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Epidemiological Assessment of the Rift Valley Fever Outbreak in Kenya and Tanzania in 2006 and 2007

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Abstract. To capture lessons from the 2007 Rift Valley fever (RVF) outbreak, epidemiological studies were carried out in Kenya and Tanzania. Somali pastoralists proved to be adept at recognizing symptoms of RVF and risk factors such as heavy rainfall and mosquito swarms. *Sandik,* which means "bloody nose," was used by Somalis to denote disease consistent with RVF. Somalis reported that *sandik* was previously seen in 1997/98, the period of the last RVF epidemic. Pastoralists communicated valuable epidemiological information for surveillance and early warning systems that was observed before international warnings. The results indicate that an all or none approach to decision making contributed to the delay in response. In the future, a phased approach balancing actions against increasing risk of an outbreak would be more effective. Given the time required to mobilize large vaccine stocks, emergency vaccination did not contribute to the mitigation of explosive outbreaks of RVF.

INTRODUCTION

Rift Valley fever (RVF) is a viral disease that primarily affects cattle, sheep, and goats, but also affects people and wildlife.[1,2] The majority of human infections take the form of mild fevers, but a small percentage (< 1%) lead to more severe manifestations including fatal hemorrhagic disease.[3,4] In East Africa, RVF is mainly noted in arid and semi-arid areas as sudden, dramatic epidemics of the disease at intervals of approximately 10 years, associated with widespread flooding and the resultant swarms of mosquitoes.[5–9]

In late 2006 through early 2007, following a period of heavier than usual rainfall and widespread flooding, an outbreak of RVF occurred in East Africa.[10,11] By the time the disease abated more than 1,000 people had been diagnosed with RVF and more than 300 people had been confirmed to have died of the disease.[11] The economic and social impacts, caused by morbidity and mortality of livestock and disruption of livelihoods, markets, and the meat industry that resulted from a ban on livestock slaughter, were considerable.[12] Shortly after the outbreak, studies were carried out by researchers from the International Livestock Research Institute (ILRI) who worked closely with the official veterinary services of Kenya and Tanzania. The objective of these studies was to document the principal lessons learned from the recent outbreak as tools to inform veterinary preparedness and response plans for future RVF outbreaks in East Africa.

MATERIALS AND METHODS

The studies consisted of focal group discussions with pastoralist livestock keepers, for which villages were the unit of analysis, and key informant interviews.

In Kenya, the focal group discussions took place in 15 villages in two districts, Garissa and Ijara, which are located in North Eastern Province. This is a semi-arid area, which normally has two rainy seasons a year: the so-called short rains between October and December and the long rains in March and April. Typical annual rainfall averages between 300 to 500 mm. The people in North Eastern Province are ethnically nearly all Somali pastoralists. Vegetation is predominantly shrubs and acacia bushes, and livestock includes cattle, goats, sheep, camels, and donkeys. Livelihoods depend primarily on livestock. A total of 204 Somali pastoralists took part in the focal group discussions, of whom over 91% were men.

In Tanzania, the focal group discussions took place in 18 villages in Ngorongoro and Monduli districts of Arusha Region, a semi-arid rangeland area in the Rift Valley just to the south of the Kenyan-Tanzanian border. This area normally experiences two rainy seasons: a short rainy season between October and December, and a long rainy season between March and May. Typically, the annual precipitation averages between 500 and 1,000 mm. The vegetation mainly consists of various shrubs and acacia bushes, and livestock species kept are primarily cattle, goats, sheep, and donkeys. In each village, focal groups were convened, which consisted of between seven and 30 people, most of whom were men and all of whom were ethnically Maasai. The focal group participants relied primarily on extensive rearing of livestock and eco-tourism for their livelihoods, supplemented with limited cultivation of crops.

During the focal group discussions, a variety of participatory tools, previously described, were used.[13,14] Because of time constraints, however, not all tools were applied in every village.

Semi-structured interviews. The interviews were used to collect general information about the livestock owners, types of livestock kept, use of livestock, and livestock diseases encountered. The interviews also collected descriptions of the clinical presentation of RVF in people and livestock.

Proportional piling. This tool was used to rank livestock species by numbers and relative contribution to livelihoods. For this, participants first listed the livestock species kept. A circle was drawn on the ground representing each species. Participants allocated 100 counters (beans or maize seeds) to the circles according to the relative numbers of each species. The exercise was then repeated, except this time participants were asked to allocate the counters in proportion to the relative contribution each species made to their livelihoods. Follow-up questioning explored the range of benefits that each livestock species provided.

Relative incidence of RVF. This was assessed using two methods. First, participants were asked to list all the diseases that had affected each livestock species in the past year. Discussions were then initiated on the clinical signs of RVF, as well as its incidence relative to other diseases. For the second

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approach, participants were asked to focus on the period when the RVF outbreak was observed and to divide the individual piles of counters previously used to rank the livestock species by numbers into two sub-groups: those that developed RVF and those that did not. For those that had RVF, the counters were further subdivided into the proportion that died and the proportion that recovered. This method provided an estimate of the incidence of RVF in each species during the outbreak, as well as the outbreak case fatality rates and the overall mortality rate during the outbreak.

Abortions attributable to RVF. Using the results of the proportional piling exercise for the relative numbers of each livestock species as the starting point, participants were asked to allocate the counters into two groups in proportion to those livestock that were pregnant before the RVF outbreak and those that were not. For the pregnant group, participants next divided the counters in proportion to those animals that aborted because of RVF and those that carried their pregnancies to full term. The pregnant pile was then restored, and participants asked to divide the counters to represent the proportions that would have been expected to abort in a normal year (with no RVF outbreak) and those that would have carried to full term. Supplementary questioning probed the causes of abortion other than RVF.

Disease impact matrix score. For each livestock species a matrix was constructed on the ground, with benefits derived from that species along the *y* axis and diseases on the *x* axis. Participants were given 100 counters and asked to allocate them among the livestock-associated benefits according to the relative importance of each benefit, with the most important benefit receiving the highest number of counters. The counters for each benefit were then sub-allocated to each disease to show the relative negative impact of each disease on a family's ability to achieve that benefit, with the disease having the greatest impact receiving the highest number of counters. The number of counters allocated for each disease was totaled: this was a measure of the overall impact of that disease on livestock-derived livelihoods.

Perceived association between diseases and clinical signs and risk factors. Simple matrices were constructed on the ground. In the first for cattle, various clinical signs formed the *y* axis and diseases, one of which was RVF that formed the *x* axis. For the second, the same was done for sheep and goats. For the third, risk factors formed the *y* axis and diseases formed the *x* axis. For each clinical sign or risk factor, participants allocated 25 counters in proportion to their relative importance for the different diseases.

Timelines. These were developed with pastoralists to identify events that occurred before, during, and after the RVF outbreak. First participants identified events of their own choosing before being guided to identify specific events related to the RVF outbreak, such as onset of heavy rains, upsurge in mosquito populations, and occurrence of the first and last cases of RVF in livestock and people. Finally, participants were asked to identify the timing of any disease control interventions they witnessed and to identity the organization providing the intervention.

Key informant interviews. The interviews were conducted with various officials who had been involved in the management of the 2006–2007 outbreaks, such as local government officers with responsibility for veterinary and public health issues, along with community-based animal health workers (CAHWs) and village leaders.

Data management and analysis. A database was constructed and statistical analysis done in Microsoft Excel (Microsoft Corp., Redmond, WA). Data obtained from the scoring tools were summarized using medians (to determine central tendency) and lower 10th and upper 90th percentiles (to define their dispersion). Timelines were summarized using means. Events were categorized as occurring in three 10-day periods within each month named successively as first, second, and third period. Events were assumed to have occurred at the midpoint of a given time period. The difference in the number of days between any two given events was obtained and averaged over all the timelines constructed. Sample sizes from Kenya were too small to be statistically evaluated. To determine the significance of association between clinical signs or risk factors and diseases reported in Tanzania, the Friedman's test was used. The null hypothesis was that for each clinical sign or risk factor there was no significant difference in the degree of association between the different diseases reported. The Friedman's test is the nonparametric equivalent of the two-way analysis of variance and is used in situations where observations on the different treatments are not independent[15]; this was the case when each focus group was asked to rank the same set of diseases. It provided a test for consistency of ranks rather than one for location. Applications of this test have been well documented in statistical literature.[16]

RESULTS

Pastoralists' recall of outbreak events. In both Kenya and Tanzania, livelihoods depend, at least in part, on livestock. In the North Eastern Province of Kenya, goats made the greatest contribution to livelihoods in Garissa District, while in Ijara District cattle were the most important. In Arusha Region, Tanzania, cattle were the species that made by far the greatest contribution to livestock-based livelihoods.

For all livestock species in both countries, the main benefit derived from livestock was reported to be food, which included meat, milk, ghee, and fat. The second most important benefit was income from sales of surplus animals or produce. Other lesser benefits include transport for camels, skins for sheep, and various socio-cultural roles for various species, such as payment of bride price with cattle or goats. In Arusha Region, an agro-pastoral area, manure was also mentioned as an important livestock-derived benefit.

In both countries, pastoralists reported that high proportions (31–77%) of their goats, sheep, and cattle had been sick during the 12-month period July 2006–June 2007, which included the duration of the RVF outbreak (Table 1). The highest morbidity

Table 1

Proportion of animals reported by Somali and Maasai pastoralists to have acquired any disease between July 2006 and June 2007*

	Median (10th percentile, 90th percentile)	
Livestock species	North Eastern Province, Kenya	Arusha Region, Tanzania
Cattle	31.0% (28.6%, 67.4%) (N = 5)	62.0% (27.0%, 76.9%) (N = 12)
Goats	77.0% (44.2%, 78.6%) (N = 3)	66.0% (38.0%, 74.6%) (N = 13)
Sheep	35.0 (N = 1)†	63% (32.2%, 75.8%) (N = 13)
Camels	15.0 (N = 2)†	Not applicable

* N = number of villages involved in proportional piling exercises.
† No percentiles were calculated when $n \leq 2$.

TABLE 2

The four diseases most frequently mentioned by pastoralists as having affected their livestock between July 2006 and June 2007 in North Eastern Province, Kenya*

Cattle		Goats		Sheep		Camels	
Disease	*N*	Disease	*N*	Disease	*N*	Disease	*N*
LSD	14	CCPP	9	RVF	11	Trypanosomosis	4
TBDs	14	RVF	7	Enterotoxaemia	11	Unidentified lameness	4
RVF	12	TBDs	7	Gastrointestinal parasitism	7	Anthrax	3
FMD	12	PPR	6	TBDs	4	Sudden death	3

* *N* = number of villages that mentioned that disease; LSD = lumpy skin disease; TBDs = tick-borne diseases (anaplasmosis, babesosis, and heartwater); FMD = foot-and-mouth disease; CCPP = contagious caprine pleuropneumonia; PPR = peste des petits ruminants.

rate was reported for goats, with 77% (10th and 90th percentiles of 44.2% and 78.6%, respectively) and 66% (38.0%, 74.6%) of goats in Kenya and Tanzania, respectively, reported to have fallen sick during this period.

Although the frequency of diseases that pastoralists reported varied somewhat between the two study areas, RVF featured prominently for cattle, sheep, and goats in both areas. Table 2 shows the four most commonly mentioned diseases for all four species as reported by Somali pastoralists in Kenya. Other diseases not mentioned in Table 2 that were reported in Kenya included 3-day sickness, anthrax, black-quarter, mange, mastitis, pneumonia, tick paralysis, diarrhea, foot rot, indigestion, pox, eye infections, and lymphadenitis. In addition, Maasai pastoralists in Tanzania reported contagious ecthyma (orf).

The Somali pastoralists of North Eastern Kenya and the Maasai of northern Tanzania proved adept at recognizing symptoms of RVF in their livestock (Table 3A and B), whereas only the Somalis were adept at identifying risk factors associated with the disease (Table 4A and B). Results obtained for sheep and goats were similar to those presented in the tables for cattle. The Somali pastoralists consistently listed symptoms such as abortion and froth emanating from the nose as being indicative of a disease they named *sandik*, and associated this disease with heavy rain and mosquito swarms. They noted that the mosquitoes were large and possessed white legs. *Sandik* was translated into English as "bloody nose." The Somalis reported that they had last seen *sandik* during the floods in 1997/98 (the previous RVF epidemic in East Africa).[8] The Tanzanian Maasai pastoralists most strongly associated abortion with RVF and least with trypanosomosis and anthrax ($P = 0.000$), however they generally failed to recognize other characteristic symptoms of RVF as both calf death and frothy nasal mucus were least associated by the Maasai with RVF (both $P = 0.000$). They most strongly associated calf death with foot and mouth disease (FMD) and East Coast fever (ECF), and frothy nasal mucus with ECF. The Tanzanian Maasai made only very weak associations between RVF and risk factors. They associated heavy rains and mosquito swarms most strongly with FMD ($P = 0.001$ and 0.061, respectively). Heavy rains were least associated with trypanosomosis and anthrax, and mosquito swarms least associated with RVF, ECF, and anthrax. In addition, they incorrectly thought that the tsetse fly was a major risk factor associated with the disease for sheep and goats, though not cattle (results not shown).

Somali pastoralists in Kenya reported that sheep were most affected by the RVF outbreak; this species had the highest outbreak incidence, fatality, and mortality rates (Table 5A and B). They estimated that 88.3% (56.0%, 89.7%) of their sheep died during the outbreak compared with 56.2% (38.1%, 74.3%) of goats and 36.5% (20.1%, 61.5%) of cattle. The Maasai pastoralists in Tanzania estimated considerably lower values for outbreak incidence, case fatality, and mortality rates for their cattle, sheep, and goats. They reported that cattle were most severely affected, with 4.4% (0%, 14.9%) of sheep, 4.3% (0%, 34.8%) of goats, and 5.1% (0%, 16.2%) of cattle estimated to have died during the outbreak.

Abortion rates experienced during the outbreak were high in North Eastern Province of Kenya, where pastoralists estimated that 47.1% (6.2%, 50.0%) of pregnant cattle, 69.5% (55.6%, 81.1%) of pregnant sheep, and 62.5% (54.0%, 81.0%) of pregnant goats aborted because of RVF (Table 6A). In Arusha Region of Tanzania the comparable figures were considerably lower: 7.2% (–11.9%, 39.3%) of pregnant cattle, 12.5% (–34.5%, 50.9%) of pregnant sheep, and 30.8% (–34.9%, 47.1%) of pregnant goats (Table 6B). The negative 10th percentile indicates that some pastoralists in Tanzania perceived abortion rates during the RVF outbreak to be lower than baseline rates. The one village that owned camels in North Eastern Kenya estimated that less than 1% of them aborting because of RVF.

The Somali pastoralists in Kenya considered that RVF was the disease that had the highest impact on livestock-derived livelihoods for all four livestock species. Meanwhile, the Maasai pastoralists in Tanzania ranked RVF the fourth or fifth highest ranking disease for cattle, sheep, and goats in terms of impact on livelihoods (Table 7A and B).

TABLE 3A

Proportions derived from simple matrices constructed with Somali pastoralists in North Eastern Province, Kenya, ranking five diseases of cattle according to the degree to which they manifest selected clinical signs (*N* = 4)*

	Median (10th percentile, 90th percentile)‡				
Clinical sign†	RVF	Trypanosomosis	Gastrointestinal parasitism	FMD	Anthrax
Abortion	13.1 (6.4, 15.5)	3.1 (0, 8.9)	0 (0, 0)	0 (0, 5.3)	6.0 (4.1, 11.4)
Bloody diarrhea	6.0 (4.3, 7.0)	2 (0, 5.4)	3.5 (0,9, 4.7)	0 (0, 0)	7.5 (5.0, 13.5)
Coughing	5.5 (3.6, 7.4)	4.5 (0.6, 8.4)	0 (0, 2.8)	0 (0, 2.8)	7.5 (4.9, 12.2)
Fever	6.0 (4.4, 7.6)	3 (3, 4.6)	0 (0, 2.4)	4.0 (4.0, 4.0)	5.0 (4.2, 6.6)
Froth from nose	8 (7.3, 8)	0, (0, 0)	0 (0, 2.8)	10.5 (5.5, 12.7)	1.5 (0, 3.7)
Lachrymation	0 (0, 4.9)	10 (7.9, 17.0)	0 (0, 1.4)	0 (0, 3.5)	5.5 (1.5, 7.4)
Pruritus	0 (0, 0)	3.5 (0, 8.4)	12.5 (5.0, 20)	0 (0, 0)	3 (0, 7.4)
Salivation	5.0 (3.6, 5.7)	0 (0, 2.1)	0 (0, 0)	9.5 (9.0, 14.9)	3.5 (0.6, 5.7)

* RVF = Rift Valley fever; FMD = foot and mouth disease; *N* = the number of villages involved in the matrix scoring exercises, which considered this symptom as being associated with at least one of the five diseases.

† Statistical tests not performed because of small sample size.

‡ The higher the score, the more strongly pastoralists associated that clinical sign with the given disease.

Table 3B

Proportions derived from simple matrices constructed with Maasai pastoralists in Arusha Region, Tanzania, ranking five diseases of cattle according to the degree to which they manifest selected clinical signs*

Clinical sign (N, P value)	Median (10th percentile, 90th percentile)†				
	RVF	Trypanosomosis	ECF	FMD	Anthrax
Abortions (N = 14, P = 0.000)	11.0 (7.0, 15.0)	0 (0, 4.0)	3.5 (0, 6.7)	8.5 (4.3, 13.8)	0 (0, 2.1)
Adult sudden death (N = 14, P = 0.003)	0 (0, 3.8)	0, (0, 1.7)	6.5 (0, 11.4)	0 (0, 4.7)	15.5 (5.3, 25.0)
Calf death (N = 14, P = 0.000)	0 (0, 0)	0 (0, 1.4)	10.0 (2.9, 17.8)	11.5 (4.6, 19.0)	1.5 (0, 6.4)
Diarrhea (N = 12, P = 0.000)	0 (0, 0)	1.5 (0, 11.8)	15.5 (11.8, 25.0)	0 (0, 2.7)	0 (0, 8.4)
Frothy nasal mucous (N = 14, P = 0.000)	0 (0, 1.9)	0 (0, 0)	13.0 (1.8, 22.3)	10.0 (1.6, 17.2)	0 (0, 6.1)
Enlarged lymph nodes (N = 13, P = 0.000)	0 (0, 0)	3.0 (0, 8.9)	18.0 (12.1, 21.0)	4.0 (0, 6.8)	0 (0, 5.6)
Salivation (N = 14, P = 0.000)	0 (0, 0)	0 (0, 0)	0 (0, 6.1)	14.5 (12.0, 17.0)	0 (0, 6.1)

* RVF = Rift Valley fever; ECF = East Coast fever; FMD = foot and mouth disease; N = the number of villages involved in the matrix scoring exercises that considered this symptom as being associated with at least one of the five diseases; P value = Friedman's test.
†The higher the score, the more strongly pastoralists associated that clinical sign with the given disease.

Timelines were constructed in the villages based on pastoralists' recall of key events during the RVF outbreaks. The mean intervals between key events, derived from the individual villages' timelines, are summarized in Table 8. These show that the mean interval between the start of heavy rains and first appearance of mosquito swarms was estimated to be 23.6 days by pastoralists in North Eastern Province, Kenya, and 56.7 days by pastoralists in Arusha Region, Tanzania. The mean interval between first appearance of mosquito swarms and first suspected RVF case in livestock was estimated to be 16.8 days in North Eastern Province, Kenya, and 25.0 days in Arusha Region. The estimated mean intervals between first suspected livestock cases and interventions by either the Ministry of Health (MoH) or Department of Veterinary Services (DVS) were longer in Tanzania than Kenya, although the estimated mean interval from first suspected human case and first intervention by the MoH was shorter for Tanzania.

Key informant interviews. Kenya officially reported the RVF outbreak to the World Organization for Animal Health (OIE) on December 4, 2006. The first veterinary intervention occurred on December 17 with the closing of Garissa livestock market. The DVS confirmed the diagnosis of RVF on 22 December and vaccination of livestock began on 8 January 2007.

Key informant interviews conducted in Kenya revealed that the veterinary personnel in North Eastern Province were unable to mount an immediate response against the disease. Reasons given for this were that most of the roads were impassable because of the floods; there was lack of suitable equipment, especially vehicles, and insufficient personnel; and there was a lack of funds. Key informants reported that the MoH responded when human cases started occurring and provided a helicopter that was used to access the affected areas. Immediately thereafter, a task force headed by the District Commissioner was formed. The task force coordinated all the interventions that were provided by the various agencies including provincial medical and veterinary services, police, international organizations, and non-governmental organizations (NGO). Technical teams comprising two veterinary surgeons, five doctors, and three NGO personnel were constituted in early January 2007 and sent to the affected areas to manage relief and emergency interventions that were put in place by the task force, including the distribution of food. The number of teams per district was five each for Garissa and Wajir, and two each for Ijara and Tana River.

These teams vaccinated livestock; treated sick animals that had other infections; provided insecticides (pour-ons for the control of mosquitoes); and took samples from suspected livestock cases, which were delivered to the Central Investigation Laboratory in Kabete (near Nairobi) for analysis.

Control measures that were taken in North Eastern Province included closing livestock markets and butcheries, imposing movement controls and quarantines, and providing advice warning against drinking raw milk, slaughtering animals, or eating uninspected meat.

Key informant interviews suggested that collaboration between the provincial veterinary service and public health service were generally good. Cases were reported, however, where the initial information provided by the public health service prohibiting consumption of meat and milk was at

Table 4A

Proportions derived from simple matrices constructed with Somali pastoralists in North Eastern Province, Kenya, ranking five livestock diseases with respect to their perceived strength of association with selected risk factors (N = 3)*

Risk factor†	Median (10th percentile, 90th percentile)‡				
	RVF	Trypanosomosis	Gastrointestinal parasitism	FMD	Anthrax
Biting flies	5.0 (4.2, 6.6)	11.0 (8.6, 12.6)	0 (0, 0)	0 (0, 0)	4.0 (0.8, 7.2)
Contact with wild animals	0 (0, 3.2)	10.0 (8.4, 10.8)	0 (0, 0)	6.0 (3.6, 8.4)	4.0 (0.8, 7.2)
Wet grass	0 (0, 0)	0 (0, 0)	12.0 (8.0, 12.0)	0 (0, 0)	8.0 (8.0, 12.0)
Mosquitoes	13.0 (10.6, 18.6)	0 (0, 1.6)	0 (0, 0)	0 (0, 0)	7.0 (1.4, 7.8)
Abnormally heavy rains	20.0 (8.0, 20.0)	0 (0, 0)	0 (0, 0)	0, (0, 8.0)	0 (0, 4.0)
Soil and dust	0 (0, 0)	0 (0, 0)	0 (0, 8.0)	8.0 (1.6, 15.2)	10.0 (4.4, 11.6)
Stagnant water	0 (0, 0)	7.5 (1.5, 8.5)	17.3 (4.3, 16.3)	0 (0, 0)	0 (0, 6.4)
Ticks	10.0 (2.0, 10.0)	0 (0, 8.8)	0 (0, 0)	0 (0, 0)	10.0 (9.2, 10.0)
Wind	0 (0, 7.2)	0 (0, 0)	0 (0, 0)	20.0 (12.8, 20.0)	0 (0, 0)

* RVF = Rift Valley fever; FMD = foot and mouth disease; N = the number of villages involved in the matrix scoring exercises that considered this risk factor as being associated with at least one of the five diseases.
† Statistical tests were not performed because of small sample size.
‡The higher the score, the more strongly pastoralists associated that risk factor with the given disease.

TABLE 4B

Proportions derived from simple matrices constructed with Maasai pastoralists in Arusha Region, Tanzania, ranking five livestock diseases with respect to their perceived strength of association with selected risk factors*

Risk factor (*N*, *P* value)	Median (10th percentile, 90th percentile)†				
	RVF	Trypanosomosis	ECF	FMD	Anthrax
Sharing pasture (*N* = 13, *P* = 0.000)	0 (0, 0)	0 (0, 0)	0 (0, 4.8)	25.0 (11.0, 25.0)	0 (0, 7.4)
Floods (*N* = 9, *P* = 0.134)	0 (0, 5.8)	0 (0, 2.4)	0 (0, 14.6)	12.0 (0, 25.0)	0 (0, 6.4)
Tsetse (*N* = 13, *P* = 0.000)	0 (0, 3.2)	25.0 (8.6, 25.0)	0 (0, 2.4)	0 (0, 6.4)	0 (0, 0)
Mosquito swarms (*N* = 4, *P* = 0.061)	0 (0, 1.4)	4.5 (0, 11.8)	0 (0, 4.2)	15.0 (7.9, 23.5)	1.5 (0, 4.4)
Heavy rains (*N* = 13, *P* = 0.001)	2.0 (0, 5.0)	0 (0, 5.4)	7 (0, 12.8)	12.0 (5.2, 23.8)	0 (0, 3.6)
Ticks (*N* = 12, *P* = 0.000)	0 (0, 0)	0 (0, 11.6)	25.0 (13.4, 25.0)	0 (0, 0)	0 (0, 0)
Sharing water point (*N* = 13, *P* = 0.000)	0 (0, 3.6)	0 (0, 0)	0 (0, 3.6)	25.0 (11.6, 25.0)	0 (0, 7.9)

* RVF = Rift Valley fever; ECF = East Coast fever; FMD = foot and mouth disease; *N* = the number of villages involved in the matrix scoring exercises that considered this risk factor as being associated with at least one of the 5 diseases; *P* value = Friedman's test.
†The higher the score, the more strongly pastoralists associated that risk factor with the given disease.

variance with that given by the veterinary service, which suggested meat and milk was safe if it had been officially inspected and passed as fit for consumption. Communication messages were later harmonized.

Key informant interviews conducted in Tanzania revealed that the District Veterinary Office in Ngorongoro District first investigated reports of RVF and lumpy skin disease in mid-January 2007, after which they immediately requested assistance from the Arusha Veterinary Investigation Center (VIC). A team from the VIC collected specimens from suspected clinical cases of RVF and dispatched them to Onderstepoort Veterinary Institute, South Africa. The first suspected human RVF case was admitted to the hospital at the end of January: specimens were sent to the Centers for Disease Control and Prevention (CDC laboratory in Nairobi). Following the confirmed human case, an inter-ministerial meeting was held in Arusha in early February, after which the District Commissioners went back to their districts and began to coordinate the RVF response campaigns. Tanzania officially reported RVF to the OIE on February 12, 2007.

DISCUSSION

It is noted that the northern Tanzania Maasai and North Eastern Kenya Somali pastoralists interviewed during this study had different levels of traditional knowledge concerning livestock diseases in general and RVF in particular.[13] The Somali pastoralists provided more detailed and accurate clinical descriptions of diseases affecting their livestock, including RVF, had greater appreciation of the risk factors associated with the disease, and showed a stronger recall of the outbreak history. Because the difference in knowledge levels was noted to relate to all diseases, this suggests that recall bias caused by differences in elapsed time between the RVF outbreak and the study in the two areas was not the principal source of differences in RVF knowledge. The Somali in the study area were principally dependent on their livestock for their livelihoods, whereas the Maasai in the study also depended on ecotourism and cultivation of crops. The Tanzanian Maasai also benefited from greater access to animal health services and conventional veterinary drugs, which may have decreased their need to closely monitor disease problems in their herds.

Although RVF was not the most prevalent disease in North Eastern Kenyan livestock from July 2006 to June 2007, it proved to be the disease that had the greatest impact on the livelihoods of Somali pastoralists in the area. The lower morbidity, mortality, abortion rates, and livelihood impacts reported by the Maasai may be caused by differences in the local ecology of the virus, differences in breed susceptibility, or the virulence of the RVF virus involved in the outbreak in North Eastern Kenya. It is known that multiple RVF viral lineages were active during the East African outbreak and that genetic reassortment had occurred.[10] The RVF outbreak was also less widespread in northern Tanzania than in other regions and as a result probably had less of an impact on traditional knowledge systems. In addition, the northern Tanzania Maasai in the study experienced a simultaneous outbreak of lumpy skin disease (LSD) during the RVF outbreak in their area. The outbreak of LSD started just before the RVF outbreak and confused both livestock owners and official investigations.

Timely outbreak response requires effective early warning and surveillance systems. This study points out the important role that livestock keepers can play in veterinary surveillance.[13,17,18] Timeline and matrix scoring results showed that the pastoralists in this study, especially the Somalis in North Eastern Kenya, were aware of the unusually heavy nature of the rains and flooding before the outbreak of RVF in their areas, noticed mosquito swarms that were unusual because

TABLE 5A

Outbreak incidence, case fatality, and mortality rates caused by Rift Valley fever (RVF) in cattle, sheep, and goats during the RVF outbreak 2006/07 as scored by Somali pastoralists involved in the study in North Eastern Province, Kenya (*N* = 5)*

Livestock species	Median outbreak incidence % (10th percentile, 90th percentile)	Median outbreak case fatality % (10th percentile, 90th percentile)	Median outbreak mortality % (10th percentile, 90th percentile)
Cattle	36.5 (20.1, 61.5)	49.0 (31.0, 72.7)	23.4 (6.3, 41.6)
Sheep	88.3 (56.0, 89.7)	61.5 (55.0, 93.6)	57.1 (32.3, 75.3)
Goats	56.2 (38.1, 74.3)	40.9 (22.0, 57.8)	25.0 (11.1, 29.9)

* *N* = number of villages involved in the proportional piling.

TABLE 5B

Outbreak incidence, case fatality, and mortality rates caused by Rift Valley fever (RVF) in cattle, sheep, and goats during the RVF outbreak 2006/07 as scored by Maasai pastoralists in Arusha Region, Tanzania*

Livestock species	Median outbreak incidence % (10th percentile, 90th percentile)	Median outbreak case fatality % (10th percentile, 90th percentile)	Median outbreak mortality % (10th percentile, 90th percentile)
Cattle (*N* = 13)	34.3 (21.1, 66.7)	17.6 (0, 42.1)	5.1 (0, 16.2)
Sheep (*N* = 14)	32.6 (17.9, 60.5)	14.3 (0, 41.2)	4.4 (0, 14.9)
Goats (*N* = 15)	50.0 (24.0, 92.2)	14.3 (0, 48.1)	4.3 (0, 34.8)

* *N* = number of villages involved in the proportional piling.

TABLE 6A

Abortion rates as estimated by Somali pastoralists in North Eastern Province, Kenya ($N = 6$)*

Livestock species	Meidan baseline abortion % (10th percentile, 90th percentile)	Median abortion % (10th percentile, 90th percentile)	Median corrected abortion % (10th percentile, 90th percentile)†
Cattle	17.6 (0, 43.5)	50.0 (44.0, 64.3)	47.1 (6.3, 50.0)
Sheep	18.1 (10.4, 23.0)	87.6 (78.6, 91.4)	69.5 (55.6, 81.1)
Goats	16.7 (8, 23.0)	87.5 (72.0, 89.0)	62.5 (54.0, 81.0)

* N = number of villages involved in the proportional piling.
†This is the median value of the ($N = 6$) individual corrected abortion percentages, where individual corrected abortion percentages = abortion during outbreak % minus baseline abortion %.

of their intensity and the physical characteristics of the species involved (*Aedes* spp.), and noted unusually high morbidity and mortality in their flocks consistent with RVF.[5–8,19–21] These facts were common knowledge among livestock owners well in advance of the detection of RVF by veterinary service surveillance systems. They also noted human cases consistent with RVF well in advance of detection by the public health surveillance system.[11,20] This suggests that veterinary surveillance systems could detect RVF outbreaks earlier by taking advantage of livestock owner observations through the integration of active syndromic surveillance, such as participatory disease surveillance (PDS) geared to the level of outbreak probability.[13,17]

Weaknesses in both RVF preparedness and response were highlighted by this study. Late detection of the disease in both animals and humans meant that the disease was well established in the livestock population before veterinary and public health interventions were initiated. Timelines show that outbreaks of RVF in livestock were occurring in multiple dispersed areas of North Eastern Province, Kenya, by mid-October 2006. This suggests multiple point sources. However, livestock vaccination campaigns did not begin until early-January 2007. Key informants reported the intention to vaccinate areas surrounding infected areas in an attempt to control the spread of the disease. However, the disease was already widespread and present in the areas where vaccination campaigns were implemented by the time the vaccination logistics could be coordinated. In part, veterinary services were limited in where they could vaccinate by flooding and access to transport; their vehicles were in a poor state of repair and vaccine was often delivered by veterinary officials hitching rides on helicopters primarily provided for public health officials who were targeting high risk areas for human cases. Veterinary interventions in northern Tanzania were similarly late.

Early warning indicators and the early warning processes need to be reassessed. This study highlights the importance of improved RVF preparedness and early warning systems. Both Kenya and Tanzania are now in the process of developing RVF preparedness plans.[22] However, these plans are unlikely to reduce the severity of the impact of the next RVF outbreak in the Greater Horn of Africa without additional changes to institutionalized early warning and response practices at the national and international levels. The United Nations Food and Agriculture Organization (FAO) issues an early warning forecast to countries at risk of an RVF outbreak. During the recent outbreak, FAO warnings to the government were not issued until November 2006.[23] These warnings were based on global early warnings predicting a possible RVF outbreak for the Horn of Africa.[7,5,20] However, both human and livestock cases were already occurring by November 2006.

To be effective, early warning systems must provide information before the onset of events in a manner that allows authorities sufficient lead time to respond. The forecast model used in 2006/7 incorporated data on vegetation changes (normalized difference vegetation index, NDVI) that occurred only after conditions were in place for an RVF outbreak.[20,23] This increased model accuracy, but delayed the warning until after the apparent onset of the outbreak. The results of this study indicate that the observation by local communities of climatic, entomologic, and clinical events consistent with RVF within the known risk-prone areas were more timely and definitive risk indicators than the global early warning system in place at the time of the 2006/7 outbreak. Although inclusions of

TABLE 7A

The relative impact of livestock diseases as scored by Somali pastoralists in North Eastern Province, Kenya*

Median (10th percentile, 90th percentile) of aggregate scores for impact of diseases on a basket of livestock-derived livelihoods†			
Cattle ($N = 4$)	Goats ($N = 2$)‡	Sheep ($N = 1$)‡	Camels ($N = 1$)‡
RVF 26.0 (19.1, 35.0)	RVF 37.5	RVF 49	RVF 44
LSD 18.0 (13.9, 24.2)	PPR 25.5	Enterotoxaemia 20	Sudden death 28
FMD 17.0 (9.4, 24.6)	TBD 24.5	Trypanosomosis 18	Anthrax 23
TBD 14.0 (6.5, 21.5)	CCPP 12.5	Worms 13	Pneumonia 5
CBPP 13.5 (9.2, 18.5)			Trypanosomosis 0
Trypanosomosis 10.0 (6.2, 15.9)			

* N = number of villages involved in the proportional piling; RVF = Rift Valley fever; LSD = lumpy skin disease; PPR = peste des petits ruminants; FMD = foot and mouth disease; TBD = tick born diseases; CCPP = contagious caprine pleuropneumonia.
†The higher the score, the greater the negative impact of the disease on livelihoods.
‡No percentiles were calculated when $N \leq 2$

TABLE 6B

Abortion rates as estimated by Maasai pastoralists in Arusha Region, Tanzania*

Livestock species	Median baseline abortion % (10th percentile, 90th percentile)	Median abortion % (10th percentile, 90th percentile)	Median corrected abortion % (10th percentile, 90th percentile)†
Cattle ($N = 14$)	26.8 (16.3, 40.1)	34.0 (18.7, 69.9)	7.2 (−11.9, 39.3)
Sheep ($N = 15$)	27.3 (10.9, 60.0)	35.3 (19.3, 76.9)	12.5 (−34.5, 50.9)
Goats ($N = 15$)	37.5 (27.2, 57.5)	62.5 (25.3, 84.5)	30.8 (−34.9, 47.1)

* N = number of villages involved in the proportional piling.
†This is the median value of the ($N = 14$ or 15) individual corrected abortion percentages, where individual corrected abortion percentages = abortion during outbreak % minus baseline abortion %.

TABLE 7B

The relative impact of livestock diseases as scored by Maasai pastoralists in Arusha Region, Tanzania districts ($N = 10$)*

Median (10th percentile, 90th percentile) of aggregate scores for impact of diseases on a basket of livestock-derived livelihoods†		
Cattle	Goats	Sheep
Anthrax 32.5 (14.6, 51.2)	Pox 27.5 (14.8, 49.7)	Pox 28.0 (16.9, 53.1)
ECF 28.0 (19.5, 45.0)	Anthrax 20.5 (0, 34.3)	Anthrax 24.5 (9.0, 31.1)
FMD 12.0 (5.8, 18.3)	HW 19 (6.3, 36.0)	HW 15.5 (9.0, 27.9)
RVF 11.5 (6.9, 19.2)	CCPP 16.5 (8.1, 24.6)	Worms 14.5 (0, 20.5)
Trypanosomosis 7.5 (0, 15.7)	RVF 10.5 (0, 16.3)	RVF 13.5 (0, 23.1)

* N = number of villages involved in the proportional piling; RVF = Rift Valley fever; ECF = East Coast fever; HW = heart water; CCPP = caprine pleuropneumonia.
†The higher the score, the greater the negative impact of the disease on livelihoods.

Table 8
Mean intervals between key events in 2006/07 RVF outbreak, based on pastoralists' recall

Events	Mean intervals between these two events (*N*)* (number of villages on which mean is based)	
	North Eastern Province, Kenya	Arusha Region, Tanzania
Start of heavy rains and appearance of mosquito swarms	Mean interval in days: 23.6 (11) Start of heavy rains Average reported start date: mid-October 06 Earliest reported state date: mid-September 06 Appearance of mosquito swarms Average start date: late-October 06 Earliest state date: early-October 06	Mean interval in days: 56.7 (6) Start of heavy rains Average reported start date: early-November 06 Earliest reported state date: mid-September 06 Appearance of mosquito swarms Could not accurately assess
First appearance of mosquito swarms and first suspected RVF case in livestock	16.8 (11) First suspected RVF case in livestock Average date: mid-November 06 Earliest date: late-October 06	25.0 (4) First suspected RVF case in livestock Average date: late-December 06 Earliest date: mid-October 06
First suspected RVF case in livestock and first suspected human case	17.5 (8) First suspect RVF case in humans Average date: late-November 06 Earliest date: early-November 06	66.7 (4) First suspect RVF case in humans Average date: late-February 07 Earliest date: late-January 07
First suspected RVF case in livestock and first veterinary service response	61.7 (6) First veterinary service response Average and earliest date: mid-January 07	113.1 (7) First veterinary service response Average date: late-March 07 Earliest date: mid-February 07
First suspected RVF case in livestock and first public health service response	50.0 (4) First public health service response Average and earliest date: mid-December 06	76.7 (6) First public health service response Average date: mid-March 07 Earliest date: late-February 07
First suspected human case and first public health service response	30.0 (4)	18.3 (3)

* *N* = number of villages involved in the calculation.

on-the-ground surveillance for these local events would enhance the timeliness of current surveillance systems, these events are not suitable decision-points for the procurement and mobilization of preventive inputs, such as vaccination, as they do not allow sufficient lead time.

Providing warnings based on models that place more emphasis on climatic information, such as sea surface temperatures, will reduce the accuracy but increase the lead time before events. Such warnings would be indicative of increasing risk levels and enhance the ability of decision-makers to take timely action.[24] The preliminary nature of the warnings and their appropriate interpretation would need to be clearly communicated as part of the warning. In response to initial warnings, national stakeholders could reinforce local climate monitoring and disease surveillance in known high risk areas, and alert response systems to begin preliminary mobilization of resources.[9,24–27]

The use of vaccine in the emergency prevention and control of RVF outbreaks should be re-considered.[24] The Smithburn vaccine provides effective immunity against RVF after a single inoculation, making it an appropriate choice for emergency vaccination programs, although it does cause abortions in sheep and the vaccine virus can be transmitted by vectors. This research suggests that the livestock vaccination campaigns during the 2006/7 RVF outbreak in the Greater Horn of Africa were probably not effective because of the constraints to timely delivery of vaccination as part of a response plan linked to early warnings. Because epidemics of RVF in the Greater Horn of Africa are infrequent events and annual demand for vaccine is unclear, large vaccine stocks are neither maintained by countries nor manufacturers. The time needed for governments to order, manufacturers to produce and supply, and governments to deliver vaccine to remote areas in significant quantities make it highly unlikely that adequate vaccination can be carried out in time to mitigate wide-scale outbreaks such as occurred in 2006/7 in the Greater Horn of Africa. It is likely that routine preventive vaccination would be epidemiologically more effective than heroic attempts to deliver emergency vaccination in response to early warnings, but this probably does not make economic sense given the infrequency of outbreaks in the region. One sustainable solution that could be justified economically would be the development of multi-valent vaccines that combined valencies that justified more frequent vaccination with an RVF component.

In collaboration with the FAO and a wide range of stakeholders, ILRI developed a decision support tool to assist chief veterinary officers in the Greater Horn of Africa to take proactive steps to prevent and mitigate potential RVF outbreaks.[24] The tool is based upon the identification of key decision points in the progression of events leading up to an outbreak, and allows investment in mitigations to be balanced against the escalating level of risk of an outbreak. The concept is that a phased response minimizes the risk of incorrect decisions and maximizes preparedness in the event of an outbreak.[28] Decision makers use of such a tool can be enhanced by more timely international warnings and simulation exercises to help stakeholders capture the benefits of risk-based decision making. Donors and international organizations must also re-evaluate the policies that resulted in the bulk of financial aid being provided to affected countries only after human cases had been documented. Rift Valley fever outbreaks are explosive events and by the time of the first human cases it was probably too late to prevent the 2006/7 outbreak from running its course; the opportunity to control the disease in livestock and prevent human cases in affected areas was past. Initiatives such as the risk-based decision support tool can be further enhanced by continued research. Priority should be placed on developing combined economic and epidemiologic models that evaluate the economic benefits achieved by different disease prevention and control decisions at critical points before and during outbreaks.

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