CHARACTERIZING MOVEMENT PATTERNS OF NOMADIC PASTORALISTS AND THEIR EXPOSURE TO RIFT VALLEY FEVER IN KENYA

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ABSTRACT:

The role of animal movement in spreading infectious diseases is highly recognized by various legislations and institutions such as the World Organisation for Animal Health and the International Animal Health Code. The increased interactions at the nexus of human-animal-ecosystem interface have seen an unprecedented introduction and reintroduction of new zoonotic diseases with high socio-economic impacts such as the COVID-19 pandemic. Rift Valley fever (RVF) is a zoonotic disease that affects both humans and animals and is transmitted by Aedes mosquitoes or through contact with the body fluids of infected animals. This study seeks to characterize movement patterns of pastoralist and how this movement behaviour increases their susceptibility to RVF virus exposure. We levarage on a rapidly growing field of movement ecology to monitor five herds collared from 2013 – 2015 in an RVF endemic semi-arid region in Kenya. The herds were also sampled for RVF antibodies to assess their exposure to RVF virus during the rainy seasons. *adehabitatLT* package in R was used to analyze the trajectory data whereas the first passage time (FPT) analysis was used to measure the area utilized in grazing. Sedentary herds grazed within 15km radius while migrating herds presented restricted space use patterns during the dry seasons and transient movement during the start and end of the rainy season. Furthermore, RVF virus antibodies were generally low for sedentary herds whereas the migrating herds recorded high levels during their transition periods. This study can be used to identify RVF risk zones for timely and targeted management strategies.

1. INTRODUCTION

Rift Valley fever (RVF) is a zoonotic disease that affects both humans and animals alike with high socio-economic impact. The infection can cause a severe hemorrhagic fever in humans and in ruminants such as cattle, sheep and goats with young animals being more vulnerable. It is also known to cause abortions in livestock resulting in huge losses to farmers who depend on livestock production for their livelihoods (Baudin et al., 2016).

The disease was first confirmed in 1931 in Kenya after a successful virus isolation (Daubney et al., 1931). RVF virus (RVFV) belongs to genus *Phlebovirus* of family *Phenuiviridae* viruses and RVFV is transmitted through bites by infected mosquitoes or by coming in contact with body fluids of infected animals (Sang et al., 2010). *Aedes* species are the primary vectors that maintain the virus through transovarial transmission during interepizootic periods while secondary vectors of *Culex, Anopheles* and *Mansonia* species amplify RVFV spread resulting in outbreaks during heavy rainfall seasons (Fafetine et al., 2013; Sang et al., 2010).

The World Organization for Animal Health classifies RVFV as high impact transboundary pathogen (Nanyingi et al., 2015). Since its discovery in Kenya, several epidemics have been reported in 15 countries while virus isolaton and serologial evidence have been detected in several countries in Sub Saharan Africa (Balenghien et al., 2013). The transboundary nature of the disease became more evident when it crossed over from continental Africa to Madagascar, Mayotte, Islands of Comoros and most recently to Arabian Peninsula (Nanyingi et al., 2015). Furthermore, phylogenetic studies on RVFV strains reveal this transboundary nature as multiple re-introductions of RVFV strains, e.g. in Senegal and Mauritania the strains were genetically related to South African and Zimbabwean strains (Soumaré et al., 2012). Similarly, an RVFV strain in Madagascar has genetic linkages with Egyptian, Zimbabwean and Kenyan isolate while the Arabian Penisulan isolate was closely related with the Kenyan isolate (Balenghien et al., 2013).

The long range dispersal of RVFV is linked to movement of viremic livestock through local and international trade (legal and illegal) or through exportation of infected mosquitoe vectors through airlines and cargo (Soumaré et al., 2012). This poses a threat to RVFV introduction to RVF-free continents where similar mosquito vectors found in endemic countries and susceptible ruminants are present (Golnar et al., 2014; Chevalier, 2013). Furthermore, the risk is hightened by climate change and the ability of the vector to occupy diverse ecological zones ranging from arid to semi arid regions in West Africa, Horn of Africa and Arabian Penisula to mountainous regions in Madagascar and highlands of Kenya (Chevalier, 2013).

Cofounding factors that maintains virus circulation during epizootic and enzootic periods have been an area of research interest in many studies where both biotic and abiotic factors have been identified (Anyamba et al., 2002; Anyangu et al., 2010; Olive et al., 2016; Pepin et al., 2010). However, studies that characterize and quantify the influence of movement of viremic animals especially, nomadic pastoralism in spreading RVFV is still limited and often proxy methods such as social network analysis and network modelling are used to quantify movement (Craft, 2015; Kim et al., 2018; Nicolas et al., 2014). In this study, we seek to deepen insights on the role of nomadic pastoralism in maintaining RVFV circulation.

We levarage on a rapidly growing field of movement ecology to characterize livestock movement patterns of pastoralist in an RVF endemic region in Kenya to understand how they move in space and time and how this movement behaviour increase their susceptibility to RVFV exposure (Nathan, 2008). Movement ecology has grown in the last two decades due to the advancement in tracking technology such as GPS and radio frequency at high spatial-temporal resolution and in data computation with applications in human, animal, and plant mobility (Miller et al., 2019).

2. MATERIALS AND METHODS

2.1 Study area and livestock collaring

The study was conducted in an RVF endemic region in Northeast Kenya where five livestock herds were GPS-collared from 2013 to 2015. Two herds were in Tana River County herein, herd4168 and herd4169 and three in Isiolo County herein, herd4006, herd4167 and herd4170 (Figure 1). The Tana River is the eastern border for the Tana River County, which stretches from Isiolo County in the north to the coast of Indian Ocean in the south. The two counties are in the semi-arid to arid regions characterized by average daily temperatures ranging from 30 – 35°C with a bimodal rainfall pattern where the long rains occur from March to May and the short rains in October to December with occasional variation. The rainfall amount ranges from 300 – 800 mm annually with extreme cases occurring during El Niño that results in excessive flooding.

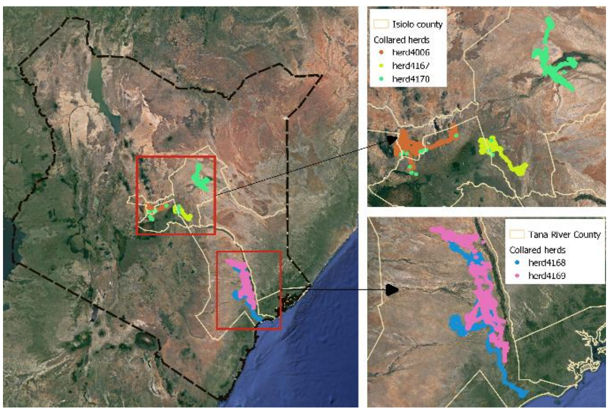

Figure 1: Study location with telemetry data points of five collared herds in Isiolo and Tana River Counties, Kenya.

The vegetation is mainly open shrubland with woody acacias and the community are mainly pastoralist who settle around water points and *dambos* (shallow depression on land that provide breeding for mosquitoes during rainy season) and live closely with their animals, increasing chances for zoonotic disease contraction (Owange et al., 2014). During the tracking period some of the GPS collars failed to capture data due to battery life while in some instances, the animals were out of reach with the GPS signal, resulting in some missing data points. Despite recording over 20 RVF outbreaks since 1961, Tana River and Isiolo counties have varying RVF risk levels (Murithi et al., 2011; Sang et al., 2017). Tana river county is classified as a high-risk county while Isiolo is a medium risk area.

2.2 Sero surveys along the migratory routes

The GPS-monitored herds were surveyed for anti-RVF immunoglobulin M (IgM) antibodies in their blood to assess their exposure to RVFV along their migration routes. Cattle aged not more than three years old were randomly sampled from each herd every time sampling was done. The strategy of sampling animals (< 3 years of age) was meant to leave out those with possibility of having RVFV antibodies due to previous outbreaks, the last one being experienced in 2007. In this study, we used results obtained from laboratory analysis of the serum survey conducted at the onset of the long and short rainy seasons and details regarding sampling will be presented in another report (manuscript in preparation).

2.3 Characterizing livestock movement pattern

We used *adehabitatLT* package in R (version 4.0.2) software to characterize the movement patterns of the herds and to understand how pastoralist utilize their landscape in time and space across landscape scales. *adehabitatLT* first generates several descriptive statistics of the trajectory for each successive relocation points (i.e., j, $j+1$) which forms the basis for further analysis (Calenge et al., 2008). Of interest to this study was characterizing the trajectory of the herds to identify change in the movement behaviour and the scale at which this behaviour was evident. Firstly, we summarized the speed the herds moved daily and monthly by dividing the step length with time taken between points. This was particularly important for understanding how pastoralist move on their landscape across time and seasons. Secondly, we used first passage time (FPT) analysis to identify the scale at which the behaviour occurred and to measure the area used for grazing based on the time the herds took to enter and leave a specified radius. If the circle is greater than the defined radius, intensely used spaces results in high FPT plateau while transient movements have smaller and often varying FPT (Fauchald & Tveraa, 2003).

3. RESULTS

3.1 Movement characterization

Figure 2 shows monthly (A and B) and hourly (C and D) mean speed at which the herds moved on their landscape during the collaring period. The herds presented similar daily movement patterns, especially the Tana Rivers herds (Figure 2D), with the highest speed being recorded at around 11:00hrs and 17:00hrs followed by a slower speed in between from 13:00hrs – 16:00hrs. Except for herd4006 in Isiolo, all the herds had a gradual increment of speed from 07:00hrs to 10:00hrs and a gradual decrease from 17:00hrs – 19:00hrs. In contrast, herd4006 had the highest speed in the morning and in the evening (Figure 2C). At monthly scale (Figure 2A and B), all the herds had varying movement speed with a notable contrast from herd4006 in Isiolo. The lowest speed of herd4006 (less than 0.1m/s) was recorded in January to February and in May to July with the highest speed occurring in April and November. Despite little variation in the daily speed, herd4006 showed a cyclic pattern with peak speed occurring in mid-February and August and lower speed from April to June and in October. On

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the other hand, herd4167 which had similar daily speed pattern with herd4170, showed little variation across the year. The herd maintained a speed greater than 0.2m/s across the year with peak speed occurring from June to September and lower speed from February to April. For Tana River herds, their monthly patterns also contrasted despite having identical daily movement pattern (Figure 2B). Herd4169 presented a cyclic pattern with peak speed occurring in February, April, July, and October while the lowest speed occurred in March, June, and August. For herd4168, peak speed occurred in March and October and a gradual decline in sped from May with the lowest speed occurring from July to September.

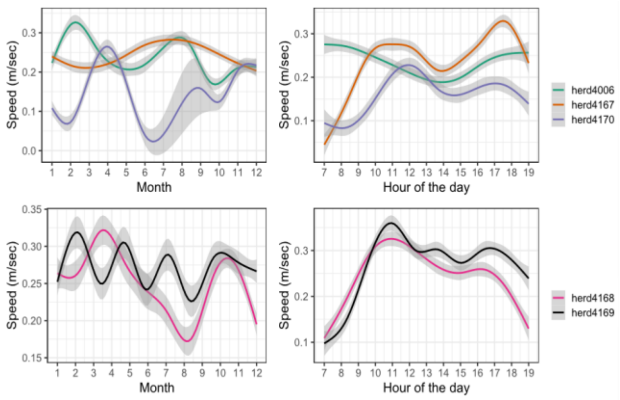

Figure 2: Monthly (A and B) and hourly (C and D) mean speed at which the herds moved on their landscape during the collaring period.

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3.2 Scale and space use intensity

The movement behaviour (i.e., foraging and transient movement) of the herds in space and time are summarized in Figure 4. At large scale (15 km radius), the movement behaviour of the herds was well classified by FPT analysis than at local scale (5 km radius). herd4170, herd4168 and herd4169 maintained similar movement patterns across scales while herd4006 and herd4167 showed contrasting patterns. At 15 km radius, herd4006 and herd4167 presented restricted movement patterns whereas at 5 km radius, the space use pattern varied with more transient movement occurring during the dry season (June to September 2014) and restricted space use occurring during the long and short rains. For the migrating herds, the movement patterns of herd4168 and herd4169 were similar with the highest FPT plateau recorded from July to November 2014 while herd4170 was from December 2013 to early March 2014, which all coincided with the dry seasons in Kenya whereas the transient movements occurred at the start and end of each rainy season.

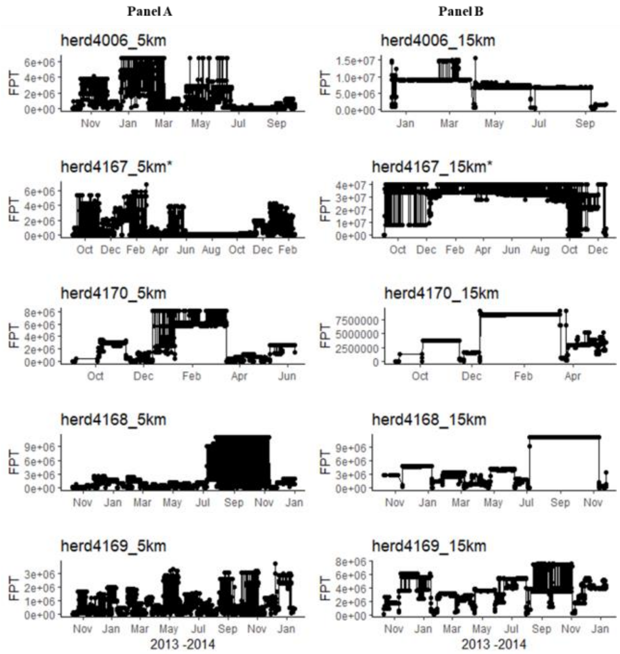

Figure 3: Space use intensity at 5 km and 15 km radius of Isiolo (herd4006, herd4167 and herd4070) and Tana River (herd4168 and herd4169) herds collared from September 2013 to 2014 except for herd4167* which was collared up to February 2015

3.3 Livestock movement and exposure to RVFV

The FPT value for all the herds at local scale (FPT_5km) were low in in all the time of sampling perid indicating that animals were in transient movement while at the large scale, only herd4168 in Tana River and herd4170 in Isiolo were sampled in locations were the FPT values were high indicating that they had spent a long time grazing there.

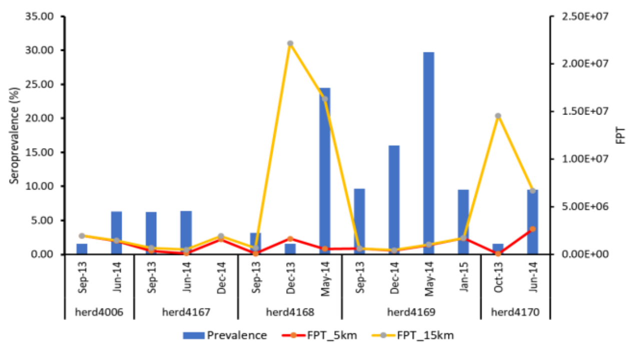

Figure 4: Relationship between RVFV serology survey and intensity of space use at the time of sampling. The movements of herds and seroprevalence were measured in Isiolo County (herd4006, herd4167 and herd4170) and Tana River County (herd4168 and herd4169), Kenya. High first passage time (FPT) alludes to intensely used space while low values indicate transient movements.

Overall, the herds in Isiolo generally recorded lower levels of RVF virus antibodies while the migrating herds in Tana River recorded the highest levels of RVF antibodies. herd4169 in Tana River county recorded the highest seroprevalence levels in all the sampling period, especially in May 2014 (30%) and this coincided with low FPT both at local and large scales whereas the counterpart, herd4168 recorded the highest seroprevalence but only in May 2014 (25%) (Figure 4). The Isiolo county herds recorded seroprevalence levels less than 10% despite the low FPT value both at local and large scale.

4. DISCUSSION AND CONCLUSION

Movement of viremic animals during active virus transmission play a critical role in the spread of RVF virus over short and long distances however quantifying its impact or understanding the dynamics of how it contributes to the spread of the disease is unclear (Balenghien et al., 2013). Role of livestock movement especially because of trade in spreading diseases has been exemplified by a review done by (Fèvre et al., 2006) and its effect quantified by (Adkin et al., 2016). Developed countries are in a better position in quantifying these dynamics due to established infrastructure unlike in many developing countries (Bajardi et al., 2011). We innovatively examined the dynamics of livestock movement in the context of nomadic pastrolism in an RVF endemic region in Kenya. Using GPS collars and conducting serum surveys to check on RVFV antibodies in herds collared in Tana River and Isiolo counties in Kenya, we established the relationships between movement and RVFV exposure.

Despite the two counties being endemic to RVF since 1961, severity levels have varied in the outbreaks with Tana River being classified as a high risk whereas Isiolo as medium risk. Our serum surveys confirmed this variation since we recorded the highest seroprevalance in Tana River herds than in Isiolo herds. The factors causing this variation is not well understood and a study by Sang et al., (2017) began by examing the diversity and abundance of primary RVF vectors in these two counties. They noted that *Aedes ochraceus,* a key primary RVF vector was missing in Isiolo but *Aedes mcintoshi* was present whereas in Tana River both the vectors were present in high abundance. Our study examined another factor that could be contributing to the variation by looking at the movement patterns of pastoralists and we first noted differences in the general movement patterns of pastoralist in the two counties. Tana River herds exhibited a nomadic pattern utilizing their landscape at a large scale (greater than 15km radius) whereas Isiolo herds exhibited two type of pastoralism, one that migrated and another that was more sedentary. Two of the Isiolo herds presented a restricted space use pattern at less than 15 km radius but at local scale (5 km radius) there was high variability in their movemnt patterns.

We analyzed how the movement speed of the herds varied across time scales. Daily movement patterns were characterized by increasing speed in the mid-mornings when the herds leave where they rested over night ('*boma*') to look for pastures and decreased in the evening when going back to rest in their '*boma*'. In the afternoon, the herds slowed their speed and we associate this slowed speed to an increase in foraging due to pasture availability and possibly herds being around water points. We hypothesize that the herds' risk to RVFV infection increased during this period and this is supported by an interview conducted by Owange et al., (2014) on what the pastoralist perceive as a key risk pathway for RVFV exposure. This is because RVFV vectors have been shown to prefer habitats with green vegetation and shallow water for breeding (Mosomtai et al., 2016). Furthermore, convergence of different herds at the watering point presents an opportunity for virus transmission among different herds from different locations to occur.

Looking at monthly movement speed of the herds, seasonal influence was evident however, every herd presented unique movement patterns including Tana River herds which had identical daily movement patterns. This unique annual movement patterns points to the various decisions pastoralist make regarding grazing strategies for their livestock and the seemigly similar movement pattern may actually vary across the year and this can have an influence on RVFV exposure. For instance, herd4169 was very mobile than the rest of the herds and from the serum surveys, it recorded the highest seroprevalence in all the sampling periods whereas herd4168 only recorded the highest seroprevalence yet both herds grazed in closed proximity but using different grazing strategies, with herd4168 spending much of its time in one area. Further studies however, need to be conducted to examine why in one specific sampling period (May 2014) the seroprevalence was generaly high for all the Tana Rivers herds.

In the study area, the livestock movement pattern involved pastoralists returning to their homes during the long and short rains, whereas during the dry season, they migrated to regions where pasture was available (Gomes, 2006). Availability of pasture and water is largely influenced by both human and environmental factors. The erratic climatic conditions due to climate change threatens the livelihood of pastoralist and increase their susceptability to zoonotic diseases. It is now established that RVF outbreaks are linked to El Nino rains that leads to flooding, providing unlimited habitat for mosquitoes to breed and amplify the virus (Anyamba et al., 2009). On the other hand, landscape modification due to human activities such as irrigation schemes in the arid regions, increase the risk for RVFV infections (Sang et al., 2018). The study area has also faced frequent drought events and the ongoing 2020 – 2022 drought has resulted in massive death of livestocks and the community is facing extreme mulnutrition, which has forced pastoralist to migrate to the neighbouring countries (WHO, 2022).

This study broaden our understanding on how pastoralist move and how it influence their exposure to RVFV. We characterized livestock movement patterns across spatial and temporal scale in two RVF endemic counties with varying RVF severity in Northeastern Kenya. Tana River county recorded high seroprevalence than Isiolo county and this was associated to the increased livestock movement pattern. This study shows the potential of levarging movement ecology to understand RVF disease ecology better by incorporating the aspect of movement of viremic animal that is often understudied.

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