Analysis of the 2010 outbreak of foot-and-mouth disease in Mongolia

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Contents

Executive summary

In the 2010 foot-and-mouth disease (FMD) incursion, FMD occurred in five aimags and 24 soums. The first detection occurred on 21 April 2010 (confirmed 26 April 2010) with the last detection occurring on 13 December 2010. The number of livestock detected in the spring phase of the outbreak was 323 cattle and in the summer phase was 13485 sheep, 6748 cattle, 5692 goats, and 10 camels (Total livestock 25935). Infection of livestock was confirmed by PCR for each outbreak cluster (soum).

The percentage of affected herders with cattle detected with clinical signs was 76%, versus 48%, and 43% with sheep and goat detected, respectively. Where data was available on the number of susceptible livestock by species for an affected herder, the median percentage of cattle detected was 26% versus 8% and 6% of sheep and goats respectively. There was widespread infection of gazelles with FMD; however, in 11 soums gazelles were detected with FMD by PCR, yet no affected livestock were detected.

The length of time that FMD continued to circulate with an outbreak foci provided a source of virus for other outbreaks. It also supports the likelihood that the summer phase of the outbreak was a continuation of the spring event. In the spring phase the spatio-temporal pattern of spread suggested an extension of infection from the main Sukhbaatar cluster. There was also a number of long distance clusters established. There was some association between main thoroughfares/roads between population centres providing some indication that spread by fomites could explain some of the dissemination. Despite fomite transmission being low risk in comparison to animal contacts the frequency of movement from an infected area is likely to be high, meaning the overall risk could be higher than animal contacts. The estimated dissemination ratio (EDR) did not provide evidence of high rate of transmission of infection between herders; however, the data is limited by the quality of surveillance.

Analysis of data and response actions was carried out for the 2010 FMD outbreak in Mongolia. The following points are provided for consideration for improvement of future responses:

1. Further time is spent in trying to improve the quality of spatial data from the 2010 outbreak and rectify errors for further analysis.
2. Training on epidemiological investigation of affected herders including aging lesions and tracing is carried out. Consideration should be given to establishing an epidemiological response unit for investigation of index cases of FMD.
3. A full investigation on livestock from the index herder with aging of lesions and limited active surveillance on traces for high risk conveyers i.e. transfer of livestock, herders visiting from known areas of infection.
4. Data (including spatial location, date of investigation, and the type of investigation carried out) is collected on herders that were negative on investigation. In order to understand how infection has been transmitted it is important to collect data on herders where no clinical disease was detected in livestock. In addition, it is important that there is evidence to justify the change in status of a property from infected to free.

5. A standard set of data is collected for each affected herder (See appendix).
6. Post-outbreak analyses are determined prior to any future response to FMD (see subsequent section for description of analyses that may be applicable).
7. One GPS unit is provided per soum to enable veterinary practitioners to record spatial coordinates of properties visited as part of a transboundary disease investigation. It is also important that those likely to use GPS equipment are trained on its use as some of the coordinates provided as part of the 2010 outbreak were impossible to decipher.
8. Data quality in general is improved particularly in relation to the dates that events actually occurred and the number of livestock involved i.e. slaughter. The number of livestock for each susceptible species per herder must also collected accurately.
9. Private veterinary practitioners are compensated for time carried out in transboundary disease investigation. Because veterinarians are not compensated for time carried out the sensitivity of the passive surveillance system for early detection of transboundary disease is compromised. This is a major weakness in Mongolia's response system.
10. Funding is provided to the provisional veterinary service for investigation carried out subsequent to alerts of suspect transboundary disease by soum veterinarians.
11. Consideration to providing a disinfection kit to all herders in the quarantine zone (or at least in close proximity to known areas of infection). Herders do not always exit the quarantine zone through the legal entry and exit points. Provision of a disinfection kit offers the opportunity for education of the importance of being careful when visiting other herders.
12. Mongolia discontinues the policy of modified stamping out. The sensitivity of detection of clinical cases is low and therefore this practice is of negligible value in controlling an outbreak.
13. A study is carried out to quantify movements of conveyers (livestock, gazelle, fomites used on animals) between bordering countries. Analysis will not point to the direct source but may mean that the most important risk pathways are identified justifying any mitigation steps applied.
14. Spatial data of herders is collected by GPS at the time of vaccination by soum veterinarians
15. Funding is provided to the Mongolian centre for statistical office to provide data in electronic format identifying herders and numbers of livestock.

Review of the 2010 outbreak of foot-and-mouth disease in Mongolia

Introduction

Mongolia is divided up into 21 provinces (aimags). Provinces are further divided into approximately 20 counties (soums), (Shiilegdamba *et al.* 2008). Herders within soums are generally organised into family groups (khot-ail). These family groups manage livestock collectively. Multiple species of livestock including cattle, sheep, goats, camels and horses are managed by herders under a nomadic pastoral system. Although movements of herders and their livestock do not follow any set rule, there are generally four major movements per year coinciding with each season. There is a preference of locations by herders for each of these seasons, although factors such as climate will have a major influence on locations selected. Over the summer period grazing of livestock follows water systems that are shared between herders. There may be multiple contacts with livestock from other herders at common water sources, although this will depend on the water system i.e. river versus a well. Over the winter period, permanent shelters are sometimes established by herders for wintering livestock.

Over the last decade there have had multiple incursions of foot-and-mouth disease virus (FMDV) into the eastern provinces of Mongolia (Shiilegdamba *et al.* 2008, Thomson 2011). Several previous analyses have discounted the possibility that FMDV has been maintained from endemic infection within Mongolian gazelles (*Procapra gutturosa*), (Joly 2010, Thomson 2011). The strain of FMD in 2010 was confirmed as type O, the same strain causing the 2004 outbreak in Mongolia. It was also likely to be the same virus circulating in China, South Korea and Japan (FAO world reference laboratory for foot-and-mouth disease, 2 June 2010; OIE regional reference laboratory for foot-and-mouth disease 2010). It is likely that infected livestock in China represents the main source of virus release and subsequent exposure of susceptible livestock in Mongolia.

In the 2010 FMD incursion/s into Mongolia, FMD occurred in five aimags and 24 soums. The first detection occurred on 21 April 2010 (confirmed 26 April 2010) with the last detection occurring on 13 December 2010. Subsequent to FMD outbreak in the spring, vaccination for FMD was instituted, and then later again following the summer outbreak. Descriptive analysis of data and response actions from the 2010 outbreak is described and points for consideration provided for future responses to FMD.

Release and exposure of FMDV

Thomson (2011) reported that the general movement of livestock was away from Mongolia and into China because of higher livestock values. The transport of livestock between the borders of China and Mongolia are prohibited and it is claimed that the borders are double fenced with checkpoints for official movement of people and goods. If illegal traffic of livestock occurs the exact quantity and nature of this activity is not known, but likely a rare event. Hence, potentially other pathways could be responsible for introduction of FMDV. Migratory movements of gazelles have been identified as a potential source. It is clear that whilst fencing of the border is present between Mongolia and China it is not sufficient to prevent all migratory movements of gazelles. The general movements of gazelle is towards China in March-April (spring) and back to Mongolia in August-October (summer), (Lhagvasuren and Milner-Gulland 1997); however, the species is nomadic and spatio-temporal patterns of movement have not been defined, although likely to relate to feed availability and quality (Mueller *et al.* 2008).

Thomson (2011) identified that trucks bringing horticultural product into Mongolia through the province of Dornod could have been used to transport livestock in China. Therefore, use of these trucks could result in release of virus into Mongolia. Presumably exposure of livestock in Mongolia could occur by exposure to contaminated product or later use of these trucks to transport Mongolian livestock. However, the largest numbers of risk movements are likely to come from relatively free movements of people and product between Mongolia and its neighbouring countries.

In essence the pathways for entry (risk of release) of FMDV could occur through movements of fomites (vehicles and goods) or livestock (either wildlife or domesticated animals). The relative importance of these pathways is not known however, it is likely to be a function of the frequency of movements and the risk they pose. The risk of pathways is based on the amount of viable virus present i.e. more virus associated with animal movements (also varying with species of animal) than fomite movements. To understand the risk of release it is necessary to quantify the factors described for each pathway i.e. frequency of cross border movements; frequency of animal contacts resulting from movements; and risk of virus transfer from that pathway. Given the number of incursions of FMD over the last decade, determining the likely source of virus entry by quantifying the risk that each pathway poses to Mongolia would be of value.

Subsequent to FMDV release in Mongolia the amount of virus disseminated (risk of exposure) will depend on the number of direct contact events between animals from different herders; from gazelles and sympatric livestock; and the number of indirect contacts resulting in virus transfer from fomites. The consequences of a large number of contacts within a confined area may be less disastrous then a small number of contacts with movements over large distances. In this instance multiple clusters will arise with a consequential increase in response activity necessary to bring the outbreak under control.

Response and reporting system

The reporting system for alerting authorities of suspect FMD has been previously described by Shiilegdamba *et al.* (2008) and involves an initial report by a herder to a soum veterinarian who undertakes a clinical examination of affected livestock. On the basis of clinical findings a report is made to the aimag veterinary laboratory with a subsequent visit by a government veterinarian to collect diagnostic specimens. A rapid test is undertaken for FMD. On the basis of these findings diagnostic specimens are sent to the state central veterinary laboratory for further molecular and immunological tests. All positive samples undergo confirmatory tests and sequencing at an OIE international laboratory.

At this point in time there is limited funding for carrying out transboundary disease investigation. The lack of compensation for private veterinary practitioners is a limiting factor for surveillance of transboundary disease. Veterinarians either alerted by herders of suspect FMD or detecting suspect FMD during a visit to a herder are neither compensated by the government nor the herder. One such example is of a veterinarian who detected the first case of FMD in the Sukhbaatar soum. That veterinarian spent four days carrying out daily examination of animals without any recompense. In addition, veterinarians that carried out surveillance of livestock known to share a common water source as the second affected herder in the same soum were paid only expenses i.e. petrol costs. Non-compensation and relying on the goodwill of private veterinarians is likely to reduce the quality and efficiency of any response activities carried out.

In addition to restricted funding at the veterinary-surveillance level, funding limitations are placed on the provisional veterinary service. Prior to authorising any further investigation subsequent to a report of suspect transboundary disease from a soum veterinarian, permission must be obtained from central government (Food, agriculture and light industry) in Ulaanbatar. Delays and inefficiencies in surveillance activities ensue as a result of this policy. The delays for response to suspect FMD may be up to a day; but for other transboundary diseases up to several days.

Response actions occur subsequent to the provincial government veterinarian’s investigation and involve placing a quarantine zone of up to 25 km around herders with affected livestock. Animals showing clinical signs are isolated by the herder for later examination by the veterinarian. The type of examination of the herd/flock by the veterinarian varies. It may be an examination from a distance with obvious clinical cases yarded for close hands-on examination or a hands-on clinical inspection of each individual from the herd/flock. New cases with clinical signs of FMD are identified for slaughter as part of the response policy of modified stamping out (MSO). Quarantine restrictions are removed from outbreak foci after a period of 21 days after the last observed case or after the last animal had been vaccinated.

Results of data analysis

Methods

Data used in analysis was obtained from the Mongolian department of veterinary and animal breeding. Exploratory analysis of data of the FMD outbreak was performed using the base, lattice and epR packages in R (Ihaka and Gentleman 1996). Maps were created using the spatial analyst function of ARCMAP (ESRI, New York, USA). A search radius of 57721 km was used to create kernel density maps.

Outbreak foci of FMD were defined by Mongolian authorities as a collection of herders in one soum with disease present in susceptible livestock. Thus, whilst the epidemiological unit of interest was the herder, outbreak foci involved livestock from multiple herders. Data of newly detected animals were collected by species and by herder.

Description of the outbreak

Two disease events of foot and mouth disease occurred in Mongolia in 2010. The first event occurred in spring 2010 and involved three outbreak foci from three different soums in the Dornod province. Foci were separated by a distance of approximately 200km and were detected on 26 April 2010, 14 May 2010 and 14 June 2010. The total livestock detected from these foci with clinical signs was 323 cattle.

The second event occurred 77 days after the last report from the spring event. It began on 30 August 2010 during the summer in the neighbouring province of Sukhbaatar. This event was significantly greater than the first and resulted in 23 outbreak foci (defined by soum) in 5 aimags and affected 956 herders. A sample of clinical cases detected for each outbreak foci was confirmed by PCR as FMD. In addition to livestock, gazelles were also determined to be positive for FMD by 3 AB-ELISA, 3 ABC-ELISA, RT-PCR and real time RT-PCR. During September 2010 gazelle from 11 soums were positive by either real time RT-PCR or RT-PCR (Sukhbaatar (6/10), Matad (1/4), Bulgan (2/3), Khalzan (1/1), Tumentsogt (1/1), Tsagaandelger (1/1), Bayantsagaan (5/9), Darkhan (3/8), Ikhkhet (4/4), Altanshiree (2/2), Tumentsogt (1/1)).

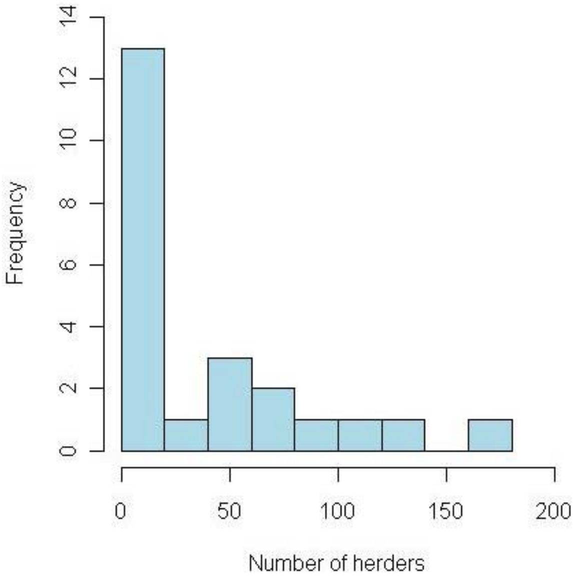
The median number of livestock detected in outbreak foci was 743 (Range 4-6072). The median number of herders affected per soum was 18 (Range 2-180), (Figure 1). The average number of susceptible livestock placed under quarantine within a soum was 15546 (Range 1481-76603).

The median percentage of cases detected in relation to susceptible livestock under quarantine for all outbreak foci was 6.5%, but varied from 2% to 33%, (Table 1). The average period that new cases were detected during an outbreak was 35 days (SD = 23 days, Range 1-69 days).

Table 1. Livestock detected clinically as being infected with foot-and-mouth disease in relation to susceptible livestock placed under quarantine within an affected soum.

Soum	N herders affected	N cases in livestock detected	N livestock under quarantine	% quarantine livestock affected
Asgat	46	743	28418	0.03
Baruun-Urt	69	1762	29703	0.06
Bayan	18	905		
Bayandelger	57	395	20128	0.02
Bayanjargalan	7	125		
Bayanmunkh	13	80		
Bulgan	10	2242	10290	0.22
Choibalsan	22	2002	15407	0.13
Chuuluunkhoroot	9	114	4981	0.02
Dariganga	129	1751	31532	0.06
Erdenetsagaan	54	1013	21706	0.05
Gurvanzagal	3	655	2366	0.28
Khalzan	104	2396	30700	0.08
Kherlen	4	60		
Matad	18	657	4013	0.17
Murun	4	46		
Norovlin	2	4		
Ongon	99	1530	35710	0.04
Sergelen	3	1720	5151	0.33
Sukhbaatar	180	6072	78797	0.08
Sumber	9	74		
Tuvshinshiree	18	300	4912	0.06
Uulbayan	78	1289	19508	0.07

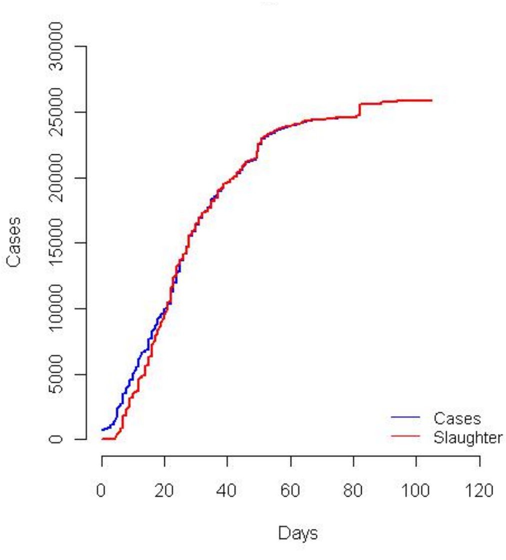
Figure 1. Histogram of the number of herders affected for each foot-and-mouth disease outbreak foci.



Efficiency and effectiveness of controls

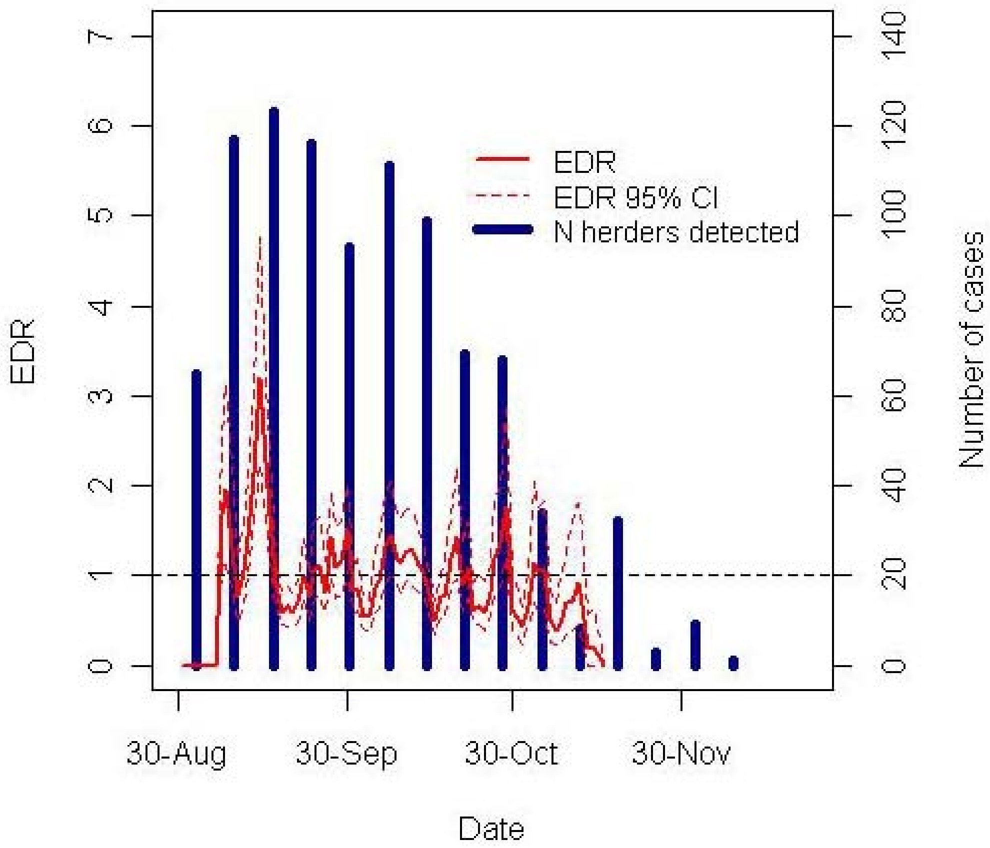
The lag between identification of newly detected cases and slaughter was determined as a measure of efficiency of the response over time (Figure 2). Efficiency measures provide an indication of how well the operational response to disease is going. They generally measure the time interval between two events i.e. from report to diagnosis and diagnosis to mitigation step (vaccination or depopulation).

Figure 2. Efficiency of slaughter as a control method, measured as the lag between detection of cases and slaughter of livestock over time.



The estimated dissemination rate (EDR) was used to quantify transmission between herders over time as a measure of efficiency of response measures. A value of one indicating that the number of cases is not increasing and the epidemic is likely to die out versus a value consistently greater than one indicating that the epidemic is continuing to propagate (Figure 3).

Figure 3. A frequency histogram of the number of new herders with livestock detected clinically with foot-and-mouth disease for all soums and the effectiveness of the response as measured by estimated dissemination rate (and 95% confidence intervals) for new herders detected clinically with foot-and-mouth disease.

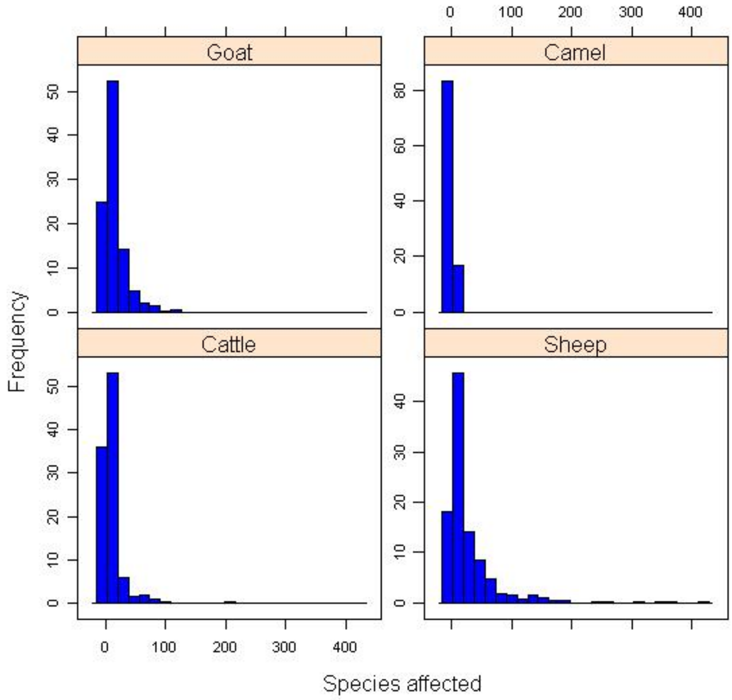


Animal species affected

The numbers of sheep and goats with clinical signs within a flock was generally greater than the numbers of cattle affected per herd. The median number of cattle, sheep and goats detected per herder was 4 (Range 1-101), 7 (Range 1-787) and 6 (Range 1-112), respectively (Figure 4).

Where data was available on the number of susceptible livestock by species for an affected herder, the median percentage of cattle detected clinically with FMD was 24% versus 6% and 5% of sheep and goats, respectively. There were obvious errors in the data with 2% of data for cattle herds having more cases than present within the herd.

Figure 4. Histogram of the number of new cases of foot-and-mouth disease detected clinically for each species by herder



The percentage of affected herders with cattle detected with clinical signs within their herds was 75% (718/956), versus 46% (442/956), and 42% (398/956) with sheep and goats detected, respectively.

There was some variation in whether infection was detected within both herds and flocks run by the same herder. There were 28% of affected herders (265/956) with both sheep/goats and cattle detected with clinical signs of FMD. Forty two percent (399/956) of herders had cattle detected with clinical signs, but no sheep or goats, despite sheep or goats being present; and 19% (184/956) of herders had sheep or goats detected with clinical signs, but no cattle. The total number of livestock detected with clinical signs by species was 13485 sheep, 6748 cattle, 5692 goats, and 10 camels (Total livestock 25935).

Vaccination

Subsequent to the spring FMD event an average of 82% (SD=11%) of cattle and 32% of all susceptible livestock (median = 8%, range=3-100%, SD=32%) were vaccinated from the Dornod and Sukhbaatar soums; later affected by FMD in the summer phase of the outbreak.

There was no difference (p=0.68) in the proportion of sheep detected with clinical signs for herders from those soums where <5.2% (lower quartile of proportion vaccinated for affected soums) and those soums >70% (upper quartile of proportion vaccinated for affected soums) of sheep were vaccinated.

Temporal

The epidemic curves of detected livestock with clinical signs were determined for each soum (Figure 5). In addition, the epidemic curves were produced for the date of first detection of herders with affected livestock (

Figure 6).

Figure 5. Epidemic curve of the number of new cases of foot-and-mouth disease detected clinically in livestock by soum over time.

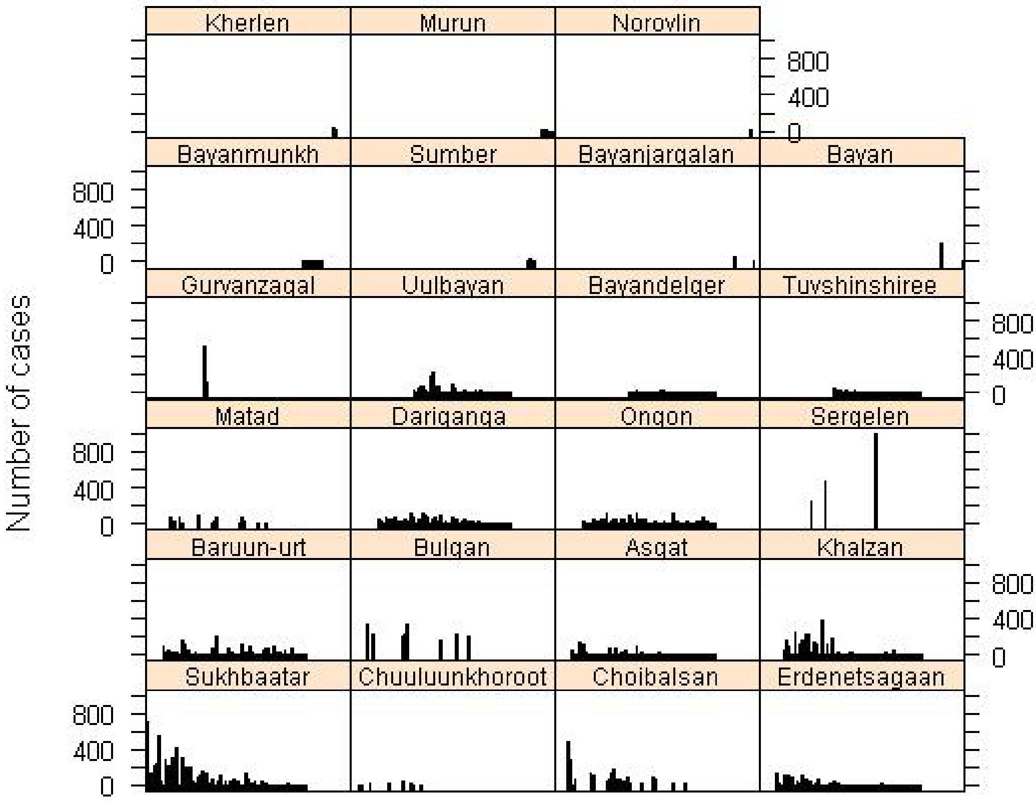
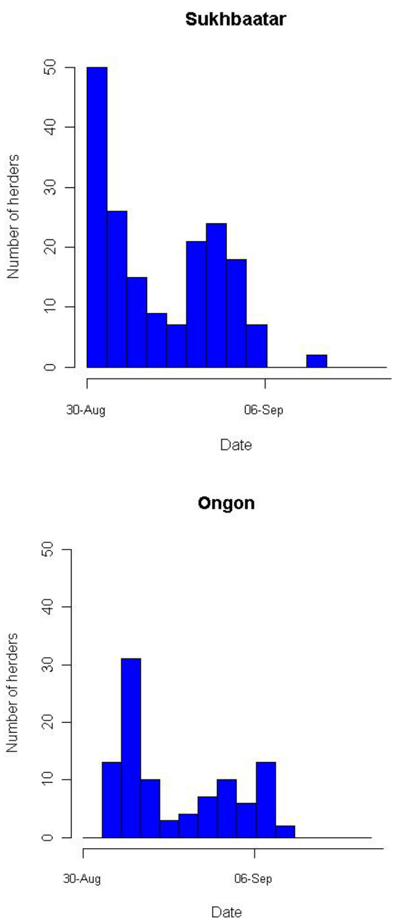
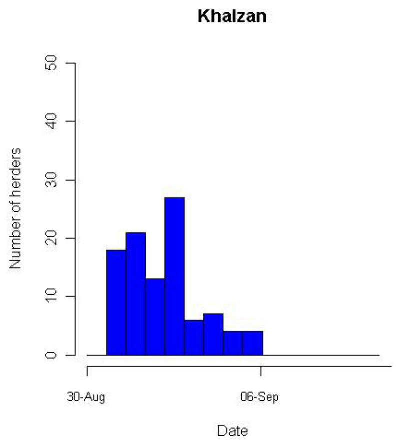


Figure 6. Epidemic curves of date of first detection of new herders with livestock detected clinically with foot-and-mouth disease for selected soums.




Khalzan
Number of herders
0
10
20
30
40
50
30-Aug
06-Sep
Date

Spatial

Maps were created for the locations of outbreak foci (Figure 7), the relationship between outbreaks and main roads/thoroughfares (Figure 8), the relationship between locations of affected livestock and affected gazelle (Figure 9), the proportion of livestock placed under quarantine for affected soums

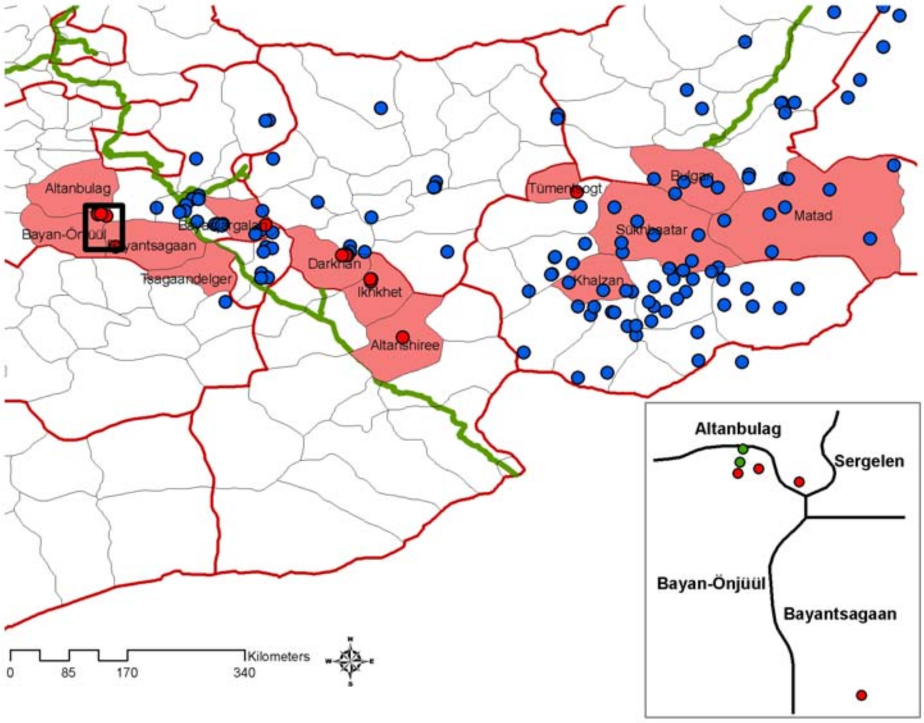


Figure 10(Figure 10) and the proportion of livestock vaccinated subsequent to spring outbreak 2010 (Figure 11).

Figure 7. GPS locations of FMD outbreak foci occurring during spring and summer 2010 (errors in GPS locations of outbreaks have not been corrected).

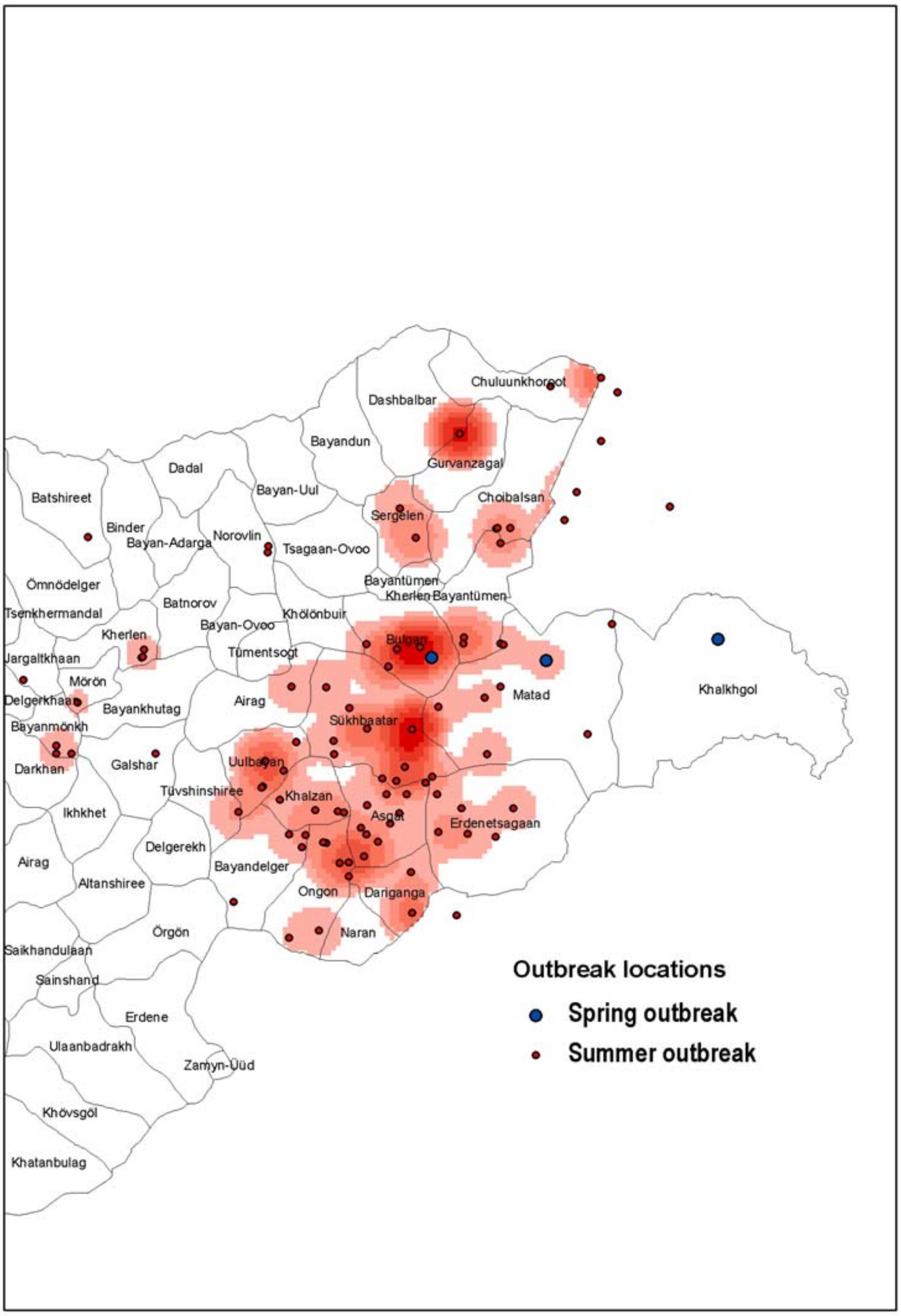


Figure 8. GPS locations of FMD outbreak foci in relation to main thoroughfares/roads in Mongolia.

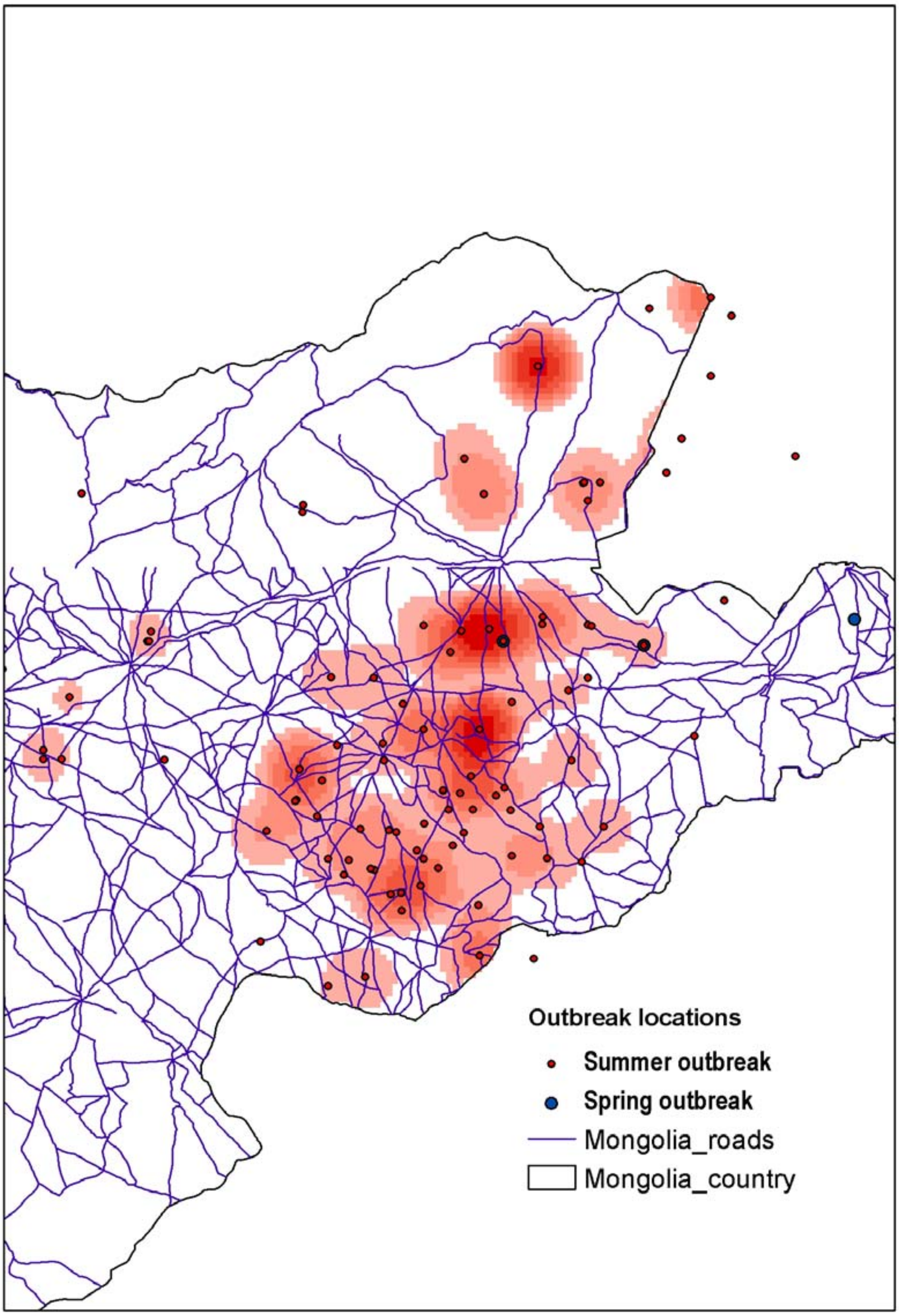


Figure 9. Spatial proximity (based on exact GPS locations or where unavailable from the soum location (▭) where spatial coordinates were not available) of gazelle positive (●) or negative (●) by PCR for foot-and-mouth disease (FMD) to livestock positive (●) for foot-and-mouth disease.

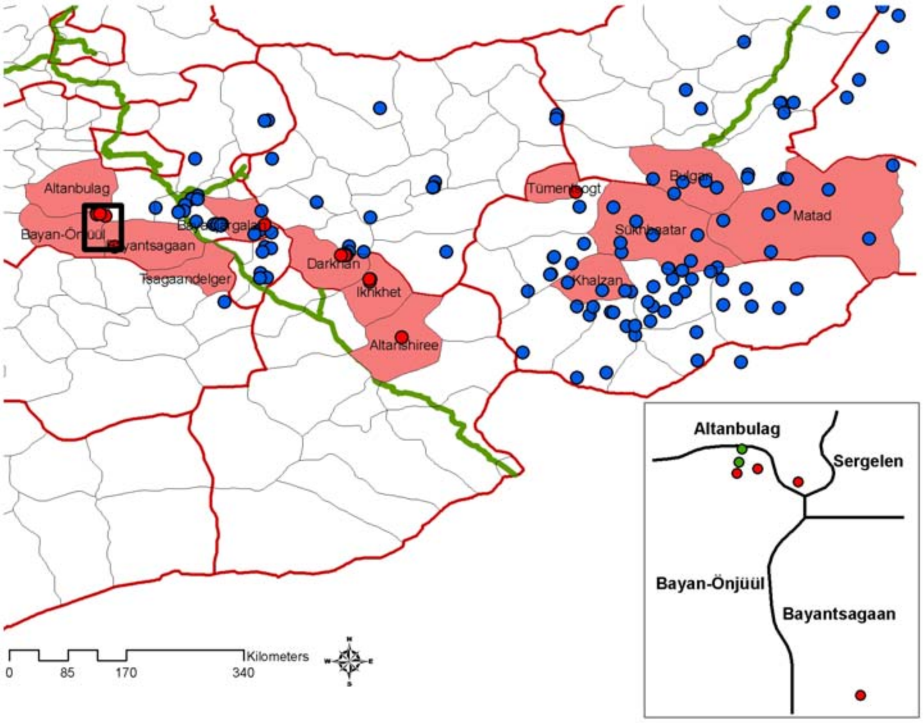


Figure 10. Map of the proportion of susceptible livestock placed under quarantine for each soum as part of response measures for foot-and-mouth disease

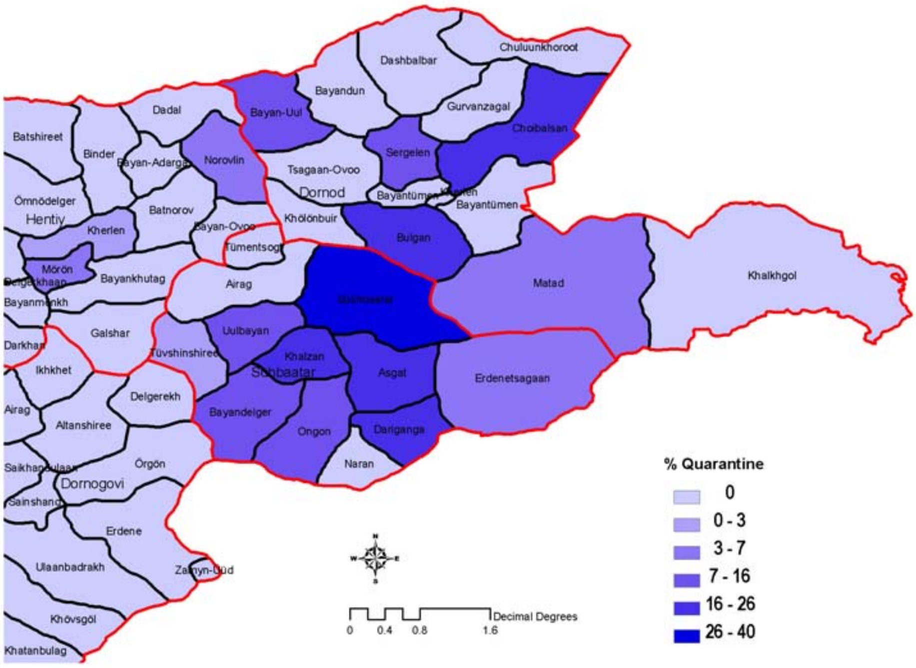
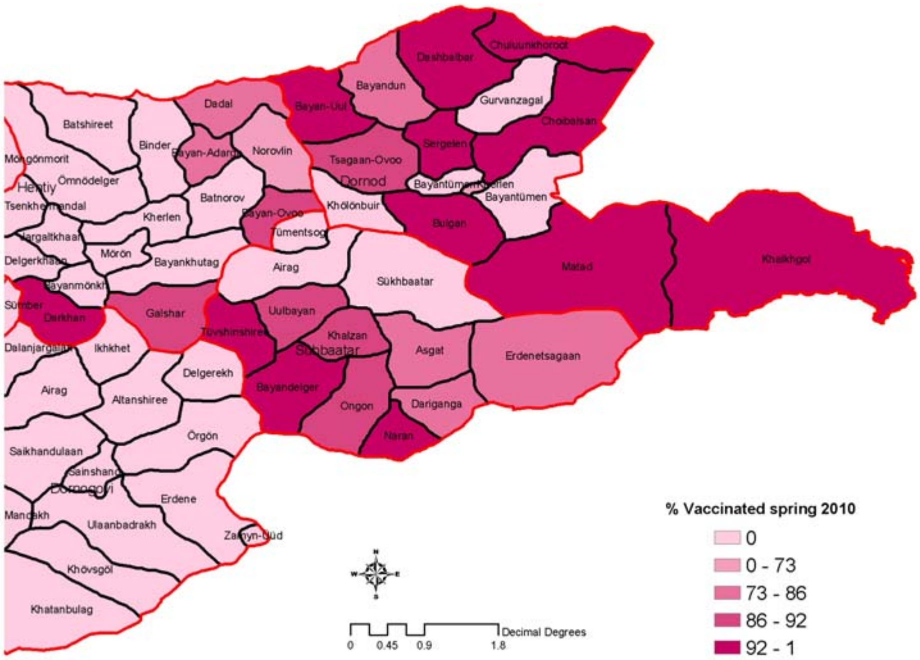


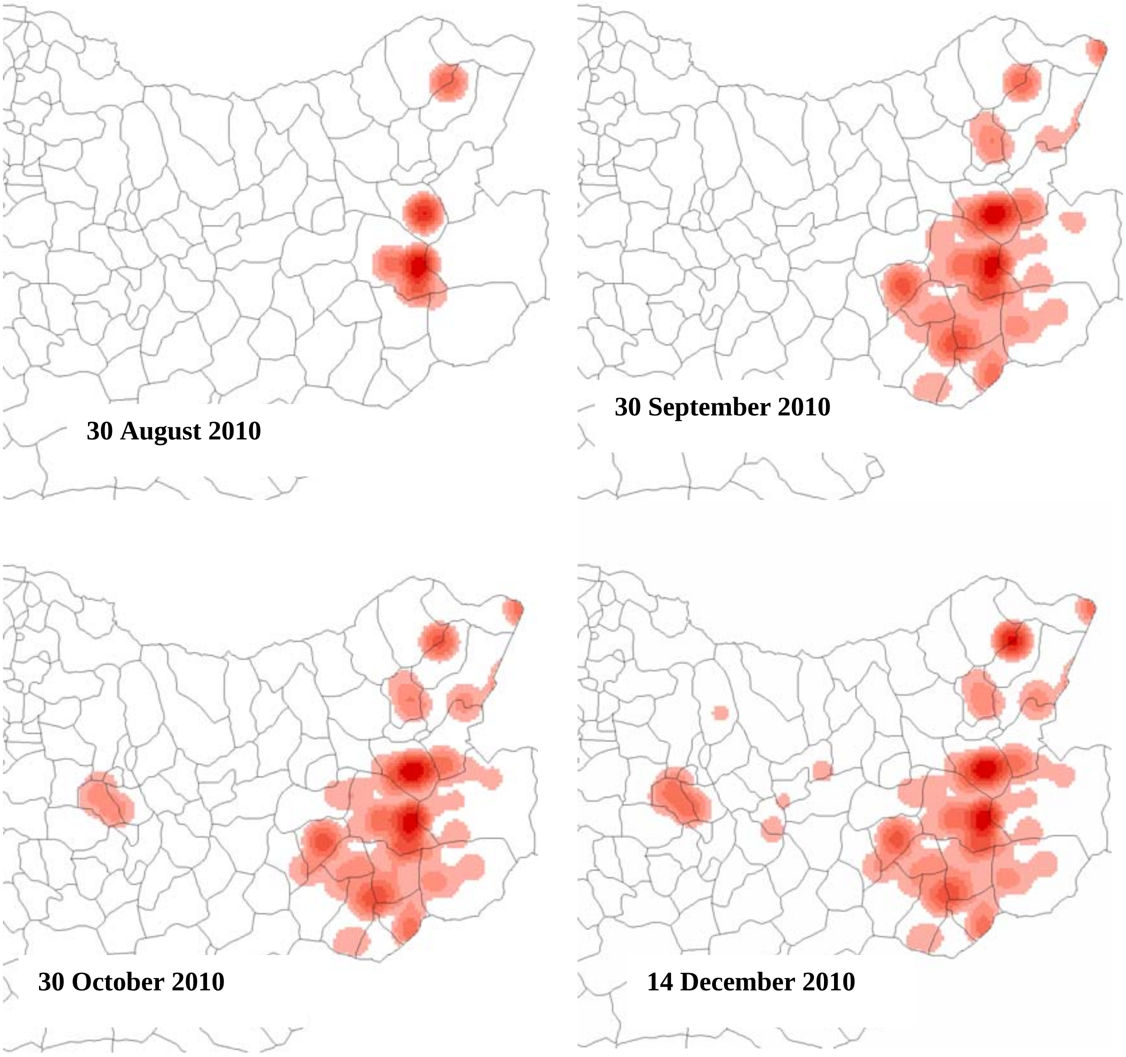
Figure 11. Map of the proportion of susceptible livestock vaccinated with foot-and-mouth disease O Manisa strain during May 2010



Spatial temporal

The general pattern of where infected livestock were detected over time is presented spatially (Figure 12). New clusters radiate out from the main cluster of infection in Sukhbaatar over time.

Figure 12. Change in livestock population affected with FMD over time and space for the foot-and-mouth disease summer outbreak event 2010.



Discussion

Data quality

Collecting high quality data during a response to a major transboundary disease outbreak can present a challenge as resources and focus are placed on operational activities rather than data collection. Data collection is often seen as an unnecessary task and an inconvenience to responding to the outbreak. Nevertheless, improving future response efficiencies rely on analysing data collected.

There are some improvements that could be made to data collected as part of the response to the FMD outbreak in 2010. There was a significant amount of missing data, for instance missing data relating to the number of susceptible livestock for each affected herder. In addition, there was data that appeared to be inaccurate. Data suggesting that a significant number of herders had only one susceptible animal making up the herd or flock is probably incorrect. Information collected during several interviews with herders for the number of affected animals detected did not match the data provided.

There are improvements that could be made in spatial data collection, which was generally poor and difficult to interpret (with some coordinates in China or in different soums to where the outbreak supposedly occurred). Inaccuracies undermine confidence in results of analysis. Spatial data is important to understand associations between herders with positive livestock and factors such as proximity to roads, water lines, soum/aimag borders or soum centres. It is important that the projection used for GPS data collected is in a standard projection i.e. WGS 1984, in standard format i.e. decimal degrees and is recorded accurately.

No data was available on the spatial locations of the underlying herder population. This data is also important for exploring differences in risk (or associations) between affected and unaffected populations and the factor of interest.

Release and exposure

The spatial and temporal patterns of the outbreak foci occurring during spring 2010 (April, May and June) in Dornod aimag highlight the difficulties in understanding release and exposure of FMD in Mongolia. The three outbreak foci were each separated by approximately 200km and occurred one month apart. In between the first and second foci there was heavy concentration of mining activity with very low numbers of livestock in that area. Hence, silent spread across a long distance would seem unlikely.

A main road connects the first foci to the second; therefore transfer of virus on fomites or illegal transportation of live animals would seem to be the most likely pathway. However, multiple incursions cannot be completely excluded. Despite fomite spread being low risk in comparison to animal contacts the frequency of movement from an infected area is likely to be high. A significant amount of virus would be required to initiate infection as approximately 100 to one million times as much virus is required to initiate infection in cattle by the oral versus respiratory route (100–1 million times higher than that required for infection via the respiratory route (Sanson 1994, Alexandersen *et al*. 2003, Thomson and Bastos 2004). One herder from Dornod whose livestock were affected with FMD claimed that the only risk contact that had occurred within five days of infection being detected was from another herder who had travelled out of the quarantine zone in the same soum. FMD occurred in his livestock two days after the visit.

The natural movement of gazelle at that time of year is to the west and parallels the direction of infection from the first to the second foci. The exact role that gazelles play in both release and exposure is not clear. The freedom of movement of this group of animals is greater than that for domestic livestock. They can move across country borders and also across aimag borders without restriction. Hence, they are an obvious target for implicating as a cause of transmission in the absence of other knowledge. Be this as it may some transmission to livestock is likely to have occurred from this species during the 2010 outbreak. FMD virus was detected in gazelles in multiple soums over the summer FMD event. One herder claimed that FMD occurred in his livestock two days subsequent to his dog capturing and dragging a gazelle back to where his livestock were located. The supposition being that the gazelle was debilitated by FMD. Whether transmission occurred from this event is impossible to determine, however, it is likely that rare contact events such as this could result in transmission. Shared grazing may also represent a point of transmission.

The likelihood of transmission of virus to livestock from pasture will depend on a number of factors determining the amount of virus on pasture, the survivability of virus and the time lag between shared grazing events. In open pasture, FMDV can survive 2-5 days in summer (Voinov 1956, cited in Arambulo and Steele 1977), and as long as 30 days when the average temperature is 1.3^{o}C (Shilnikov 1959). It is clear that transmission from shared grazing does not always occur as gazelles were found to be infected with FMDV in eight soums where no infection was detected in livestock. Hence, many shared grazing events are likely to have occurred with apparently no transfer of virus between gazelle and sympatric livestock.

It is possible that the importance of this species in transmission is dependant on whether infection pressure from livestock is sufficient to result in infection in the first place. There was a significant numbers of livestock infected in Sukbataar soum during the summer FMD event to result in a large amount of environmental contamination with FMDV. Hence, it is possible that multiple herds of gazelle were infected providing a pathway for infection of susceptible livestock.

Officials considered that movement of livestock between aimag borders is negligible and generally only happens in a poor season when there is a scarcity of food. In this instance herders can apply for a permit to move livestock. Hence, transmission by livestock movements may also be a rare event.

The length of time that FMD continued to circulate within outbreak foci means that there is a continued environmental source of virus for other outbreaks. It also supports the likelihood that the second summer outbreak event was a continuation of the spring event. The outbreak occurring in the Sukhbaatar soum in the summer event is likely to have been the main source of virus transmission to other foci/soums.

Surveillance

Data from investigations was focused on the numbers of livestock affected rather than when infection was likely to have occurred. A thorough investigation of an affected herder is critical for detecting other affected herders in a timely manner. It is important that good data is obtained on the age of FMD lesions present in livestock for the purposes of determining the likely date of introduction of FMDV. Once the age of lesions has been determined and after accounting for the incubation period of FMD, the date of FMDV exposure can be calculated. The accuracy of any date determined will depend on the length of period that virus has been circulating within the herd or flock. If exposure has been recent and clinical examination of livestock is carried out by a skilled veterinary clinician the date can be determined with some accuracy and an estimate on when the virus was likely to have been introduced made. Once the date of exposure has been determined it is possible to formulate a list of potential events that could have resulted in infection (backward traces) and also potentially lead to further infected herders (forward traces), for instance those herders using the same water source or herders that have brought or sold livestock, or herders that have interacted both with affected livestock and unaffected livestock over the period introduction of virus could have occurred.

Analysis of data was restricted to data collected on outbreak foci. Limited active surveillance was carried out during the response; however, some herders sharing the same water sources as livestock from infected herders were visited as part of response activities and herders questioned as to the occurrence of clinical signs. No data is available on the location of these herders or the dates that investigation took place. Most investigative and surveillance activities were limited to areas placed under quarantine within affected soums.

There is the potential for active surveillance to be carried out on livestock just outside the quarantine zone (and particularly of livestock in close proximity to main thoroughfares) to confirm that infection has not spread beyond this area. Surveillance around this zone may be prudent given that people movements occur regularly out of the quarantine zone, but not necessarily through the main disinfection point. In order to increase efficiency, cattle as the indicator species for FMD could be targeted for clinical examination. If vaccination has occurred, younger cattle not necessarily vaccinated could be selected.

The status of an affected property is changed to free if there have been no further cases of FMD reported 21 days after vaccination or after the last clinical case. However no data is available on the quality and quantity of any investigation carried out to support the change in status. Ideally any surveillance data supporting this change in status should be collected.

Species affected

It was of note that clinical signs in sheep and goats appeared to be relatively common. Generally, in these species the signs are milder than cattle (Thomson and Bastos

2004). Whilst the numbers of sheep detected clinically was greater than cattle the proportion detected as a function of susceptible numbers present was less.

Efficiency and effectiveness

The bar chart showing the lag between detection of cases and slaughter would suggest an extremely efficient organism management process through slaughter; however, the data is unlikely to be reality in terms of the true dates that slaughter occurred. It is important to collect this information accurately to allow a genuine assessment of any control process.

Spatial and temporal analysis

Clinical disease from the summer episode was first detected in the Sukhbaatar soum. There were a high number of affected herders present at the time that FMD was first identified, as demonstrated by the sharp rise in cases in epidemic curves for this soum and for Mongolia as a whole. Hence, the sensitivity of early detection of FMD was likely to have been poor.

The spatio-temporal pattern of spread suggests an extension of infection from the main Sukhbaatar cluster. There was also a number of long distance clusters established. There was some association between main thoroughfares/roads between population centres providing some indication that spread by fomites could explain some of the dissemination (Figure 8).

The estimated dissemination ratio (EDR) did not provide evidence of high rate of transmission of infection between herders; however, the data is completely limited by the quality of surveillance both in terms of self reporting by herders and by any active surveillance carried out by Mongolian authorities. It is possible that the EDR presented does not reflect the true dissemination of infection. Serological surveillance (detecting non-structural proteins) may provide some measure of silent spread.

As part of modified stamping out (MSO), new clinical cases of FMD were recorded for each outbreak foci. The sensitivity of herd/flock examination used to detect livestock with clinical signs subsequent to an affected herd/flock being identified appeared to be poor as in many cases only a low proportion of livestock were detected with clinical signs. Furthermore the epidemic curve for new cases did not match that expected for a highly infectious disease such as FMD, even accounting for the extensive Mongolian pastoral system. An additional explanation for the epidemic curve is that the day of detection of new cases reflected detection at any point of clinical progression of disease rather than the first day of clinical signs. It may also reflect inaccurate data collection of the exact date that examinations and numbers detected occurred.

Once FMDV has been introduced to livestock, infection will spread between livestock until no more susceptible animals are present and infection dies out. Thomson (2011) observed that in extensive systems spread can sometimes be slow despite the high infectivity of FMDV. Data from the outbreak supported this supposition with clinical cases being detected even after 69 days within outbreak foci. The speed of transmission is likely to vary with a number of factors governing contact between livestock, species of livestock present and environmental factors affecting the amount of viable virus on fomites. Just what affect the response option of MSO adopted by Mongolian authorities had on transmission of infection between susceptible livestock is not clear. The general policy followed by herders was to isolate livestock showing clinical signs and wait for slaughter. Given the delay between isolation and slaughter it is likely that shedding of virus was minimal by the time slaughter was carried out. Herders also appeared to be very adept at keeping infection out of non-affected livestock groups. It was of note that for some affected herders there was only one species group detected with clinical signs. This finding refutes homogenous mixing of livestock within a herder operation. It shows that separation of herds/flocks does occur and that it is possible to limit infection even within one herders operation.

Vaccination

Whilst a proportion of livestock had received vaccination for FMD in June subsequent to FMD occurring in the spring, the vaccine used on all livestock at this time contained the O Manisa strain which was poorly matched to the outbreak strain (VNT, 0.21 (reference range, <0.21 non-protective); liquid phase blocking ELISA 0.22 (reference range <0.3 non-protective)). Hence, vaccine is likely to have had only a mild affect in masking clinical signs. The data supported negligible protection from vaccination with the highest proportion of clinical cases detected in cattle versus sheep and goats, despite vaccination being predominantly carried out in cattle. In addition, the prevalence of detected sheep was not greater when a small percentage (<5.2%) of animals were vaccinated in comparison to soums where a large proportion were vaccinated (>70%).

There were delays in ring vaccination subsequent to the second FMD event in summer. In Sukhbaatar, vaccination began on 27 September 2010, one month after the first case (27 August 2010) and was carried out in five batches, finishing on 21 November 2010. The delays in instituting vaccination are likely to have had an affect on the size of the Sukhbaatar outbreak and the number of episodes resulting in spread to other soums.

Based on results from a review of the 2010 FMD outbreak data and interviews carried out with herders and government officials the following recommendations are suggested for consideration.

Recommendations

It is recommended that:

1. Further time is spent in trying to improve the quality of spatial data from the 2010 outbreak and rectify errors for further analysis.
2. Training on epidemiological investigation of affected herders including aging lesions and tracing is carried out. Consideration should be given to establishing an epidemiological response unit for investigation of index cases of FMD.
3. A full investigation on livestock from the index herder with aging of lesions and limited active surveillance on traces for high risk conveyers i.e. transfer of livestock, herders visiting from known areas of infection.

4. Data (including spatial location, date of investigation, and the type of investigation carried out) is collected on herders that were negative on investigation. In order to understand how infection has been transmitted it is important to collect data on herders where no clinical disease was detected in livestock. In addition, it is important that there is evidence to justify the change in status of a property from infected to free.
5. A standard set of data is collected for each affected herder (See appendix).
6. Post-outbreak analyses are determined prior to any future response to FMD (see subsequent section for description of analyses that may be applicable).
7. One GPS unit is provided per soum to enable veterinary practitioners to record spatial coordinates of properties visited as part of a transboundary disease investigation. It is also important that those likely to use GPS equipment are trained on its use as some of the coordinates provided as part of the 2010 outbreak were impossible to decipher.
8. Data quality in general is improved particularly in relation to the dates that events actually occurred and the number of livestock involved i.e. slaughter. The number of livestock for each susceptible species per herder must also collected accurately.
9. Private veterinary practitioners are compensated for time carried out in transboundary disease investigation. Because veterinarians are not compensated for time carried out the sensitivity of the passive surveillance system for early detection of transboundary disease is compromised. This is a major weakness in Mongolia's response system.
10. Funding is provided to the provisional veterinary service for investigation carried out subsequent to alerts of suspect transboundary disease by soum veterinarians.
11. Consideration to providing a disinfection kit to all herders in the quarantine zone (or at least in close proximity to known areas of infection). Herders do not always exit the quarantine zone through the legal entry and exit points. Provision of a disinfection kit offers the opportunity for education of the importance of being careful when visiting other herders.
12. Mongolia discontinues the policy of modified stamping out. The sensitivity of detection of clinical cases is low and therefore this practice is likely to be of negligible value in controlling an outbreak.
13. A study is carried out to quantify movements of conveyers (livestock, gazelle, fomites used on animals) between bordering countries. Analysis will not point to the direct source but may mean that the most important risk pathways are identified justifying any mitigation steps applied.

Future analyses of data from FMD outbreaks

Monitoring of an outbreak and the population at risk

Monitoring of an outbreak requires two things, a knowledge of the population at risk (where it is and what numbers and species are present) and accurate surveillance data (where and when disease occurs from each herder "epidemiological unit of interest"). In other countries where the epidemiological unit of interest is a farm rather than nomadic herder; and a high quality of veterinary infrastructure is available to respond to disease outbreaks active surveillance of farms can be carried out (surveillance of farms not necessarily reported as having disease present). Active surveillance implies that some organism management activity can be carried out to mitigate further exposure events such as farm/conveyer disinfection, depopulation of susceptible livestock, and/or vaccination of livestock. Active surveillance and subsequent response activities reduces the likelihood that further exposure events are likely to occur.

As herders are nomadic a up-to-date knowledge of location would require continuous GPS tracking of all herders. At this point in time this is considered infeasible. However, it is possible that recording multiple past locations of herders could provide some level of prediction of whether it is likely that a herder could be present in a general location of interest i.e. Soum. Future work could create a probability function per herder on the likely location.

Whatever system developed to capture this data must be incorporated into normal activities associated with herders. For instance one option would be to collect GPS coordinates of herder location at every Soum veterinary visit i.e. for vaccination of livestock or any other health intervention. Hence, over a period of time every herder would have multiple GPS coordinates. Vaccination activities are generally carried out between early April and November. Hence, winter locations would not be obtained using this method. In order to undertake this type of collection Soum veterinarians would need to be provided with GPS units. The advantages of data collection in this way are that Soum veterinarians:

- visit herders on a semi-regular basis
- they are paid by the government for vaccination and thus need to fill in a form for payment (part of the condition of payment could be that they provide GPS coordinates along with other data i.e. numbers present etc

An alternative to using handheld GPS units is Smart phone technology; however, the use of this system would require adequate coverage of GSM mobile data networks (Aanensen *et al.* 2009). In addition sending data is an additional cost and use of phones in this way is more complicated than taking readings of x and y coordinates from hand GPS units.

At this point in time, veterinary infrastructure is not sufficiently developed to have the capability to carry out intensive active surveillance of multiple unaffected herders in a surveillance zone as well as infected herders. However, this will change and the model of surveillance and disease response is likely to take on more active components.

Even without using the population at risk and surveillance data for active surveillance it can still have value in a more general sense to response activities. A spatial database of the population at risk may provide information on:

1. The areas (not necessarily defined by Soum) where the population density is greatest and therefore important to prevent exposure occurring.
2. The areas where population density is the least (not necessarily by Aimag or Soum) that could be used as natural buffers to vaccinate out to and thereby act as a barrier to exposure of susceptible livestock beyond the buffer.

3. Identification of susceptible livestock that are likely to required vaccination for the purposes of:
    - planning efficient use of vaccination resources
    - auditing those herds that are likely to need vaccination versus those where vaccination has actually been carried out
    - determining herds not present in the vaccination zone (yet with the potential to move into the vaccination buffer zone albeit illegally (based on GPS coordinates of past locations)
    - carrying out analysis (for instance risk ratios) of clinical disease present in livestock for herders where a specific factor is present or absent i.e. those vaccinated with a specific strain of FMD vaccine versus those with another.
4. Planning of some form of active surveillance activities.
5. Carrying out post-outbreak epidemiological analyses that help understanding of the outbreak and measure the efficiency of surveillance and effectiveness of response activities.

Recommendations:

1. Spatial data of herders is collected by GPS at the time of vaccination by soum veterinarians
2. Funding is provided to the Mongolian centre for statistical office to provide data in electronic format identifying herders and numbers of livestock.

Analysis of data

Prior to development of data requirements it is important to determine the type of post outbreak analyses that may be required. Generally speaking analysis of data from an outbreak can be broken up into several different report/analysis categories (Sanson and Stevenson 2007): Epidemiological, Efficiency, and Effectiveness of response strategies.

Post outbreak analyses

Some of the analyses that may be relevant to Mongolia and adapted from Sanson and Stevenson (2007) are presented below:

<u>Epidemic curves</u>

It is possible to create a number of curves that provide slightly different insights into the rate of propagation of the epidemic over time:

- Number of herders diagnosed per day or per week.
- Number of herders infected per day or per week (based on known or estimated infection date).
- Summation of the number of infectious farms present on each day throughout the epidemic (based on likely time for virus die-out in susceptible animals per herder)

Spatial analysis

Plotting spatial coordinates of affected herders gives some indication of whether spread is occurring outwards or whether new infected herders represents “infilling” of new infected herders as a result of close proximity to known infected herders. It can be used to identify clusters where spread is greater than expected given the size of the underlying population.

The distribution of infection can also be presented as the prevalence of infection per spatial area i.e. soum.

Spatial analysis also allows determining trends in new infected herders in relation to known environmental or geographical factors i.e. water sources, roads, areas of high productive grazing.

Time interval analysis

Time intervals from report to diagnosis and diagnosis to mitigation step i.e. vaccination.

Estimated dissemination rates (EDR)

The EDR is the ratio of the cumulative incidence in one time period to the cumulative incidence in the previous time period (Miller, 1979). The time period is based on the generation interval for the disease. (for FMD 4-7 days).

The EDR can show how disease control measures are working before there is any observable reduction or increase in the weekly incidence.

Effectiveness of surveillance

Distributions of time (days) from onset of clinical signs to diagnosis by species. Based on age of oldest lesions reported at time of diagnosis.

Post vaccination surveillance

Surveys are very expensive and generally compromise is necessary to carry out the survey within an acceptable budget. No survey will be able to answer all questions; therefore, you must define the question/s that is the most important to be answered.

First define the question/s you are trying to answer in relation to post-vaccination surveillance.

1. What percentage of livestock (cattle) have protective levels of immunity in areas/soums of high risk?

2. Is there a difference in antibody protective levels between soums (The assumption being that any differences relates to either cold chain or application technique)?

Confounding factors may relate to livestock that have not been vaccinated, either through being missed or having been moved into area subsequent to vaccination being undertaken. Other confounders relate to discriminating immunity due to vaccination and field virus exposure; this is particularly important where silent spread may have occurred and vaccine quality (where vaccines have not been purified of non-structural proteins).

Sampling occurs at three levels. What soums, herders and livestock within herder are selected. At the soum level, those soums bordering China and Russia should be included as part of sampling because of their proximity to sources of infection. Other soums of interest could also being purposively selected i.e. Sukhbaatar because of its apparent low prevalence of protective immunity in livestock and because of the size of the previous outbreak.

At the herder level, the sampling frame should be stratified on herd size and distance the herder was from the soum centre at the time of vaccination (distance relating to potential break-down in cold chain). Stratifying on size of herd relates to potential differences in care taken in vaccination (possible livestock being missed) for small versus big operations.

Blood needs to be collected from livestock from multiple herders i.e. consider collecting samples from livestock from at least eight herders per soum. Ideally, herder should be selected where cattle have breed vaccinated by multiple veterinarians (if more than one veterinarian per soum carries out vaccination).

At the animal level consideration should be given to sampling cattle only because of limitations on the number of animals that can be sampled for the available budget. Cattle are more important with regards to the epidemiology of spread and virus production (in contrast to sheep and goats) because of the small amounts of virus to initiate infection and their relatively large inspiratory volumes.

Assuming that the ideal vaccination coverage is 90%, forty samples would be sufficient to determine a difference in immunity of livestock at the soum level where there was a difference of 90% vs. 60% (at a sample size of 20 you would only be able to detect a difference in proportion affected of 90% vs. 50%). This sample size would also allow the prevalence to be determined with a 10% error at the 95% confidence level i.e. between 80-100%.

Collect data relating to the sample collected. Data should include confirmation that vaccination was carried out, date of vaccination, age of cattlebeast, breed of cattlebeast, veterinarian who carried out vaccination, herders name and contact details, date sample collected, location of herder when vaccination occurred.

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Appendix

Data to be collected from each affected herder

Inf ected herder table

1. Herder identification
2. Herder name
3. Longitude
4. Latitude
5. Visit date
6. Surveillance type (reported by herder or identified as part of active surveillance)
7. Diagnosis date (date diagnosis confirmed by laboratory)
8. Age of clinical maximum clinical signs (maximum age based on examination of all species)
9. Date of the first appearance of clinical signs
10. For each species
    - Number of animals
    - Number affected
    - Number examined
    - Age of earliest clinical signs
11. Date slaughter started
12. Date slaughter finished
13. Date disposal started
14. Date disposal finished
15. Date vaccination started
16. Date vaccination finished
17. Date C & D (cleaning and disinfection) started
18. Date C & D finished

Tracing table

1. Source herder identification
2. Source herder name

3. Destination herder identification
4. Destination herder name
5. Source date
6. Destination date
7. Trace type (animal movement, people movement, people movement associated with livestock, movement of goods (hay, animal equipment))