suggests that LFOs and farmers
515 in some wards were much more engaged and motivated than in others. To date, much

516 investment in animal and human surveillance has been directed towards strengthening
517 laboratory diagnostic capacity. While this is clearly essential, support also needs to be given
518 to engaging, training, and motivating farmers and front-line animal health workers to
519 effectively report both routine and unusual animal disease events. Understanding why and
520 how animal keepers and LFOs are incentivised to report and investigate livestock health
521 events will be essential for improving the reach and sensitivity of future surveillance
522 platforms. The infrastructure for LFO engagement across Tanzania provides a valuable
523 platform for timely and cost-effective reporting of abortions and other disease events but
524 seems to be underutilised in existing surveillance systems.
525
526 The effectiveness of the platform in allowing an aetiological diagnosis to be reached was
527 significantly impacted by the timeliness of investigation. The impact of delays may be
528 explained by degradation of diagnostic samples, which also affected the utility of
529 histopathological diagnosis (Thomas et al. 2022). Delays were caused by several factors,
530 including the time taken by the investigation team to reach households due to remoteness of
531 some areas and multiple cases being reported in different areas on the same day. These
532 findings underscore the importance of being able to respond rapidly to cases and, where
533 access is difficult, of providing locally suitable means of transport.
534
535 A reactive surveillance platform that is managed locally, for example by ward-based LFOs, will
536 require the establishment of effective and safe protocols for collection and transport of
537 samples for laboratory diagnosis that can be carried out without the need for long-distance
538 travel of more highly trained investigators. Protocols for collection of vaginal swabs from
539 aborting dams, which proved effective for both pathogen detection and attribution, may be
540 of value. In this study, vaginal swabs performed better than placental samples and foetal
541 samples when detecting abortigenic pathogens (Figure 7). They also require less handling of
542 potentially infectious tissues and are more reliably accessible than placental and foetal
543 tissues, which are often consumed by scavengers or disposed of by the farmer. Indeed,
544 collection of vaginal swabs from the dam was possible in almost all cases investigated in this
545 study. Thus, while logistic, financial, and capacity constraints for comprehensive sampling and
546 investigation of livestock abortions are likely to exist across Africa, these need not preclude
547 the establishment of simple and robust protocols that can yield valuable surveillance data.

548 **Attribution**

549 From this platform, an attribution was reached in 19.5% of cases (Thomas et al. 2022), which
550 was not far below the typical range of 25-45% achieved in industrialized farming systems in
551 high-income settings (Campero et al. 2003; Amouei et al. 2019; Derdour et al. 2017;
552 Anderson, Barr, and Hoffman 1990). During this study, samples were tested for only ten
553 abortigenic pathogens and it is likely that rates of detection and attribution would be higher
554 with inclusion of tests for other known abortigenic agents (such as *Listeria* spp.,
555 *Campylobacter* spp., *Salmonella* spp. and fungal pathogens), with more locally relevant
556 aetiological data informing the suite of pathogens to be tested, and with metagenomic
557 approaches.

558

559 As elsewhere in the world, non-infectious conditions, including nutritional, metabolic, and
560 toxic conditions (Alemayehu et al. 2021; Mee et al. 2023; Woodburn et al. 2021), are also
561 likely to cause livestock abortions in Tanzania. Our study suggests a possible role for recent
562 stressful events, including episodes of drought and attacks by wild predators, which were
563 reported from approximately a third of unattributed abortion cases. However, these events
564 are a common occurrence in our study population, so attribution is likely to be challenging.

565

566 We do not have an immediate explanation as to why the likelihood of attribution was lower
567 for goats than for sheep or cattle. Given this is just one study, it could just be a random finding.
568 Another possible explanation is that, in comparison to sheep and cattle, fewer data are
569 available worldwide on causes of abortions in goats and very little is known about the
570 aetiology of goat abortions in Africa, so the pathogens included in our diagnostic panel may
571 not have been as relevant for goats as for sheep and cattle. This lack of knowledge is
572 highlighted by the unusual finding of *Neospora caninum* as a cause of abortion in a goat
573 detected through this platform (Thomas et al. 2022).

574

575 The challenges of attribution, discussed also in Thomas et al. (2022), should not detract from
576 the value of reporting and investigating livestock abortion cases. Recent studies have
577 indicated that the economic costs of livestock abortion in Tanzania and impacts on food
578 security are much more substantial than previously recognized (Semango et al. under review)
579 and data collected on the number of cases and species/breed affected will be of considerable

value in highlighting the importance of this syndrome in the context of livestock productivity, household livelihoods and food security.

Patterns of livestock abortion in northern Tanzania

Data from the household questionnaire indicated that livestock abortion was a common occurrence across the study area with almost a third of cattle herds and two-thirds of small ruminant herds having experienced a previous case of abortion in the preceding twelve months. Our results also suggest a possible link between abortion and low rainfall, although further work will be needed to examine this relationship in detail.

This study indicated that investigated cases occurred more often than expected in non-indigenous breeds (cross-bred and exotic cattle and cross-bred goats) than in local breeds. This is consistent with studies reporting a four-times higher risk of abortion in cross-bred cattle in Ethiopia in comparison to local breeds (Deresa, Tulu, and Deressa 2020) and studies in Nigeria (Yakubu, Awuje, and Omeje 2015) and India (Khan, Manoj, and Pramod 2016) reporting breed effects in relation to cattle abortion. Our results may simply reflect a higher likelihood of reporting of abortion in animals that are of higher value and more likely to be zero-grazed or tethered while grazing (and hence abortions would be more apparent) and for which an existing relationship with animal health services is more likely.

More than a fifth of the dams that aborted were reported to have experienced a previous abortion, and several had experienced multiple abortion losses, with non-indigenous breeds more likely than indigenous breeds to have had a previous abortion. Chronic repeat abortions can arise from infection with pathogens such as *Neospora caninum* and Pestiviruses which were detected as common causes of abortion in this study. Repeat aborting dams could be identified as candidates for slaughter with accruing potential benefits for herd fertility and productivity, as well as reduced risks of potential zoonotic transmission. However, any advice around removal of these animals from a herd may result in sale rather than slaughter, with the risk of further spread of the pathogen.

The risk of exposure to zoonotic pathogens through abortion cases was underscored by two findings: first that, in nearly 80% of cases in which a pathogen was detected, the pathogen

612 was zoonotic and second, that in nearly a quarter of all cases, someone had assisted with the
613 aborted delivery, very likely without any form of personal protective equipment. Of these
614 people who assisted, 20% were female, of which most were of reproductive age and therefore
615 at particular risk following infection with pathogens such as Toxoplasma gondii.
616
617 In conclusion, this study has demonstrated that livestock abortion surveillance, even at a
618 relatively small scale, can capture valuable aetiological and epidemiological information on
619 important livestock pathogens, including pathogens that are zoonotic and those with
620 epidemic potential. The study demonstrated the utility, acceptability, and feasibility of
621 livestock abortion as a target for both syndromic and event-based surveillance and showed
622 that an effective reporting and investigation system could be operationalized across a range
623 of settings in Tanzania, including remote rural areas. Key elements of effectiveness were high
624 levels of engagement of community-based field officers and the establishment of practical
625 and robust field sample collection and molecular diagnostic protocols, with prompt response
626 to reporting of cases, and prompt feedback of results.
627
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638
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