Preventive Veterinary Medicine xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

Feasibility study on the spatial and temporal movement of Samburu's cattle and wildlife in Kenya using GPS radio-tracking, remote sensing and GIS

E.A. Raizman[a,*], H. Barner Rasmussen[b], L.E. King[c,d], F.W. Ihwagi[c], I. Douglas-Hamilton[c,d]

[a] *Department of Comparative Pathobiology, School of Veterinary Medicine, Purdue University, W. Lafayette, IN 47907, USA*
[b] *Department of Evolutionary Biology, University of Copenhagen, Universitetsparken 15, DK-2100 Copenhagen Ø, Denmark*
[c] *Save The Elephants, P.O. Box 54667, Nairobi 00200, Kenya*
[d] *Animal Behaviour Research Group, Department of Zoology, University of Oxford, United Kingdom*

ARTICLE INFO

Article history:
Received 31 October 2012
Received in revised form 20 April 2013
Accepted 26 April 2013

Keywords:
Cattle movement
Wildlife–livestock interface
GPS collars
Pastoralists
Samburu Kenya

ABSTRACT

The study was conducted to assess the technical feasibility of studying the spatial and temporal interaction of traditionally herded livestock and wildlife using global positioning system (GPS) tracking technology in Northern Kenya. Two types of collars were used on nine cows: radio frequency and global system for mobile communications (GSM) collars and GPS-satellite (SAT) collars. Full results of cattle tracking were available for eight cows (3 GSM and 5 SAT) tracked between July 2008 and September 2010. A cumulative total of 1556 tracking days was recorded over the 17 month period. On average cows walked 10,203 m/day (average total monthly distance walked was 234 km). Significant seasonal differences were found; on average cows walked 9.607 m and 10,392 m per day in the rainy and the dry seasons, respectively. This difference was also significant for total monthly and daily distance walked between the dry and the rainy season. On average cows walked daily 9607 m and 10,392 m on the rainy and the dry season respectively. During the dry months a 48 h cycle was observed with cows walking 15–25 km to water every 2nd day but only 5–8 km/day between watering days. There was a 24% overlap of cattle range with both elephants and zebras. This study demonstrated the feasibility of tracking cattle using radio collars. It shows the complexity of spatial use by cattle and wildlife. Such information can be used to understand the dynamics of disease transmission between livestock and wildlife.

1. Introduction

Animal movement has been considered a major cause of the spread of livestock and wildlife infectious diseases whether through local and international transportation or traditional herd movement (Fèvre et al., 2006). Both the number of movements and the volume of animals moved can have important ramifications for disease spread. The network of contacts between individuals is a key determinant of the pattern of spread of an infectious disease (Woolhouse et al., 2005). The nature of social groupings and their interaction is of crucial importance when considering the spread of infectious diseases through a population (Beardmore and White, 2001). Intuitively, temporal clustering of individuals will enhance disease transmission whereas spatial dispersal amongst individuals should contribute to the transmission reduction. Understanding the structure of the livestock movement networks and the potential for the transmission of infections within

* Corresponding author at: The Saskatoon Colostrum Company LTD, Saskatoon Canada. Tel.: +1 765 5864532; fax: +1 765 4973795.
E-mail address: eraizman@gmail.com (E.A. Raizman).

0167-5877/$ – see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.prevetmed.2013.04.007

them is also crucial for understanding the epidemiology of diseases and for efficient control of livestock diseases, both epidemic and endemic. Recent novel technology offers the opportunity to obtain accurate empirical data on animal movement, which when coupled with our knowledge on pathogen characteristics can elucidate the epidemiology of disease transmission, especially through animal movements. Remote-sensing technology has been widely used to study the ecology of wildlife for several decades, however, only recently to better understand the dynamic of disease transmission (Brook et al., 2013). In Sub-Saharan Africa previous studies have addressed animal movement using GPS technology (Adriansen and Nielsen, 2005; Butt et al., 2009; de Garine-Wichatitsky et al., 2009; Sonneveld et al., 2009; Moritz et al., 2010, 2012), especially in pastoralist societies, using a small number of animals over a relatively short period of time.

In this study we adopted remote sensing technology that has been extensively used for tracking elephants. The main objective of this study was to describe cattle movement patterns using a novel technology. A secondary objective was to assess an overlap between cattle movement with that of elephants and zebras.

2. Material and methods

2.1. Study area

The region chosen for the feasibility study to delineate patterns of cattle mobility is within the vast 21,000 km^2 Samburu District in the Rift Valley Province of Northern Kenya. The area is typically a dry savannah, which is characteristically hot and dry for most of the year with highly variable bimodal rainfall of less than 400 mm per annum (Barkham and Rainy, 1976). About 90% of the mean annual rainfall occurs during April–May and November–December (Barkham and Rainy, 1976). Large migrant animals congregate in the reserves during the long dry season because of permanent availability of green riverine vegetation along Ewaso Nyiro River (Barkham and Rainy, 1976). The resident Samburu pastoralists rear cattle, sheep, goats, donkeys and camels. The inhabitants dwell in communal homesteads where different families and clans share grazing resources with wildlife. They are seminomadic; grazing their herds around temporary livestock enclosures during times of drought and also maintain semipermanent home bases in their home territory to which they retreat when resources are in plenty. The study area contains a complex network of government owned open grazing land otherwise referred to as trustlands, formally protected National Reserves and community conservation areas (CCA) under the umbrella of the Northern Rangelands Trust (NRT). Unlike the National Reserves in which cattle grazing are officially banned, the CCAs strive to balance wildlife conservation and controlled grazing by zoning occupied land into the respective areas.

2.2. Collar specifications

2.2.1. GPS-GSM collars

Collars were sourced from Savannah Tracking Ltd, (Nairobi, Kenya). We used GPS collars, which transmits data by one of three possibilities (i) mobile phone (GSM) network (ii) satellite or (iii) radio frequency beacon (RF). Selection of collars was based on availability only since the output was the same. A GPS embedded in the collar recorded positions at approximately five to ten minute intervals. Custom made software was used to download the data transmitted through short message service (SMS) onto local machines via the internet. If the unit was outside GSM coverage the data were sent as soon as the unit returns to coverage. For the RF collars, the GPS data were stored in the onboard memory card as backup. This collar includes a VHF beacon to assist manual tracking of cows should the GPS capabilities fail. The data was periodically downloaded via RF in close proximity to the collar. The collar obtained positions via GPS at user defined intervals, at least one hour. Programming of the data collection schedule and data recording parameters is done by sending a SMS containing the key parameters to the unit from any mobile phone (user and collar must both be within mobile phone coverage but not necessarily together or even on the same continent).

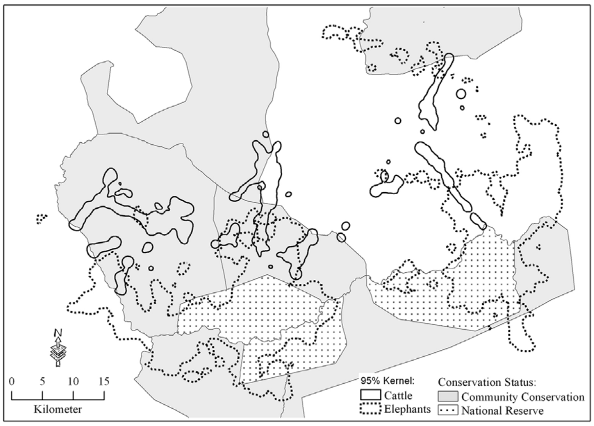

Fig. 1. Home ranges of eight cows and nine elephants estimated using 95% Kernel for the entire study period, July 2008 and September 2010, Samburu Kenya.

2.2.2. GPS-satellite collars

Position acquisition was by GPS. Data transmission was via satellite, downloaded via the internet to Bluetrax^{TM} software (http://bluetrax.software.informer.com). The collars also included VHF beacon. The satellite collar obtained positions via GPS at user defined intervals but had been programmed prior to deployment by the manufacturer. The data was sent via the Immarsat D+ satellite system. The technical challenge for these collars was to integrate the current downloading via the BlueTrax software into custom made software.

GSM collars were set to collect positions every hour whereas satellite collars, due to the higher battery requirement were set to transmit positions every 3 h.

2.3. Animals and communities

Collars were deployed within West Gate, Namunyak, Kalama community conservancies (Fig. 1a and b). The main cattle breed in the study area is the East African Zebu (*Bos indicus*). A typical herd contains approximately 150 individuals with a majority of non bred heifers and a smaller percentage of young bulls. Adult cows compose about 30% of the herd. Samburu pastoralists usually take their herds for grazing each day and supervised by 1–3 herders, depending on the herd size. Usually the herd returns to the enclosure (boma) before nightfall. Only during drought a trip to water and grazing source can last a few days.

Nine adult cows, representing nine different herds were chosen to carry the collars. Cows were chosen based on the owner suggesting the healthiest animals that would have the highest likelihood of surviving for at least 12 months. The herds were numbered 1–9. The average herd size, number of cows and number of bulls was 44 (range 10–101), 36 (range 8–89) and 8 (range 4–20), respectively. Two zebras from two different herds were tracked in the year 2008, one from May to July and the other from May to October. We decided to use elephants to assess cattle-wildlife movement overlap because of the availability of an existing elephant tracking program that had deployed collars on elephants alongside the cattle. Additionally, elephants are known to be a key species in the ecosystem and their distribution is well representative of other wildlife species (Didier et al., 2009). From the elephant database, a subset of nine elephants' movement data was extracted. This comprised of elephants tracked concurrently with cows and also within the same spatial extent defined by cattle collars at the completion of cattle tracking data collection. These were both GSM and Satellite GPS collars.

2.4. Statistical analyses

Statistical analyses were conducted using R® and STATA (2012, College Station, Texas). All tests were considered statistically significant at $P \leq 0.05$. Due to variations in exact time GPS fixes were taken, hourly distances were not used in the analyses. Instead, the mean daily distances walked by each animal was computed for each month. After assessing normal distribution ANOVA was used to test for the differences in average daily and total monthly distances walked by the study herds throughout the study period. We defined the dry season as January–March and July–October and the rainy season April–June and October–December. In the case of Zebra data only two datasets were available with a widely varying number of data points. An estimate of home range sizes of each species, 95% Gaussian Kernel was computed for each dataset using Geospatial Modeling Environment Tools available at http://www.spatialecology.com/gme/kde.htm. The tool works within a combination of ESRI ArcGIS and R statistical framework. The 95% kernel density estimate for all cattle, zebra and elephant data was conducted on each combined set of 9222, 5498 and 32,345 data points for each species, with a cell size of 500 m. The elephant data was clipped for a rectangle defined by the maximum extent of cattle range.

3. Results

3.1. Animals movement patterns

Cows were tracked for a cumulative sum of 1556 days spanning a 19 months period (Table 1). Because one herd was followed for only one month, it was removed from the analysis. Each of 8 herds was followed for an average of 173 days (min. 33 max. 260 standard deviation (s.d.) 78.3) or 24 days a month (min 9 max 31 s.d. 5.7). During this period all herds walked a total of 15,882 km over an area estimated to be 232.65 km^2 from a 95% kernel of all GPS fixes. On average cows walked 10,203 m/day (min 7.4 m, max 28, 913 m, s.d. 5761 m). Average total monthly distance walked was 234 km (min 12.8 km, max 562.8 km, s.d. 136.2 km). Herd 7 was tracked for only one full month and hence was omitted from the ANOVA analysis. ANOVA results indicated significant difference in the daily average as well as total distances walked by herds between months ($P < 0.01$). Similarly, significant difference ($P < 0.05$) was found for average daily distance walked and total monthly distance walked between the four seasons. This difference was also significant for total monthly and daily distance walked between the dry and the rainy season. On average cows walked

Table 1
Average daily distances (km) covered by GPS collared cows in Samburu area, Kenya. The number of days tracked in each month is presented in brackets.

	Herd 1	Herd 2	Herd 3	Herd 4	Herd 5	Herd 6	Herd 7	Herd 8	Herd 9
July 2008	10.6(9)				14.1(10)	9.4(10)	9.8(9)		
August 2008	11.3(31)				13.4(31)	17.2(31)	10.6(24)		
September 2008	11.2(29)				9.8(27)	13.1(30)			
October 2008	11.0(31)				13.5(31)	12.2(31)			
November 2008	6.3(9)				13.9(30)	9.2(30)			
August 2009		12.2(10)	11.9(22)	9.9(25)				9.9(26)	4.6(26)
September 2009		10.8(30)	8.1(30)	9.3(30)				6.0(30)	5.9(30)
October 2009		7.2(31)	3.8(31)	8.3(31)				1.8(31)	2.1(31)
November 2009		13.4(30)	7.3(30)	14.6(30)				2.05(30)	1.8(30)
December 2009		14.1(31)	11.4(31)	18.2(31)				1.05(13)	3.6(31)
January 2010		11.7(12)	12.0(12)	15.7(12)				5.2(11)	1.6(14)
March 2010			10.9(14)	14.5(12)				14.3(15)	1.4(15)
May 2010		10.8(11)							
June 2010		7.3(2)	9.5(7)					13.7(6)	10.6(6)
July 2010		10.6(31)	10.9(31)					12.4(31)	13.4(31)
August 2010		11.2(26)	9.6(31)					14.2(31)	14.3(31)
September 2010		13.2(15)	8.3(16)					12.0(14)	11.7(15)
Mean	10.1	11.1	9.430	12.9	12.9	12.2	10.2	8.4	8.9

Please cite this article in press as: Raizman, E.A., et al., Feasibility study on the spatial and temporal movement of Samburu's cattle and wildlife in Kenya using GPS radio-tracking, remote sensing and GIS. PREVET (2013), http://dx.doi.org/10.1016/j.prevetmed.2013.04.007

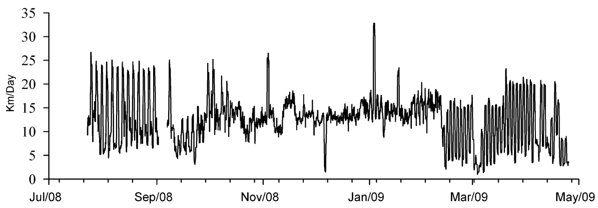

Fig. 2. An example of one GPS collared herd movement tracked in Samburu area, Kenya. There is a clear 48 h cycle in daily movements during dry season where cows going for water every 2nd day covered 15–25 km but only 5–8 km/d on feeding days.

daily 9607 m and 10,392 m in the rainy and the dry seasons respectively (SE = 315, $P < 0.05$).

3.2. Daily movement patterns

A clear 48 h cycle in daily movements was seen in most herds during dry season with cows going for water every 2nd day covering 15–25 km but only 5–8 km per day on feeding days. However, during the rainy season this pattern started to break down, probably as a result of readily available drinking water (Fig. 2). The daily pattern observed between herds was generally very similar except for one herd which was generally taken out later in the day followed by a more rapid mid morning movement with the cattle returning later in the day. From a data collection point of view the 3 h data, collected from the satellite collars, does not capture the dynamics nearly as well as recording hourly movement data (data not shown).

3.3. Home range overlaps

The 95% kernel distributions were calculated for each species for assessment of inter-species home range overlap. The cattle herds overlapped with elephants spatially over an area of 45 km^2 representing 19.4% of the cattle range, and 21 km^2 with zebra, 9% of cattle range. Ten regular watering points along the main river were noted from the regular movement of cows. Two patches of complete overlap between the three species were observed at two of the watering points. A combination of overlap between the two tracked wildlife species shows that at least 24% of cattle range overlaps with the sample data used for the two wildlife species we examined. Cattle spent 61% of time in Community Conservation Areas (CCAs), 30% and 9% in National reserves and Trust lands respectively. The national reserves were mainly traversed by cattle en-route to the drinking points along Ewaso River.

3.4. Collar failures and replacements

The number of cows tracked at any one time was one to five averaging at four. The month of February 2010 was the peak of the worst drought in recent history. The cows were very weak and hence herders removed the existing collars from the herds 2, 3, 4, 8, and 9. These were later returned onto selected cows within herds 3, 4, 8, and 9 in March 2010. The collars on herds 3, 8, and 9 were removed and re-placed with new ones in June 2010 due to transmission battery failure and lasted till September 2010.

Some of the collar failure due to short battery lifespan probably resulted from being removed and kept indoors by the cattle owner. This is because collars that are out of coverage or in weak signal reception consume more batteries trying to acquire and transmit fixes. Overall the main reason for premature failure was the destruction of the antenna by cows or humans.

4. Discussion

This study describes unique cattle movement patterns, particularly from observations recorded during the dry season which showed 48 h cycles of cattle moving toward and away from a water source. This is the first time this cyclical pattern has been described using GPS technology. In their study in Senegal, Adriansen and Nielsen (2005) describe a similar pattern; however this was based on the herd owner notes rather than by detailed GPS records. The authors found that as long as the pasture is moist animals were watered every second day. Adriansen and Nielsen (2005) reported that during the rainy season, cattle movements typically consisted of short treks with the average daily walking distance increasing as the dry season commences. Sonneveld et al. (2009) followed Afar pastoralists in Ethiopia between October and December, the dry season, and described herd movements characterized by daily return to the homestead. According to the authors limited availability of water points limited cattle movement over larger distances. In our study the distances walked were influenced by herder's choices rather than a purely natural choice by animals. It is possible that in the current study water points were closer than in the study described by Sonneveld et al. (2009) and hence herders ventured taking their cattle to drink. In the current study a lapse in law enforcement led to incursion by some herds into the national reserves where forage and water were relatively abundant, thus some livestock herds were herded for shorter distances despite observation of an overall a seasonal trend.

The average daily walking distance during the dry season was 10,393 km. Coppolillo (2000) followed 24 households' cattle for 72 days during the dry season, manually recording their position hourly and found that herding distances to water source varied between 1 and 4 km. Similarly, Butt et al. (2009) and Butt (2010) also describe a significant difference in animal movement (distance walk) between the dry and wet season. Using the combination of direct observation and GPS data, Butt (2010) also found differences in cattle behavior as a function of distance from the household as well as seasonality.

This study confirms the spatial overlap with elephants and by extension with other wildlife species. Indeed, it is not uncommon to see cattle and elephants sharing water sources at the same time. Water sources such as rivers, springs, pans and ponds can be an important point of encounter between livestock and wildlife. The water points frequented by cattle during this study should be monitored as potential disease transmission sites, noting that there could have been other sites not pointed out on our map and

Please cite this article in press as: Raizman, E.A., et al., Feasibility study on the spatial and temporal movement of Samburu's cattle and wildlife in Kenya using GPS radio-tracking, remote sensing and GIS. PREVET (2013), http://dx.doi.org/10.1016/j.prevetmed.2013.04.007

usually visited by other non tracked cattle herds. Furthermore, in one study, 17% and 24% of livestock owners and field rangers respectively in Kruger National Park, South Africa, reported contact between livestock and buffalos (41/year) and impalas (14/year) especially during the dry summer months (Brahmbhatt et al., 2009).

To the best of our knowledge, this is one of few studies published on cow movement using radio-tracking and remote sensing deployed on the animal in the sub-Saharan Africa within pastoral societies where animal movement has an important, unexplored, role in the epidemiology of disease transmission.

This study, however, presented numerous challenges that all have an important impact on the quality of data that can be obtained using this kind of technology. A key challenge was encouraging rural pastoralists to engage in our study in an area where tensions exist between them and the wildlife authorities. Using translators, every attempt was made to explain the aim of the project to both ensure the herdsmen understood the importance of the study, and to train them in the functionality of the collars. Based on the number of collars that were finally deployed, and were followed for over a year, we consider this aspect of the study as a success.

Another significant challenge was the physical damage to the collars. Indeed, overall damage to the collars from cattle seemed to be higher than initially expected and the main reason for premature failure seems to be destruction of the antenna part. It appears that cattle collars must be at least as robust as any equipment deployed on wildlife. Hence less expensive and less robust equipment cannot be recommended for future studies of cattle movement, especially in these tough environmental conditions. Collar breakdown leads to discontinuity of data as described for some of the herds above.

5. Conclusions

This feasibility study showed the usefulness of GPS technology in tracking cattle movement even under the extreme semi-arid conditions of Samburu, northern Kenya. Better understanding of disease transmission between livestock and wildlife will require the use of the same technology on wildlife species that use the landscape in the same area, where frequency of contact can be accurately quantified. The information gathered from elephant movements is a precursor to this and should be replicated on other species.

Acknowledgements

This project was supported by Globe Foundation, Indiana, USA to whom the authors are thankful.

References

Adriansen, H.K., Nielsen, T.T., 2005. The geography of pastoral mobility: a spatio-temporal analysis of GPS data from Sahelian Senegal. Genetika 64, 177–188.

Barkham, J.P., Rainy, M.E., 1976. The vegetation of the Samburu-Isiolo game reserve. East Afr. Wildl. J. 14, 297–329.

Beardmore, I., White, K.A.J., 2001. Spreading disease through social groupings in competition. J. Theor. Biol. 212, 253–269.

Brahmbhatt, D.P., Fosgate, G.T., Dyason, E., Gummow, B., Jori, F., Budke, C., Srinivasan, R., Ward, M.P., 2009. Contacts between wildlife and domestic livestock at the Kruger National Park interface of the Republic of South Africa. In: Proceedings of the 12th International Symposia of Veterinary Epidemiology and Economics, Durban South Africa, August 9–14.

Brook, R.K., Vander Wal, E., van Beest, F.M., McLachlan, S.M., 2013. Evaluating use of cattle winter feeding areas by elk and white-tailed deer: implications for managing bovine tuberculosis transmission risk from the ground up. Prev. Vet. Med. 108, 137–147.

Butt, B., Shortridge, A., WinklerPrins, A.M., 2009. Pastoral herd management, drought coping strategies and cattle mobility in Southern Kenya. Ann. Assoc. Am. Geogr. 99, 309–334.

Butt, B., 2010. Seasonal space-time dynamics of cattle behavior and mobility among Maasai pastoralists in semi-arid Kenya. J. Arid Environ. 74, 403–413.

Coppolillo, P., 2000. The landscape ecology of pastoral herding: spatial analysis of land use and livestock production in East Africa. Human Ecol. 28, 527–560.

de Garine-Wichatitsky, M., Gomo, C., Jomane, L., Pfukenyi, D., Hove, T., Foggin, C., Caron, A., 2009. Prevalence of main diseases in wild and domestic ungulates at three contrasted wildlife/livestock interfaces in the south east lowveld of Zimbabwe. In: Proceedings of the 12th International Symposium of Veterinary Epidemiology and Economics, Durban, South Africa, August 10–14.

Didier, K., Wilkie, D., Douglas-Hamilton, I., Frank, L., Georgiadis, N., Graham, M., Ihwagi, F., King, A., Cotterill, A., Rubenstein, D., Woodroofe, R., 2009. Conservation planning on a budget: a resource light method for mapping priorities at a landscape scale. Biodivers. Conserv. 18, 1979–2000.

Fevre, E.M., Bronsvoort, B.M.C., Hamilton, K.A., Cleveland, S., 2006. Animal movement and the spread of infectious diseases. Trends Microbiol. 14, 125–131.

Moritz, M., Galehouse, Z., Hao, Q., Garabed, R.B., 2012. Can one animal represent an entire herd? Modeling pastoral mobility using GPS/GIS technology. Human Ecol. 49, 623–630.

Moritz, M., Soma, E., Scholte, P., Xiao, N., Taylor, L., Juran, T., Kari, S., 2010. An integrated approach to modeling grazing pressure in pastoral systems: the case of the Logone floodplain (Cameroon). Human Ecol. 38, 775–789.

Sonneveld, B.G.J.S., Keyzer, M.A., Georgis, K., Pande, S., Seid Ali, A., Takele, A., 2009. Following the Afar: using remote tracking systems to analyze pastoralists' trekking routes. J. Arid Environ. 73, 1046–1050.

Woolhouse, M.E.J., Shaw, D.J., Matthews, L., Liu, W.-C., Mellor, D.J., Thomas, M.R., 2005. Epidemiological implications of the contact network structure for cattle farms and the 20-80 rule. Biol. Lett. 1, 350–352.