# Connecting divergent worlds

## Social and ecological factors influence tick-borne diseases in tropical drylands

Richard K. Chepkwony

**Propositions**

1. Neither sex nor age, but body condition is the main biological factor determining tick infestation in Boran cattle.

   (this thesis)

2. The use of mobile phones in addressing socio-ecological challenges is overrated.

   (this thesis)

3. Exploring Mars for human colonization is a waste of time and money.

4. To be successful in life, you are better off being wise than having high academic qualifications.

5. Transhumance livestock management by pastoralists is incompatible with wildlife conservation.

6. Monetary wealth is more important than governance structures to reduce the growing socio-economic disparities in many developing countries.

7. The principle of universal health care is in many developing countries a political tool rather than an innovative approach for improving public health care.

Propositions belonging to the thesis, entitled

Connecting divergent worlds: Social and ecological factors influence tick-borne diseases in tropical drylands

Richard Kiprotich Chepkwony

Wageningen, 29 November 2021

**Connecting divergent worlds:** Social and ecological factors influence tick-borne diseases in tropical drylands

Richard Kiprotich Chepkwony

**Thesis committee**

**Promotor:**

Prof. Dr F. van Langevelde

Professor of Wildlife Ecology and Conservation

Wageningen University & Research

**Co-promotor:**

Dr S. van Bommel

Senior Lecturer

University of Queensland, Australia

**Other members:**

Prof. Dr C. Leeuwis, Wageningen University & Research

Dr C.J.M. Koenraadt, Wageningen University & Research

Dr T.A. Crane, International Livestock Research Institute, Kenya

Dr C. Pfeifer, Research Institute of Organic Agriculture, Switzerland

This research was conducted under the auspices of the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) and Wageningen School of Social Sciences (WASS)

**Connecting divergent worlds: Social and ecological factors influence tick-borne diseases in tropical drylands**

Richard Kiprotich Chepkwony

**Thesis**

submitted in fulfilment of the requirements for the degree of doctor at
Wageningen University
by the authority of the Rector Magnificus,
Prof. Dr A.P.J. Mol,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Monday 29 November 2021
at 11.00 a.m. in the Aula.

Richard Kiprotich Chepkwony

Connecting divergent worlds: Social and ecological factors influence tick-borne diseases in tropical drylands

163 pages

PhD thesis, Wageningen University, Wageningen, NL (2021)

With references, with summaries in English and Dutch

DOI: https://doi.org/10.18174/554705

ISBN: 978-94-6395-506-5

**Table of Contents**

**Chapter 1**

# General Introduction

The spread of tick-borne diseases is one of the major challenges related to livestock production, wildlife management and human health in tropical countries (Cleaveland et al. 2001, Ghosh et al. 2006, Keesing & Young 2014). Ticks cause high impact tick-borne diseases (TBDs) such as East Coast fever, bovine anaplasmosis and babesiosis in livestock (Jongejan & Uilenberg 2004). Furthermore, ticks cause direct damage and losses in livestock such as cattle, goats and sheep due to their nuisance bites causing serious debility, tick worry, blood losses, weight loss and reduced milk yield (Jongejan & Uilenberg 2004). Ticks also cause pathogenic infections in humans such as tick-borne encephalitis and tick typhus (Perry & Young 1995, Jongejan & Uilenberg 2004). Cumulatively, ~10-80% of the annual pathogenic infections in humans, wildlife and livestock and their associated mortalities are tick-related (Cleaveland et al. 2001, Bengis et al. 2002, Jongejan & Uilenberg 2004, Gachohi et al. 2012a).

In areas with high human-wildlife and livestock interfaces, TBDs can cause human-wildlife conflicts, due to the perceived role of wildlife in amplifying the spread of ticks and by acting as disease reservoirs (Mizutani et al. 2005a). It is estimated that TBDs such as East Coast fever alone cause an annual loss estimated at USD 168 million and 1.1 million deaths of cattle in eleven Eastern, Central and Southern African countries with ramifications on food safety in the region (Jongejan & Uilenberg 2004). Moreover, East Coast fever is among the zoonotic diseases that can lead to a ban on movement and trade in livestock and associated products locally, regionally and internationally, and cause substantial economic losses, affecting many livelihoods (Jongejan and Uilenberg, 2004; Minjauw and McLeod, 2003).

The livestock industry is increasingly being threatened by TBDs due to the interaction of unknown ecological, biological, social, institutional or political factors (Awa et al. 2014, Wilcox et al. 2019). Scientists investigating the increasing risks of infectious disease transmissions and associated mortalities have converged upon the realisation that the spatio-temporal distribution of ticks and their associated diseases are, broadly, caused by either the local environmental (ecological), biological or social (human) factors (Randolph 2004, Medlock et al.

2013). For instance, environmental factors (rainfall, temperature and humidity) (Randolph 1997, Cumming 2002b, Rogers & Randolph 2006a), animal (age, sex, body condition) (Harrison et al. 2010, Kiffner et al. 2013) and human factors (human behaviour, land use practices and tick control practices) (Ogden et al. 2005, Estrada-Peña et al. 2016, Allan et al. 2017) can positively or negatively influence the spread of ticks. In particular, moderate rainfall, high temperatures and high humidity in tropical areas provide conductive micro-climatic conditions for massive reproduction, survival and spread of ticks and infestation of hosts (Medlock et al. 2013). Additionally, rainfall causes increased vegetation biomass in tropical drylands which is a major attractant of tick hosts and their associated mobility (Bock et al. 2004, Medlock et al. 2013). Furthermore, rainfall may indirectly affect the proliferation of diseases due to its effect on forage availability influencing the host body condition (Gachohi et al. 2012a). Some studies have suggested that environmental factors such as rainfall, temperatures and humidity directly or indirectly affect the pathogen and longevity in a host, affecting the levels of mortalities (Subak 2003, Rogers & Randolph 2006b, Gachohi et al. 2012a). From all these studies, it is apparent that rainfall is an important environmental factor that influences the spread of TBDs. However, there is still a poor understanding of whether there are any associations between TBD-induced mortalities and rainfall in the tropics due to within-year variations in rainfall (Heuer et al. 2004, Gachohi et al. 2012a, Keesing et al. 2013a).

Moreover, animal husbandry practices such as transhumance movements of livestock by pastoralist communities in many areas in the tropics affect the spread or control of TBDs (Rogers & Randolph 2006a). For instance, the transhumance movements of livestock in search of the limited forage and water during the dry seasons may lead to loss of body condition and subsequent immunity levels in animals (Randolph 1997, Keesing et al. 2006). Furthermore, studies have also suggested that factors such as the sex of an animal can affect tick infestation levels. For instance, lactating female animals have been shown to have lowered immunity levels than males increasing tick infestations and the risks of diseases transmission (Heuer et al. 2004, Randolph 2004). Hence, there is a limited understanding of what factors influence tick infestation levels possibly amplifying the spread of diseases in the tropics (Estrada-Peña et al. 2016). In particular, the interactive effects of, on the one hand, animal and human factors and, on the other hand, on the tick infestation levels in animals is poorly understood and form an important knowledge gap in host-parasite-pathogen dynamics with ramifications on the transmission of infectious diseases (Heuer et al. 2004, Medlock et al. 2013).

Farmers in the tropical areas strive to control ticks by either burning vegetation, pasture spelling, vaccination of animals or using chemical acaricides (Estrada-Peña & Salman 2013a). However, the most predominant strategy for controlling ticks in many tropical areas is the use of acaricides (Ghosh et al. 2006, Brito et al. 2011). Unfortunately, the control of ticks using acaricides is not uniformly applied in many areas because of wide-ranging and least understood context-specific factors. Factors such as individual farmer capital outlay, stocking densities, prevailing government policies and regulatory frameworks, lack of information and incentives, farmer behaviour and the management strategies applied impact on what farmers do, increasing the risks of the spread of diseases (Perry & Young 1995, Paziewska et al. 2010, Keesing & Young 2014, Estrada-Peña et al. 2016, Allan et al. 2017). For instance, in some pastoral areas in Kenya and Uganda, it was shown that farmers applied acaricides on livestock in an erratic manner or even adulterated the chemicals due to limited capital outlay for the purchase of quality farm inputs and hence resorted to the purchase of poor quality acaricides, coupled with large stocking densities, and hence decreasing their ability to implement good animal husbandry (Mugisha et al. 2008, Mugambi et al. 2012, Mutavi et al. 2018). Conversely, commercial farmers in the same region regularly applied good quality acaricides sourced directly from the pharmaceutical companies and their TBDs control seems effective (Mutavi et al. 2018). Furthermore, the governments in these regions have weak extension services following the decentralization of agricultural production systems and extension services to the individual farmer, increasing the risks of the spread of diseases (Walker 2011, Vudriko et al. 2018). Even when the economic conditions of the farmers seemed favourable, the application of the best tick control practices by farmers have been slow and erratic in many areas with ramifications on the control of diseases, impacting on livestock production (Minjauw & McLeod 2003, Vudriko et al. 2018). For effective control of TBDs in the dry tropical areas of Africa, a better understanding of the social and ecological factors and their interactive effects is profoundly needed.

The control of TBDs in many areas can be viewed as a confluence of ecological and human behaviour shaped by *practices* and *interactions* (including information sharing) operating at various spatio-temporal scales, herein referred to as *contexts* (see chapter 5 for further definitions). To develop models that can be used to predict or implement tick control measures and mitigate future TBDs infections and risks with public health concerns (Walker 2011, Hart & Hart 2018), there is a profound need to understand the interactive effects of the social and ecological factors in an area, representing a socio-ecological system (SES) (Estrada-Peña et al. 2016, Allan et al. 2017, Cieslik et al. 2018). SESs are defined as systems of biophysical and social factors that interact at multiple spatial, temporal, and organizational scales and whose flow is regulated in dynamic and complex ways (Evans, 2011; Lischka et al., 2018; Wilcox, Echaubard, de Garine-Wichatitsky, & Ramirez, 2019). When viewed through a single disciplinary lens, these systems may appear to operate independently. However, when viewed from a wider lens, the social and ecological systems often overlap spatially with varying feedbacks among the interacting social and ecological factors (Fig. 1a, Fig. 1b).

In our SES framework on ticks (Fig. 1), we can see the spread of TBDs is a function of individual species, attributes of the host and attributes of the environment. Beginning at that level, the individual attributes are magnified to population levels (e.g., tick population, host population). What happens within a population affects the communities because of the shared environment which are also nested at the ecosystem level (Fig. 1b). Similarly, in the social systems, the behaviour of an individual is affected by the individual attributes which will define their decision-making processes. Several individuals and their decisions will ultimately affect the group dynamics because of the shared ecosystem services, values and norms (Ostrom 1990, 2010). Since the groups operate within a certain framework, we assume that the actions of the different groups are either aligned, conflicted or complement each other in a society.

In this conceptual framework, we assume that the human society and ecosystems cannot operate independently and hence they are nested at various levels with the dynamics of the systems being dictated by the attributes (negatively or positively) starting at the lower level with uncertainties (Fig. 1c). Although human behaviour is one of the most important proximate drivers of tick spread, the contexts shaping those behaviours are also defined by multiple, nested levels of external social and ecological factors (Fig. 1c). To address the TBDs challenges in an area, we need to identify the social and ecological factors and the effects of their interactions on their spread and control.

Furthermore, from the sociological dimensions of SESs, actions and perceptions can individually and collectively affect their relationships with the environment, with implications on the control practices of diseases (Beratan 2007, Jochum et al. 2014, Jones et al. 2016a). For example, most recent studies have shown that tick control activities of an individual farmer in tropical drylands can affect the landscape-scale control of the disease due to the open and shared grazing fields and the prevailing environmental or social conditions (Wilcox et al. 2019). To develop models that address TBDs, there is a need to study the interactions of the factors that link human (cultural, economic and social) and natural (biological, physical and chemical) factors and their interactions (Cieslik et al. 2018). Furthermore, there is a need to understand the TBDs control from the SES perspective to bridge the knowledge gap in between the ecological conditions, the behaviour of farmers and other actors with divergent views, perceptions and interests in an area (Jones et al. 2016a). In particular, the study of human behaviour and their *practices* is important, yet relatively neglected research, which can be used to map how SESs work (Jones et al. 2016a). For instance, there is a paucity of information and knowledge gap on the interaction effects of the social, ecological and political factors influencing TBDs in the tropical regions of Africa (Estrada-Peña & Salman 2013a, Wilcox et al. 2019).

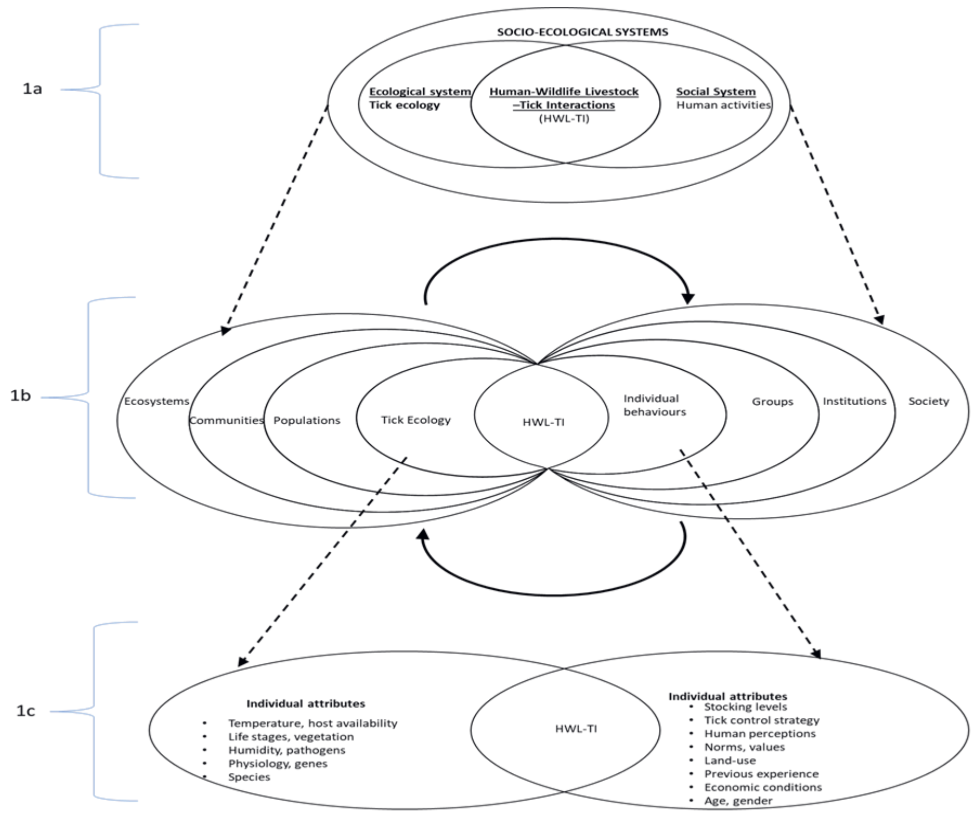



**Fig. 1** Conceptual framework of socio-ecological systems illustrating human-wildlife-livestock interfaces (1a), how social and ecological factors are nested at various levels, (1b) contexts influencing the spread and control of TBDs in tropical drylands, and (1c) preaviling social and ecological factors

The early work of Rogers (1962) in Miller (2015) and Van den Ban (1963) and more recently Ostrom (2003), Cieslik et al. 2018 and Leeuwis & Aarts (2020) has highlighted the importance of communication and information provision in supporting adoption and scaling up agricultural production. Agricultural production can be enhanced through improved diseases management (e.g., TBDs) as a "common bad'' in the society. In the current age of the enhanced mobile phone and internet connectivity in developing countries (De Bruijn & Van Dijk 2012, Miller 2015, Dey et al. 2016), there is a lot of attention and optimism as to how digital platforms may be leveraged in scaling up of disease control interventions. For instance, increasing access to information technology in rural areas in Africa such as in Kenya has sparked optimism that their availability and adoption by various actors can presumably alleviate collective action problems that characterise the agricultural production systems in many rural areas (Kilelu et al. 2013).

Furthermore, the timely adoption and appropriate use of easily and widely available mobile phone technology in agricultural operations is one opportunity that may help in enhancing rural agricultural productivity through enhanced extension services and may contribute to reducing urban-rural inequalities inherent in many developing countries (Van Den Ban 1963, Kwon & Chidambaram 2000, Cieslik et al. 2018, Leeuwis & Aarts 2020). It is also presumed that if mobile phones can be used to monitor environmental conditions and activities and in the coordination of heterogenous actors with competing interests, then we can spur actionable knowledge on TBDs management (Ostrom 2010, 2010, Cieslik et al. 2018, Leeuwis et al. 2018). Furthermore, it is assumed that the adoption and diffusion of new digital technologies can help to transform the nature of doing certain things in an area by catalysing behavioural change and subsequent human activities such as the control practices of diseases (Ostrom 1990, Jochum et al. 2014, Jones et al. 2016a). Moreover, it is assumed that the emergence of mobile phone-based citizen science ("crowd-sourcing'') platforms may be leveraged for robust information sharing on TBDs from a local area to a wider landscape-scale perspective (Haklay 2010, Dickinson et al. 2012, Cieslik et al. 2018, Leeuwis et al. 2018). However, despite this optimism on the use of mobile phones and other ICT-based infrastructure for monitoring of environmental conditions, incidences of TBDs and extension services are influenced by various context-specific factors such as the prevailing socio-economic conditions (i.e., poverty levels, electricity connectivity, literacy levels, and motivations, etc., see chapter 5) (Chepkwony et al. 2018, Cieslik et al. 2018, Leeuwis et al. 2018). While all these novel approaches are quite promising; however, the use of mobile phones in rural areas of a developing country context, such as in Kenya, for addressing complex agricultural problems such as TBDs control has remained relatively unexplored (Kilelu 2013, Leeuwis et al. 2018).

Although farmers in rural areas of developing countries have become an important target for mobile phone services, studies of technology adoption and the diffusion processes in such contexts are relatively scarce (Klerkx & Leeuwis 2008, Leeuwis

& Aarts 2020). Equally, Kwon and Chidambaram (2000) found out that much of the variance in the studies of the usage of mobile phone technology for agricultural production in the rural areas of many developing country-contexts remains unexplained, and addressing this gap should be an important direction for future research in development (R4D) (Klerkx & Leeuwis 2008, Leeuwis & Aarts 2020). Therefore, a relevant question is how 'interactional' and 'sociologically enhanced' understanding of reasons for (non)adoption of technologies may impinge on communicative intervention and information provision through ICT (or other media) (Hounkonnou et al., 2012; Leeuwis, 2013; Leeuwis et al., 2018; Leeuwis & Aarts, 2020). A better understanding of the factors influencing (non) adoption of technologies in an area could also be used to galvanize greater support for citizen science in the monitoring of diseases and coordination of actors for urgent interventions and to alleviate collective action problems (Klerkx et al. 2012, Leeuwis 2013, Cieslik et al. 2018).

Mapping of the interaction effects of the social and ecological factors influencing the spread or control of TBDs is thus crucial in developing collective actions and actionable knowledge exchange between heterogeneous actors involved in the management of zoonotic diseases in the tropical drylands. To develop collective actions (herein connective actions) through information sharing by farmers and actors, then I studied the TBDs problem from a social-ecological system approach which remains a neglected yet important approach of studying the spread and control of zoonotic tick-borne diseases (Jochum et al. 2014, Allen 2015, Wilcox et al. 2019). This is informed by the numerous studies worldwide showing that the ecological and social factors influencing the spread and control of infectious diseases such as TBDs are complex because of the coupled nature of the natural and social systems (Cieslik et al. 2018, Leeuwis et al. 2018). Hence, this PhD thesis aims to address the question: **what are the social and ecological factors and their interaction effects on TBDs, and what could be the potential role of mobile phones in reporting TBDs in tropical drylands?**

To address this question, I will answer the following sub-questions:

1. What is the association between rainfall and tick-borne disease-induced mortalities in livestock?

2. What social, biological and environmental factors determine tick loads in wildlife and livestock?
3. To what extent do the social-political factors influence the spread and control of TBDs?
4. What could be the potential role of mobile phones and citizen science in information sharing on TBDs?

**The study area**

This study was conducted in Laikipia county, Kenya, located between 0°18" S and 0 °51" N, 36°11" and 37°24' E (Bond 2014a) (Fig. 2). The county covers an area of ~ 10,000 km$^2$ and receives highly variable rainfall annually varying between 400 mm (towards the North) and 1200 mm (towards the East bordering and Mt Kenya and west bordering the Aberdare ranges) (Keesing & Young 2014). The main wet season occurs between April-May and often accounts for 80% of the annual rainfall (Keesing and Young, 2014). The second wet season occurs between October-November (Mwangi 2013, Bond 2014a). Daily temperatures vary with the season and generally ranges from 22-26°C; with minimum and maximum temperature of 6-14°C and 35°C, respectively (Bond, 2014b). Due to its erratic rainfall patterns and the dry areas encompassing the larger parts of the county, the county has been classified as a semi-arid area or dryland (Government of Kenya 2016). The soil is predominantly deep clay "black cotton'' soil of impeded drainage and moderate fertility, primarily ideal for savannas characterised by high wildlife population densities and open fields where farmers often prefer to graze their livestock (Taiti 1992, Young et al. 1992, Keesing & Young 2014). The vegetation is mainly classified as scattered tree grassland (Acacia-Themeda grassland). The climatic conditions in the area are favourable for the all-year-round survival of ticks (Keesing et al. 2013a).

The study area has the second-highest wildlife densities outside of the protected area systems, hence classified as a wildlife conservation "hotspot'' in Kenya (Bond 2014a, Allan et al. 2017, VanderWaal et al. 2017). The common wildlife species include African elephant (*Loxodonta africana*), Burchell's zebra (*Equus burchelli*), Grant's gazelle (*Gazella granta*), impala (*Aepyceros melampus*), buffalo (*Syncerus caffer*), giraffe (*Giraffa camelopardalis*), beisa oryx (*Oryx beisa ruppel*), eland

(*Taurotragus oryx*), black rhino (*Diceros bicornis*) and white rhino (*Ceratotherium simum*). Common carnivores include lions (*Panthera leo*) and spotted hyenas (*Crocuta crocuta*). The most common livestock are cattle, goats and sheep, and was estimated at ~350,000 in 2013 (Keesing et al. 2013a). Farmers in the area have started adopting camels as important livestock due to their promising economic returns (Mizutani et al. 2005a). There are no government gazetted protected areas in the county. However, the area has many private conservancies with high wildlife and livestock interfaces with a possibility of influencing the host-parasite dynamics and the subsequent transmission of TBDs (Keesing et al. 2013a, Allan et al. 2017).

The estimated human population in the county in 2019 was ~ 520,000 and has been gradually increasing over years (Kenya National Bureau of Statistics 2019), exerting pressure on land use activities such as pastoralism, with ramifications on the spread of TBDs. The county is predominantly a pastoral community area with resident and nomadic pastoral farmers adept at keeping livestock as culture and wildlife conservation as an economic activity for survival (Lesorogol 2003, Bond 2014a, 2014b). Industrial development in the county is still in its nascent stage although several horticultural farms are coming up in the area (Bond 2014b). The various wildlife conservation and livestock production activities in Laikipia County attracts heterogeneous actors who are either involved or affected by TBDs and may have competing or complementary interests in disease management issues.

In the rural arid and semi-arid lands of Kenya such as in Laikipia, livestock production is critical and is the main economic activity contributing to ~45% of the total beef production for local, regional and international consumption (Minjauw & McLeod 2003). In the arid and semi-arid drylands of Kenya dominated by pastoral communities such as the Maasai, Kalenjin, Samburu, Somali, Turkana and Borana, livestock production contributes to food safety, employment, income, and a source of cultural identity. Livestock production in such areas as alternative livelihood insurance that cushions farmers against uncertainties and stochastic events such as droughts and disease outbreaks (Minjauw & McLeod 2003). The Food and Agriculture Organisation (FAO) and livestock actors have identified three livestock production systems in Kenya: intensive, semi-intensive and extensive systems (FAO & UNICEF 2017a). The extensive and semi-intensive systems contribute to ~ 60 % of all livestock production in the country with 40% being intensive production systems (FAO & UNICEF 2017). These livestock production systems are best exemplified in Laikipia county. Livestock production is thus an important socio-economic activity in Kenya in terms of value and employment.

The county is characterised by poor road networks and connectivity with most areas being remote and relatively inaccessible compared to other areas in the central Kenya region. Hence, people in the area are gradually adopting mobile phones for communication and socio-economic activities. However, the (non)adoption levels of mobile phones and related infrastructure has not been well documented and remains an impediment towards the development of innovative technologies for improved agricultural production in the area. The gradual (non)adoption of mobile phones provided me with an opportunity to study: (i) the potential of mobile phones on information sharing, including how people share knowledge on TBDs across the farming domains, and (ii) how farmers keep data or information on diseases and actors involved, and (iii) the implications of the study on the development of mobile phone-based platforms such as citizen science for TBDs.

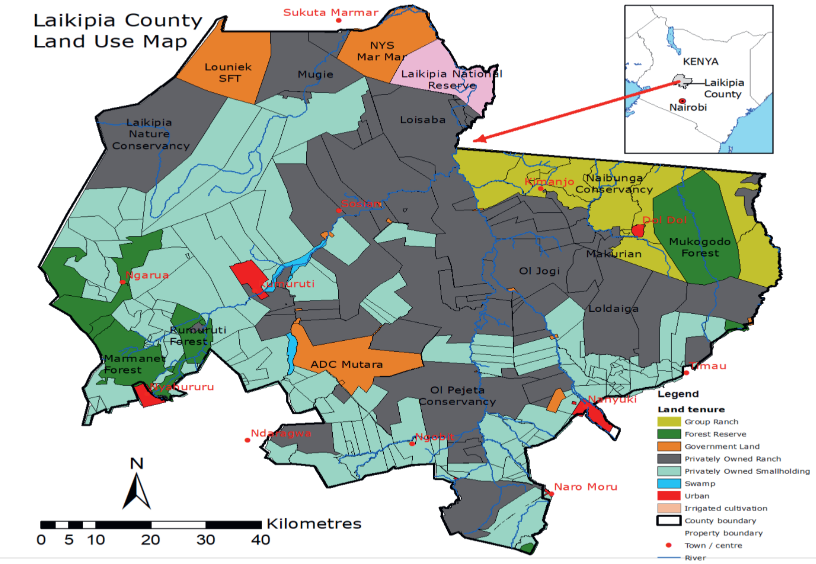



**Fig. 2:** Map of Laikipia County, Kenya, showing land ownership and use (Space for Giants, Laikipia, 2018). There are over 41 private, government or local community-owned ranches in Laikipia. NYS stands for the National Youth Service, while ADC=Agricultural Development Corporation and SFT=Settlement Fund Trustee.

## Thesis Outline

To answer the 4 sub-questions in this PhD thesis, I present four studies: In **chapter two**, I examined whether there are any associations between rainfall on the observed TBDs-induced mortalities using long-term mortality data of Boran (*Bos indicus*) cattle from Olpejeta Conservancy (OPC) in Laikipia. In **chapter three**, I conducted field studies to better understand the interactive effects of the biological, social (human) and environmental factors influencing tick loads in animals such as the effects of sex, age, body condition of cattle and the management types and their interactions with seasons. In **chapter four,** I explore the potential role of mobile phones in information sharing by actors and its implications on the development of citizen science platforms for information exchange on TBDs. In **chapter five**, I conducted field studies using the sociological concepts of *practices, interactions* and *contexts* to explore the socio-political factors influencing the spread and control of TBDs in tropical drylands. Finally, in **chapter six,** I synthesize the key findings of these chapters, applying the broader context of the socio-ecological systems approach for the management of TBDs in the tropical drylands of Africa. Finally, I draw conclusions based on these findings and identify gaps and recommendations for future research on TBDs.

## Chapter 2

# Associations between monthly rainfall and mortality in cattle due to East Coast Fever, Anaplasmosis and Babesiosis

Chepkwony, Richard, Carolina Castagna, Ignas Heitkönig, Severine van Bommel & Frank van Langevelde

Published in *Parasitology,* 2020, 147 (14): 1743-1751

***Abstract***

Weather conditions can impact infectious disease transmission, causing mortalities in humans, wildlife and livestock. Although rainfall in dry tropical regions is highly variable over the year, rainfall is thought to play an important role in the transmission of tick-borne diseases. Whether variation in rainfall affects disease-induced mortalities is, however, remains poorly understood. Here, we use long-term data on monthly rainfall and Boran cattle mortality (1998-2017) to investigate associations between within-year variation in rainfall and cattle mortalities due to East Coast Fever (ECF), Babesiosis and Anaplasmosis in Laikipia, Kenya, using ARIMAX modelling. Results show a negative correlation between monthly rainfall and cattle mortality for ECF and Anaplasmosis, with a lag effect of 2 and 6 months, respectively. There was no association between Babesiosis-induced mortalities and monthly rainfall. The results of this study suggest that control of the tick-borne diseases ECF and Anaplasmosis should be intensified during the dry season to reduce mortalities.

**Keywords**: *Time series analysis, animal diseases, indigenous cattle, ticks, tick-borne diseases*

## Introduction

Weather conditions are thought to play an important role in the transmission of many infectious diseases that cause significant mortalities in humans, wildlife and livestock in both temperate and tropical countries. For instance, the outbreaks of diseases such as trypanosomiasis are correlated with rainfall that provides favourable conditions for survival and reproduction of trypanosomes (Rogers & Randolph 2006b). Also, avian influenza is positively influenced by rainfall (Brown et al., 2017). Temperature, relative humidity and precipitation have been shown to play a vital role in the incidences of Dengue fever (Gubler et al., 2001), Rift Valley fever (Maloo 1993, Anyamba et al. 2009, Lwande et al. 2015) and malaria (Wangdi et al. 2010).

Tick-borne diseases (TBDs), such as tick-borne encephalitis (Subak, 2003), Boutonneuse fever (de Sousa et al. 2006) and Lyme disease (Rogers & Randolph, 2006), are known to be also positively correlated to rainfall. In dry tropical areas, rainfall patterns are often highly variable. For instance, ticks reproduce massively at the onset of any rainfall episode and slowly develop into nymphs in three weeks to one month (Cumming 2002a). Moreover, the nymphal and adult stages are the stages where pathogens are transmitted from the tick to the mammalian host, resulting in mortalities (Dantas-Torres, 2015; Rogers & Randolph, 2006). Furthermore, the growth of the vegetation during rainy periods attracts mammalian hosts facilitating the transmission of pathogens (Norval et al. 1988, Cumming 2002b, Awa et al. 2015). Conversely, as more forage is available for mammalian hosts during periods of rainfall, their body condition (and immunity levels) also improve, reducing their susceptibility to TBDs.

Essentially, TBDs cause severe economic losses and are associated with 10-80% of the livestock mortalities, with ramifications on human livelihoods. To stem the impacts of tick-borne pathogens and diseases, then we need a clear understanding of the associations between disease pathogens and their environmental determinants, especially in dry tropical areas with highly variable environmental conditions. To date, few studies on the associations between weather conditions such as rainfall and TBDs on livestock mortality have been conducted in dry tropical areas. In the absence of tick monitoring in many regions in the tropics, livestock mortalities, which are indications of effective disease transmission, may provide understanding about the associations between within-year variation in rainfall and the incidences of TBDs.

Although there is a need to determine if there are any associations between rainfall and TBDs-induced mortalities, long-term data are generally lacking (Heuer et al. 2004, Keeling & Rohani 2008, Kołodziej-Sobocińska 2019). Here, we use long-term data on Boran cattle mortality to determine associations between monthly rainfall and three TBDs, namely East Coast Fever (ECF)*,* Babesiosis and Anaplasmosis, to further improve our understanding of the extent weather conditions play in the dynamics of disease transmission and for use in disease control. We expect that high monthly rainfall would lead to an increase in mortalities induced by these TBDs. ECF causes most mortalities (65%; Kanyari & Kagira, 2000) in cattle of all TBDs, as the vector, the tick *Rhipicephalus appendiculatus*, is one the most abundant tick species in East Africa, infesting both wildlife and livestock (Zieger et al. 1998, Wesonga et al. 2006, Swai et al. 2009, Keesing et al. 2013a, Mwamuye et al. 2016). Babesiosis accounts for 5.1% and Anaplasmosis for 4.5% (Kanyari & Kagira 2000), and these two TBDs share the same main vector, the tick *R. decoloratus*. Other common tick species in the area include *R. evertsi* and *Ambyomma variegatum* (Allan et al. 2017).

## Methods

### *Study area*

The data on cattle mortality was collected in Olpejeta Conservancy (OPC), a facility for commercial livestock production and wildlife management in Laikipia County, Kenya. Laikipia county is located between 0°04'60.00"N and 36°39'59.99"E (Figure 1). The county covers ~10,000 km$^2$ and the rainfall is typically bimodal and unpredictable throughout the year. Laikipia county has an estimated human population of ~ 520,000 living in either urban or rural areas and relies on wildlife conservation, livestock production and crop farming for their livelihoods (Kenya National Bureau of Statistics 2019). The interfaces between human, wildlife and livestock coupled with the local environmental conditions in the area may provide all-year-round conditions for tick survival, the spread of TBDs with resulting mortalities with major ramifications on livestock production and wildlife conservation (Odadi et al. 2011, Keesing et al. 2013a, Allan et al. 2017, VanderWaal et al. 2017). OPC is an intensively managed protected area in Laikipia County and covers 364 km$^2$ (Fischhoff, Sundaresan, Cordingley, & Rubenstein, 2007). The facility manages ticks in livestock through weekly acaricide spraying (Chepkwony et al., 2018).

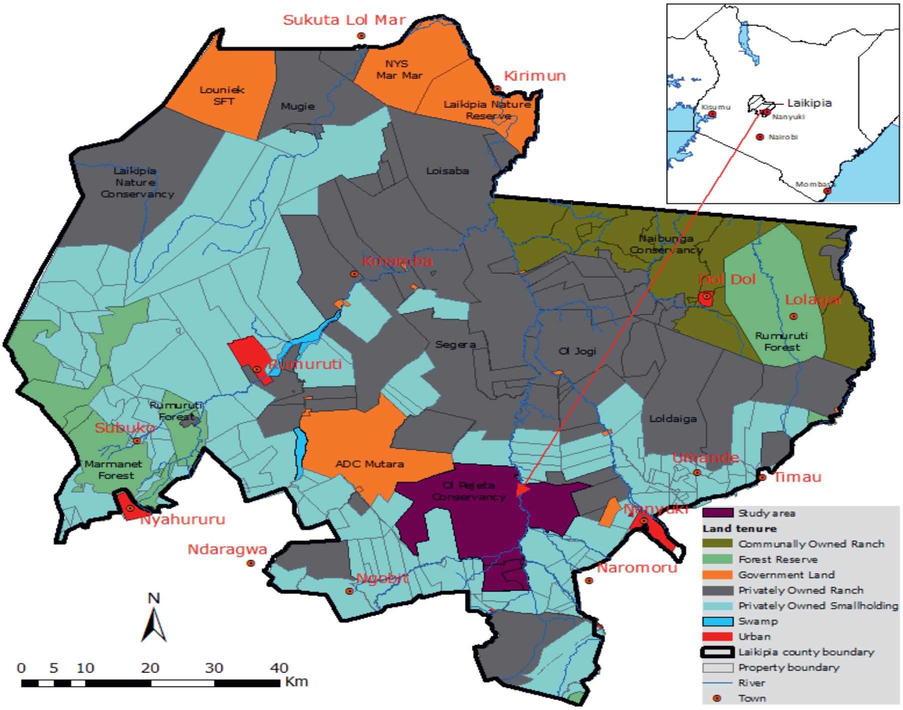



**Figure 1** Map of Kenya and the location study site Olpejeta Conservancy (OPC), in Laikipia, Kenya. OPC is located to the south of Laikipia county and borders Mutara ranch to the West and Naro-Moru township to the South East.

### ***Data collection***

We obtained monthly data on domestic cattle mortalities from OPC for a period of 19 years beginning from October 1998 to October 2017. The data is used at OPC to monitor performances of commercial cattle ranching, one of the key land use activities in the property. Besides ECF, Babesiosis and Anaplasmosis, other causes of cattle mortalities, namely Anthrax, Brucellosis, dysentery and stillbirths, among others, were also recorded. When the disease was not confirmed via laboratory diagnostics, it was generally classified as non-specified in the data. Other forms of mortalities recorded included depredation from wild carnivores, poisoning by plants or chemicals, bloat, debility, accidents occasioned through falling-off cliffs while grazing in the wild, snares and trampling by other members while aggregated in places such as in chemical spraying-race or supplemental feeding areas.

We also have monthly data on the herd size of cattle. We interpolated missing data sets for the herd sizes for the years 2015 and 2016 using the data sets of herd sizes of the previous and next year. Cattle mortality per TBD was calculated as the percentage of animals diagnosed with ECF, Anaplasmosis or Babesiosis per month from the corresponding herd size. We obtained monthly rainfall (mm) data from OPC's Kamok meteorological station spanning over five decades since 1965. We used the monthly rainfall over the period that coincided with the mortality data.

***Testing for associations between monthly rainfall and cattle mortalities***

As our data contained the time series of mortalities and rainfall, we used Autoregressive Integrated Moving Average (Lester et al.) models (Huang & Shih 2003, Gaur & Gaur 2006). In these models, the percentage of cattle mortalities per month per TBD (ECF, Anaplasmosis and Babesiosis) was used as the response variable and monthly rainfall as the predictor variable. Time series analysis allows us to understand whether the underlying structure of monthly rainfall can explain the observed mortality observations, and it tests whether there is a seasonal pattern in mortality that can be related to monthly rainfall with or without a lag effect.

We excluded all outliers due to known causes from the analysis since they significantly affected the model performance (Wangdi et al., 2010). Our sample size was 228 observations of monthly cattle mortalities per TBD. ARIMA uses the parameters p, d and q, where p represents the autoregressive (AR) order, d stands for the differencing order and q for the moving average (MA) order. AR orders specify which previous values from the time series are used to predict current values. Our ARIMAX model using the predictor variable rainfall can be specified as:

$$Z_t + \sum_{p=1}^{p} \phi_p Z_{t-p} = \mu + \sum_{i=1}^{I}\sum_{n=1}^{N} \beta_i, n X_{i,t-n} + \sum_{q=1}^{Q} \theta_q \varepsilon_{t-q}$$

where $Z_t$ is the mortality due to the TBD at month t, $Z_{t-p}$ is the mortality in the previous month with a lag of p (i.e. AR), $\mu$ is the intercept, $X_{i,t-n}$ is the independent variable *i* (here rainfall) with a lag of *n* months, and $\varepsilon_{t-q}$ is the error at lag q (i.e. MA). $\phi_p, \beta_i$ and $\theta_q$ are the model parameters for the AR term, the independent variable and the MA term, respectively (Monamele et al., 2017). MA orders specify the deviations from the series mean for previous values and are used to predict current values. With monthly rainfall as an exogenous variable (X) to make predictions in the ARIMA models, the models are then referred to as ARIMAX. Following the procedures described by Huang and Shih (2003), we developed the ARIMAX models for the TBDs using the Forecasting Expert Modeler in SPSS 25 IBM statistics (Huang & Shih 2003, Gaur & Gaur 2006). The Expert modeller was used to fit the best model for the time series data. The ARIMAX model assumed that all other conditions, such as control and preventive measures including vaccination of infected animals, do not vary systematically over time. We did not distinguish a training and test set in the data as monthly rainfall in a semi-arid region such as Laikipia is highly variable. For training the model, we used a long period of data, but short-term predictions of the mortalities for say 1 year are not reliable due to the highly variable monthly rainfall.

As a general rule in time series analysis, stationarity or non-stationarity of the series is indicated by the existence of a sigmoidal pattern with sharp points at the peak of the sequence plots indicating seasonality. If an increasing trend is observed, then the pattern is deemed as exhibiting a non-stationary trend (Geweke & Porter-Hudak, 1983). When the data is non-stationary, differencing will be necessary to "stationary" it through either log-transformation, deflating or raising-to-some-power to convert the data to a form where its local random variations over time vary around zero (Huang & Shih, 2003). The stationarity of the data was checked by the autocorrelation function (ACF) and the partial autocorrelation function (PACF). We then used the seasonally adjusted factor (SAF) to determine the peaks of seasonal variations of the three TBDs*.* We used the Ljung-Box (modified Box-Pierce) test to evaluate if the model was correctly specified (Huang & Shih 2003, Clement 2014). Besides, we used the mean absolute percentage error (MAPE) to characterize the model, which is a test of the smoothness of the time series. The lower the MAPE, the more reliable is the model as MAPE is a measure of error (Huang & Shih 2003, Clement 2014).

## Results

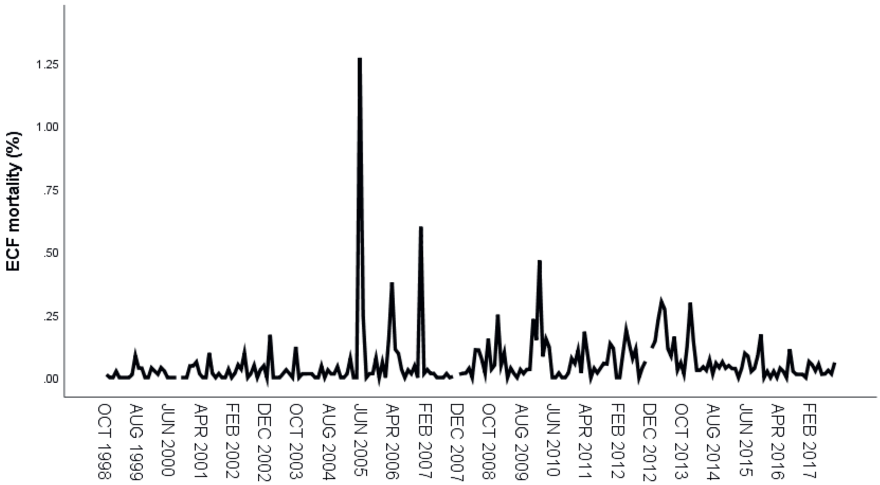
### *Livestock mortalities*

Depredation by wild carnivores was responsible for 23% of the cattle mortalities over the entire period, while the three TBDs, namely ECF, Anaplasmosis and Babesiosis, accounted for 20% of the mortalities, which made them the second most common cause of mortalities for the Boran cattle at OPC. The population of Boran cattle varied from 4591 to 8368 cattle over the years we studied. The time series of the mortalities due to ECF, Anaplasmosis and Babesiosis are shown in Figure 2. The unusual observations in May and June 2005 were attributed to the OPC management's decision to change the chemical acaricides used for tick control from "Triatix©" to "Delete EC©", causing a spike in cattle mortality. In August 2005, there were some reported cases of resistance by blue ticks (vector for Anaplasmosis and Babesiosis) to the applied acaricide leading to increases in Anaplasmosis and Babesiosis-induced mortalities. Because this affected the models as a confounding factor not related to monthly rainfall, we treated them as outliers and they were removed from the analysis.

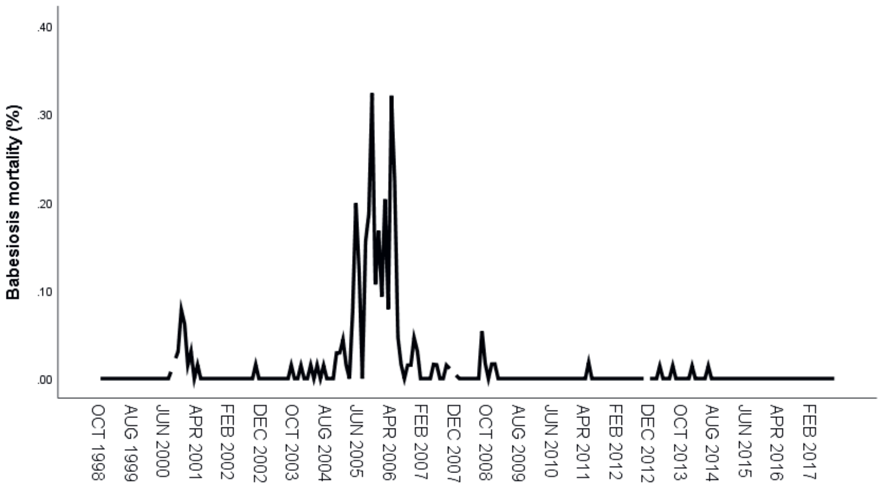
### *Associations between rainfall intensity and cattle mortalities*

The ARIMAX models show that ECF and Anaplasmosis were negatively correlated with rainfall, with a lag of 2 months and 6 months for ECF and Anaplasmosis, respectively (Tables 1 and 2; Figures 2 and 3). The results for ECF and Anaplasmosis suggest that there were fewer mortalities a period after rainfall (after 2 and 6 months for ECF and Anaplasmosis, respectively). For example, a low rainfall level in January with a predicted lag effect of 2-month and 6-months would result in mortalities in March and June for ECF and Anaplasmosis, respectively. Babesiosis could not be correlated to rainfall. In the Discussion, we will mainly deal with the association with monthly rainfall. For both ECF and Anaplasmosis, the number of autoregressive (AR) orders in the model is 2, whereas this number is 1 for Babesiosis (Table 1). For example, an autoregressive order of 2 specifies that the mortalities of the series two months in the past be used to predict the current mortality. For Babesiosis, the number of moving average (MA) orders in the model are 1, which means that that deviation from the mean mortality of the series from each of the last months is considered when predicting current mortality. The Ljung–Box test indicated that the models for ECF and Anaplasmosis were correctly specified ($p > 0.05$) (Table 2). For each TBD, cattle mortalities seem to be stationary with a constant variance oscillating around 0 (Figure 4).

(A)




(B)



(C)

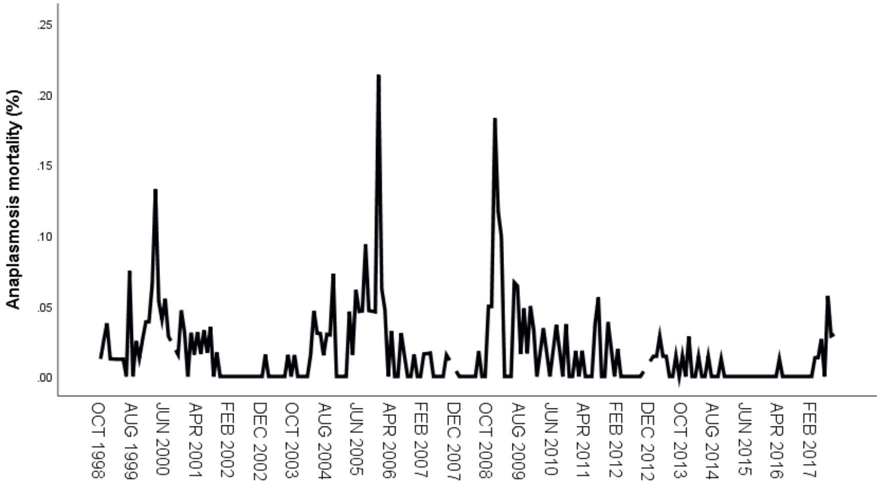



**Figure 2** Monthly Boran cattle mortality as a percentage of the total herd sizes for (A) East Coast Fever (ECF), (B) Babesiosis, and (C) Anaplasmosis in Olpejeta Conservancy, Laikipia, Kenya. The outliers were: May 2005 for ECF, May and August 2005 for both Babesiosis and Anaplasmosis.

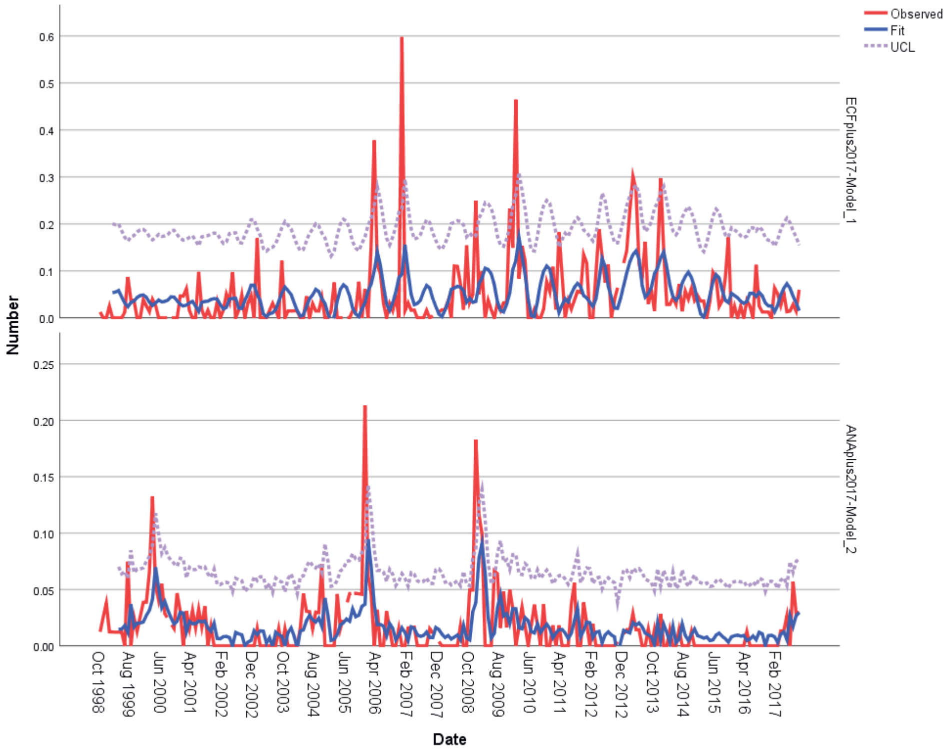



**Figure 3** Observed cattle mortalities due to East Coast fever (ECF) and Anaplasmosis at Olpejeta Conservancy, Kenya from October 1998 to October 2017. The best fit of the ARIMAX models (blue) with the upper confidence limits (UCL).

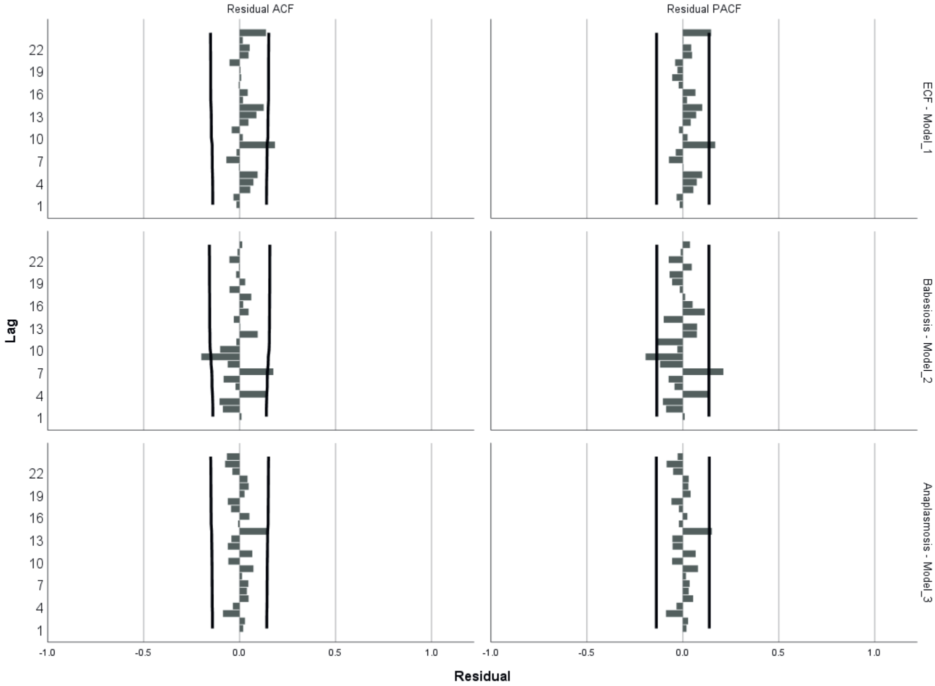



**Figure 4** Correlograms of the residual autocorrelation function (ACF) and partial autocorrelation function (PACF) of the suggested ARIMAX models for cattle mortalities due to East Coast fever (ECF) (top panels), Babesiosis (panels in the middle) and Anaplasmosis (lower panels) at the Olpejeta Conservancy, Kenya from October 1998 to October 2017. The dark grey lines indicate 95%, confidence bands.

**Table 1** Summary of the ARIMAX models with rainfall as a predictor variable for the three tick-borne diseases East Coast Fever (ECF), Babesiosis and Anaplasmosis

| | | | Estimate | SE | t | P |
|---|---|---|---|---|---|---|
| ECF | Constant | | .070 | .010 | 6.880 | <.001 |
| | AR | Lag 1 | .171 | .070 | 2.437 | .016 |
| | | Lag 2 | .179 | .071 | 2.532 | .012 |
| Rainfall | Delay | | 2 | | | |
| | Numerator | Lag 0 | .000 | 4.317E-5 | -2.934 | .004 |
| | Denominator | Lag 1 | 1.536 | .024 | 63.823 | <.001 |
| | | Lag 2 | -.935 | .031 | -30.137 | <.001 |
| Babesiosis | AR | Lag 1 | .830 | .051 | 16.179 | <.001 |
| | MA | Lag 1 | .368 | .080 | 4.595 | <.001 |
| | | Lag 6 | -.329 | .070 | -4.684 | <.001 |
| Anaplasmosis | Constant | | .021 | .004 | 4.728 | <.001 |
| | AR | Lag 1 | .378 | .070 | 5.412 | <.001 |
| | | Lag 2 | .195 | .071 | 2.764 | .006 |
| Rainfall | Delay | | 6 | | | |
| | Numerator | Lag 0 | -7.768E-5 | 3.526E-5 | -2.203 | .029 |

**Table 2** Summary of ARIMAX model statistics with rainfall as a predictor variable for the three tick-borne diseases East Coast Fever (ECF), Babesiosis and Anaplasmosis (see Table 1 for the model performance).

| | | Model Fit statistics | | | Ljung-Box Q | | |
|---|---|---|---|---|---|---|---|
| Model | Number of Predictors | Stationary $R^2$ | MAPE | Normalized BIC | Statistics | df | P |
| ECF | 1 | .183 | 88.634 | -5.091 | 18.859 | 16 | .276 |
| Babesiosis | 0 | .520 | 91.777 | -6.924 | 32.454 | 15 | .006 |
| Anaplasmosis | 1 | .275 | 45.561 | -7.304 | 13.675 | 16 | .623 |

MAPE: Mean absolute percentage error, BIC: Bayesian information criterion

**Discussion**

This study aimed to understand the association between monthly rainfall and mortalities in Boran cattle due to the three TBDs ECF, Anaplasmosis and Babesiosis. We found a clear association between monthly rainfall and the occurrence of mortalities due to ECF and Anaplasmosis with a disease-specific lag after rainfall. However, this association was negative, whereas we expected that high monthly rainfall would lead to an increase in mortalities due to TBDs. The negative association between monthly rainfall and cattle mortalities associated with ECF and Anaplasmosis had a 2-months and 6-months lag after a rainfall event for ECF and Anaplasmosis, respectively. For Babesiosis, we did not find an association with monthly rainfall.

Most studies indicate that *R. appendiculatus* numbers (vector tick for ECF) are higher during the rainy season (Okello-Onen et al. 1999, Wesonga et al. 2006, Laisser et al. 2015). Fyumagwa et al. (2007) and Zieger et al. (1998) found, however, that the nymphs were more abundant during the dry season and others found no clear seasonality pattern for *R. appendiculatus* (Fyumagwa et al., 2007; Rogers & Randolph, 2006; Walker et al., 2014; Zieger et al., 1998). An explanation for the negative correlation we found could be that the nymphs were indeed more frequent during the dry season and that these numbers were overall higher than the adult numbers, as Zieger et al. (1998) have found. For *R. decoloratus* (vector tick for Anaplasmosis), a higher number was found during the wet period (Walker, 2011; Wesonga et al., 2006). However, Okello-Onen et al. (1999) did not find a seasonal effect probably due to the high densities of this tick species, because the control interventions by farmers are still low as compared to other areas such as in Kenya. So for both vector tick species, there is no clear relation between rainfall and their densities.

Different TBDs have different aetiology that influences their transmission, incubation and subsequent infectiousness in humans and animals. ECF caused by protozoan *Theilleria parva* has been shown to take a period of between 10 days to three weeks from the transmission, development into full-blown infections (Gachohi, Skilton, Hansen, Ngumi, & Kitala, 2012). Because of its short incubation period and effect on an animal, ECF is considered a more lethal and high impact disease than other TBDs such as Babesiosis and Anaplasmosis. Anaplasmosis also has its aetiology with its development that may take up to 4-5 months between the period of transmission in an animal, incubation and subsequent effect and manifestation in an animal (Gachohi et al. 2012b). Anaplasmosis, therefore, takes a long latency or incubation than either ECF or Babesiosis. Moreover, the time between infection with a disease and the time the infected animal dies, i.e. the time of death, may vary between the TBDs. Several studies have found the time of death for ECF-infected cattle to be around 26 days, with ranges from 11 to 44 days (Brocklesby 1962, Radley et al. 1974, Robson et al. 1977). For Anaplasmosis, the time of death is currently unknown. As a proxy, the incubation period varied from 7 to up to 100 days (Theiler 1911, Pipano et al. 1992, Kocan et al. 2003). These differences in aetiology between the TBDs may probably explain the differences in the lag period of 6 months that this study found for Anaplasmosis compared to the lag period of 2 months for ECF.

The effect of the different TBDs on livestock may also be influenced by an animal's immunity levels or responses, and are often influenced by an animal's body condition (Fyumagwa et al. 2007). When an animal loses condition through parasite infestation or lack of forage and water such as during drought, the animal may easily succumb to the disease, increasing the risk of mortality (Swai, Karimuribo, Rugaimukamu, & Kambarage, 2006). During the high rainfall season when forage is abundant, the animal's body condition may improve considerably boosting the animal's immune response and decreasing its mortality risk. In addition to the aetiology of the TBDs, the negative relationships between the Boran cattle mortalities and monthly rainfall may be also attributed to the lower immunity levels of the animal during the dry months (Potkanski, 1994; Kanyari & Kagira, 2000; Subak, 2003; VanderWaal et al., 2017). Yet another explanation could be that during the dry season contact between herds at OPC increases near water resources, which causes more potential for pathogen spread than during the wet season (VanderWaal et al., 2017).

Furthermore, previous studies in China showed that monthly rainfall was positively correlated to monthly notification of Japanese encephalitis, spread by either ticks or mosquitoes, and their lag times varied from one to two months (Bi et al. 2007). Although this study did not account for the resultant mortalities, it was nevertheless consistent with our observations that tick-borne disease transmission is influenced by environmental variables (rainfall) and the pathogen infection has lagged effect due to vector biology and perhaps immunity levels in hosts.

We used mortality data of Boran cattle to determine if there is an association between the long-term mortalities due to the three TBDs and monthly rainfall. However, one shortcoming of this study is that we did not have data to compare how many animals were infected and recovered from each infection due to these TBDs. We also made the general assumption that the control interventions for TBDs were relatively uniform and were based on consistent use of acaricides over the period, which was based on the information obtained from the ranch management (Chepkwony et al., 2018).

Our study shows a negative correlation between rainfall intensity and TBDs-induced mortalities in Boran cattle. Our findings suggest that Boran cattle mortalities are probably amplified in the dry season after rainfall events. The analysis presented in this study may have some implications for the prevention and control of TBDs. We suggest that warnings of enhanced risk should take into account knowledge of the lag times of the diseases and the measured rainfall conditions in relation to the risk of the spread of diseases. Tick control strategies may be intensified, such as increasing the frequencies of the application of chemicals (acaricides), during the dry season and perhaps improving the body condition of cattle to reduce TBD-induced mortalities. This study contributes to a better understanding of the occurrence of mortalities in Boran cattle due to three

TBDs, namely ECF, Anaplasmosis and Babesiosis, and to our ability to predict ECF- and Anaplasmosis-induced mortalities based on monthly rainfall, a prerequisite for disease control in livestock.

**Acknowledgements**

This study was funded by the Wildlife Ecology and Conservation Group of Wageningen University, The Netherlands, and the INREF Programme 'Environmental Virtual Observatories for Connective Action (EVOCA)'. We wish to thank the Kenya Wildlife Service for authorising the research to be conducted in Laikipia and its staff for providing security during the fieldwork. We also thank Samuel Mutisya, Alfred Kibungei and Joseph Mathenge for providing part of the data and counter-checking the data for errors and omissions. We sincerely thank the entire management of Olpejeta Conservancy Ltd, Laikipia, Kenya, for allowing fieldwork in their conservancy.

**Chapter 3**

# Interactive effects of biological, human and environmental factors on tick loads in Boran cattle in tropical drylands

Richard Chepkwony, Severine van Bommel & Frank van Langevelde

Published in *Parasites & Vectors,* 2021, 14: 1–8

***Abstract***

Tick-borne diseases (TBDs) are a serious threat to humans, wildlife and livestock, and cause severe economic losses in many tropical drylands. The effective control of TBDs has been constrained by a limited understanding of what determines tick loads in animals. We tested the interactive effects of several biological factors (sex, age and body condition), one environmental factor (rainfall), and one human factor (management type) on tick loads in animals. We collected ticks on animals using four sampling sites in the semi-arid savanna area of Laikipia County, Kenya, of which two are commercial ranches and the other two are open pastoral grazing areas. From 2017 to 2019, we collected a total of 2038 ticks from 619 livestock from various cattle and camel herds and 79 sedated wildlife. Generally, wild herbivores (zebras, rhinos and elephants) had higher tick loads than livestock. As we had the largest sample size for Boran cattle (83%), we analysed their tick load in more detail. We found that Boran cattle had high tick loads in the wet season, especially the animals with poor condition. We did not find differences between females and males, regardless of the season. The calves had high tick loads during both the wet and dry season, whereas the sub-adult and adult cattle had fewer ticks during the dry season. Cattle on the intensively managed ranches had a lower tick load than the transhumant management system. These findings highlight the importance of establishing effective control of ticks in livestock in transhumant management systems as tick loads were high in both wet and dry seasons.

**Keywords:** *Tick-borne diseases, wildlife, Boran cattle, commercial ranches, transhumance, tropical areas*

## Chapter 3

### Introduction

Tick infestation in animals is one of the major challenges in tropical drylands related to animal and human health and causes diseases with substantial economic losses (Cleaveland et al. 2001, Ghosh et al. 2006). Ticks transmit pathogens that can cause diseases such as East Coast fever, anaplasmosis, babesiosis and tick-borne encephalitis, leading to mortalities in livestock, wildlife and humans (Bengis et al. 2002, Jongejan & Uilenberg 2004). It is estimated that tick-borne diseases (TBDs) cause ~10-80% of livestock mortalities in Africa, affecting many livelihoods (Cleaveland et al. 2001, Medlock et al. 2013). Control of TBDs by farmers in tropical drylands is difficult due to the interactions of human, biological and environmental factors (Cumming 2002b). These factors can influence tick load in host animals due to the effects of the reproduction of ticks (Cumming, 2002), the host-seeking strategies of the ticks (Estrada-Peña & de la Fuente 2014), and the efficacies of tick control (Ghosh et al. 2006, Awa et al. 2015). Furthermore, the tick infestation level of animals is the focal point for the control of TBDs (Jongejan & Uilenberg 1994, Medlock et al. 2013). Hence, it is crucial to estimate what animal species have high tick infestation and identify factors influencing these differences between species to plan for their effective control (Cumming 1999, Dantas-Torres 2008). Many studies on the risk of TBDs have mainly focused on several factors, such as environmental (rainfall, temperature and humidity) (Randolph 2004), biological (age, sex, body condition) (Harrison et al. 2010, Kiffner et al. 2013) and human factors (land use, animal husbandry) (Perry & Young 1995, Paziewska et al. 2010, Keesing & Young 2014, Allan et al. 2017). However, the interactive effects of biological, environmental and human factors on tick loads in animals are poorly understood (Cumming 2002a, Dantas-Torres et al. 2012, Estrada-Peña & Salman 2013a).

It has been established that changes in rainfall influencing humidity and temperature may influence tick load in animals (Chepkwony et al., 2020). For instance, moderate rainfall and high humidity provide conductive micro-climatic conditions for mass reproduction of ticks and subsequent infestation in animals (Cumming 1999). We, therefore, expect a higher tick load in animals in the wet season than in the dry season (hypothesis 1). Studies have shown that biological factors such as age, sex and body condition of the host animals influence tick load (Ostfeld & Keesing 2000, Wesonga et al. 2006). As the two seasons are important drivers of tropical drylands, we tested the interactive effects of each of the biological factors and management type with the season. For example, adult animals may face a lower risk of pathogens due to lower tick loads because of their good body condition (Dantas-Torres 2008). We, therefore, expect animals with poor conditions to have a higher tick load than those with good body conditions, especially during the wet season (hypothesis 2). Moreover, lactating female hosts may have poor body conditions due to higher net energy spent on breeding and are more prone to tick infestation than males or non-lactating females. We thus expect females, in general, to have more ticks than males, especially during the wet season (hypothesis 3). Several hypotheses have predicted that calves will carry higher tick loads than adult hosts (Sol et al. 2003, Hawlena et al. 2006), either because (i) adult hosts develop immunity and/or behavioural adaptations to avoid or remove parasites, or (ii) heavily infested calves die before adulthood (i.e. the selection hypothesis). We thus expect calves to have more ticks than sub-adults and adults, especially during the wet season (hypothesis 4).

In many tropical drylands, fences have been widely used to delineate property ownership boundaries and other human activities such as farming, influencing the movement of host species (Odadi et al. 2007, Bond 2014b). For example, studies have shown that large-scale movement of animals during dry seasons (transhumance) searching for scarce water and pasture have increased chances of either spreading or even introducing new tick species in areas, increasing the risks of the spread of diseases (Swai et al. 2006, Chepkwony et al. 2018). Furthermore, in intensively managed production systems, farmers frequently apply chemicals to control tick load in animals. For example, studies in Kenya and Tanzania showed that frequent chemical control of ticks in livestock also benefited wildlife (Keesing et al. 2010, 2013b) and reduced tick densities in vegetation (Kambarage 1995, Swai et al. 2006, Medlock et al. 2013, Allan et al. 2017). Conversely, failure to control ticks has been shown to increase tick load in hosts aggravating the risks of pathogen spread (Riginos & Young 2007, Adakal et al. 2013, Estrada-Peña & de la Fuente 2014). We, therefore, expect lower tick loads in intensively managed systems compared to transhumant management systems, especially during the wet season (hypothesis 5). Given the wide range of determinants potentially affecting tick burden in animal hosts, a clear understanding of the interaction effects of these factors is paramount for their effective control and remains an important knowledge gap in the emerging field of infectious disease ecology (Bond 2014a, Cieslik et al. 2018, Wilcox et al. 2019).

## Materials and methods

### *Study area*

This study was conducted in Laikipia County located at 0°18″ S and 0 °51″ N, 36°11″ E and 37°24′ E in Kenya (Odadi et al. 2007) (Figure 1). The county has an area of ~10,000 $km^2$ with high densities of wildlife and livestock (Keesing & Young 2014). The average annual rainfall in the county varies between 400mm and 750mm, with higher precipitations in the areas bordering the Aberdare ranges and Mt. Kenya (Keesing et al. 2010). The short rains occur in October and November, while the long rains occur from March to May (Odadi et al. 2007). The temperature ranges between 16 $^0$C and 26$^0$C; with the low-lying areas in the north being generally hotter (Odadi et al. 2007). The farms are managed as either open or fenced and their sizes vary and range from a few acres to ≥ 100, 000 acres (Young et al. 2005, Bond 2014b, Allan et al. 2017).

The county experiences regularly high immigration rates of transhumance livestock from pastoral communities such as the Pokot, Samburu, Borana, Turkana and the non-resident Maasai, due to prolonged droughts. Some of the common wildlife species in the area include African elephant (*Loxodonta Africana*), African buffalo (*Syncerus caffer*), black rhino (*Diceros bicornis*), white rhino (*Ceratotherium simum*), eland (*Taurotragus oryx*), impala (*Aepyceros melampus*), common zebra (*Equus burchellii*), Grevy's zebra (*Equus grevyi*), bushbuck (*Tragelaphus scriptus*) and waterbuck (*Kobus defassa*) and lion (*Panthera leo*) (Odadi et al. 2011, Keesing et al. 2013b). Common livestock includes cattle breeds such as are Boran (*Bos indicus*), Aberdeen Angus (*Bos taurus)* and Ankole (*Bos taurus africanus*). Detailed descriptions of common wildlife and livestock in the study area are provided by Young et al. (Young et al. 2005, Odadi et al. 2011).

### *Sampling sites*

We used four sampling sites to collect ticks on animals in Laikipia County, of which two are commercial ranches and the other two are open pastoral grazing areas.

The two distinct livestock management systems in the area differ in the intensity of acaricide applications and animal husbandry, with possible implications on tick infestation levels in animals (Horak et al. 2010). The commercial ranches are Olpejeta Conservancy and Loldaiga Hills Conservancy, while the community areas are Naibunga-Makurian and Segera-Endana (Figure 1). The two commercial properties have well-maintained fences and integrate wildlife conservation and livestock ranching as their core activities. The two community grazing areas are open and allow unrestricted movement of wildlife and livestock (Odadi et al. 2011, Mutavi et al. 2018). These study sites are located in two important movement corridors linking Mt. Kenya to the east and the Aberdare ranges to the west. The two mountain ranges have formed traditional dry season grazing refuges for wildlife and livestock.

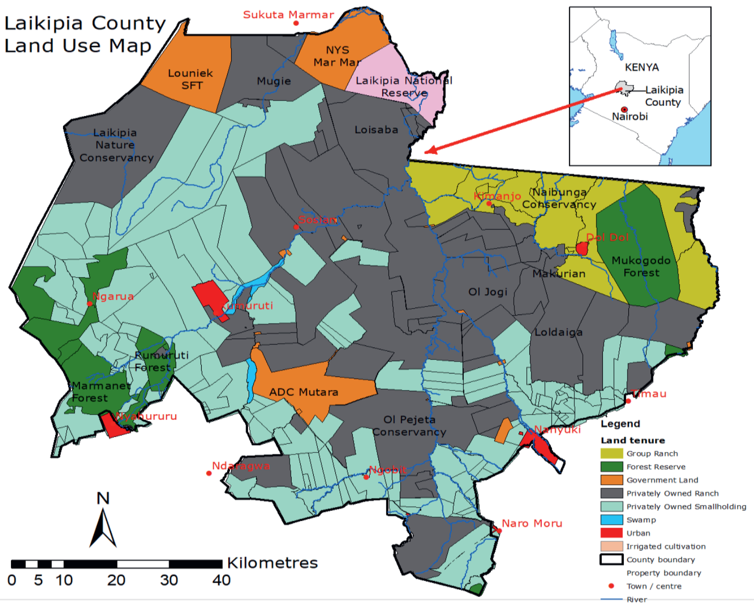



**Figure 1:** Land use map of Laikipia. The study sites were Olpejeta and surrounding areas, Loldaiga and Naibunga-Makurian (yellow) and Segera-Endana (blue) to the north of Olpejeta Conservancy.

***Data collection***

***Host species***

We conducted our study from February 2017 to September 2019 to determine the tick loads in livestock and wildlife. We investigated cattle of different management systems which constitute exotic, cross and local breeds: Boran, Aberdeen Angus and Ankole of different sex, age and body conditions. Besides, we investigated camels (*Camelopardalis dromedarii*). These animals were sampled in spraying races or temporary holding pens in pastoral areas. For wildlife, we collected ticks in black rhino, elephant, lion, Grevy's and Burchell's zebra during wildlife translocation or treatment of sick animals by Kenya Wildlife Service (KWS) veterinary teams. We collected ticks in lions because they have a wide predator-prey relationship with herbivores and may have a variety of ticks from different hosts (Seeber et al. 2019).

Generally, farmers in the area categorise the age of cattle as either: calf (0-9 months), sub-adult (between 9 months - 36 months) or adult (> 36 months). Also, the wildlife hosts were categorised as either calf, sub-adult or adult. Therefore, we estimated the age categories for wildlife species based on their relative withers height for zebra (*E. burchellii*) (Henrichs et al. 2016) and African elephant (*Loxodonta africana (*https://www.elephantvoices.org); whiskers, dental structure and manes appearances in the lion (*Panthera leo*) (http://agingtheafricanlion.org). We used the black rhino monitoring records from Olpejeta conservancy to estimate the age categories for rhino. We scored the body condition of both wildlife and livestock hosts as either poor, fair or good, based on Heinrichs & Ishler (Walker 2003). We treated the management systems as either intensive (fenced areas) or transhumance (open grazing pastoral). We classified the mode of chemical applications as 1) high-pressure spray race nozzles (for intensive management system), 2) portable hand-sprays (for transhumance systems), or 3) none (for wildlife).

***Tick sampling***

Before sampling ticks in cattle, we obtained consent from the farmers and research authorization from KWS. We deployed three collectors and one enumerator to count and record tick sampling details. The tick collectors stood on either side of a spray race or temporary cattle holding pen to optimise tick checking and collection. We examined the ears, brisket (dewlap in the case of cattle), groin region, tail, belly and neck region for the presence of ticks (Ogden et al. 2005). All visible ticks were collected through either hand-picking or the use of a pair of forceps. The tick specimen was then placed in vials with 70% ethanol and labelled. In the labelling of the specimens, we used a unique sample ID, comprising the farm ID or locality, host species/breed and body location. A similar approach was used to collect ticks in tranquilised wildlife.

Since ticks were notoriously difficult to accurately identify in the field, we resorted to temporarily identifying them using their morphology, colour or names used by the local pastoral farmers or workers who are adept at tick species description. The specimens were transported to the KWS forensic laboratory for morphological identification. Tick morphological identification was done using a dissecting stereomicroscope (L500, Lens Incorporation, USA) at the KWS forensic laboratory in Nairobi, Kenya. The identification of ticks followed the available taxonomic keys and the monographs of the ticks of Kenya following the work of Walker et al. (Walker 2003). We updated our data with the correct tick species names.

### *Rainfall data*

We obtained rainfall data from the rain gauges located at the Olpejeta conservancy and Loldaiga Hills Conservancy. The rainfall data were collected daily by the two commercial ranches for routine range management. Since the community areas had no rain gauges, we used rainfall data from the two adjacent conservancies to represent rainfall amounts in the respective community areas. We used the minimum rainfall in the two areas and set the lower limit of < 50 mm of rainfall as 'dry' for two or three consecutive months and > 100 mm as 'wet' over a similar duration.

### *Data analysis*

We used the total number of ticks per host species as a dependent variable. The explanatory variables were a season, sex, age, body condition of the host, and management type for tick control. We first performed an exploratory data analysis following the protocol described in Burnham & Anderson (Anderson & Burnham 2002). We used Poisson Generalized Linear Model ($G_ZLM$) with a log-link function which is appropriate for count data. We tested all the main and two-way interactions of the explanatory variables. Differences between groups were tested using multiple pair-wise comparisons (Sidak test) (Anderson & Burnham 2002)[46]. All analyses were performed in IBM SPSS Statistics 25.

**Results**

A total of 698 domestic and wildlife (577 Boran cattle, 2 Ankole cattle, 11 Aberdeen Angus cattle, 6 Cherokee cattle, 23 camels, 19 elephants, 28 black rhino, 3 lions, 17 Grevy's zebra and 12 Burchell's zebra) were examined for ticks. Of all the animals sampled for ticks, 53.2% were female and 46.8% males, comprising 62.9% adults, 24.1% sub-adults and 13% calves.

In total, 2038 adult Ixodid ticks (female: 1,053; male: 985) were collected. They belonged to three genera: Rhipicephallus (88.4%), Amblyomma (6%), Hyalomma (5.6%). The ticks in the three genera comprised 17 positively identified tick species. The most common species were: *Rhipicephallus evertsi*, *R. pulchellus, R. decoloratus, R. appendiculatus, H. dromedarii* and *H. rhinocerotis*. We also collected rare species: *Rhipicephallus camicasi, R. pravus, H. scupense, R. rufipes, H. lusitanicum* and *R. sanguines*. *Rhipicephallus evertsi, R. pulchellus*, *R. decoloratus*, *R. appendiculatus* and *H. trancatum* were found in almost all the hosts sampled (generalists). *Amblyomma rhinocerotis* and *A. coherence* were specific to black rhino, while *R. camicasi* was specific to a camel. However, *H. dromerdarii* known to be specifically hosted by camel was also found in Boran cattle. The mean number of ticks per animal was 2.9 ± 0.1, regardless of the season (see Figure 2 for the division over the animal species; see the data for the tick species per animal host). As some host species had very low sample sizes, we compared the tick load in all domestic species with all wild herbivore species (zebras, rhinos and elephants). The wild herbivore species had a higher tick load per individual than the domestic species (Mann-Whitney U test: $U = 18825.5$, $N_{wild} = 102$, $N_{domestic} = 596$, $P < 0.001$).

For the remaining analyses, we only considered ticks on Boran cattle as the other species had low sample sizes: 83% of the samples were taken from Boran cattle. Overall, tick load in Boran cattle was significantly higher during the wet than during the dry season. We found a difference in tick load between the animals of poor and good body condition, but there was no interactive effect of body condition and season (Table 1; Figure 3a). Animals with poor body conditions had the highest tick loads. Also, we did not find a difference between females and males or an interactive effect of sex and season on tick load in Boran cattle (Table 1; Figure 3b). We found significant differences in tick load between calves, sub-adults and adult hosts and significant interaction with the season (Table 1; Figure 3c). During the dry season, the adults and sub-adults had lower tick loads than calves. The interaction between season and management type was also significant (Table 1; Figure 3d). The tick load on the cattle on the intensively managed ranches was lower during both dry and wet seasons. Cattle in the transhumant management systems had the highest tick load during the wet season but the difference with the dry season was not significant.

**Table 1:** Results of the Generalized Linear Model (GzLM) for tick load (number of ticks/individual) on Boran cattle as response variables. Each model is numbered. The table specifies for each explanatory variable in the model (including the interaction between two explanatory variables) the test statistic Wald Chi-Square and the corresponding P-values, and the Akaike Information Criterion (AIC). For all models, N = 571.

| **Model** | **Explanatory variables** | **Wald Chi-square** | **AIC** | **df** | **P** |
|---|---|---|---|---|---|
| 1 | Season | 61.96 | | 1 | < 0.001 |
| | Body condition | 48.40 | | 1 | < 0.001 |
| | Season x Body condition | 2.67 | 2527.4 | 1 | 0.102 |
| 2 | Sex | 0.35 | | 1 | 0.550 |
| | Season | 66.02 | | 1 | < 0.001 |
| | Sex x Season | 1.56 | 2649.5 | 1 | 0.211 |
| 3 | Age | 6.18 | | 2 | 0.046 |
| | Season | 39.23 | | 1 | < 0.001 |
| | Age x Season | 9.97 | 2639.4 | 2 | 0.007 |
| 4 | Season | 14.29 | | 1 | < 0.001 |
| | Management system | 35.05 | | 1 | < 0.001 |
| | Season x Management system | 5.41 | 2606.6 | 1 | 0.020 |

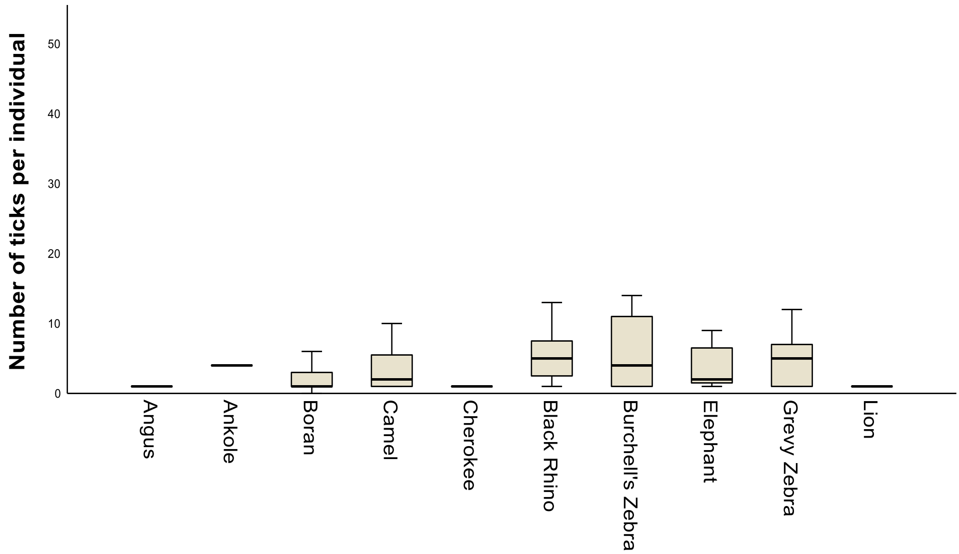
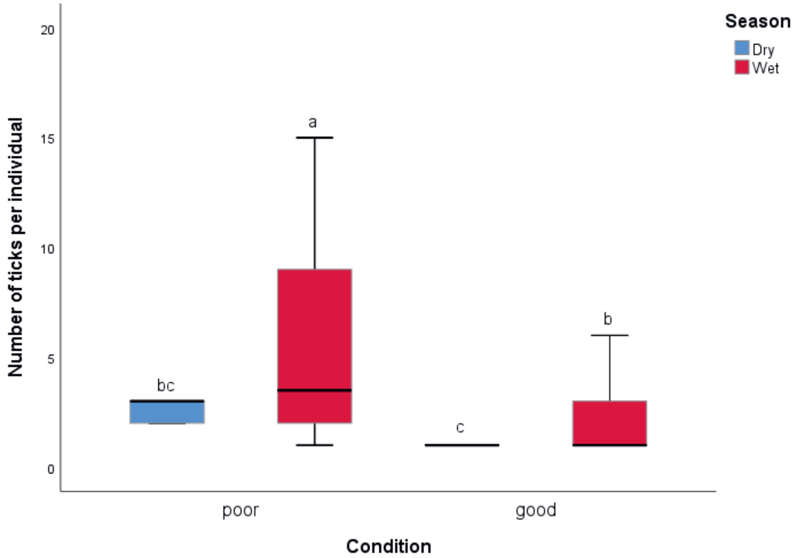
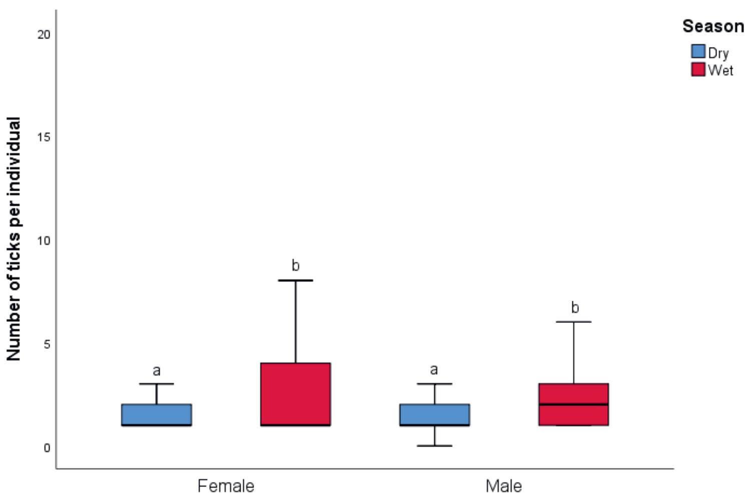



**Figure 2.** Mean tick load per individual for the different host species (Angus, Ankole, Boran and Cherokee are breeds of cattle). The order of the host species is first the livestock and then the wildlife species. For the total number of animals per host species, see the main text. The minimum and the maximum number of ticks per host species were Angus (3 – 20), Ankole (2 – 2), Boran (0 – 39), Cherokee (1 – 2), camel (1 – 13), black rhino (1 -14), Burchell's zebra (1 – 6), elephant (0 – 3), Grevy’s zebra (0 – 43) and lion (1 – 6).

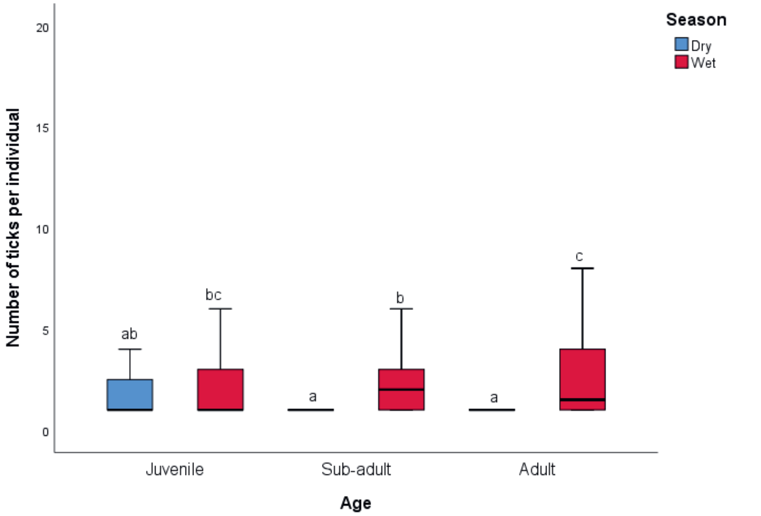
(a)


Season
Dry
Wet
Number of ticks per individual
20
15
10
5
0
a
bc
c
b
poor
good
Condition

(b)


Season
Dry
Wet
Number of ticks per individual
20
15
10
5
0
b
a
a
b
Female
Male

(c)




(d)

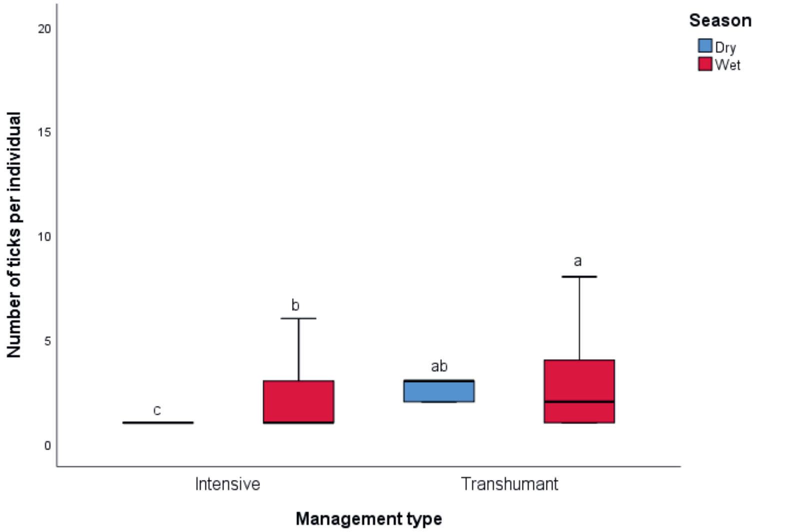



**Figure 3.** Differences in tick load in Boran cattle between (a) body condition and season, (b) sex and season, (c) age and season, and (d) management type and season. Letters indicate significant differences. Bars show mean ± SE.

**Discussion**

Our study aimed to identify tick species in wildlife and livestock and the determinants of the observed tick loads. The analysis of the biological, environmental and human factors determining tick load could only be done for the domestic Boran cattle. We found interactive effects of season, host characteristics (age, sex and body condition) and the management system on tick loads. Tick load in Boran cattle in Laikipia was generally low compared to findings from other areas such as Tanzania (Ogden et al. 2005), Ethiopia (Kemal et al. 2016) and Uganda (Mugisha et al. 2008). This could be attributed to the massive application of acaricides by some farmers in Laikipia. For example, a high prevalence of up to 82% of Ixodid ticks was reported in domestic transhumance cattle from different parts of Ethiopia (Kemal et al. 2016). The high tick infestations in many parts of Ethiopia is also attributed to poor tick control strategies and the large-scale transhumance movement of livestock in search of water and pasture during the dry season (Kemal et al. 2016). The relatively low tick loads in our study seem to align with other studies in the study area that found low tick count in the vegetation (Allan et al. 2017). We acknowledge that visual inspection may be limited; to prevent this as much as possible, we conducted pre-counting inspection and validation to ensure consistency in counting and observer bias. Moreover, we used domestic animal herders who are adept at tick observation. Although we found relatively low tick loads on the host species, mortalities due to tick-borne diseases are considerable (Chepkwony et al. 2020).

The results of this study suggest that there were more ticks on Boran cattle during the wet season (support for hypothesis 1), especially the animals with poor body condition in the wet season had a high tick load (support for hypothesis 2). The wet season conditions in tropical drylands are characterised by moderate to high rainfall intensity, increased humidity, increased vegetation cover and increased presence of suitable hosts (Ogden et al. 2005, Medlock et al. 2013). The wet season conditions provide more conducive micro-climatic conditions for the mass reproduction and distribution of ticks in hosts than the dry season (Cumming 1999)[6]. Chepkwony et al. (2020) describe that cattle mortalities due to tick-borne diseases (East Coast fever or anaplasmosis) are higher during the wet season after a few months of drought. The months of drought lower the body condition of the animals due to limited forage and water, exacerbating their tick loads, resulting in mortalities (Poulin 1993, Ogden et al. 2005, Swai et al. 2006). In contrast, VanderWaal et al. (2017) found out in Kenya that the parasite load such as ticks, fleas and mites were more often shared at watering points during the dry than wet season (Randolph 2004, Ogden et al. 2005). Seasonality and body condition are important determinants for tick loads in animals due to the biology and behaviour of the ticks and their hosts, impacting on pathogen transmission (Ogden et al. 2005, Swai et al. 2006, Wesonga et al. 2006, Hart & Hart 2018).

Sex-biased differences in parasite intensity are commonly observed (Hart & Hart 2018), with studies suggesting that males are often more likely to come into contact with ticks than females due to behavioural or physiological differences, as exemplified in chipmunks (Keesing et al. 2010, Kiffner et al. 2013), and domestic cattle in Ethiopia (Kemal et al. 2016), and rodents (Kiffner et al. 2013). These findings are in contrast to our findings that we did not find differences in tick loads between females and males, regardless of season (in contrast to hypothesis 3). In contrast to the absence of differences between males and females in Boran cattle, calves had high tick loads during both the wet and dry season, whereas the sub-adult and adult cattle had less ticks during the dry season (support for hypothesis 4). Several hypotheses (Sol et al. 2003, Hawlena et al. 2006) predicted that calves will carry heavier tick loads than adult hosts, either because (i) adult hosts develop immunity and/or behavioural adaptations to avoid or remove parasites; and/or (ii) heavily infested calves die before adulthood (i.e. the selection hypothesis).

Cattle on the intensively managed ranches had a lower tick load than the transhumance management system (support for hypothesis 5). The intensive management systems use acaricides (Horak et al. 2010, Mugambi et al. 2012) and generally have fences to limit host movements that reduce tick loads in cattle. Conversely, transhumance which is an important adaptation for pastoralist communities in tropical drylands has been shown to positively influence parasite spread and disease dynamics (Keesing et al. 2013b), as livestock from surrounding areas may probably import ticks (Allan et al. 2017, Mutavi et al. 2018). The results of this study thus provide empirical evidence that tick loads in animals at intensive management systems had lower tick loads than those in transhumant management systems.

To our knowledge, this is one of the few studies in tropical drylands that has quantified the role of season, biological factors, management type and their interactions in determining tick loads in animal species. To develop models that can be used to predict, design or implement tick control measures and mitigate future TBDs infections, there is a profound need to better understand the interaction effects of these biological, human and environmental factors on tick load in hosts (Allan et al. 2017, Cieslik et al. 2018, Wilcox et al. 2019). The findings of this study increase our understanding of tick-host-pathogen interactions, a fundamental prerequisite for their effective control. The findings highlight the importance of establishing effective control of ticks in livestock in transhumant management systems as tick loads were high in both wet and dry seasons. For effective control of ticks in tropical drylands, we need an integrated approach that includes the involvement and coordination of farmers, veterinary officials, wildlife managers, environmentalists, acaricide manufacturing companies and chemical regulatory authorities. The integrated approach may increase the space for information and knowledge sharing, which may enhance the decision-making process by farmers and other actors for effective tick control under the prevailing human and environmental conditions in an area.

**Acknowledgements**

The authors would like to thank Victor Chira, Duncan Wangomi and Simon Ndungu and Dr Matthew Mutinda of the Kenya Wildlife Service (KWS), Joseph Mathenge of Olpejeta Conservancy and Richard Tonui of Loldaiga Hills Conservancy for their participation in the tick sampling process. We thank the farmers' Veterinarians and KWS Capture and KWS Forensic Laboratory teams and the Office of Directorate of Veterinary Services-Kenya, for allowing Mr Samuel Matheka to lead the tick identification process at KWS forensic laboratory.

## Chapter 4

# Citizen science for development: Potential role of mobile phones in information sharing on ticks and tick-borne diseases in Laikipia, Kenya

Richard Chepkwony, Severine van Bommel & Frank van Langevelde

Published in *NJAS-Wageningen Journal of Life Sciences,* 2018, 86-87: 123-135

***Abstract***

Ticks and tick-borne diseases (TTBDs) constitute a lethal and widespread problem in many tropical areas, with major ramifications for livestock production, wildlife management, human health and livelihoods. Despite various control strategies applied, TTBDs remain a complex problem, and integrated approaches must be developed to control them effectively. To address this problem, Wageningen University and Research established an interdisciplinary project in 2015 – Environmental Virtual Observatories for Connective Actions (EVOCA) – that focuses, among other things, on mobile phone-based information-sharing platforms for TBDs in Kenya. This study in Laikipia, a semi-arid savanna area of Kenya, is designed to (i) identify issues that complicate effective TTBD control, (ii) explore whether and how local people use mobile phones to address problems, including TBDs, and (iii) reflect on what citizen science can contribute to the development of mobile phone-based platforms for TBDs. The study, conducted between November 2016 and August 2017, adopted a mixed-methods approach comprising 21 interviews, field observations, document reviews, and a workshop. Results suggest that the TTBD problem is compounded by a combination of local issues. Insecurity, human-wildlife conflicts, and occurrences of notifiable zoonotic diseases are among the most pressing issues that affect people and influence the kind of information that they share using mobile phones. The motivation to share information on insecurity and human-wildlife conflicts stems from the urgent need for people to collaborate and facilitate prompt action by the security agencies and expectations of compensation from the government for wildlife damages, respectively. The mobile phone adoption rate in Laikipia is ~70%, suggesting that mobile phones (simple and smart) are widely used for various socioeconomic

activities: to communicate with family members and friends and to access information on pressing issues, forming issue-based networks of communication. The widespread use of mobile phones for economic activities such as businesses and banking services have empowered people economically, improving their livelihoods, whereas those without access are probably excluded (disconnected). This study suggests that, despite the widespread adoption of mobile phones, sharing information on TBDs does not seem to be a major priority for Laikipia residents, as other issues such as insecurity or human-wildlife conflicts take precedence. The design of mobile phone platforms and citizen science for TBDs should consider such confounding factors to connect with the issues affecting local people.

**Keywords***: EVOCA, Insecurity, Human-wildlife conflicts, Diseases, Empowerment, Mobile phones.*

## 1. Introduction

Ticks and tick-borne diseases constitute one of the most lethal and widespread problems in many tropical areas, with major ramifications for livestock production, wildlife conservation, and human health (Bengis, Kock, & Fischer, 2002; De Castro et al., 1997; Gachohi et al., 2012; Minjauw & McLeod, 2003). TTBDs such as East Coast fever (ECF), Bovine babesiosis and Anaplasmosis, among others, constitute 10–80% of the pathogenic infections causing severe mortalities in humans, wildlife and livestock (Cleaveland, Laurenson, & Taylor, 2001; Estrada-Peña & Salman, 2013; Jongejan & Uilenberg, 2004). TTBDs may also reduce milk and beef production by 40–50% or lower the quality of skin meant for commercial purposes (Jonsson, Mayer, Matschoss, Green, & Ansell, 1998; Norval, Sutherst, Kurki, Gibson, & Kerr, 1988). In areas where wildlife and domestic co-occur, the spread of TBDs is aggravated due to increased mobility and spread of ticks, increasing the potential risks of disease transmission (Gachohi et al., 2012; Keesing, Allan, Young, & Ostfeld, 2013). Moreover, when wildlife is perceived to be involved in the disease transmission process, human-wildlife conflicts often occur to the detriment of conservation efforts (Benka, 2012). Human-wildlife conflict refers to the negative consequences of the interfaces between people and wildlife, often characterised by human deaths, injuries, crop and property destruction (Kiringe, Okello, & Ekajul, 2007; Okello & D'amour, 2008), and transmission of diseases (Benka, 2012). If uncontrolled, TTBDs, therefore, remain a threat to human health, food security, and cultural wellbeing, and they negatively affect relationships between farmers and conservationists.

In the eastern and southern Africa region, some widely applied TTBDs control strategies include the use of chemical acaricides (Minjauw & McLeod, 2003; Mugambi, Wesonga, & Ndungu, 2012), burning of vegetation to reduce tick loads (Goodenough et al., 2017; Trollope, 2011), and keeping livestock thought to be resistant to tick attack, such as Boran cattle (Gachohi et al., 2012). However, cases of tick resistance to chemical acaricides have been reported (Mugambi et al., 2012). Despite all these control strategies applied in the region, TTBDs continue to be a major problem, and integrated approaches must be developed to control them effectively (Gachohi et al., 2012; Mugambi et al., 2012). To address this problem, Wageningen University and Research established an interdisciplinary project in 2015 – Environmental Virtual Observatories for Connective Actions

(EVOCA) – that focuses, among other things, on mobile phone-based information-sharing platforms for TBDs in Kenya. Such integrated approaches may include collaboration and collective actions by many stakeholders directly or indirectly involved in TTBDs control, necessitating a robust means of information sharing and coordination, which may be addressed using mobile phones and other ICT-based tools (Cieslik et al. 2018, Leeuwis et al. 2018). Generally, mobile phones have become new methods for engaging participants through technology, and provide unprecedented ways for participants to have immediate access to their own and others' observations, fostering effective information sharing (Graham, Adams, & Kahiro, 2012; Now & Nominations, 2011). Because of the utility of mobile phones, there is an urgent need to explore how this technology may be leveraged to address the TBDs problem.

To effectively coordinate and enhance the collaborations of many stakeholders with divergent views, interests, and perceptions, innovative approaches are critical to improve monitoring, offer extension services, and improve data or information sharing. The advent of the mobile phone and its widespread adoption and usage in many developing countries in African, such as Kenya, coupled with emerging information sharing approaches such as citizen science (Haklay, 2010), could offer a promising pathway to such efforts. To date, most citizen science approaches are well developed and embedded in Europe and other developed countries where mobile phones and citizen science approaches have increased knowledge and understanding of, for example, biodiversity distribution, disease surveillance, and interventions (Haklay, 2010). The term *citizen science* which is also referred to as environmental or participatory monitoring is used here to describe public engagement in scientific activities of collecting and disseminating data-driven by a social conscience (Haklay, 2010). In developing countries in Africa, the citizen science approach has just started and is gaining traction. For example, in Kenya and Tanzania, human-wildlife conflicts are monitored and reported voluntarily, either directly or indirectly by the affected citizenry (Graham et al., 2012). However, to embed citizen science in developing countries, there is a need to understand various issues that may negatively impact the approach, including the existing information-sharing culture in an area.

The advent of citizen science approaches and the advent of mobile phones could be leveraged in tackling complex environmental and agricultural problems such as

TTBDs that have remained a serious threat to human health, food security, and the cultural well-being of many people, especially rural poor pastoralists relying on livestock production. The Environmental Virtual Observatories for Connective Actions (EVOCA) programme of Wageningen University and Research established in 2015 seeks to explore the potential role of mobile phones and citizen science approaches in addressing several another complex environmental and agricultural problems in six case studies in Africa to transform the development landscape. The TBDs on which we focus in this paper is one of those case studies. EVOCA in Kenya is envisaged to be developed by using an inclusive virtual platform for information sharing that enables effective mapping of the situation, linked to a participatory process that fosters collective action (herein connective action) for effective TBD control (Cieslik et al. 2018). The assumption is that mobile phones and related technologies can be used for collective action – in light of the current lack of information and knowledge sharing, which is perceived to be one of the causes of poor control or eradication of diseases (Allen, 2015; Gustafson et al., 2015). The reasoning is that, in developing countries, formal organisations involved in addressing problems such as TBDs are often weak and lack sufficient capital or suffer from a lack of resources either to effectively control or provide elaborate extension services or to conduct long-term research (Minjauw & McLeod, 2003). Citizen science approaches can empower local people to bypass the need for such formal systems, thereby fostering collective action (Cieslik et al. 2018, Leeuwis & Aarts 2020). This warrants a critical examination of the views, perceptions, and information sharing the culture of all stakeholders involved in the TBDs problem to identify areas where ICT-based innovations can be embedded. In this paper, we address the main research question: what is the potential role of mobile phones for sharing information on TBDs?

In this paper, sections 1 & 2 provide an introduction and the conceptual framework in which this study was anchored, while section 3 provides the methodology that was used to collect and analyse the data. In section 4, we provide the results of our study with the historical perspectives of land ownership and rights issues in Laikipia, setting the scene of how it affects the dynamics of the issues of concern such as (in)security, human-wildlife conflicts and diseases, including TBDs, and how it shapes the communication landscape in the area. In section 5, we reflect on the implications of the dynamics of the issues of concern identified on the citizen science (EVOCA) for TBDs in Kenya.

## 2. Conceptual framework

In this technological era, the envisioned citizen science platform in Kenya links up to a broader trend in research and practice in which increasingly development interventions are taking advantage of perceived possibilities offered by the digital age, such as the use of mobile phones and other ICT-based infrastructure. A promising example of how development is anchored through digital innovations includes e-agriculture, where farmers, for instance, share information on the control of pests and diseases, the market produces, and share knowledge on the best agriculture practices to further improve their productivity (Mwabukusi, Karimuribo, Rweyemamu, & Beda, 2014; Temba, Kajuna, Pango, & Benard, 2016). Other examples include extreme citizen science projects where pygmy hunter-gatherers in the Congo Basin, although unable to read the numbers on banknotes or write their names, have begun to use handheld computers attached to global positioning systems (GPS) to monitor illegal logging and poaching in their territories (JD Lewis, 2007; Jerome Lewis, 2012; Jerome Lewis & Nelson, 2006; Vitos, Lewis, Stevens, & Haklay, 2013); and, while sharing information, the local people and other entities create networks of communication that can be harnessed to collaboratively improve local resource management (Mwabukusi et al., 2014; Roy et al., 2012). Citizen science for development is thought to hold the promise of empowering local people, opening up possibilities for democracy through participation, and increasing the accountability of governments (Hellström, 2008, 2011) and non-governmental organisations (NGOs) (Lewis & Madon 2004). Thus, mobile phone-based citizen science for development might be envisaged as a potential *technology of humility* that may be used to spur public participation and the intellectual environment to collectively address common problems affecting people (Jasanoff, 2003a, 2003b).

In thinking about the African digital public sphere, postulations of what ICTs and citizen science might mean for African societies frequently draw on modernisation paradigm shifts about the development concept, with development organisations, such as the World Bank (Cohen, 2012), FAO (2001), or Flora and Fauna International (Banks & Burge, 2004) advocating ICTs and mobile phone technology for local people in developing countries to deal with rapid environmental and social change. Looking more closely into these arguments, we find that many reflect a linear, apolitical, and historical discourse on innovation and social change and neglect the social processes and power relations that are inherently part of any innovation and social change process (Dormon, Van Huis, Leeuwis, Obeng-Ofori, & Sakyi-Dawson, 2004; Kline & Rosenberg, 1986; Leeuwis, 2004; Rip, 1995; Rip, Misa, & Schot, 1995; Roling, 1988; Stuiver, Leeuwis, & van der Ploeg, 2004). Further literature reviews indeed showed that, in some cases, citizen science and ICT technologies have unintended and unforeseen negative consequences in developing countries, such as exacerbating existing classed or gendered power relations (Britwum, 2009; Chiumbu, 2012; Etzo & Collender, 2010; Orloff, 2009). So, instead of being a technology of humility, in some cases citizen science for development might become a *technology of domination* that reproduces or even exacerbates existing inequalities or negative consequences of the technology, making it necessary to take a critical look at the environment and the potential role of transformative ICT-based tools and processes such as citizen science.

The anticipated citizen science-based EVOCA in Kenya is intended to enable information sharing and to facilitate learning to foster collective action on TTBDs amongst many stakeholders. These stakeholders have varying degrees of policy, technological, institutional, and organisational issues or power relations that often impede effective control of TBDs. In this context, there is a need to understand all these complexities affecting society and the direction of the transformative power of information sharing using mobile phones through citizen participation. To investigate this, we used RAAIS which is an integrated diagnostic toolkit that has been developed and successfully used to unravel complex issues affecting environmental or agricultural systems and innovations such as pests, diseases, and stakeholder collaborations. For instance, this approach was used to address the control of rice parasitic weeds in Tanzania and Benin, and in the Research Program on Integrated Systems for the Humid Tropics (Hounkonnou et al., 2012; Schut et al., 2015). Essentially, the RAAIS framework has generally identified complex environmental or agricultural problems as either affected or influenced by technical, economic, sociocultural, or political issues, making them difficult to solve (Hounkonnou et al., 2012; Leeuwis & Aarts, 2011; Schut et al., 2015). Because the TBDs may be compounded by other issues such as land ownerships and management regimes, economic or cultural issues relating to animal husbandry, disease management policy, and stakeholder collaboration, we adopted the RAAIS approach to analyse our data (Schut et al., 2015). Following RAAIS, we started by investigating the historical context of land ownership issues to set the scene for understanding the complexity of the TBD problem. We then explored the biophysical, technological, sociocultural, economic, institutional and political dimensions of the TBD problem. We also explored 1) what people identify as a pressing issue of concern; 2) their perception of the cause of the problem; 3) the perceived solutions; 4) how people communicate about these issues as they strive to manage them while considering the role of mobile phones in this respect. Last but not least, we analysed the mobile phone adoption and the changes in the communication landscape. This diagnostic study gave us insights into (i) identifying various issues complicating the effective control of TBDs, (ii) explore whether and how people in the area use mobile phones to address problems, including TBDs, and (iii) reflect on what we can expect of the promises of citizen science for the development of mobile phone platforms for addressing TBDs.

## 3. Materials and methods

### *3.1 Study approach and design*

We conducted this study in the semi-arid savanna area of Laikipia, Kenya, located at 0°18″ South and 0 °51″ North, 36°11″ and 37°24′ East (Fig. 1). The county covers ~10,000 $km^2$, with an estimated human population of ~ 520,000, and relies mainly on wildlife conservation, livestock production and crop farming (Kenya National Bureau of Statistics 2019). The many resource-poor pastoral communities living in remote areas are characterised by poor transport and communication, and perhaps require an effective means of information sharing for their livelihoods. The county has a huge assemblage of wildlife and livestock, a recipe for the spread of diseases, with major ramifications for livestock production and wildlife conservation (Keesing et al., 2013; Odadi, Karachi, Abdulrazak, & Young, 2011). The complexity of the activities in the area has attracted many stakeholders involved in various issues related to security, conservation, or livestock production. Some of the major organisations include Kenya Wildlife Service (KWS), Ministry of Agriculture, Livestock Development and Veterinary Services, International Livestock Research Institute (ILRI), The Institute of Primate Research, The Centre for Disease Control, local and international research institutions, and extension service providers. Despite the efforts of many stakeholders, TBDs continue to be a major challenge to many farmers in the area, and there is a critical need to explore the extent of the problem and to determine the potential of mobile phones for information sharing to address the problem.

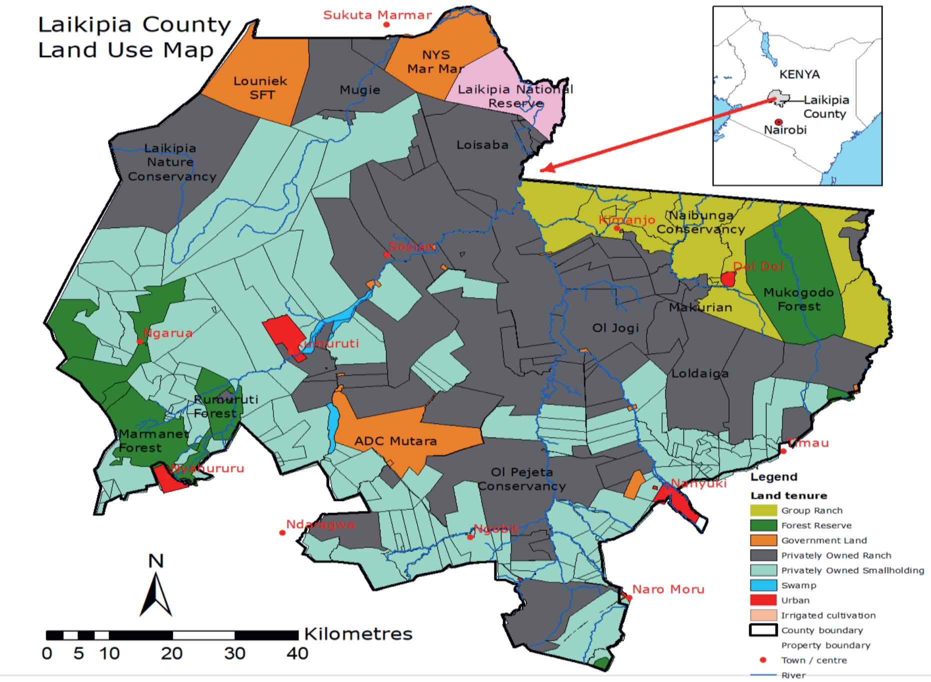



**Fig. 1** Map of Kenya showing the location of Laikipia County with various forms of land uses (**Source**: Space for Giants, 2018). There are over 41 private, government or local community-owned ranches in Laikipia. NYS stands for the National Youth Service, while ADC=Agricultural Development Corporation and SFT= Settlement Fund Trustee.

Prior to the study, we conducted a reconnaissance survey in the study area between October and December 2016. The objectives of the reconnaissance study were three-fold: to (i) gauge and understand the extent and the dimensions of the issues underlying TBD control, (ii) identify the stakeholders involved in TBD control and (iii) purposefully select informants for the in-depth interviews and possible translators. We used the results of the reconnaissance study and the outcome of workshop proceedings to develop themes that were used to conduct in-depth interviews. We also conducted an extensive literature review before and during the reconnaissance study to gain insights into various issues underlying the TTBD problem. As the involved stakeholders emanate from organisations, farmers, and extension service providers operating at various levels in different parts of the study area, we used a multi-stage sampling protocol.

Being interested in general issues surrounding TBD control, the information-sharing culture, and stakeholder collaboration in the area, we used ethnographic methods such as in-depth interviews, field observations, and document reviews (Baxter & Jack 2008, Yanow 2009, Paschen & Ison 2014), as opposed to random sampling protocols (Bowen, 2008). The choice of these ethnographic methods was premised on the general understanding that how people 'story' their past experiences and actions will ultimately determine their future practices and adaptation towards problems (Yanow, 2009). Informed by the reconnaissance study and the workshop, we identified and broadly classified the stakeholders responsible for TBD control as either: governmental or non-governmental agencies, smallholder agro-pastoral farmers, large-scale commercial farmers, and private extension service providers commonly referred to as agro-veterinarians (agro-vets). We used the stakeholder classification to systematically and purposefully select interview informants at two levels (i) stakeholder category and (ii) localities in which the identified stakeholders operate: in general, rural or remote agro-pastoral areas, urban centres, or large-scale commercial ranches.

### *3.1.1 Workshop*

Because of the central role of this study and the EVOCA project in the area, the first author was nominated by KWS to attend a stakeholder workshop in November 2016, dubbed The Laikipia County One Health Initiative. The overall objective of the workshop was to bring all stakeholders together to develop a common approach to address zoonotic and TBD problems in the area. The workshop was instrumental in shaping this study because (i) it elucidated the TTBD problem and shaped the interview approach, (ii) it included stakeholders involved in the management of disease problems, (iii) it identified the agro-pastoral farmers as forming the critical pool of those affected by zoonotic diseases, including TBDs,

(iv) it led to the formulation of the way forward, and action plans prepared after the workshop provided contacts and opportunities for future stakeholder engagements. Some of the data used in this study were derived from the information garnered at the workshop.

### *3.1.2 In-depth interviews*

Informed by the reconnaissance study and the informant selection protocols, the in-depth interviews were conducted between January and August 2017. The interviews were conducted using a dialogue approach and revolved around a set of discussion points identified. A total of 24 individuals from the various stakeholder categories identified were approached to take part, and 21 respondents consented, with each interview taking one and half hours on average. Two women and one man from the agro-pastoral communities declined to be interviewed citing personal or family issues. Because the emphasis of this study was on obtaining quality information from the in-depth interviews rather than on quantity, we maximised the diversity of the respondents representing the various stakeholders identified. The dialogue revolved around thematic issues such as informant characteristics (age, occupation, locality), land ownership and security issues, human-wildlife conflicts, animal diseases, TBD control practices, among others.

To derive a clear picture of the information-sharing culture in the area, informal discussions were tailored to include discussions on people, events, and timelines of various issues or activities that either directly or indirectly affected them and their perceived solutions. Informant characteristics such as age (young/old), sex, income (poor/rich), locality, or occupation were deemed important as they reflect the diversity, influence stakeholder collaboration and power relations, and inform the local information-sharing culture (De Bruijn 2009, Etzo & Collender 2010, Graham et al. 2012).

The respondents comprised local nomadic pastoral herders (*n=10*), commercial ranch managers involved in either livestock or wildlife conservation initiatives (*n=4*), government officials involved in livestock extension activities (*n=3*), and agro-vets (*n=4*) involved in the sale of livestock vaccines and pesticides such as acaricides in Laikipia county. The age of the respondents ranged from 19 to 59 years, and their education level varied from illiterate (never attended school) to tertiary (university level and others with professional qualifications in veterinary, animal health, and social development work). Agro-vets interviewed were mostly located in urban centres where their shops or offices are located. The local community leaders such as the chiefs were also interviewed as they form an important policy link between the local governmental and non-governmental agencies responsible for addressing various issues that affect people in the area.

The interviews were conducted primarily in English, but, when the interviewee could not adequately communicate in English, they were conducted in either Kiswahili or a local dialect to avoid loss of indigenous knowledge or information through the respondent's inability to communicate in the English language. Because the interviews took a long time and exhausted the memory of the Philips Inc. MP3 recorder, the interviews were instead recorded in a field notebook as "statements" from the respondents. The decision on the optimal number of respondents was based on the quest to obtain diverse stakeholders up to the point at which no new information was observed in the data (Bowen 2008, Ness 2015). The dialogue approach was preferred as it enabled the researchers to learn and reflect on the issues being discussed and allowed the informants to provide information that could be perceived to be either socially, institutionally, or politically sensitive. To address confidentiality issues, the informants' names were anonymised for ethical reasons. The interview notes were later analysed using qualitative approaches.

### *3.1.3 Participant observations*

To learn about the activities of the stakeholders in their natural settings, we accompanied some agro-pastoral farmers on four (4) occasions, each taking a day, while on their routine activities such as herding livestock (e.g., cattle, sheep, goats, and camels), purchasing products at agro-vet stores, or spraying their livestock with acaricides. This approach also enabled us to interrogate some of their activities to gain more insights, which might not be possible without participation. We took some photographs of the activities in which we participated.

### *3.1.4 Archival document review*

To gain a greater understanding of the various topical issues in our study and to corroborate the information obtained from other approaches, we reviewed ~70 published documents obtained via the Google Scholar search engine and ~10 unpublished documents. The unpublished documents comprised wildlife and livestock management plans, farm records, diseases and epidemiological reports, and websites of telecommunication companies such as Safaricom Plc, Airtel-Kenya, and Telkom-Kenya. A review of these documents followed Bowen's (2008) guidelines.

### *3.1.5 Data analysis*

As we were interested in unravelling the extent of the TTBD problem and issues complicating its effective control, we adopted the framework and guidelines of the Rapid Appraisal of Agricultural Innovation Systems (RAAIS) (Schut et al. 2015). Our data were primarily qualitative, and therefore we classified the datasets from the informant interviews, field observations, document reviews, and workshop into various dimensions that characterise complex environmental or agricultural problems. Using RAAIS, we developed a matrix where we classified the issues that affect people in the area, including TTBDs (complexities) and their dimensions, to also identify necessary information gaps where innovations such as mobile phone usage might be embedded to address the problem.

## 4. Results

### *4.1 Historical perspectives of land ownership and issues in Laikipia, Kenya*

Land ownership and land rights in Kenya became a fundamental political and economic issue after the country's independence from Britain in 1963, with implications for various issues such as security for humans and animals, human-wildlife conflicts, and disease transmission, including TBDs. During the pre-colonial period, land in many areas in Kenya, and particularly in Laikipia, was primarily managed as communal property by nomadic pastoral communities who traversed the vast semi-arid county herding their livestock. The human population in the area at that time was composed of small pastoral communities, mostly reliant on livestock nomadism (Letai, 2011; Mizutani, Muthiani, Kristjanson, & Recke, 2005). Culturally, nomadic pastoral communities such as Maasai, Samburu, Turkana, and Borana traversed the various counties unrestricted in search of pasture and water for their animals, especially during the dry season (Bond, 2014a; Lengoiboni, Bregt, & van der Molen, 2010; Lesorogol, 2003). They probably had sufficient pasture and water for their animals. Land ownership and boundaries in pastoral areas were defined by tribal or ethnic groupings, kinships, and family lineages (Lesorogol, 2003; Osamba, 2000).

However, during the struggle for, and the partition of, Africa by European powers around the turn of the twentieth century, British imperialists in Kenya, either forcibly or through agreements such as the British–Maasai agreement of 1904, removed the pastoral Maasai, Borana, and Samburu communities from the greater Rift Valley region, including from the Laikipia, Samburu, and Isiolo areas (Hughes, 2015). In the process, many nomadic pastoral communities lost access to their ancestral grazing areas, affecting their culture. For example, some members of the Maasai community, ostensibly those perceived to be hostile to the settlers' establishment, were moved from Laikipia to the southern part of Kenya, in the present-day Maasai Mara, an area that extends into the Serengeti Plain, which is located mainly in Tanzania (Hughes, 2015). The land annexation and adjudication that followed led to the delineation of land ownership boundaries and the establishment of large-scale commercial farms commonly referred to as ranches.

When Kenya won independence from Britain in 1963 and following the subsequent return of many British settlers to Europe, the new government in Kenya began to nationalise land and re-distributed vacant parcels to indigenous communities. The new arrangement was hailed by many Kenyans as a nationalistic move, but these schemes were soon criticised by others for putting the vacant parcels of land in the hands of a few well-connected political elites (Letai, 2011; Syagga, 2011). In Laikipia for instance, most local nomadic pastoral herders were settled on small landholdings in the west or remained landless. In this process, group ranches in Laikipia county such as Tiemamut, Lekurruki, Koija, and Ill'Ngwesi, in Laikipia North, were collectively allocated to the remaining Maasai, and the remaining parcels were retained by the white settlers (Bond, 2014a; Letai, 2011). Large-scale commercial ranches legally held by settler farmers under a 99-year lease agreement with the government of Kenya form the main ownership type and vary in size from ~ 5000 and 100,000 acres (Letai 2011).

The rapid population increase in Laikipia after independence had serious implications such as dwindling land parcel sizes and reduced pasture for water and animals. Land ownership, therefore, became a pressing political mobilisation tool in Laikipia. In Kenya, three major forms of land tenure systems are recognized by the Kenyan laws: public, communal and private properties. The proof of land ownership is a sacrosanct document-title deed (Letai, 2011). The land tenure systems and rights often influence the various land uses in Laikipia. Because the immigrant communities are in pursuit of pasture and water for their animals, they move and invade private, public and communal land, and without land ownership documents, it constitutes illegality. The loss of grazing areas reduced the pastoral communities' ability to make their livelihood. Because of political agitation, the increasing human population, and poor access to social and economic activities, some communities resorted to illegal invasions of private and government land, resulting in increased insecurity. Insecurity in this context is defined as a bridge of peaceful co-existence amongst people in an area and is sometimes characterised by violent conflicts alternating with negotiated settlements (Bond, 2014a). Insecurity and large-scale movements of livestock in the area have also led to increased human-wildlife conflicts due to the displacement of wildlife from their habitats, and as a consequence, it promotes the spread of TBDs (Keesing et al., 2010). Land ownership and rights, and mobility of wildlife and livestock, have aggravated the complexity of security, human-wildlife conflicts, and disease transmission.

Most of the informants cited and ranked the lack of security, which is often characterised by private land invasions by nomadic pastoral communities and cattle rustling, fear of attack and damage by wildlife, and the transmission of notifiable diseases as the most pressing local issues. They reported that land invasion normally increased during the dry season when pasture and water are scarce, that armed invaders often moved around with large herds of animals, and that they constantly lived in fear of possible attacks by them. The residents also complained that, because of huge assemblages of wildlife in the area, they also feared attacks from wildlife resulting in human death or injuries, crop and property damage, and transmission of diseases to humans and their livestock. The residents of the area cited diseases such as foot and mouth, brucellosis, rabies, and ECF as the most common diseases spread from wild and livestock. The TTBD issue, despite being a problem, did not feature prominently in their discussion as they were often preoccupied with the identified issues of concern that takes precedence amongst the local people and were more often talked about and shared information about them because they wanted them addressed by the government or other relevant stakeholders. The informants also suggested solutions to these issues (Table 1). These issues will be elaborated successively in the preceding sections of this paper.

### 4.2 Descriptions of the TBD problem and challenges in Laikipia, Kenya

Although TTBDs did not appear to be the most pressing issue for the residents, we explore the extent of the problem dimensions of TTBDs, their challenges and their perceived solutions derived from the interviews, field observations, and document review (Table 2).

#### *4.2.1 Biophysical dimensions*

Biophysical characteristics refer to either biotic or abiotic factors that make complex agricultural problems such as pests and diseases difficult to control (Schut et al., 2015). Biotic and abiotic factors such as the massive reproduction of ticks, resilience to hostile environments (extreme temperature, humidity, and vegetation), and their multiple species and multi-host and pathogen adaptations (Keesing et al., 2010; Medlock et al., 2013; Riginos et al., 2012) make TTBDs a complex problem to solve. Interviews with agro-pastoral farmers, large-scale commercial farmers, and livestock and veterinary extension officers revealed that agro-pastoral farmers, despite their experience with pastoralism, have limited or vague knowledge on TTBD ecology compared to either the large-scale commercial farmers or the extension officers. Because of their limited understanding of TTBD characteristics, we observed that agro-pastoral farmers infrequently applied acaricides, ignored prescriptions on acaricide usage, and kept large numbers of livestock without corresponding farm inputs. Agro-pastoral farmers, unlike large-scale commercial farmers, mainly took action when ticks were visible in their adult stages and full engorged, ignoring other critical life stages. From their long-term experience with livestock and wildlife issues, agro-pastoral farmers could vaguely identify tick species based on their morphology and body colour. Large and small-scale farmers in the area seem to understand the relationship between common invasive plant species such as *Opuntia stricta* and the spread of TBDs. Invasive plant species generally attract foraging tick hosts and increase their interfaces, aggravating TBD transmission. Unlike large-scale farmers and other officials, agro-pastoral farmers interviewed showed either a limited understanding of or complicity in, land-use practices such as land invasions in which fences and barriers are breached, affecting host movements and TBD transmission. All informants generally acknowledged tick resistance to acaricides and often changed brands to enhance their efficacy. Farmers were also aware that indigenous breeds of livestock such as Boran cattle were probably more resistant to TBD attacks compared to exotic breeds such as Friesian or Guernsey. Unlike large-scale farmers, agro-pastoral farmers blamed wildlife more for the spread of diseases.

**Table 1: Overview of identified issues of concern affecting people, perceived solutions, and information gaps**

| Pressing issue identified | Perceived cause of the problem | Perceived solutions | Information sharing before the advent of mobile phone | The current method of information sharing | Type of information shared | Information gaps |
|---|---|---|---|---|---|---|
| Insecurity (land invasions and property damage, cattle rustling, and indiscriminate movement of livestock) | Cultural practices (Pokot, Samburu, and Borana communities) | Improved collaboration between security and wildlife conservation agencies<br>Government to control haphazard movements of livestock from neighbouring areas<br>Improved education levels amongst pastoralist communities | Word of mouth – *serian* amongst the local Maasai community used messengers referred to as *Olkilinkwai*<br>Radio calls, letters, faxes for government institutions responsible for addressing the problem, such as the police | Mobile phones and radio receivers | Sightings of armed cattle rustlers<br>Movement of immigrant herders and their livestock | TTBD distribution and eco-epidemiology at human-wildlife–livestock interface<br>Tick control strategies |
| Human-wildlife conflicts, including transmission of diseases and disease vectors | Movement of wildlife, human deaths and injuries, crop and property damage | Pay compensation claims<br>Improve stakeholder collaboration<br>Data and information sharing on wildlife movements, crop and property damage<br>Public education and extension | Word of mouth – *serian* amongst the local Maasai community used messengers referred to as *Olkilinkwai*<br>Radio calls, letters, faxes for government institutions responsible for addressing the problem, such as the KWS | Mobile phones, radio calls, and emails | Human deaths, injuries, crop damage, depredation damage | Wildlife movement patterns<br>Location of watering points |
| Zoonotic diseases occurrences (foot and mouth disease, brucellosis, rabies, and East Coast fever (ECF) | Lack of information on availability and prohibitive cost of animal vaccines<br>High livestock stocking rates (cultural practices) and lack of markets for farmers<br>Lack of disease diagnostic tools | Improve coordination and information sharing<br>Government to offer incentives and subsidies to farmers<br>Provide information to farmers regularly through field extension services or mobile phone alerts<br>Reduce livestock densities amongst pastoralist communities<br>Provide markets for framers to dispose of excess livestock<br>Provide information on location of laboratory and diagnostic services | Reported by making visits to local government livestock officials<br>Field visits, workshops, and seminars<br>Visit to livestock auction markets<br>Reliant on government extension services | Unstructured and irregular meetings<br>Radios, irregular extension services, unstructured mobile phone usage (calling, texting)<br>Visit to livestock auction markets | Zoonotic and other notifiable diseases<br>Availability of acaricides and vaccines<br>Symptoms of disease in livestock, animal health status<br>Market prices of livestock | Data and information on TTBD and wildlife–livestock mortalities<br>Provide market prices of vaccines<br>Provide comparative market prices for their animals<br>Provide information on location of laboratory and diagnostic services |

**Table 2: Overview of the extent of the TTBD problem in Laikipia, Kenya**

| **Identified TTBD problem dimension** | **Biophysical** | **Technological** | **Sociocultural** | **Economic** | **Institutional** | **Political** |
|---|---|---|---|---|---|---|
| **Description of the problems** | Massive reproduction and resilience (adaptations) of ticks to extreme environmental and human conditions (Jongejan and Uilenberg, 1994)<br>Host-pathogen characteristics and invasive plant species (*Opuntia stricta*) attract tick hosts | Inability to determine, and cost of determining, the efficacy of TTBD control methods<br>Lack of mechanised systems for spraying ticks<br>The growing resistance of ticks to chemical acaricides | Cultural practices by nomadic pastoral communities, e.g. Maasai, Samburu, and Borana | Lack of sufficient monetary outlay by farmers and costly prevention of TTBDs | Divergent policies, views, and power relations issues slow implementation of TTBD strategies | Structure of government of Kenya at national and county government level with poor reporting and information sharing frameworks, political agitation, and land activism |
| **Causes of the challenges** | No control mechanisms for TTBDs in wildlife<br>Land-use activities (interfaces between wildlife and livestock)<br>Lack of information on TTBD distributions | Lack of data or information on acaricides' efficacy resistance<br>Insufficient information on the resistance of livestock breeds to tick attack and infestation of livestock<br>Inability to identify tick species and pathogens transmitted<br>Infrequency or failure by farmers to follow instructions or apply acaricides<br>Lack of disease diagnostic tools and information | Lack of awareness on the negative impacts of high livestock stocking densities and TTBD control | Decentralisation of responsibility for TTBDs from the government to farmers<br>World Bank SAP programme removed subsidy<br>Lack of funding for systematic research on TTBDs<br>Poor farmer-oriented extension services<br>Poor infrastructure and communication | Conflicting or competing interests of wildlife and livestock management and research institutions<br>Lack of knowledge and awareness | Competing interests of national and county government and skewed resource allocation<br>Insecurity: land invasions, human-wildlife conflicts<br>Poor institutional linkages and collaborations<br>Limited funding and resource allocation by the national government to devolved units of government and institutions |

### 4.2.2 Technological dimensions

Technological dimensions refer to the role that improved technology can play in addressing agricultural issues (Schut et al., 2015) by increasing efficiency and reducing the operating costs in agricultural systems (Schut et al., 2015). For example, different TBDs are difficult to positively identify because of their similarity in symptoms or are sometimes asymptomatic, but they can be positively diagnosed if testing kits are readily available (Minjauw & McLeod, 2003). In the interviews, farmers complained that they administer drugs to their animals based only on observable symptoms, which in most cases may be confusing. The misapplication of drugs may make TBDs difficult to control and often leads to mortalities. There are no animal disease diagnostic laboratories in Laikipia, and farmers rarely consult them, unless through government interventions when massive outbreaks are reported. Farmers in the area are possibly administering drugs to animals based on assumptions rather than on confirmatory tests. We also observed that large-scale farmers used mechanised spray pumps and spray races, which appeared effective and less time consuming, as opposed to agro-pastoral farmers who relied on hand sprays. Unavailability of, or failure by farmers in the area to consult or utilise, technology to either diagnose or take appropriate actions on TTBDs seem to be some of the problem dimensions that undermine their effective control.

### 4.2.3 Sociocultural dimensions

Sociocultural-related dimensions reflect the long-standing practices and beliefs that people espouse in an area (Schut et al., 2015). Practices by people in an area may influence behaviour and how people perceive or do certain things, despite the various improvements that may have occurred over time. Because of general practices or past experiences, many people may become fixated with traditions, making them complacent in addressing issues. Field observations showed that pastoralists in the area culturally keep high livestock numbers without any corresponding capital investments such as improved animal husbandry and control of diseases, including TTBDs. The repercussion of such a practice is poor TTBD control resulting in heavy infestation and increased livestock mortalities. We observed that, in contrast, large-scale farmers in the area, as a best practice, matched resources with their stocking densities.

### 4.2.4 Economic dimensions

Economic dimensions relate to issues of cost and benefit analysis, which often have implications for addressing complex agricultural problems (Schut et al., 2015). Interviews with farmers and extension officers revealed that generally farmers are affected by a lack of funding for their operations and a lack of markets for their livestock. They complained that the removal of subsidies, increased taxes, and the decentralisation of livestock issues from the government to farmers following recommendations of World Bank-led structural adjustment programmes (SAPs) had particularly increased livestock production costs. The increased cost of production has a multiplier effect on the ability to control diseases in animals. Furthermore, a lack of funding for systematic research on TBDs was reported by the extension officers as a challenge to their effective control. The decentralisation and the increased costs of operations have demotivated farmers, and, as expected, farmers rarely consult government extension services in the area. A clear understanding of the economic dimensions of TBDs is critical for informed decision making.

### 4.2.5 Institutional dimensions

Institutional dimensions relate to institutional arrangements, policies, regulations, and interests that govern the way institutions operate in a country (Schut et al., 2015). Institutional set-ups may affect institutional collaborations and power relations, factors that have been identified as critical in addressing complex agricultural problems and innovations (Kilelu, Klerkx, & Leeuwis, 2013; Schut et al., 2015). Lack of direct engagement and extension service provision to farmers affects stakeholder relationships and institutional linkages, hampering data and information sharing (Schut et al., 2015). In Kenya, it is the responsibility of the government to control diseases, but interviews with government officials showed that lack of funding for their operations and extension services have hampered their quest to help farmers. Government officials interviewed complained that they were poorly resourced and rarely provided on-farm extension services or visits to farmers. We observed that there are ~ 5 extension officers in the area and that these had to travel by motorcycle. They complained that motor-cycle use was life-threatening because of the presence of dangerous wildlife and that they need security support to carry out their duties. The large-scale farmers, however, indicated that they had the institutional capacity to link up with researchers, extension services providers, and livestock vaccine manufacturing companies. In contrast, we observed that small-scale farmers lacked information on the availability of drugs and other extension services. Therefore, to effectively address TBDs in the area, there is a need to develop ICT-based innovations that will allow stakeholders to freely interact and share data and information.

### 4.2.6 Political dimensions

Political dimensions refer to attributes relating to management structures and the span of control of the organisations involved in a problem (Schut et al., 2015). The political dimensions of the TBD problem are particularly important because different institutions have different spans of control at the local, national, or regional level, and this often affects decision-making processes, information exchange, innovations, and action (Kilelu et al., 2013). Interviews with the stakeholders and the workshop participants showed that stakeholders involved in TBDs operated at the local, national, or international level. The stakeholders represented government, NGOs, and research institutions such as KWS, county government, and national government. From the informant interviews, some challenges identified included: suspicion and lack of trust, stringent regulations about sharing data among institutions, and lack of structured systems of engagements among the stakeholders. We found that institutions submit reports on disease issues in the area internally within their institutions, with few interactions across institutions. Farmers in the area share information with the government on some notifiable diseases such as foot and mouth disease and rabies because this elicits government intervention measures. We also observed that farmers in the area report TBDs to private agro-vets only to acquire vaccines for their animals and rarely, if ever, to government officers as this is not deemed worthwhile (motivational issues). To share such information across and within organisations, ICT-based tools such as mobile phones may provide an opportunity for coordinating all stakeholders in the area for surveillance and action across the organisations responsible.

### 4.3 Information sharing culture and changes in the communication landscape

From the analysis of the identified dimensions and the challenges of the TBD problem, here we present the possible solutions and gaps that exist in the spectrum to apply ICT-based tools such as mobile phones and citizen science approaches to the problem (Table 2). Using the local Maasai pastoral farmers as an example, we provide a short historical context of the information-sharing culture that has existed in the area and how the adoption of mobile phones has changed the culture, with implications for citizen science.

#### 4.3.1 Traditional approaches to information sharing

Interviews with the local nomadic pastoral communities showed that, since time immemorial, they have had informal networks to address issues of concern in the area. Information sharing was commonly done by word of mouth, often referred to as *serian* and the message was referred to as *Olkilinkwai* by the local Maasai community. This mode of information sharing was probably then the only effective way in which communities could share information. Interviews with the local Maasai also revealed that to maintain confidentiality, some sensitive information was maintained between trusted kinsmen and friends or neighbours using trusted messengers commonly referred to as *Olkipaaret*. The messengers often travelled over long distances on foot to deliver the information. For example, some local pastoral community informants recalled that selected messengers moved across villages to share information on the repercussions of the severe droughts of 1984 to enable people to seek areas to which to move. Similarly, such methods were used to share information during the *El Nino* period of 1997, as most people in the area had not acquired phones because of poor mobile phone infrastructure and the prohibitive prices of phones. Other forms of information shared included outbreaks of livestock or human diseases.

Formal modes of information sharing included the use of letters, faxes, telegrams, and radio communication. For example, most of the governmental and non-governmental offices and large-scale commercial ranches that we visited relied heavily on print information, as exemplified by the many files and registries in use. Reports are prepared and kept on file, although we were informed that attempts are being made to digitise the records.

### 4.3.2 Mobile phone adoption and communication landscape

The rapid adoption of mobile telephony in Laikipia began in the year 2000 when mobile phones became more affordable and accessible to the area's residents. All the informants reported that they acquired their mobile handsets between 2003 and 2010. This probably coincided with the rapid phase of mobile phone adoption in several other areas in Kenya. Since then, the local pastoral herders seem to have reduced the use of physically mobile messengers to relay information and have opted instead to use mobile phones to share information. The mobile phone adoption rate in the area is ~70%, compared to Kenya's national average, ~66% (CIDP, 2016) and reflects the adoption rates in Kenya's Rift Valley Region, where Laikipia county is situated, as reported in the Demographic Health Survey data for 2014 (Kenya National Bureau of Statistics et al., 2015). We could not, however, ascertain the approximate percentage of smart or simple phones used in the area but the choice of a smartphone was generally influenced by factors such as better access to power to the charge phones and higher literacy levels and lower age of users.

Interviews were conducted with some local pastoral farmers such as Masikonde, Kipish, and Kirobi (pseudonyms) from Laikipia North. Masikonde, a 40-year-old Maasai pastoralist from Laikipia North, described how he uses his phone:

"*I have now become addicted to phones. I call family members, friends, and even the livestock extension officers for help when I see unusual diseases in my herd. I also call the agro-veterinarians explaining the symptoms of the disease and from there I am advised what drugs to buy or, if possible, I ask him to deliver it to where I am because I can direct him via my phone to our grazing fields. So, I don't have to travel looking for him. When the livestock officers in the area cannot be reached, we call the director of livestock or the chief if we have his number or, if we don't have it, we solicit his number from friends. The phones have thus made our work easier and faster. We no longer have to trek over long distances looking for our friends or the veterinarians for information."* Masikonde's statement is an assertion shared by many pastoralists that we encountered in the area. The information shared by mobile phone includes (i) location of forage and water for livestock, (ii) livestock health status report from the grazing fields, (iii) location of wildlife predators, and (iv) information on schedules of livestock auction markets, among other things. This example illustrates that the communication landscape amongst the agro-pastoral farmers in the area has changed with the advent of the mobile phone. The agro-pastoral farmers asserted that mobile phone use has reduced their travel distances and provides quick access to networks of practitioners who can help them solve the issues affecting them.

Interviews with Elijah and Francis (pseudonyms), agro-vets, and livestock health officers in Laikipia North also confirmed this trend. They reported that unlike before – when they used to move from one point to another – they are now regularly in contact with the livestock herders with access to mobile phones. Livestock herders describe symptoms or send pictures to the agro-vets, and these give advice based on this virtual information. The agro-vet officers interviewed also stated that they offer extension services by regularly communicating and sharing information with farmers on diseases and possible vaccines for their animals.

Interviews with officials from government agencies responsible for wildlife conservation and livestock revealed that people often call different agencies to seek support in urgent cases such as cattle rustling incidences, wildlife attacks, or flooding. Mobile phones are also used by officials in the area to answer public queries and attend to issues raised by the residents, and through regular engagement, they build trust with the officials on some issues. For example, the agro-vets reported that they occasionally receive reports about human-wildlife conflicts and redirect them to KWS as they have their contacts. From our experience in the area and interviews with KWS personnel, people predominantly use mobile phones to report human-wildlife conflict incidences. Taking cognisance of these developments, KWS has emergency mobile phone numbers, called hotlines, dedicated to receiving information of human-wildlife conflicts and compensation cases. The incidences are used to prepare reports for (i) compensation requests to the County Wildlife Conservation and Compensation Committee, (ii) management purposes such as to generate conflict hotspot maps, and (iii) informed decisions on the deployment of personnel and resources to combat human-wildlife conflicts in the area. Some details captured on human-wildlife conflict incidence reports include the date of the incident, locality or GPS coordinates, species of animal responsible, type of damage occasioned, and actions taken by KWS or any other agency that may be involved in addressing human-wildlife conflicts.

According to the interviews and observations, local people in Laikipia have also subscribed to various money wallets such as M-PESA, Airtel Money, and Telkom money for economic reasons (https://www.mobile worldlive.com). These money wallets in Kenya are an alternative to conventional banking systems, which are often characterised by bureaucratic regimes and rules. For example, the M-PESA platform, the most popular in Laikipia and many other areas in Kenya, was an innovation by Safaricom plc and Vodafone UK. The M-PESA is used to transact business relating to livestock market sales or utility payments. Features of the M-PESA system include: (i) send or withdraw money, (ii) mobile banking, (iii) mobile airtime, among others. The features are regularly updated by Safaricom plc based on subscriber requirements and platform improvement. To ease transactions, the wallets are linked to the conventional banking services in Kenya. Mobile wallets are described by users as fast and simple to use. The money wallets are widely adopted and used in Kenya and its neighbouring countries, Rwanda and Tanzania, as well as the United Kingdom (https://www.mobile worldlive.com). To minimise money laundering and illegal infiltrations, the platform is regulated by the Central Bank of Kenya and the Communication Commission of Kenya, although cases of systems infiltration have remained relatively low (further details on the M-PESA platform and related services are available at https://www.safaricom.co.ke/business/corporate/m-pesa/). The use of mobile phone wallets in the study area provides another dimension and illustration of how mobile phones are becoming tools of economic empowerment, especially among rural poor agro-pastoral communities.

From the interviews, mobile phone use in the area has enabled local farmers and stakeholders to develop networks across international boundaries. Sepeika (pseudonym), a 49-year-old local area chief from Laikipia North provided an interesting dimension of how mobile phones have radically changed his life and that of others in the area. He bought his first mobile phone in 2006 and since then he has used it for his official work and domestic chores: "*In my honest opinion, the mobile phone has changed my life dramatically. I have now upgraded my phone to a smartphone, and I can now read emails and be on social media at all times. I have a sister working with the Kenyan Embassy in London, and I can call* *her anytime I feel I like it. I am always updated about what's happening in the UK, and I have made new international friends linked to her through WhatsApp and Facebook applications installed on my phone. Her friends also chat with me, inquiring about issues in our area concerning wildlife, security, and features of interest in the area because they want to tour the area. I also organise meetings such as the grazing committee meetings to agree on how to share scarce pasture and water for our animals and access to these resources in the neighbouring commercial ranches. Before, it was impossible to have such linkages, but phones have made it possible. My life without a phone is now unbearable. I can live in any place however remote or hostile as long as I have a phone with subscriber connectivity*. *However, part of my work has also been made difficult because land invasion in the area is most probably organised by people who readily share information using mobile phones about the availability of pasture and water. It is also difficult to control them since they share information about the movement of various security teams more easily and evade them."*

Sepeika (pseudonym) thus provides a candid example of how mobile phone connectivity has shifted networks from local to international levels. For example, some pastoral livestock herders have a fast and direct linkage to local governmental and non-governmental agencies and to international ones such as Oxfam, SNV-Dutch International, and World Vision to address issues such as livestock production, drought resilience mitigation, financial funding and economic empowerment, and other issues relating to insecurity such as cattle rustling. The fast access to such local and international development partners, as educed by Sepeika, shows how mobile phone usage has revolutionised linkages and reduced the distance between local farmers and development partners at the local and international levels. Furthermore, the residents of Laikipia informed us that the drought periods of 1984 and the *El Nino* phenomenon of 1997, which many still recall vividly, were more catastrophic because of limited access to information and emergency services. However, similar catastrophic events such as the 2009–2010 drought were tempered by faster responses and interventions by local and international stakeholders, courtesy of mobile phone use.

From the interviews and observations, mobile phone applications commonly used in the study area include voice calls, texting, photography, social media applications such as WhatsApp or Facebook. In Laikipia North, for instance, we came across WhatsApp groups such as *Kiyaap, Ol Lentile*, or *Nasaruni*, which are youth or conservation-oriented groups where topical issues such as prevailing weather conditions, job advertisements, politics, farming, and conservation issues are discussed. In the process of our interviews, they voluntarily included the first author of this paper in all three WhatsApp groups after learning that he originated from an organisation involved in addressing human-wildlife conflicts, one of the key problems in the area.

The use of mobile phones is widespread in Laikipia, with penetration of ~70% (CIDP, 2016), but this implies that 30% of residents are excluded (disconnection) from access to mobile phones. Various informants acknowledged that they knew of friends, kinsmen, or kinswomen without phones and that they could be thereby disadvantaged. The spatial distribution of mobile phones in the area cannot be formally ascertained; rather, we relied on informants' statements that indeed there are some people in the area without phones or access to phones. The residents without mobile phone access could represent a sizable proportion of people excluded from the existing information-sharing network of users and stakeholders, with implications for their access to socio-economic activities and to timely information on other issues of concern. There are certain remote areas in Laikipia where there is no mobile phone connectivity. Respondents indicated that access to mobile phones is also hindered by a lack of mobile phone infrastructure such as electricity to charge phones, connectivity, and prohibitive prices. We observed several mobile phone charging shops in the study area, especially where electricity or solar power was limited.

In interviews, three local Maasai *morans*, pseudonyms: Loosenka (50 years old), Joseph (30 years old), and Lekamario (27 years old), whom we found herding livestock in the thickets of Laikipia North, individually stated that they had never attended school but had mobile phones to connect to their families or to monitor the availability of pasture and water for their livestock. They also reported that they had a network of other pastoral farmers with whom they keep in touch to share and appraise information regularly, especially on security, wildlife, and the health status of their livestock. According to these three illiterate men, literacy levels were not a hindrance to the general use of mobile phones but impeded applications such as texting. We observed that they had simple phones sufficient to meet their needs, implying that the adoption and use of mobile phones are also influenced by individual users' literacy levels. Other informants such as governmental or NGO officials and extension workers all had smartphones. Contrary to our expectations, we also encountered school-going young men and women with mobile phones.

From the documents analysed, such as county integrated development plans, the wildlife conservation and management strategic plan (2012–2017), and integrated livestock development plans, we found that most of the issues addressed in these documents corroborated the results of our interviews and field observations. Almost all the documents mentioned water and pasture issues, human-wildlife conflicts and diseases, land use, infrastructure and development, and youth development. All these issues have either a direct or an indirect bearing on TTBDs.

## 5.0 Discussion and conclusion

This study assessed the potential for the citizen science EVOCA project, which is envisaged to be developed in Laikipia, Kenya. We, therefore, aimed to (i) identify the issues complicating the effective control of TBDs (ii) ascertain whether and how people use mobile phones or other methods to address these issues, and (iii) reflect on what we can expect of the promises of citizen science for the development of EVOCA.

### 5.1 Issues of concern and mobile phone usage

The advent and use of the mobile phone in many African countries were motivated by the assumption that mobile phone technology would present new opportunities for development and the empowerment of people (De Bruijn, 2009; A. L. Lewis, Baird, & Sorice, 2016). Access to communication technology was expected to "develop" Africa thanks to the opportunities that supposedly came with the technology. Thus, a major change was expected in the social and political sphere, namely, by diminishing distances and increasing connectivity (though not always and not for everybody) between people by using mobile phones (Asongu, 2013; De Bruijn, 2009).

This study in Laikipia has provided insights into the TTBD problem in Laikipia, suggesting:

(i) that TTBDs, despite being a problem, are not considered to be very important compared with other issues that are ranked by residents as more pressing. Issues such as insecurity characterised by land activism and property damage, cattle rustling, human-wildlife conflicts, and the spread of zoonotic diseases relegate and make the TTBD issue less problematic in people's eyes, influencing what people communicate and share information about. The TTBD problem is compounded by a combination of biophysical, sociocultural, economic, institutional, and political-related problems, making their control difficult.

(ii) that lack of structured data and information sharing, coordination of stakeholders, and policies on disease management remain impediments to TTBD control, and mobile phones and citizen science can be leveraged to partly address the problem.

(iii) that the mobile phone adoption rate in the area is ~70%, compared to the national average in Kenya of ~66%, suggesting that mobile phones (simple and smart) are widely used by people for various socio-economic activities, despite the residents being classified as poor. In addition, some people who do not own a phone have reported owning SIM cards, suggesting that phone use is even higher than these statistics. SIM card ownership by people who do not own a phone enables them to access services and may increase the observed adoption rate of mobile phones in the area.

(iv) that mobile phones are widely used in the area to communicate with family members and friends and to access information on the pressing issues of concern, forming issue-based communication networks. The use of mobile phones for economic activities such as business and banking services has empowered people economically, improving their livelihoods, whereas those without access are probably excluded (disconnected).

Although the advent of the mobile phone in Laikipia has significantly improved social interactions and the sense of economic empowerment through fast and regular access to information among mobile phone users, this study also revealed some negative or unintended consequences of mobile technology. People with no access to mobile phones may become socially isolated from the network of users to the detriment of their livelihoods. For example, the widespread use of money wallets, such as M-PESA platforms, in many areas in Laikipia to transact businesses or banking services means that people without mobile phones are probably excluded and economically or socially disempowered. To overcome these exclusions, many people who do not own a phone are reported to own a SIM card and borrow a phone when they need access to those services. This suggests that the rate of mobile phone use is higher than the rate of phone ownership.

Our study identified that land ownership and rights influenced other issues of concern in Laikipia such as insecurity characterised by land activism and property damage, cattle rustling, human-wildlife conflicts, and the transmission of zoonotic diseases (Table 1). Our study also identified that these issues (insecurity, human-wildlife conflicts and animal disease transmission) as the most prominent and pressing for many residents, and the latter often share information about them and seek redress from the responsible agencies. Land in the area is regarded as an important factor of production from where other forms of livelihoods are derived. Most residents are thus preoccupied with these issues more often than with the TTBDs. Land ownership and rights directly influence the availability of, and access to, water and pasture for both humans and animals. Water and pasture are scarce natural resources in the area, and their scarcity affects the status and movement patterns of both wildlife and livestock, influencing security, human-wildlife conflicts, the transmission of diseases and the social and political dynamics in the area (Bond, 2014a). The increasing human population in the area also exerts influence on land availability with consequences for socioeconomic activities. Water scarcity directly affects agricultural crop production, livestock husbandry, and wildlife conservation, with implications for the security of people, wildlife, and livestock (Bond, 2014b). Most pastoral communities have a strong economic and cultural attachment to livestock issues, and consequently, they keep large herds of livestock comprising cows, goats, sheep, and camels for economic and cultural purposes (Bond, 2014a). Because of the scarcity and competition over these scarce resources such as water and pasture in semi-arid areas, large-scale movements of livestock and wildlife over a wide area are common in the dry season, sometimes resulting in massive loss of livestock to drought and conflicts with wildlife (Bond, 2014a; Huho, Ngaira, & Ogindo, 2011; Wiesmann, Gichuki, Kiteme, & Liniger, 2000). To restock animals lost to drought, nomadic pastoralists may opt for cattle rustling (cultural practice) and private land invasion, further complicating land ownership and property rights issues, human-wildlife conflicts, and the spread of animal diseases. Our study corroborates with the findings of other studies in the area (e.g., Bond 2014b, Weismann et al., 2000) that revealed that insecurity was influenced by competing claims over scarce natural resources such as water and pasture, leading to violent conflicts.

In this study, we found that, although at first sight, it seemed that land ownership and land rights, insecurity, wildlife conflicts, and disease transmission were not related, a closer look at the dynamics of the issues revealed that they are related, thereby complicating the TTBD problem and control in the area. For instance, insecurity because of land activism has become common during the dry season when pasture and water are exhausted in the pastoral areas. Illegal land invasions in the area are characterised by destruction of boundary fences, a common tool for demarcating land as proof of ownership, displacement of wildlife from their habitats into settlements or farming areas causing human-wildlife conflicts. Studies elsewhere in Africa such as in Sudan and Ethiopia, both in the East African region, with almost similar pastoral communities and practices, have also demonstrated a direct relationship between pastoral activities such as livestock movements and the spread of diseases, including (Dejene et al., 2016). The spread of these diseases has major ramifications for the wellbeing of many poor pastoral communities reliant on livestock for economic and cultural purposes (Gebremariam, Amare, Baker, Solomon, & Davies, 2013).

Our study shows that this has implications for stakeholder relationships and how information is communicated and shared. To entrench their activities, pastoral communities in Laikipia have formed groups for social networking, synonymous with the situated political agency, for agitating for access to water and pasture from large-scale commercial and government-owned ranches. These social networks are maintained and organised using mobile phones, which are now commonly used as a mode of communication in the area. Pastoral farmers in Laikipia were observed to use mobile phones for social networking, information sharing, purchase of farm inputs, and sale of livestock products, effectively empowering them. However, social media such as Facebook and WhatsApp can only be used by smartphone users, who tend to be mainly sedentary youth and more highly educated stakeholders who know how to operate those phones and have regular access to electricity. In particular, land invasion and property destruction were cited as sources of suspicion among stakeholders such as small-scale agro-pastoral farmers, large-scale commercial farmers, and security agencies, affecting their relationships. For example, immigrant pastoral communities from neighbouring counties use mobile phones to plan illegal invasions of private or community land and cattle rustling raids, effectively complicating security issues. This is a classic example of how mobile phones are used to share information in unanticipated ways. Governmental agencies such as the National Police Service, KWS, and livestock extension officers also use mobile phones to respond faster to their respective clientele and thus help improve response time and build synergies amongst them to address the problems. With mobile phone use in the area, the security situation has further deteriorated because of improved communication between land activists. Similar findings were observed in a study of the role of mobile phones and conflicts in Sudan and Mali (De Bruijn, 2009), where armed conflicts were planned and executed by warring parties using mobile phones.

## 5.2 Reflection on mobile phone usage and implications for citizen science (EVOCA)

The increasing use of mobile phones for various socioeconomic activities in Laikipia has important implications for the citizen science platform (EVOCA) that is envisioned to address the TBD problem in the area. We, therefore, reflect on what we can expect from EVOCA's potential role in addressing TTBDs vis-à-vis other issues of concern. First, residents in Laikipia are faced with pressing issues such as insecurity, human-wildlife conflicts, and notifiable zoonotic diseases that influence what people communicate and share information about (Table 1). These pressing issues eclipse stakeholders' motivation to share information on TTBDs. Second, although our research illustrates that pastoral farmers have very effective networks for sharing information about issues of concern, including diseases, this study encountered little evidence of EVOCA's underlying assumption, namely, that the ineffective control of TDBs is caused by imperfect information sharing and limited mobile phone connectivity, because people in the area have since time immemorial shared information using other traditional approaches and networks and mobile phone usage has only complimented – and even strengthened – the traditional social connectivity.

Institutional and policy issues linked to the stakeholders involved in the TTBD problem, such as those related to World Bank SAPs, policies that removed the subsidy for acaricides and decentralised livestock disease control from the government to farmers, have affected efforts to control TBDs. For example, small-scale livestock farmers in the area were unable to effectively apply acaricides and other control interventions because of the prohibitive costs involved, demotivating farmers from effectively addressing the problem (Minjauw & McLeod, 2003; Mugambi et al., 2012). Conversely, large-scale commercial farmers in the area have adequate budgets to combat livestock diseases (Mizutani et al., 2012). This study, therefore, found insufficient information to support EVOCA's initial assumption that ineffective TBD control in Laikipia is driven by imperfect information sharing issues.

This diagnostic study critically questions whose problem it is that the citizen science EVOCA on TBDs in Kenya is trying to address. The central implication is that a citizen science platform in Laikipia can only be made to work if it aligns well with the pressing issues of concern, offers a motivation to share, and indicates how information collected would be used by all stakeholders. For instance, in several other studies on innovations platforms and projects (Hounkonnou et al., 2012; Röling, Hounkonnou, Offei, Tossou, & Van Huis, 2004; Sinzogan, Jiggins, Kossou, Vodouhè, & van Huis, 2006) in West Africa's Benin Republic and Ghana (whose underlying assumptions were similar those of EVOCA's), it was anticipated that the innovation project was going to empower local farmers, but it was found from diagnostic studies that the project did not align well with the contemporary issues affecting them.

Here in Laikipia, residents voluntarily report on insecurity and human-wildlife conflict-related issues thanks to incentives such as payment of wildlife compensation claims by the government and prompt response from security agencies such as the National Police Service to emerging insecurity issues. The success of citizens reporting other issues of concern in the area suggests that EVOCA and citizen science for TBDs have the necessary infrastructure that includes a high mobile phone adoption rate and the presence of stakeholders involved with the problem, but residents do not perceive the issue as a prominent problem. Consequently, local people's perception of the issue reduces their motivation to report about TBDs.

We started by questioning whether citizen science for development is a technology of humility or technology of domination. We can now conclude that it is neither but that it has the potential to be both. The interest of researchers then is, of course, not in one of these states, but in the conditions that determine whether a citizen science initiative will become a technology of humility or technology of domination. Citizen science for development provides a unique opportunity to supplement conventional scientific approaches and participation to create synergies to include even "amateur" scientists in the collection and dissemination of information to address a problem in an area (Silvertown 2009, Roy et al. 2012), enhancing collaborations and building social networks to address development goals (Klerkx & Leeuwis, 2008a, 2008b; Klerkx, Van Mierlo, & Leeuwis, 2012). In so doing, citizen science holds the promise of providing new insights that can help us successfully address the emerging challenges in different spheres of life in many areas. Despite all the necessary technological infrastructure in the area, including a high mobile phone adoption rate and the presence of various stakeholders, this study found insufficient grounds to demonstrate that lack of information sharing and mobile phone use may be leveraged to address the TBD problem. The study also found that other pressing issues, including poor security, human-wildlife conflicts, and occurrences of notifiable diseases, eclipse the TBD problem in the area. Therefore this study suggests that to make citizen science work effectively and address the TBD problem in Laikipia, it should address the local pressing issues – such as poor security, human-wildlife conflicts, and occurrences of notifiable diseases - that people communicate and report about using mobile phones.

**Chapter 5**

# Biopolitics of tick-borne disease control in the tropical drylands of Africa

Richard Chepkwony, Severine van Bommel & Frank van Langevelde

Submitted to *Society & Natural Resources (under review)*

***Abstract***

The proliferation of tick-borne diseases (TBDs) is a major constraint for wildlife management, livestock production and human health, particularly in the tropical regions of Africa. Although the use of chemical acaricides is a widely promoted approach for the control of TBDs in this region, this strategy is severely constrained by unknown social factors. In this paper, we explore how biosecurity and the spatial biopolitics relating to the control practices of TBDs and governance is enacted or challenged by farmers in Laikipia, Kenya. Our results suggest that control of TBDs in the area is the product of indigenous knowledge of pastoral farmers and western veterinary thought with two different logics, sometimes converging but often at odds over fundamental socio-economic conditions stemming from historical contexts and the pastoralist logic of herd immunity. Commercial farmers with the social and economic capital to manage uncertainties relating to TBDs can do so, while resource-poor pastoralists face a compounding uncertainty stemming from the socio-ecological challenges which build on each other. Here, the analysis of the interplay of historical *contexts*, *practices* and *interactions* reveals power relations, tensions and contradictions emerging from an attempt to impose a western model for the management of TBDs with different biological and health outcomes. Successfully addressing TBDs challenges requires a clear understanding of their complexity, rather than reducing them to their most simplistic parts.

**Keywords**: *Biopolitics, Kenya, social-ecological systems, tick management, pastoralism*

## Introduction

Livestock production, wildlife management and human health in the tropical drylands of Africa are constrained by tick-borne diseases (TBDs) such as East Coast fever, anaplasmosis and babesiosis, affecting many livelihoods (Chepkwony et al. 2020). TBDs account for ~10-80% of livestock mortalities and human infections (Cleaveland et al. 2001). Moreover, the spread of TBDs is also an impediment to livestock trade due to a possible ban on livestock-related products locally, regionally and internationally. Hence, controlling TBDs can permit higher levels of livestock production, safeguard human health and improve the livelihoods of many farmers in the tropical drylands of Africa (Minjauw & McLeod 2003, FAO & UNICEF 2017).

In the recent past, there has been a general decline in the effectiveness of control practices of TBDs in the tropics (Walker et al. 2014b, Wilcox et al. 2019). Farmers control ticks using chemical acaricides, pasture spelling and keeping indigenous varieties thought to be resistant to tick attacks (Walker et al. 2014b). Although acaricides remains a dominant strategy for tick control, however, it has proven to be challenging for many poor farmers (Minjauw & McLeod 2003, Walker et al. 2014). The adoption of economic reforms in Kenya in the early 1990s, for instance, generally reduced farmers' access to extension services that were hitherto publicly provided while at the same time devolving the administration of acaricides to farmers with different health outcomes (Mutavi et al. 2018). Furthermore, Mutavi et al. (2018) showed that the local pastoral farmers in Laikipia, Kenya, often mixed perceived weak acaricides with crop pesticides, herbicides, fungicides and insecticides with the hope of improving their efficacy. Conversely, commercial ranches administer acaricides professionally (Mutavi et al. 2018) resulting in considerably lower tick loads in their herds (Chepkwony et al. 2021). Thus, the poor acaricide application by mainly the pastoral farmers may impact disease transmission on humans-wildlife and domestic animals, and possible spread to other areas due to open and communally shared grazing fields that allow free movement and interactions of livestock and wildlife (Riginos et al. 2012, Keesing et al. 2013b). The poor application of acaricides by pastoral farmers not only affects the effectiveness of the chemicals but may also increase the tick resistance to acaricides with unintended consequences (Minjauw & McLeod 2003, Mugisha et al. 2008). Hence, farmers in the tropics must manage a compounding uncertainty:

uncertainty that comes with livestock production, the TBDs and their drivers (Chepkwony et al. 2020), and changing environmental conditions (Minjauw & McLeod 2003); uncertainty about state support and extension services and access to resources (Mizutani et al. 2005b, Mutavi et al. 2018, Cavallo 2021). These dynamics mirror the burdens faced by farmers globally in response to the control of diseases and their agents (Cavallo 2021). These uncertainties broadly fall under the nexus of biosecurity as strategies for disease management and governance by the farmers and other actors can fundamentally change the agricultural knowledge systems when contested. The improvisation of acaricide use (Faith et al., 2018) may as well be interpreted as a reconfiguration of the spatial biopolitics.

Facoult, in Bevir (1999) & Enticott (2008) defines spatial biopolitics as an intersectional field between human biology and politics and takes the administration of life and its local inhabitants as its subjects (Bevir 1999, Enticott 2008). Through space that we can link up with biopolitics where one subject can start by opposing, with others formulating counter-proposals and from this, a counter force can emerge, increasing the democratic space for zoonotic disease governance as farmers are bound by the same challenge (Whatmore 2009, 2013). Essentially, the involvement of other actors with divergent power relations issues at various stages of the disease control widens the complexity and transforms the control practices of TBDs into a socio-ecological systems problem. Indeed, the power relations (the biopolitical exploitation of life) and force (everyday resistance that is expressed in the practices that people are involved in an area)(Scott 1989, Bevir 1999, Enticott 2008) can be tampered with to enhance collaborative efforts. Hence, in trying to understand how farmers respond to uncertainties of TBDs as a biosecurity constraint, we may provide opportunities for better management of the problem.

**Conceptual approach**

TBDs have been recognized as a complex, multifaceted problem due to the socio-ecological factors involved in the human-animal-environment interfaces. Moreover, the weak implementation of large-scale control practices complicates the problem (Wilcox et al. 2019). Hence, the spread and control of zoonotic tick-borne diseases remind us that the health of humans, animals and ecosystems are interconnected and that to better understand and respond rapidly to these diseases dynamics at the human-animal-environment interfaces requires coordinated, collaborative, multidisciplinary and cross-sectoral approaches such as in ‵′One-health′′ (Ross 2012).

In this paper, we examine the sociological dimensions of the socio-ecological system and its contribution to the ‵′One-health′′ initiative- a holistic approach to effectively address zoonotic diseases. One Health is a collaborative, multisectoral, and transdisciplinary approach — working at the local, regional, national, and global levels — to achieve optimal health outcomes recognizing the interconnection between people, animals, plants, and their shared environment (Ross 2012). Here, we use ‵′One-health′′ as an example of the best practices for addressing the zoonotic disease problem recognising its complexity from the social and ecological parts. Moreover, the focus of spatial biopolitics in socio-ecological systems with ‵′One health′′, and the genealogy of disease transmission and control is largely anchored on how the practices of biosecurity, the spatial biopolitics and the uncertainty surrounding TBDs are enacted or challenged by farmers in Kenya, and has remained largely underexplored. Recent studies (e.g., Cavillo, 2021) have shown that diseases and biosecurity practices are key agents in reshaping agricultural knowledge systems through crafting new alliances (situated agency) and dissonances between farmers, scientists, extensionists, and the state or institutions involved. Hence, to clearly understand the sociological parts of the socio-ecological systems in Kenya, we need a better understanding of the control practices for TBDs (why, where, when and how farmers and actors) and the unintended consequences of these practices.

It is increasingly being recognized that there are inextricable linkages between many social and ecological factors because people rely on the ecosystem-based services which are influenced by peoples' behaviour (Chapin III et al. 2009, Jones et al. 2016, Aguirre et al. 2019). When viewed through a single disciplinary lens, the social and ecological systems influencing these interactions may appear to operate independently; however, they often overlap spatially, with different feedbacks influenced by the social and ecological drivers. For instance, the spread of, or control of TBDs is the emergent property of biophysical and social factors that interact at multiple spatial, temporal and organizational scales through complex pathways, representing a socio-ecological system (Jones et al. 2016b, Mudliar & Koontz 2020).

Traditional approaches aimed at understanding human behaviour in socio-ecological systems have assumed that rational choice and cognitive influences guide individual actions and thus have mostly focused on understanding behavioural choices (Chapin III et al. 2009, Jones et al. 2016b, Aguirre et al. 2019). For instance, to understand why and how farmers use acaricides, researchers have studied the economic, financial, educational, technical, ecological and demographic factors influencing TBDs practices (Adakal et al. 2013, Estrada-Peña & Salman 2013). Furthermore, other studies suggest that many other factors such as finances, policies and regulatory controls affect the adoption of the best farming practices (Pavela et al. 2016, Mudliar & Koontz 2020). Moreover, meta-analyses of agricultural and innovation studies have found no universal patterns of the factors that can explain the uptake of the best management practices (Prokopy et al. 2008, Wauters & Mathijs 2014). Hence, what has become clear is that practices such as those influencing TBDs are context-specific and unwittingly interlinked (Estrada-Peña & Salman 2013b, Wilcox et al. 2019). This is supported in the literature by qualitative case studies. For example, Dzingirai et al. (2017) in their analysis of Lyssa virus in Sierra Leone, the henipah virus in Ghana, Rift Valley fever in Kenya and trypanosomiasis in Zimbabwe, suggested that exposure and vulnerability to zoonotic diseases is contextually related to wealth, gender, ethnicity, class, etc. More generally, Craddock and Hinchliffe (2015, p. 2) found that "uneven power relations, discrepant risks, and *variable* access to resources" as well as the 'biopolitics' of disease control are highly contextual".

The concurrent rise of decentralized governance and participatory research on natural resource management (Painter et al. 1994, Degnbol 1996, Benjaminsen 1997, Bassett et al. 2007) in West Africa and elsewhere signifies a broader shift in thinking, to one in which local practices of ecosystem management must be taken seriously in policy development and governance. This implicitly includes nontechnical, normative positions, in addition to technical knowledge. The inclusion of local practices is particularly important in areas where various stakeholder groups have divergent institutional structures, socio-cultural values, and perceptions of a problem their possible solutions (Frame & Brown 2008, Crane et al. 2009). Hence, scholars have argued that responses to zoonoses cannot be understood without taking into account the wider social and political context of the problem (Woldehanna & Zimicki 2015) as well as the structural power dynamics that favour certain practices while marginalizing others (Wallace et al. 2015). In this article, we aim to improve our understanding of control practices for TBDs by farmers and link the under-explored sociological aspects of the problem in the socio-ecological systems and collaborative efforts such as ''One-health''.

To investigate the control practices and governance of TBDs, we used an individual farmer practice as the basis (Aarts & Lokhorst 2012), applying the concepts of *context, practices* and *interaction*. Motivated by the social practice theory (Scott 1989, 2016, Strengers & Maller 2014) that has criticised individualist approaches, we paid attention to the wider context of the control practices of TBDs, which necessitated a clear understanding of what most farmers or actors do and why, and how they articulate agency in relation to contextual constraints and opportunities. First of all, the *social-political context* refers to institutions (policies, market conditions, culture), political processes and power relations that influence the enactment of the control practices for TBDs by keepers (Arts et al. 2013, 2014, Behagel et al. 2019). We investigated this social-political context using a genealogy of practices in which we traced the dominant control practices for ticks in Kenya and their associated power dynamics in history and mapped their links to the everyday lives of livestock keepers in Laikipia. This gave us insights into the historical perspectives of the control practices of TBDs and other zoonoses), the institutions that have co-evolved in tandem with the problem as well as how this context influences the situated agency of livestock keepers in Kenya and beyond. We paid particular attention to what was not problematised in the dominant control practices for ticks as well as the key categories that were created.

Secondly, the concept of *practices* refers to "an ensemble of doings, sayings and things in a specific field of activity" (Arts et al. 2013, p.9). In this study, practices refer to the actions by people (e.g., frequency of spraying), language (the way they talk about acaricides) and things (acaricides, technical devices used for spraying). The concept of practices gave us insight into what livestock owners do in relation to acaricide use, including why and how they purchase, store and administer acaricides as well as the underlying meanings and rationalities of why they do so. So instead of framing acaricide use by pastoralists as malpractice and assuming that pastoralists lack the skills or education to correctly apply acaricides (Mugisha et al. 2008, Mugambi et al. 2012, Adakal et al. 2013), we started from the assumption that pastoralists are 'knowledgeable' and 'capable' to solve their everyday problems within the limits of the environmental, normative or social-political context in which they operate (Giddens 1984). As such, we remained open to the possibility that the so-called 'malpractice' or 'misuse' of acaricides is, in fact, a form of 'everyday resistance' to the standard acaricide practices prescribed by the government or pharmaceutical companies'' (Scott 1989). Hence, pastoralists may have very good reasons for doing what they are doing as long as we take their perspectives seriously (Waller & Homewood 1997, Dong et al. 2011, Grillo 2012).

Thirdly, the concept of *interactions* refers to how different groups, enacting different practices, relate to each other on a wider landscape level and how control of TBDs is enacted across space. We studied whether different practices aligned, conflicted or complemented each other, including the intended or unintended consequences of these interactions. This gave us insights into how people enacted certain practices evoking relationships between them and the wider effects of their interactions.

We also discuss the tensions and conflicting practices relating to TBD management between the pastoralists and the commercial ranches in Kenya, situating it in a historical and institutional context. We then explore how this social-political context influences the enactment of TBD control practices. We also investigated how the different control of TBDs practices in Laikipia are related to each other and the wider area. We reflect on the implication of our findings to our thinking about the relationships between people and their environment from the sociological perspective.

## Methods

The study was conducted in Laikipia County, Kenya, located at 0°18′ S and 0 °51′ N, 36°11′ and 37°24′ E (Fig. 1). The county is semi-arid and occupies an area of 10,000 $km^2$ and is divided into five administrative sub-counties (East, West, North, Central and Nyahururu). The human population was > 520,000 (KNBS 2019). We decided to study the control practices for TBDs in the county because the climatic conditions favour the all-year-round survival of ticks and farmers continually administer acaricides to reduce losses from diseases (Allan et al. 2017). The area is a wildlife conservation '′hotspot′′ and attracts many actors including the public and private health-related institutions with divergent views under the domains of wildlife and livestock production (Allan et al. 2017). Hence, the entry of new actors in the control of TBDs in the area is likely to tilt the power balance and impact collaborative efforts. Two main farming systems in the area comprise the intensively managed commercial ranches owned by mostly white farmers with a few by pastoral communities or affluent Kenyans involved in livestock ranching, wildlife conservation and eco-tourism. Secondly, there is the semi-intensive pastoralism by nomadic pastoralists with strong social and communal norms (Mugambi et al. 2012). The communal ranches are less organised and farmers individually own livestock with their practices being synonymous with what pastoralists do in the area. The large-scale commercial ranches are mostly owned by Kenyans, formerly colonial settlers (Lesorogol 2003). We thus purposively chose four study sites; two commercial ranches, Olpejeta Conservancy and Loldaiga Hills, and two pastoral areas: Naibunga and Segera-Endana. In the pastoral areas, the grazing areas are open and communally, and characterised by high wildlife and livestock interfaces. Conversely, the commercial ranches have clear boundaries demarcated by fences. The two dichotomous farming systems adequately replicates what happens in the wider area and conceal important information on TBDs, critical for understanding and transforming the processes. More than 70% of the workers at the commercial ranches are drawn from the local pastoral communities (Mutavi et al. 2018).

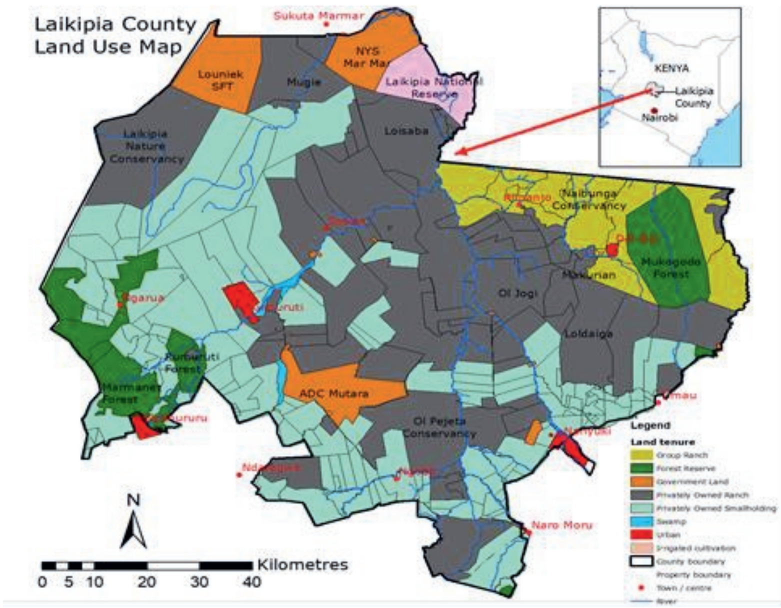



**Fig. 1**: Map of Laikipia showing the major land-use systems as of 2018. Pastoral farmers graze their livestock in open savanna areas towards the North (yellow), Central, South and West (grey) (Adapted from Chepkwony et al., 2018).

## Study design

We employed semi-structured interviews from 62 participants of male and female genders with prior informed consent, participant observation, focus group discussions (FGDs) and archival document analysis to understand how control of TBDs and governance is enacted by farmers and actors in Laikipia County from February 2018 to September 2019. The archived documents contained information on land tenure systems, maps on olden stock routes, reports of disease control initiatives and past policies. The participants varied in age distribution from 18-65 years- prime livestock herding age for herders or workers. The literacy levels for the interviewees ranged from illiterate herders up to those from tertiary level institutions. Initial study questions which guided data collection were developed by the authors and the interviews were conducted in Kiswahili and/or English languages; each interview ranged from one to one and a half hours. Interviews and discussions were conducted in private locations, usually identified by the participant(s) at his/her convenience on a scheduled date after verbal consent was sought from each anonymised participant. All interview data were recorded in field notebooks as "statements" based on the themes and existing literature on TBDs in Kenya. The discussions consisted of demographic questions, questions related to control practices for TBDs, challenges and mitigation, familiarity with TBDs, extension services and networks, knowledge sharing and questions related to the livestock-wildlife encounter. Since we were not interested in making generalizations about the study, we looked for an information saturation point at which no new information was further generated (Saunders et al. 2018).

We observed the acaricide application process by farmers vis-a-vis the status of the equipment used (i.e., broken, leaking), use of personal protective equipment and disposal of acaricide and packaging materials because not all farmers have the capacity to implement control practices for TBDs due to various limitations socio-economic factors (Adakal et al. 2013). We needed to map how these factors impede the control practices for possible transformational considerations. We hosted three reflective FGDs involving the representatives of the pastoralists-grazing committees, livestock managers of ranches and institutions operating in the locality to evaluate responses from the participants. We took photographs to complement the field observations. Finally, we employed archival document review (historical books, journals, reports, parliamentary petitions) dating back from the 1930s to 1963 (pre-independence period)-when colonialists imposed control interventions (acaricides, quarantines) on pastoralists livestock; 1963-to date (post-independence)- when government-supported disease control based on the ‘’western’’ standards; 1994 to date (the period when disease control was devolved to farmers with reduced state support with diminished extension services. Mapping these historical perspectives enabled us to discern the motivation of why and how farmers and actors behave as they did- rationalities. Moreover, mapping of the historical perspectives enabled us to understand how land uses, privatization and livestock management practices, and discrepant inequalities and the situated agency of the main pastoralist farmers was enacted in the area (Lesorogol 2003, Mizutani et al. 2005b, Chepkwony et al. 2018, Mutavi et al. 2018). Used the archived documents stored in government offices, local libraries and online searches to map the genealogy of the zoonotic disease management and the enactment of the discrepant power relations (biopower) by actors. We considered parliamentary issues on disease control as the political class are responsible for policy formulation and legislation and impact disease management and governance. Because of the iterative nature of the study, we coded our narrative accounts, review of documents, field observation notes and the FGDs into the three themes: *context*, *practices* and *interactions* Patterns and linkages between quotes, themes and existing literature were then explored in-depth to identify areas of convergence and divergence, and how these themes and linkages shape the historical *contexts*, *practices* and *interactions* relating to the control of TBDs in different farming domains. We used empirical data obtained from interviews, participant observations and FGDs to obtain first-hand information and insights from farmers and actors to understand their perceptions and possible solutions to the problem and discern whether their disease control practices are linked to historical contexts.

## Results

### *A genealogy of the control of zoonotic disease in Kenya*

The management of zoonoses, especially tick control, in Kenya cannot be understood without taking the historical context of colonialism into account (Davis & Sharp 2020). It is during this period that the assumed dichotomy between "traditional" pastoralism and the "modern" livestock sector emerged and policies on zoonoses became interlinked with boundary maintenance and conflicts over space. Before the British colonization, the Laikipia area was under pastoralism, primarily by Maasai and Samburu communities (Wiesmann et al. 2000). However, under British colonialism, Laikipia became very popular among settlers that were interested in cattle ranching (Morgan 1963), leading to large-scale relocation of the Maasai in favour of European settlement. Treaties signed by the British Colonial Administration and the Maasai in 1904 and 1911 included an eviction order of Maasai people in Laikipia to Native Reserves in the south of Kenya, presently near the Masaai Mara (Hughes 2005, Letai 2011).

The European commercial producers did not know how to live with zoonoses as an unavoidable part of the Kenyan environment in the way the pastoralists had always done. They perceived zoonoses as something that had to be battled and preferably, to be completely eradicated (Waller 2004). White commercial producers feared that the uncontrolled movement of pastoralists stock would spread TBDs, infecting their stock jeopardising the capital that they had invested in them. As the settlers started to import exotic varieties of cattle and cross-breed them with local varieties, the risk of zoonoses increased because the imported breeds were more vulnerable to these diseases. The exotic varieties of cattle were also more expensive (Waller 2012). Commercial cattle ranches called on the policymakers, researchers and veterinarians to combat TBDs to eliminate the threat (Waller 2004).

To control the spread of these zoonoses, quarantine "barriers" were erected to protect the herds of the settlers against infection emanating from the pastoralists herds. Quarantine was intended to restrict the movement of cattle unless very strict rules and regulations had been met. Animals that were suspected of having become infected with zoonoses were slaughtered, with or without compensation. The Veterinary Department assumed that TBDs were everywhere, imposing a blanket quarantine for the whole country. Quarantine boundaries prevented pastoralists from using their traditional stock routes and also denied them access to water and pasture(Waller 2004). The colonial regime tried to prevent illegal migration and control movement through "branding, counting, and registration" (Davis and Sharp 2020, p. 5). The colonial zoonoses control forced the colonial government to assess the relative value of pastoralism versus colonial stock-keeping and led them to prioritise colonial practices while at the same time marginalising pastoralist practices (Porter 2016). This policy turned pastoralists into subjects that needed surveillance, 'control' and boundaries to contain them. Some of this was intentional as the British-Kenyan protectorate regime wanted to suppress "pernicious pastoral proclivities" (Governor Belfield 1913, in Sorrenson 1968, p. 219). To collect taxes, the government needed sedentary, productive and taxable growers, instead of the migratory pastoralists that seemingly did not contribute to the economy and were difficult to manage for a state (Waller 2012). So the restrictions on movement and surveillance were not only put in place because of disease control but these were also part of a larger and systematic program of civilisation and a pre-determined state formation.

In practice, the colonial government could not enforce the quarantine measure in the entire country due to the scarce resources and consequently the blanket quarantine caused trade depressions. Because trade was no longer feasible, pastoralists could not sell their cattle and therefore they were also not able to pay their taxes. Instead of imposing blanket quarantine, areas were categorised, segregated and labelled 'clean' or 'dirty' depending on the presence of TBDs (Waller 2012). Areas, where ticks were endemic, were described in colonial writing as 'dirty', whereas in areas where ticks could not thrive or diseases had been eradicated, were described as 'clean'. Pastures could, it was believed, be 'cleansed' or kept 'clean' by the regular dipping of livestock to kill infective ticks. The pastoralists cattle were thus viewed as the main sources of infection and were categorised 'dirty' and therefore fences were created to keep them out or separate them from the colonialists' cattle, presumed uninfected and categorised as 'clean', and needed to be protected by fencing them in. It was thought that this would break the chain of transmission by stopping the zoonoses from spreading and would protect the future of colonialist cattle ranching. The dichotomy between 'clean' and 'dirty' was stark and legally manifested in the way they managed fences, roadside dips and quarantine stations. Moreover, the difficulties and expense of control posed by a patchwork of endemically stable (otherwise 'dirty') and unstable (otherwise 'clean') areas were obvious.

The pastoralist neither accepted the policies of the colonial veterinary department nor shared the assumptions underlying these policies. For the pastoralists, the zoonoses were part of the environment and instead of eradicating it, they saw them as something to live with. Their management strategies allowed them to endure the zoonoses by building up herds to allow losses, selecting migration patterns that allowed them to prevent infection and recognition that continued exposure could allow cattle to develop herd immunity. Ticks were controlled by close grazing of a succession of animals, pasture was frequently burned, and dangerous areas were avoided. Endemicity allowed cattle to develop resistance to epidemics and those that became immune to zoonoses were highly valued. In this pastoralist worldview, fences, roadside dips and quarantine did not make sense and instead were seen as an unwelcome limitation on migration that pastoralists had tried to avoid as much as possible (Waller & Homewood 1997).

The influence of colonisation in Laikipia is still visible today. The population consists out of descendants of the original European settlers and expats as well as various pastoralist communities. Some commercial ranches combine commercial cattle ranching with wildlife conservation and ecotourism while others have converted completely to wildlife conservation. In addition to the commercial ranches, there are also several communally owned ‘group ranches’ that are used by pastoralists.

***Mapping the landscape of tick management practices in Laikipia***

The commercial and the communal ranches seem quite similar. The landscape is similar, and both engage in livestock management. They also both share their environment with wildlife species that frequently move through the area. However, commercial and communal ranches are very different from their livestock management perspectives. In Laikipia, there is no official policy for livestock management and both the commercial and communal ranches can decide on how they want to manage their livestock. In practice, this means that due to historical, political and economic factors the differences in resource management and tick control are stark (Yurco 2017).

***Management of ticks based on the logic of eradication***

Commercial ranches often combine livestock production with nature conservation and ecotourism, using rotational pasture management within the ranch, i.e. movement of the livestock herds according to the pasture management plan, as well as management of ticks or vaccination schemes (Yurco 2017). Furthermore, commercial ranches work within an economic framework focussed on the market value of the stock, necessitating a dire need for the protection of valuable animals and the general improvement of stock quality. Hence, ranches control TBDs using a system of ‘cattle spraying’ which involves a systematic application of chemical acaricides to eradicate ticks and treatment of livestock. Acaricides must be applied universally and spraying must be carried out weekly to be effective.

So as a practice, commercial ranches rely on highly mechanical infrastructure for regular livestock ‘spraying’ to prevent cattle from becoming infected with TBDs. We observed that at the ranches, livestock are sprayed weekly but occasionally a spike in tick loads in livestock may warrant a reduction on the application intervals to less than five days. Firstly, the cattle were rounded up and mustered into a cattle yard. Then one by one the animals were herded into an increasingly narrowing cattle race that was lined by strong poles. This gave the cattle no other choice but to move forward in a single file. A foot bath cleaned the feet of the animals which were then pushed through the spray race one by one. The spray race can be described as a modernised dip, where cattle walk through a structure where livestock is sprayed with acaricides using a high-pressure nozzle directed to all parts of an animal's body. Moreover, the tunnel construction allows for continual stock movement through the spray race. After they left the spray race, the animals entered a second cattle yard with a sloping concrete floor that allowed for the collection and possibly recycling of the acaricides that dripped off the animal after spraying. The passageway into and out of the spraying cubicle was blinded by a cotton sack to prevent excessive de-ionisation of the acaricides and possible aerosol poisoning of the workers. Running of the spray races was technically quite demanding and operators had to be correctly trained to make sure that the spray race functioned properly. The spray race required a reliable water supply. Furthermore, the operators needed to regularly clean the nozzles and this required removing them. After cleaning them, the nozzles had to be placed back and adjusted correctly to ensure the right pressure for effective coverage to completely wet the animal. If too much pressure was used, then also too many acaricides were sprayed onto the animal resulting in wastage. If insufficient pressure was instead used, then the animal would not be completely sprayed, and certain body parts would be missed. It was also important that the acaricides did not form a mist as this would not sufficiently penetrate the coat and animals were then at risk of inhaling the chemicals. Finally, animals had to be paced carefully for them to spend sufficient time in the spray race. If they ran through, then the spray race would also not be as effective as it could have been.

We observed that ranches consistently used one brand of acaricide, Triatix, a variant of Amitraz, to prevent resistance in ticks, as illustrated by a livestock manager:*" We have consistently used Triatix for many years and we do not have problems with it. We buy them directly from the manufacturers in large quantities to reduce costs and ensure quality"*. The application of acaricides in the ranches is based on the directions of the user manuals and the advice of the livestock management teams professionally trained on livestock husbandry. To mix their acaricides, we observed that the employees of the ranches used calibrated equipment, clean water and often boosted the concentrations of the acaricides by adding more chemicals regularly as the cattle were being sprayed. Consequently, TBDs were prevented because of the reliability of the acaricide treatment.

The spray race is a more advanced and technological-oriented system in which elaborate infrastructure is needed so that disease control becomes a technocratic activity of biomedical control, where ranch owners rely on technology and control of TBDs protocols in their livestock. Similar to colonial times, the commercial ranches are "protected, clean spaces in the landscape" where western veterinary knowledge is applied for controlling TBDs (Waller 2004). Commercial livestock keepers are constantly responding to TBDs with strict tick treatment, fencing and/or boundary control to keep potentially infected livestock out.

***Management of ticks based on the logic of herd immunity***

Pastoralists in Laikipia are mostly living in communal ranches, dating back to the early 1970s when it was thought that this would support pastoralists by giving them autonomy. The land is owned collectively by several clans or families (Fox 2018). Not all people living in the group ranches and caring for the livestock are the owners of that livestock. Diversification has always been an important livelihood strategy for pastoralists and some heads of the household have moved to towns to look for employment thereby leaving the herding of their livestock up to other members of the community. This has led to institutional changes within pastoralist communities in which nowadays herdsmen are hired by the household for a monthly fee to provide herding services. This means that for some households' livestock keeping has become an investment instead of subsistence.

Traditionally pastoralists have managed and treated zoonoses based on their experiential knowledge, which is strongly linked to their spiritual practices and their relationship with their environment. In their worldview, there is no clear distinction between people, animals and the environment. As such human and animal life and the environment are interlinked and contrary to the western way of separating these forms of life into neat categories, the pastoralists tend to see them all as connected. Livestock is not only a livelihood activity but their relationship with the animals is also part of "their traditional belief systems, stories, songs" and it is integrated into their culture as well as into their everyday ways of being (Davis & Sharp 2020, p. 5). Livestock is an investment, but it is also the basis of their social network, their cosmology and their subsistence. In this pastoral life world, diseases are part of all of that too. Pastoralists are aware of the vulnerability of animals without acquired immunity, and traditionally used movement and controlled exposure to endemic disease as a way of protecting herds against epidemic outbreaks. Management of TBDs is predicated on the constant presence of disease and tended to work with rather than against the ecological grain. The restriction of movement-related colonisation and state formation has eroded the resource base of pastoralists thereby reducing their ability to manage herd immunity and leaving their livestock at higher risk of zoonoses (Davis & Sharp 2020).

Pastoralists being pragmatists and pluralists accept western veterinary treatments if these treatments are perceived to serve their interests (Waller & Homewood 1997). Disease management is a hybrid practice, based on a plurality of knowledge and bricolage (Beinart & Brown 2013). The pastoralists that we worked with treated their livestock against ticks by hand-spraying them with acaricides in small enclosures. In the early morning hours of our fieldwork, we often encountered some pastoral farmers preparing to spray their animals before taking them out to graze. Mostly the acaricides were poured into a recycled cooking oil container of 20 litres modified by having the top part cut open. This container was then filled with water from a nearby stream. The pastoralists did not use any calibration equipment to estimate the acaricide-water ratio. They did not wear hats, protective gloves or masks but were only in their 'red' cotton clothes, gumboots or fleece jackets. We observed the farmers/workers as they stirred the chemical mixture gently using a tree branch. They sprayed one animal after another with two operators: one operating the hand spray and another one busily directing the "whitish" chemicals to the predilection sites of an animal that includes the tail, ears, the groin and other tick-infested body regions. While spraying the animals, we observed that the hand spray at times sputtered because of broken nozzles tied in black rubber bands, thereby spilling the chemicals out onto bodies of both people and animals.

Although hand spraying is less effective than dipping, it is cheaper and easier to organise since each pastoralist can decide on his schedule, acaricide type and mixing ratio. Pastoralists would inspect their livestock for ticks and based on their observations, they treated the animals focussing on the tick-infested body regions instead of spraying the whole body. Most of the pastoralists purchased chemicals from town or bought chemicals from informal retailers. We observed a kind of pragmatic common-sense caution in the way that the acaricides were used by the pastoralists. Most operators applied the acaricides without reference to any material or competent authority: *"I mix the chemicals based on my own experience after doing this for many years. So, I mix 5ml of the acaricides in 20 litres of water. Based on my experience I don't need any assistance"*. Few pastoralists correctly followed the instructions and used sub-optimal concentration levels based on 'their experience'. Overall, respondents suggested that tick control had become less effective than it had been in the past, possibly because of growing resistance to the acaricides. To deal with this, they used multiple brands and frequently changed the type of acaricides.

What looks like malpractice from a western-based logic of eradication, is not so irrational when viewed from a logic of herd immunity. According to pastoralist logic and experience, disease simply cannot be eradicated. Interventions, such as tick control using acaricides, might be required to curb undue loss but a disease-free state is not necessarily desirable. The tick management practices of pastoralists seemed to reflect this logic. What we observed was prudent stock owners making cautious and selective use of what western veterinary science has to offer, based on an assessment of how it might contribute to herd immunity and the survival of the herds, and of whether there is a rationale accorded with their knowledge and experience.

The extension officers or veterinarians confided to us that the altered practices of pastoralists were an expression of pastoralists "ignorance" or an indication of their "lack of understanding". According to extension officials; '' *I don't think the pastoralists have adequate knowledge have sufficient knowledge on how they prepare the acaricides, most of what they do is guesswork*. *They rarely seek our advice''*. And indeed, a gap exists between expert and pastoralist knowledge. Pastoralists scrutinise and select rather than fully embrace western veterinary aid. In continuing to accept the limited loss to safeguard the herd and to defend the value of their system of medical knowledge by 'passive resistance', pastoralists are following the harsh logic required to maintain subsistence pastoralism under increasingly adverse conditions. According to most pastoralists, illustrated by Dickson of Naibunga area '*'I have to check how many animals I have and the tick loads then I prepare the chemicals or change them accordingly since the chemicals* *are expensive and we have to use it well*''. This response is inevitably construed as backward, apathetic and even obstructive by hard-pressed veterinarians and administrators.

***Navigating a landscape of interdependent, disconnected practices***

In Laikipia, the problem of controlling TBDs is embedded in the coexistence of two different kinds of practices and worldviews, one western and commercial, the other pastoralist and livelihood based system (Waller 2004). The commercial ranch owners and the pastoralists have different ways of valuing livestock and have different ideas about TBDs and the way these should be managed. '' *I keep livestock since we the Maasai are pastoralists and livestock is our food, source of wealth and identity. It is our bank*. *I often have to deal with ticks and diseases and buy acaricides and change them frequently to increase the probability of killing ticks and during the dry season I have to take part of my stock to the ranches and the rest to Mt Kenya to save them*'' Ole Masimpe, Laikipia North. However, according to most ranch managers, '*'We buy the acaricides directly from the manufacturers to ensure the quality of the products and we to keep the diseases control standards high since our beef is for local and international markets. We apply to spray our livestock on mechanised spray-races on a weekly-basis following the directions of our professionally trained staff*''. Although the livestock on the ranches is fenced in and the pastoralists livestock on the communal ranches is thereby fenced out, many pastoralists are working in both spaces and thus frequently crossing the artificial borders and boundaries (Yurco 2017).

First, pastoralists are commonly hired by the commercial ranches as professional cattle herders. The practice of hiring pastoralists as professional livestock herders started when Kenya was still a British colony and when 'rangeland landowners were absentee and hired third-party pastoralists to manage their livestock' (Riginos et al. 2012). As professional herders, pastoralists are required to do what they have been doing for generations, namely herding livestock, but at the commercial ranches, they are now required to follow western management practices. This means that they need to follow the rotational grazing schemes as determined by the manager of the ranch, making sure that all livestock is treated for tick infestation weekly in a spray race. When having some time off, many professional cattle herders return home to spend time with their families, and during their visit home, they may herd their livestock in the communal ranches based on their pastoralist logic. But as soon as they return to the commercial ranch, they need to step back into their role as professional herders. *According to some of the pastoralists,'' I work at Loldaiga ranch but I have my livestock with the family at home and I often go home to check on how my stock is faring. I control ticks based on my experience, so I have to do what I think is best for me since the chemicals are expensive although we buy part some of it from the ranches*. *I use a hand-spraying machine since it is convenient to move it with our livestock during the dry season".* The boundaries that they cross while travelling from the communal ranch to the commercial ranch are not only symbolic but also material. As soon as they are back on the commercial ranch they must conform to the logic of the ranch; follow the rules and regulations applicable, which also involves different roles and responsibilities and a different way of life (Yurco 2017).

Secondly, the elders from communal ranches have the authority to negotiate agistment[1] (synonym: lease) arrangements with the commercial ranches which allow the pastoralists to graze a predetermined number of cattle and sheep in certain allocated areas of the commercial ranches. During the dry season, this gives the pastoralist community access to additional pasture and water as part of their adaptation to climate change and variability. Not all commercial ranches open their grazing up to pastoralists and on those that do, the conditions for grazing, restrictions on herding practices, and the number of livestock that are allowed, vary. Usually, a communal ranch is allocated a quota and livestock owners decide how to divide the quota amongst the communal ranch members (Ameso et al. 2018). In Oljogi and Olpejeta conservancy, for example, the agistment fee is about Kenya shillings 200 per head of cattle and a specific area within the commercial ranch is allocated to the pastoralists. The pastoralists must provide their herders. While grazing at the commercial ranch, the pastoralist livestock is obliged to adhere to the livestock management plan of the property, including vaccination and weekly dipping. According to the livestock managers in the ranches,'' *I allow members of the adjacent community to bring in their livestock during the dry season for a fee based on an agreed quota determined by their grazing committee.*

[1] Agistment refers to taking in of cattle to graze in exchange of a fee payment or a contractual obligation (Oxford English dictionary).

*When they come here they have to conform with our rules including how they control ticks*''. On the one hand, the pastoralists welcome the grazing arrangements while on the other hand by being allocated under grazed areas, they also feel that their livestock is being used to 'mop' up the ticks off of the pasture with resultant heavy tick loads, as illustrated by one pastoral farmer from Endana-Segera areas, '' *We don't have any other options for our animals during the dry season but to take them to the ranches to save them from severe drought although we are allocated areas with a lot of ticks, yet we still pay for it*''. Furthermore, pastoralists feel wholly negative about having to pay pasture and water that they consider to be theirs according to customary rights.

These two examples show that pastoralists navigate the landscape of disconnected practices in Laikipia by pragmatically adhering to the strict weekly dipping schedule when grazing on the commercial ranches but going back to their tick management practices when grazing in communal areas. Pastoralists realise that they no longer live entirely in a world in which they can apply their traditional management practices, but they also realise that the world that they live in also does not allow them to fully adopt western practices either. The western way of tick control comes with enclosing pasture and it comes with the individualisation of land and water resources. Among pastoralists, sedentarisation is seen as the last survival strategy available to community members that have lost their livestock and thus it is not the preferred option. Although permanent settlement is now increasingly becoming an investment for community members that moved to towns in search of employment and who can now afford to hire herdsmen to take care of their herds, this comes at the cost of identity loss. For what is "pastoralist" when the herding family's treasure would not exist without the support of urban or out-of-country members? Thus, pastoralists hang suspended between the two types of management practices, navigating them as well as they can and using their situated agency to do so.

**Discussion and conclusion**

Using our qualitative and interpretive approach, we were able to unravel the logic behind the behaviour (*how things are done and why they are done the way they are done)* of the different livestock owners in relation to tick control in Laikipia. Our analysis shows that the management practices of pastoral communities

(Maasai) and those of the commercial ranches in Laikipia are the products of two different worldviews, sometimes converging or interlocking but often at odds over fundamental issues. The analysis presented here (interplay of historical *context, practices* and *interactions*) reveals the power relations, tensions and contradictions emergent from an attempt to impose a western model of control of zoonotic diseases onto the East African region. The results of this study have implications for the policy direction on land use and governance of zoonoses, especially TBDs. Furthermore, the highlights of this paper improve our understanding of the potential of introducing the landscape-scale concept of zoonoses management and how "knowledge" of disease management by pastoralists might be useful to inform infectious disease control and land-use policies. The compounding uncertainty around TBDs management and governance more broadly put significant pressure on the relationship between farmers, actors and the state and highlights the differential needs represented in this relationship. For example, commercial and pastoralists farmers in Laikipia apply acaricides differently based on their social and economic ability and the commercial farmers do manage the navigate these uncertainties well compared to the pastoralists who feel disenfranchised by the ranchers and the government. The divergence in relationships between the two farming communities hinders collaborative efforts and impedes a wider area control of ticks as pastoralists move over long distances in search of pasture and increase the risks of diseases transmission. The government policy should re-consider farmer subsidies on acaricides and other vaccines and create farmer-actor led initiatives of information sharing such as ''One health''. Our study also revealed that the indigenous knowledge of the pastoralists in the management of TBDs is largely ignored and does not feature in any policy document in Kenya despite the central role in improving or informing disease management and governance in a wider area. Policy documents in Kenya should consider indigenous knowledge of pastoralists as this may reduce costs and motivate farmers to actively participate in zoonotic disease management and governance. The loss of government support and diminished extension services was felt more strongly by the pastoralists in Laikipia and engaging with their indigenous knowledge on disease management then we can create space for farmers to articulate what they wanted from state extension and other actors including citing a clear absence of expertise in applying the recommended acaricide protocols.

First of all, and in line with Davis & Sharp (2020) and Hinchliffe et al. (2012, 2014, 2015), our study suggests that the tick management practices in Laikipia reflect a form of 'spatial biopolitics'. To start with, areas in the landscape are categorised as 'clean' or 'dirty', and boundaries are created to contain tick infestation and prevent the spreading of TBDs. Then the movement of people and animals is made legible through counting and registration. Last but not least, the movement of people and animals is controlled and restricted through border control and governance. Biopower (Holloway 2007)subjectifies people and animals through moral geographies that determine who belongs where in the landscape depending on the presence of TBDs (Setten 2004, Shortall & Brown 2020). The moral geography of the management of TBDs portrays the rangelands of Kenya both as a landscape that is purifiable and supposedly to be pure (free of TBDs). Pastoralists and their livestock then become a bio-security risk; they spread TBDs and this legitimises marginalising them by 'quarantining' them, either literally or figuratively by restricting their movements. A loss of traditional migratory routes is presented as a small price to pay for safeguarding the veterinary health of an entire nation. The spatial biopolitics of the management of TBDs were designed to benefit the western colonial settlers and their livestock at the expense of the pastoralists and their livestock. The issues of colonialism, ethnicity and state formation have been notably absent from earlier discussions on biopolitics and the control of zoonoses.

Secondly, our analysis shows that the spatial biopolitics of TBD control has resulted in a 'landscape of disconnected practices'. Ironically, this has increased the vulnerability of both commercial producers, who depend on the domain of western-prophylaxis for eradication, as well as the vulnerability of subsistence pastoralists, who are not able to fully embrace western practices and whose resource base needed for herd immunity is being further eroded by their quest for commercial expansion such as improving and marketing their livestock (Waller 2012). So the paradox is that too much regulation and control can create the ideal conditions for an outbreak of infectious diseases, some of which may be far more serious than would otherwise have been the case (Hinchliffe et al. 2013). From this perspective, pastoralists, commercial keepers, livestock, ticks and spaces are entangled in a process of "mutual becoming" (Shaw et al. 2010, Ingold 2011). Thinking in terms of a landscape of practices helps to map the (dis)connections, frictions and alignment between and among the tick management practices at the landscape level as well as reveal the interdependence of these practices in terms of the resilience of the socio-ecological systems at a wider area. This challenges some of the spatial assumptions underlying the conventional understanding of tick management practices and calls for a reframing of the boundaries of the system of interest from a focus on tick control practices at the farm level to a focus on the governance of tick control practices at a wider landscape level. As such it also calls for a shift in the focus of biopolitics in term of what counts as good governance.

Our qualitative and interpretive approach used in this study improved our understanding of the control of TBDs, including the challenges for individual farmers, and for the livestock sector as a whole in Laikipia including what livestock owners do, why they do what they do. This study reinforces the assertion that situating management practices related to health in changing social, economic, ecological and biophysical conditions can create an understanding of enduring complex connections and entanglements of fundamental socio-ecological issues (Parkes et al. 2005, Ziegler et al. 2016). This has also been demonstrated in recent studies on the control of emerging and re-emerging zoonotic diseases such as avian influenza (H5N1)(Brown et al. 2017) and bovine viral diarrhoea (Shortall & Brown 2020). The social side of SESs is often only superficially covered in research on zoonotic diseases, therefore reproducing western-centric biomedical practices that may increase the vulnerability of the SES, especially in tropical drylands. Hence, in line with several studies (Parkes et al. 2005, Hinchliffe et al. 2013, Ziegler et al. 2016, Davis & Sharp 2020), we argue that an extended approach to zoonotic disease management, particularly in tropics, is needed to properly understand the SES. This paper highlights how a critical social analysis can do that by giving insight into local practices, mapping the genealogy of these local practices to reveal biopower and biopolitics involved, revealing the consequences of these social processes of inclusion and exclusion and opening up a discussion on how the dominant system could be challenged and transformed into a more resilient one.

**Acknowledgements**

This research was fully funded and supported by Wageningen University and Research (WUR), The Netherlands, through the Environmental Virtual Observatories for Connective Action (EVOCA) project in collaboration with the Kenya Wildlife Service and International Livestock Research Institute (ILLRI)-Kenya. We are thankful to our colleagues Dr Yussuf Wato of WWF-Kenya, Dr Francis Gakuya of the Kenya Wildlife Service, and Catherine Pfeifer of ILRI-Kenya, who provided invaluable inputs and constructive criticisms that greatly assisted the development of the paper. We also sincerely thank Catherine O'Dea for proofreading the article.

We express our appreciation to Cees Leeuwis, Noelle Aarts, Ignas Heitkönig, Cieslik Katarzyna, and Annemarie Van Paassen of Wageningen University and Research for providing insights and experiences from various past projects, immensely improving the approach used in this research. We are also grateful to the Kenya Wildlife Service for providing approval for our research and security services during the fieldwork. We thank them all!

# Chapter 6

# Synthesis

## Connecting divergent worlds: Social and ecological factors influence tick-borne diseases in tropical drylands

### 6. 1 Background and main question of the thesis

The spread of tick-borne diseases (TBDs)  is a major challenge in the development of the livestock industry, wildlife conservation and human health because of the spread of high impact diseases such as East Coast fever, bovine anaplasmosis, babesiosis and tick-borne encephalitis (Minjauw & McLeod 2003, Mugisha et al. 2008, Ameso et al. 2018). TBDs are widespread in many tropical areas because of the conducive all-year-round social or ecological conditions for their spread despite the attempts by farmers and divergent actors (e.g., pharmaceutical companies, wildlife managers, policymakers and medical practitioners) to control these diseases (Dantas-Torres et al. 2012, 2013). For instance, various interventions (e.g., pasture spelling, use of acaricides, keeping livestock thought to be tick resistant, etc.) have been applied by farmers and other actors but these control practices are constrained by the underlying interaction effects of the unknown social and ecological factors (Minjauw & De Castro 1999, Mugisha et al. 2008, Dantas-Torres et al. 2012, 2013, Cieslik et al. 2018).

In the tropical drylands, ecological factors such as rainfall, temperature and humidity, vegetation cover and host availability provide conducive all-year-round conditions for the survival and spread of ticks, causing TBDs and subsequent mortalities (Minjauw & De Castro, 1999; Mugisha et al., 2008). Furthermore, human-induced factors, including changes in human activities such as poor implementation of TBDs control strategies, poor livestock husbandry practices and lack of collective actions by actors aggravate the spread of TBDs, with ramifications on the costs of livestock production (Jongejan & Uilenberg 1994, Adakal et al. 2013, Awa et al. 2015). Moreover, collective group behaviour (e.g., decision-making by farmers) could serve as a major risk or protective factor in the context of the control of TBDs. For instance, factors such as limited information and knowledge sharing by farmers and actors lead to the poor implementation of the control practices of TBDs (Cieslik et al. 2018). Thus, the control of TBDs and subsequent costs of livestock production can be significantly reduced or enhanced through timely information sharing using innovative digital technologies such as mobile phones and citizen science. A clear understanding of the interaction effects of the social, biological and ecological factors while leveraging on the adoption of innovative technologies for improved information sharing could play a crucial role in the effective control of TBDs. This PhD is the first step in that direction. The main aim of this PhD thesis is to address the question: **what are the social and ecological factors and their interaction effects on TBDs, and what could be the potential role of mobile phones in reporting TBDs in the tropical drylands?**

To address this question, I formulated the following sub-questions:

1. What is the association between rainfall and tick-borne disease-induced mortalities in livestock in the tropical drylands? (Chapter 2)
2. What are the interactive effects of the environmental, biological and social factors on tick loads in wildlife and livestock in tropical drylands? (Chapter 3)
3. To what extent do the social-political factors influence the spread and control of TBDs in the tropical drylands? (Chapter 4)
4. What could be the potential role of mobile phones and citizen science in information sharing on TBDs in the tropical drylands? (Chapter 5)

This thesis was carried out as part of a multidisciplinary project: "*Responsible Life-Science Innovations For Development In The Digital Age: Environmental Virtual Observatories for Connective Action (EVOCA)*". The overall aim of this project was to develop mobile phone-based digital platforms to enhance either data collection or information sharing by multiple actors to collectively address challenges such as diseases in crops, livestock, human health, wildlife and water management in the developing countries of Africa such as Kenya, Ethiopia, Ghana and Rwanda (Leeuwis et al. 2018). This PhD study thus investigated the social and ecological factors influencing TBDs and the potentials of adoption of mobile phones technologies and citizen science for information sharing by farmers and actors in the tropical drylands.

To study the social and ecological factors exacerbating the spread or control of TBDs and to determine the potentials of information sharing by farmers using mobile phones in Laikipia County, Kenya, I employed a mixed-method approach comprising of the natural and social science approaches for data collection such as sampling of ticks in wildlife and livestock, in-depth interviews, documents review, workshops, focus group discussion and participant observations, and using elements of SES approach for data analysis.

In this chapter, I present an overview of the major findings of the individual chapters and synthesis to unravel the interaction effects of the social, biological and ecological factors and the (non)adoption of innovative technologies employing systems thinking approach for managing TBDs in the tropical drylands. Furthermore, I identify potential gaps for future research on TBDs, and Finally, I discuss the implications of the current knowledge and practices on the control of TBDs, policy interventions and governance in Kenya or other tropical countries with similar contexts.

## 6.2 Main results of the thesis

In this section, the main findings from the four chapters of the thesis are presented.

### 6.2.1 Associations between monthly rainfall and mortality in cattle due to East Coast fever, anaplasmosis and babesiosis

The conducive all-year-round environmental conditions for the spread of TBDs, resulting in subsequent mortalities is a major challenge for farmers in tropical areas. While many studies have examined either the ecological factors amplifying the spread of TBDs (e.g., Cummings; 2000; Minjauw & De Castro 1999; Adakal et al., 2013); the associations between rainfall, a prominent environmental factor, and the TBDs-induced mortalities is still unexplored. In chapter 2, I thus investigated whether there are any associations between rainfall and TBDs-induced mortalities due to East Coast fever, bovine anaplasmosis and babesiosis in cattle. The results of this study suggest that East Coast fever (ECF) and anaplasmosis were negatively correlated with rainfall, with a lag of 2 and 6 months for ECF and anaplasmosis, respectively. However, Babesiosis-induced mortalities in cattle could not be correlated to rainfall. The study suggests that cattle are more likely to die from ECF or anaplasmosis in the dry season 2 or 6-months after a rainfall season when tick infestation is high. This is a new finding as there is hardly any study linking rainfall with TBD-induced mortalities in cattle. The findings in this chapter illustrate that the TBDs and the resultant mortalities were attributed to within-year variations in rainfall which is also corroborated by the findings from previous studies (Allard 1998, Medlock et al. 2013). It also demonstrates that in the absence of monitoring protocols for ticks, the long-term monitoring of TBDs-induced mortalities in cattle and within-year variations in rainfall may be used to indirectly predict the severity of the TBDs in the tropical areas.

### 6.2.2 Unravelling the interactive effects of ecological, biological and social factors on tick loads in wildlife and livestock in tropical drylands

The prevailing social and ecological conditions have been shown to influence the spread of TTBDs. Hence, the objective of this study (Chapter 3) was to determine the tick species found in the study area and the extent to which the biological, social and ecological factors influenced the observed tick loads in wild and livestock. The results of this study suggest that the tick genera *Rhiphicepahalus* were the most common (88%), followed by Hyalomma (6%) and Amblyomma (6%), respectively. As expected, wild herbivores (zebras, rhinos and elephants) had significantly higher tick loads than livestock. Using Boran cattle as the model species, my findings suggest that there were no significant differences in the overall tick loads in male and female Boran with the tick loads being higher in the wet than the dry season. Furthermore, poorly conditioned animals had higher tick loads. Furthermore, cattle in intensively managed systems (ranches) had lower tick loads than the transhumance pastoralist management systems. Overall, the findings in Chapter 3 demonstrate that the type of land-use management system such as transhumance (pastoralist) and intensive management (commercial) of livestock has a significant effect on the tick loads in animals and should be considered an important determinant in the spread of infectious diseases. This finding is supported by many other studies (Minjauw & McLeod 2003, Mugambi et al. 2012, Dejene et al. 2016). The results of Chapter 3 not only indicate the land-use management and temporal variation (seasonality) and the animal characteristics such as the body condition in the distribution of ticks in animals but also provide insight into which management systems and conditions impact tick load in animals. The results of this study were supported by other studies (e.g., Allan et al, 2017; Wesonga et al. 2012; Keesing et al. 2012) which also found out that the tick genera *Rhiphicephalus* were the most common in vegetation in the Laikipia area in Kenya. The results of Chapter 3 demonstrate that farmers in the tropical areas of Africa should thus focus on improving animal husbandry (body conditioning) and regulating transhumance livestock management systems to minimise disease risks. Furthermore, the results of Chapter 3 demonstrate that ticks load in animals differ at both individual animal and farmer characteristics level highlighting the importance of considering the interaction effects of the social and ecological factors and the importance of the collective actions of farmers in TBDs control.

### 6.2.3 Biopolitics of tick-borne disease control practices in tropical drylands of Africa

Farmers in Kenya predominantly use acaricides for control of TBDs in livestock. However, acaricide usage is severely constrained by unknown social factors and their interaction effects, motivating the behaviour and decision-making processes of farmers and actors. In this study (Chapter 4), I aimed at determining the extent to which the underlying social and political factors and their interactive effects influence TBDs control practices in Kenya. To gain insights into these approaches, I used the concepts of *practices*, *contexts* and *interactions*. The results of this study suggest that TBD control practices in Laikipia are a product of the emergent worlds; pastoral communities and western-based veterinary thought with two different logics, sometimes converging or interlocking but often at odds over fundamental issues driven by either materiality and their logic of herd immunity with different outcomes. The health outcomes were exemplified by the different tick loads in their cattle. The stack differences in the TBDs control by the commercial and pastoral farmers based on the historical contexts suggest that modern epidemiological events should be interpreted in the light of conflicts between state policy and pastoralist strategy, coalescing into the biopolitics of TBDs control in the tropical areas of Africa. These findings highlight the importance of considering the *practices*, *interactions* and *context* in which the control activities of TBDs occurs in addition to the individual and community-level factors that may influence the occurrence and control of TBDs when developing collective prevention programs for the problem. This study reinforces the findings by Mutavi et al. which also showed that most pastoral farmers had local knowledge of TBDs which was not acknowledged by the extensionists and policy-makers but was instead viewed as a ''malpractice'' based on the western-ideology of disease control. The analysis presented here (interplay of historical *context, practices* and *interactions*) reveals power relations issues, tensions and contradictions emergent from an attempt to impose a western model of management of zoonotic diseases onto the East African landscape. The existing perceptions and understandings of the acaricide use by different actors and emergent conflicts hinder the collective management of TBDs. Hence enabling diverse stakeholders' *interactions* and negotiated processes will improve trust, power relations and information exchange, for enhancing health outcomes in human livestock with a possible net benefit to wildlife.

### 6.2.4 Potentials of mobile phones in information sharing on tick-borne diseases in Laikipia, Kenya

Timely information sharing by actors is central to improving the effectiveness of the TBDs control strategies. Hence, innovative approaches such as the use of mobile phones and citizen science may improve information sharing, monitoring of TBDs and coordination of actors. The results of this chapter suggest that mobile phones were used for various socio-economic activities, forming an issue-based communication network. The issues affecting local people such as (in)security, human-wildlife conflicts and the occurrences of notifiable zoonotic diseases compounded TBDs problems, affecting the information sharing by actors. Hence, while developing digital platforms for data monitoring and coordination, we also need to add a broader discussion on what might motivate and incentivize people to collect and share data in the first place, and how this might vary across the contexts and cultures (Leeuwis et al. 2018). Although I did not apply the digital platforms for tick collection and extension services in my thesis; I nevertheless conducted a diagnostic study to identify the socio-political factors influencing TBDs control practices and information sharing by farmers and actors (chapter 4 and 5).

## 6.3 How the chapters are connected and the overall message they bring together

The overall results of this thesis suggest that the TBDs problem is compounded by the interaction effects of the social, biological and ecological factors: ecological factors (rainfall and seasonality); social (conflicts and trust relations, historical background, land management system); biological (e.g., body condition) (Table 1, Fig. 1). To clearly understand the TBDs problem, then I needed systems thinking. Sterman et al. (2000) viewed system thinking as an important approach while developing decision-making frameworks aimed at addressing complex societal problems such as TBDs in my case study. For this reason, I used the socio-ecological systems (SES) approach (Ostrom 2010) were to evaluate the interaction effects of the social, biological and ecological factors identified in chapters 2-5 influencing TBDs. I mapped the interactions of the identified social and ecological variables (Table 1) by illustrating how they are connected in the system using the causal loop diagrams (CLD) (Sweeney & Sterman 2000). The CLD is a powerful graphic tool used in systems dynamics to better understand the interrelations amongst system's parts, system's mechanisms and feedback links (Sweeney & Sterman 2000, Chen et al. 2014, Nabavi et al. 2017). CLDs makes it possible to identify potential opportunities to disrupt or slow down the negative feedback mechanisms while amplifying those that are virtuous. Hence, from a socio-ecological perspective, I used CLD to illustrate how the dynamics of environmental, biological and social factors impact the way farmers and other stakeholders deal with TBDs. Such an approach provided insights into the interactive influence of sociological and ecological factors within the socio-ecological system.

**Interactive effects of human, biological and environmental factors: Dominant themes and feedback mechanisms**

Table 1-6 provides a summary of key findings of the socio-ecological factors I identified in chapters 2-5 of this thesis influencing TBDs spread and control. I illustrate the interrelationships of these factors and their feedback mechanisms in the causal loop diagram (Fig. 1-6).

**Table 1-6 Factors influencing TBDs and livestock mortalities in tropical drylands**

| variables | Effect on ticks/control, a positive sign/polarity (+) indicates a reinforcing loop while a negative polarity (-) designates a balancing loop. |
|---|---|
| **Ecological factors** | Rainfall & seasonality: Wet (+); dry (-) |
| **Biological factors (Animal characteristics)** | Age-old (+), sex of animal (lactating females (+); poor body condition (+) |
| **Land ownership and historical context of acaricide use factors** | Tensions and conflicts between pastoralist and commercial farmers (-) & lack of trust between farmers and other actors (-); historical contexts of acaricide use (-); prohibitive prices of acaricides (-) |
| **Technological factors** | Mobile phone ownership and use (-); information on (in)security (-); poor extension services (-); perception on acaricides (-); perceptions on human wildlife conflicts (-); limited power connectivity (-); need for information (-). |
| **Individual farmer profiles** | Socio-economic standing of farmers (-); trust relations between pastoral farmers (+), perceptions on acaricides<br><br>(-); cultural believes on TBDs (-); low literacy levels of pastoral farmers (-); low incomes of farmers (-); transhumance management of livestock (-); poor equipment for applying acaricide (-); |
| **Institutional and governance factors** | Power relations trust issues of actors (-); poor implementation of acaricide use regulations and policies by responsible agencies (-) |

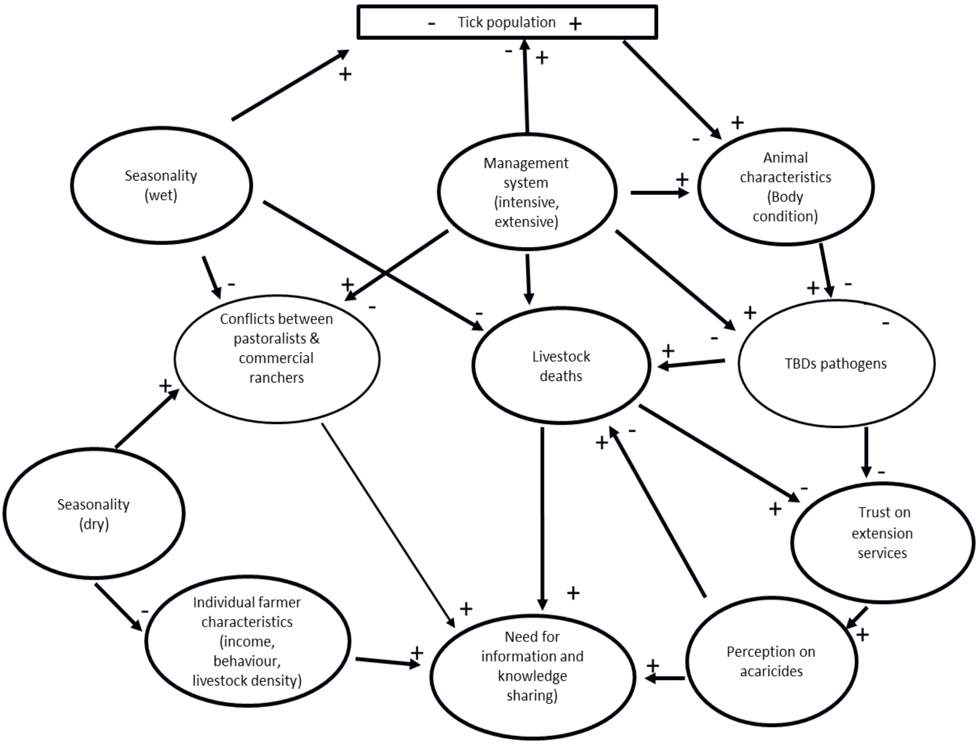



**Figure 1-6** Causal loop diagram of the interaction of the socio-ecological factors influencing the spread and control of TBDs in Laikipia, Kenya. The positive or negative sign in any arrow head shown denotes either a positive or negative effects (directionality) with different possible health outcomes in the system.

## Description of causal links and feedback mechanisms

Our causal loop diagram (Fig. 1-6) enabled us to identify the complex interplay of social and ecological factors influencing TBDs (Table 1-6). Here, I found complex interactions and feedback mechanisms represented in the causal loop diagram (Fig. 1-6) that would need to be disrupted or changed for improved TBDs control. In Fig. 1-6, for instance, rainfall is an important ecological factor influencing the seasonality hence influencing the spread of ticks and diseases, causing mortalities (Chapter 2). Moreover, during the dry season, when pasture and water are scarce, the pastoral farmers (with varying socio-economic profiles) often move with their livestock and more often invade privately managed properties established during the colonial period causing conflicts between the large-scale farmers and the pastoralists. The conflicts between the pastoralists and the commercial farmers also cause tensions and affect trust and the interactions and possible information sharing between the two farming groups.

Furthermore, during the wet season, the spread of ticks is amplified and their deleterious effects are worsened during the dry season when an animal's body condition declines, especially in the pastoralist management system. Conversely, the intensive commercial farmers had a better capital outlay for TBDs control, including the use of high-pressure nozzles and more frequently applied acaricides compared to the pastoral farmers. While acaricide usage is assumed by commercial farmers as the most pliable means of TBDs eradication, disease eradication is the ideology of the commercial farmers hinged on the historical contexts. The use of acaricides for TBDs eradication is deemed unnecessary by the pastoral farmers because they perceived animals need to build immunity hence reducing their vulnerability to TBDs especially during the dry season when animals are more likely to lose body conditions (Chapter 3). The stack differences in the perceptions on acaricide usage between the pastoralist and commercial farmers and the resultant TBD-induced mortalities influenced the information-sharing needs. The outcome of the two pastoralist and commercial management systems and practices resulted in significant differences in the tick loads and influence their level of interactions and information sharing, ultimately affecting the coordination of TBDs actors. The CLD analysis (Fig. 1-6) I have used in this study reveals that changing one feedback loop could lead to corresponding changes in the overall TBDs system because the behaviour of the system is a product of how the parts fit together and not how they act separately.

**The need to disrupt the dominant feedback mechanisms that impede TBDs control practices**

In this thesis, I found out that there were significant outcomes as exemplified by the tick loads between the commercial and pastoralists farmers management systems, motivating the discussion on the need to address the effects of the interaction of the social and ecological factors influencing TBDs from the SES approach. For instance, socio-economic inequalities amongst the farmers affect their ability to purchase quality acaricides, use effective equipment and frequently apply the chemicals. The socio-economic inequalities amongst the farmers also affected their relationships with other large-scale commercial farmers, especially during the dry season. By employing the systems thinking and SES approach in this thesis, I highlighted the extent to which the interaction effects of the social and ecological factors influence TBDs while providing a basis for the implementation of tailored control practices, governance and information sharing by actors as dominant themes detrimental to the effective management of TBDs.

## 6.4 What did we learn from the thesis? Cross-cutting issues

### *6.4.1 Balancing the complex chain of ecological and social factors and their interaction effects on TBDs*

In this thesis, I have illustrated that (1) the major issues of concern cut across the spread and control of TBDs in Laikipia County, Kenya, and are related to the interactive effects of ecological and social factors, and (2) these cross-cutting issues impinge on people's trust, power relations, communication and information sharing, extending into cases of human-wildlife conflicts and human insecurity (Fig. 1) and complicates the control of TBDs in the tropical drylands. In particular, rainfall is an important environmental factor influencing seasonality, the behaviour and the control practices of TBDs, especially the pastoral farmers, tick loads in animals and their resultant mortalities from TBDs (Chapter 2-5). Thus, rainfall is the most important factor shaping the extent of the interactive effects of the social and ecological factors complicating the TBDs system. To improve TBDs control, then we need to navigate through a complex chain of the social and ecological factors in an area by optimising on the best available opportunities for control interventions that actors are willing to practice based on the local contexts. To the best of my knowledge, this study is the first empirical study to investigate TBDs from the SES perspective in the tropical drylands. First of all, tropical systems are characterised by very variable rainfall and the behaviour of people, especially in the context of poor pastoral farmers (Wilcox et al. 2019). For instance, the frequent droughts in the tropical drylands reduce pasture and water for animals resulting in large-scale movement of livestock, especially by pastoral farmers. The behaviour of pastoral farmers during the dry season increases the risks of TBDs spread and mortalities. In particular, the social factors such as the emergent poor relationships between actors, as exemplified by the lack of trust and contradictions between the two farming domains (pastoral and commercial) and extension officials coupled with the historical contexts and level of their level of interactions (Chapter 4 & 5) is a major risk factor affecting the collective efforts of TBDs control. The findings from my studies suggest that the control of TBDs in tropical areas is difficult to disentangle due to the complex nature of the interactions of the social and ecological factors in a naturally occurring TBDs system. Moreover, the individual farmer actions affect how TBD is controlled at the collective, group or landscape level.

Recent studies on vector-borne diseases such as mosquito-malaria, potato blight and Banana Xanthomonas Wilt stem stems from the complex nature of SES. Moreover, I can argue that by adopting the SES approach (Ostrom 2010, Wilcox et al. 2019) in TBDs, we can bridge our existing knowledge gap on the complexity of the interactions and nature of SESs involving TBDs to identify tailored actionable knowledge for their effective control. Actionable knowledge is defined as the learning capability of individuals and organizations to connect heterogeneous elements (social, political, economic, technological) (Antonacopoulou 2007). Hence, the relational understanding generated by actionable knowledge can expand our knowledge and inform future actions such as in the control of TBDs (Antonacopoulou 2007, Cieslik et al. 2018). I can thus argue that the management of TBDs in tropical drylands may be managed better by considering the SESs and how it influences the behaviour and practices of individual or farming communities. Hence, we need to enhance the collective efforts of farmers and actors through improved trust and information sharing while considering local contextual issues and the aspirations of the individual farmers and local actors.

### *6.4.2 Balance between individual farmers' and collective efforts of farmers to stem TBDs*

The TBDs problem is constrained by a lack of collective, group or landscape-scale level. Individuals benefit by cooperating with a large number of group members to defend critical resources from other groups or to minimise threats such as environmental uncertainty, including frequent droughts. Hence, studies on the governance of complex problems such as TBDs should focus on collective approaches and actions. To address TBDs as a complex environmental and societal issue transcending landscapes, then we need to escalate the positive actions of the individual farmers to collective actions by farmers and actors in a landscape. The findings from my studies suggest that individual farmer profiles and activities such as farm management systems (characterised by the income levels, stocking densities, animal husbandry practices) influence TBDs at a local and ultimately at a landscape scale. Moreover, the behaviour and TBDs control activities of an individual farmer are also influenced by their individual decisions mediated by the prevailing social or ecological conditions such as their stocking densities and the rainfall-mediated seasonality. We thus require a collective effort since TBDs represents a collective risk to farmers and stakeholders locally and at a landscape level based on the land use management systems (Chapter 3 & 4). Although my study did not suggest the widespread need for information sharing on TBDs through mobile phones, we can nevertheless still explore the motivation of most farmers to share information using other approaches (see section 6.4.3). Although it can be argued that collective action is a plausible and legitimate action for addressing TBDs, we still need to further investigate whether other structural variables affect the likelihood of individuals achieving their collective action and decision-making to overcome the TBDs dilemma in the area.

### *6.4.3 Dealing with social-economic inequalities in a community and involvement of local actors in TBDs control*

The prevailing socio-economic conditions where the communities and the actors operate can affect collective action approaches. Ideally, the assumption that all individuals are fully rational in making decisions was, in the past, generally accepted due to the assumptions that fully rational individuals are presumed to know (1) all possible strategies available in a particular situation, (2) which outcomes are linked to each strategy given the likely behaviour of others in a situation, and (3) a rank order for each of these outcomes in terms of the individual's preferences as measured by utility (Ostrom 2010). However, the social differences, especially among the poor pastoral farmers in the tropical areas continue to escalate as the socio-economic conditions continue to deteriorate, affecting their individual decision-making process at the behest of collective action efforts.

The results from chapter 4 & 5 of this study, indicates that there are various socio-political factors and the effects of their interactions influencing the behaviour and the decision-making by farmers and actors on the TBDs control practices with different outcomes. In this study, I found a stack dichotomy in the practices of the well-resourced commercial and the poor pastoral farmers which resulted in different tick loads in their animals (Chapter 3). The two farming domains illustrates how the socio-economic inequalities such as income levels affect acaricide use and affect the TBDs control practices as well as the interactions between the farmers and other actors such as extension officials. My studies found out that the limited interactions between the pastoral farmers and extension officials also affected the information-sharing culture and flow pathways, including how they use mobile phones for their communication. Arrow (1974) pointed to the crucial role of addressing socio-economic inequalities as the most efficient mechanism to enhance transactional outcomes (collective-action theory). I can argue that from my results that addressing socio-economic inequalities has positive implications on the collective action such as the adoption of the best TBDs practices and upscaling of innovations. Furthermore, other studies in agricultural systems and innovations have confirmed the important role of socio-economic equity in overcoming social dilemmas inherent in the development of agricultural systems (Mugisha et al. 2008, Cieslik et al. 2018, Leeuwis & Aarts 2020).

Hence the rejection or adoption of technology should be regarded as a process of individual decision-making, even though it is recognised that individuals are part of a broader socio-ecological system (Rogers 1962). Rogers (1962) argues that the adoption (or rejection) of innovation arises from a process in which individuals go through several stages of the adoption process. Broadly the process for the adoption of technology may be stratified as 1) stage of awareness in which knowledge of the existence of innovation or policy measure is critical, 2) interest, where information about the availability of promising solutions that may be relevant in the prospective user context, 3) evaluation stage where individuals make a reflection on its advantages and disadvantages of the proposed technology, 4) trial or testing of the technology (implementation), and, 5) rejection or adoption by applying innovations/behaviour changes or hindrances such as technological illiteracy i.e., capacity to use the tech or what the farmers or other actors think as a priority to them. It is thus crucial to fully address the socio-economic inequalities inherent in SES while designing novel approaches such as digital platforms and citizen science for monitoring TBDs. Although I did not manage to implement the EVOCA platform for monitoring TBDs as envisaged in my study, I nevertheless conducted a diagnostic study to determine the socio-political factors influencing TBDs practices and the potentials of using mobile phones and citizen science for information sharing on TBDs in the tropical drylands. In this study, I showed that there is limited motivation for reporting TBDs by farmers. However, we can still develop an integrated multi-media based EVOCA considering the alternative information needs and sharing culture by the farmers and actors (Chapter 4). When this platform is developed, then we can further explore stages 2-5 of the innovation processes outlined above.

Recent studies have brought to the fore the understanding that motivation and retention of participants in citizen science projects is a function of the socio-economic standing and social processes hinged on trust and power relations (Hardy & Leiba-O'Sullivan 1998, Alender 2016, Wiggins & Wilbanks 2019, Leeuwis & Aarts 2020). Power imbalance by actors in an area is a recipe for conflicts and setbacks for collective action and the adoption of innovations. My studies corroborate other studies that indicated that the social processes play an important role in influencing the adoption and retention of the best practices for TBDs and information sharing. Hence, the co-design of innovative technologies should examine the broader context using the socio-ecological approach which had remained largely unexplored, especially in addressing complex problems such as TBDs. A clear understanding of TBDs from the SES perspective roles is also important in defining roles for different actors such as institutions for improved governance and policymaking based on the local contexts of the problem.

### *6.4.4 Dealing with divergent institutions and governance issues*

It is widely acknowledged that practices or behaviours are shaped by 'institutions. Institutions may be the formal and/or informal rules and arrangements to which people orient themselves in their (Pointer, Bosch, Chuma, & Wasserman)action (North 1990). The systems of governance in an area thus play a key role in the operation and performance of health systems such as in my case of TBDs. To restructure and decentralise health systems that often involve livestock, wildlife and human, then emphasis should lie on issues such as regulation, financing and accountability of the multi-actor arena. In multiple-actor health systems, it is often difficult to pursue a collective action unless the sense of belonging or affiliation to the same system is acknowledged by actors.

The results of chapter 4 and 5 showed that there are various actors involved in TBDs control comprising of the farmers, private, local and national government institutions such as the Directorate of Veterinary Services and the county government of Laikipia, with various stakes. The governmental actors form the higher echelons of the dominant government institutions involved in regulations, strategic resource allocation such as budgetary provisions and deployment of extension officials for TBDs control. However, most government institutions are characterised by rigid structures that often works at the behest of poor farmers (Leeuwis 2004, Leeuwis & Aarts 2020). Hence institutional innovations are necessary to re-invigorate such institutions for improved governance of TBDs problem. Institutional bureaucracies and power imbalances brew trust relation issues constraining collective action and/or adoption and upscaling of technological innovations. Moreover, institutions may also shape the knowledge and beliefs that people have about the world and/or about the outcomes of specific behaviours, hence shaping (Leeuwis & Aarts 2020). For instance, in our study (chapter 4) I found out that Maasai communities do not optimally apply acaricides because they believe that animals should be allowed to develop innate immunity, informing their reluctance or resistance to follow strict acaricide regimes for TBDs control. Hence, the degree of decentralisation of the health-related activities or scaling up of innovative approaches can be understood as an indicator of the alignment of objectives and beliefs amongst the members of the actors involved. Furthermore, the involvement of actors in a particular setting is often founded on different rationales such as the cultural background of the communities or the context of the country. Moreover, some rationales have a political inclination and their actions are an attempt to represent different actors' interests. Such a cultural belief system impinges on how people consider their relationship with nature, including how they perceive control of diseases (Laisser et al. 2015) agricultural knowledge and even adoption of technology (Leeuwis & Aarts 2020)

The institutions are thus important in shaping the governance, the adoption and the scaling up of innovations since the rules and arrangements can have an important influence on what people do or do not do (Leeuwis & Aarts 2020). Hence, in addition to technological innovations (e.g., mobile phones and citizen science) ecological interventions, motivations, the knowledge and practices of farmers and stakeholders involved, as well as institutional and cultural contexts (i.e., formal and informal rules and regulations) and their mutual influence should be taken into account while addressing TBDs as a complex societal problem. Moreover, applying systems thinking approach when designing policies or evaluating specific interventions helps foresee (and prevent) or interpret the effects of these interventions at different levels to those initially targeted. Thus, this thesis can be a basis for future studies of socio-ecological interactions and their challenges.

Some of the chapters in this study was were conducted during the 2016-2018 political electioneering period in Kenya characterised by intense political pressures, illegal invasion of privately owned properties and waves of (in)security which not only affected the fieldwork but may also have impacted on the stakeholder behaviour or actions. Nevertheless, I adequately managed to address my research questions.

**Implications of the study on TBDs, policy and future research**

By applying SES and systems thinking approach, the results of this study may be applied as a first step towards the direction that should be taken to improve the management of TBDs in tropical drylands. Furthermore, the results of these studies are important in contributing to the increasing debates on how technological innovations could be leveraged for the collective management of diseases in areas with many confounding social and ecological variables. This thesis contributes to the debates on the collective action on TBDs using citizen science in the tropical drylands. To the best of my knowledge, this is the first empirical study investigating TBDs from a socio-ecological systems perspective, which remains a neglected field of study in the management of infectious TBDs (Aguirre et al. 2019, Wilcox et al. 2019).

Even though the various chapters of this thesis have highlighted the complex interplay of the socio-ecological factors influencing TBDs in tropical drylands, a lot of research questions remains unanswered as highlighted in the synthesis of each chapter and I recommend future follow up studies on the identified issues. This calls TBDs control programs to consider the divergent actors and their rationalities and the indigenous knowledge of the pastoral communities while designing approaches for TBDs control. In this study, I found out that the widely anticipated role of mobile phones and related ICT infrastructure is not a panacea for effective sharing of information sharing by farmers and actors on TBDs due to the complex interactions of biological, human and environmental factors. Hence, an integrated digital platform that considers other modes of information sharing such as traditional pastoral community ‘’word of mouth’’, television and vernacular radio broadcasts (Chapter 4 and 5). I argue that diseases such as TBDs in tropical areas should be studied and managed from a SESs approach to clearly understand the problem, address policy interventions and governance issues inherent in many health systems in the region.

In this section, I recommend following future researches on the following areas based on the synthesis of the different themes in this thesis:

- Investigate the consequences of the (Rip et al.)application of acaricides and their relevance in building immunity levels of livestock to minimise the costs of TBDs management.
- Investigate the impact of policy weak policy interventions and governance issues on TBDs management in Kenya.
- Investigate the prospects of harnessing other modes of information sharing (Chapter 4 & 5) while considering confounding issues in the management of TBDs in tropical areas.

## Bibliography


AARTS, N. & LOKHORST, A. M. 2012. The role of government in environmental land use planning: towards an integral perspective. *Environ. L. Use Plan*:219–232.

ADAKAL, H., STACHURSKI, F. & CHEVILLON, C. 2013. Tick control practices in Burkina Faso and acaricide resistance survey in Rhipicephalus (Boophilus) geigyi (Acari: Ixodidae). *Experimental and Applied Acarology* 59:483–491.

AGUIRRE, A. A., BASU, N., KAHN, L. H., MORIN, X. K., ECHAUBARD, P., WILCOX, B. A. & BEASLEY, V. R. 2019. Transdisciplinary and social-ecological health frameworks—Novel approaches to emerging parasitic and vector-borne diseases. *Parasite Epidemiology and control* 4:e00084.

ALENDER, B. 2016. Understanding volunteer motivations to participate in citizen science projects: a deeper look at water quality monitoring. *Journal of Science Communication* 15:A04.

ALLAN, B. F., TALLIS, H., CHAPLIN-KRAMER, R., HUCKETT, S., KOWAL, V. A., MUSENGEZI, J., OKANGA, S., OSTFELD, R. S., SCHIELTZ, J. & WARUI, C. M. 2017. Can integrating wildlife and livestock enhance ecosystem services in central Kenya? *Frontiers in Ecology and the Environment* 15:328–335.

ALLARD, R. 1998. Use of time-series analysis in infectious disease surveillance. *Bulletin of the World Health Organization* 76:327.

ALLEN, H. A. 2015. Governance and One Health: Exploring the Impact of Federalism and Bureaucracy on Zoonotic Disease Detection and Reporting. *Veterinary sciences* 2:69–83.

AMESO, E. A., BUKACHI, S. A., OLUNGAH, C. O., HALLER, T., WANDIBBA, S. & NANGENDO, S. 2018. Pastoral resilience among the Maasai pastoralists of Laikipia County, Kenya. *Land* 7:78. Multidisciplinary Digital Publishing Institute.

ANDERSON, D. & BURNHAM, K. 2002. Model selection and multi-model inference: A practical information-Theoretic approach. *Second. NY: Springer-Verlag* 63:10.

ANTHONY GIDDENS. 1984. *The constitution of society: Outline of the theory of structuration*. Univ of California Press.

ANTONACOPOULOU, E. P. 2007. Actionable knowledge. Sage.

ANYAMBA, A., CHRETIEN, J.-P., SMALL, J., TUCKER, C. J., FORMENTY, P. B., RICHARDSON, J. H., BRITCH, S. C., SCHNABEL, D. C., ERICKSON, R. L. & LINTHICUM, K. J. 2009. Prediction of a Rift Valley fever outbreak. *Proceedings of the National Academy of Sciences* 106:955–959.

ARTS, B., BEHAGEL, J., TURNHOUT, E., DE KONING, J. & VAN BOMMEL, S. 2014. A practice based approach to forest governance. *Forest Policy and Economics* 49:4–11.

ARTS, B., GIESSEN, L. & VISSEREN-HAMAKERS, I. 2013. International Forest Policy and Europe: Four pathways of mutual influence. *Forest Governance*:37.

AWA, D., ADAKAL, H., LUOGBOU, N., WACHONG, K., LEINYUY, I. & ACHUKWI, M. 2015. Cattle ticks in Cameroon: Is Rhipicephalus (Boophilus) microplus absent in Cameroon and the Central African region? *Ticks and tick-borne diseases* 6:117–122.

AWA, D. N., ADAKAL, H., LUOGBOU, N. D. D., WACHONG, K. H., LEINYUY, I. & ACHUKWI, M. D. 2014. Ticks and Tick-borne Diseases.

BASSETT, T. J., BLANC-PAMARD, C. & BOUTRAIS, J. 2007. Constructing locality: The terroir approach in West Africa. *Africa*:104–129.

BAXTER, P. & JACK, S. 2008. Qualitative case study methodology: Study design and implementation for novice researchers. *The qualitative report* 13:544–559.

BEHAGEL, J. H., ARTS, B. & TURNHOUT, E. 2019. Beyond argumentation: a practice-based approach to environmental policy. *Journal of Environmental Policy & Planning* 21:479–491.

BEINART, W. & BROWN, K. 2013. *African Local Knowledge & Livestock Health: Diseases & Treatments in South Africa*. Boydell & Brewer Ltd.

BENGIS, R. G., KOCK, R. A. & FISCHER, J. 2002. Infectious animal diseases: the wildlife/livestock interface. *Revue Scientifique et Technique-Office international des épizooties* 21:53–66.

BENJAMINSEN, T. A. 1997. Natural resource management, paradigm shifts, and the decentralization reform in Mali. *Human ecology* 25:121–143.

BERATAN, K. K. 2007. A cognition-based view of decision processes in complex socio-ecological systems. *Ecology and Society* 12.

BEVIR, M. 1999. Foucault, power, and institutions. *Political studies* 47:345–359.

BI, P., ZHANG, Y. & PARTON, K. A. 2007. Weather variables and Japanese encephalitis in the metropolitan area of Jinan city, China. *Journal of Infection* 55:551–556. Elsevier.

BOCK, R., JACKSON, L., DE VOS, A. & JORGENSEN, W. 2004. Babesiosis of cattle. Parasitology 129 (Suppl): S247–S269. *Bock L. Jackson A. de Vos W. Jorgensen 2004 Babesiosis of cattle. Parasitology 129Suppl S247S269 View Article PubMed/NCBI Google Scholar*.

BOND, J. 2014a. Conflict, Development and Security at the Agro–Pastoral–Wildlife Nexus: A Case of Laikipia County, Kenya. *Journal of Development Studies* 50:991–1008.

BOND, J. 2014b. A holistic approach to natural resource conflict: The case of Laikipia County, Kenya. *Journal of Rural Studies* 34:117–127.

BOWEN, G. A. 2008. Naturalistic inquiry and the saturation concept: a research note. *Qualitative research* 8:137–152.

BRITO, L. G., BARBIERI, F. S., ROCHA, R. B., OLIVEIRA, M. & RIBEIRO, E. S. 2011. Evaluation of the efficacy of acaricides used to control the cattle tick, Rhipicephalus microplus, in dairy herds raised in the Brazilian southwestern amazon. *Veterinary medicine international* 2011.

BROCKLESBY, D. 1962. The febrile reaction in fatal East Coast fever—A review of 150 cases. *Bulletin of Epizootic Diseases of Africa* 10:49–54.

BROWN, I., MULATTI, P., SMIETANKA, K., STAUBACH, C., WILLEBERG, P., ADLHOCH, C., CANDIANI, D., FABRIS, C., ZANCANARO, G. & MORGADO, J. 2017. Avian influenza overview October 2016–August 2017. *EFSA Journal* 15.

BURNHAM, K. P. & ANDERSON, D. R. 2002. Model selection and.

CAVALLO, S. E. 2021. Navigating compounding uncertainty: farmer strategies amid biosecurity crises in Western Uganda. *Geoforum* 123:136–144.

CHAPIN III, F. S., KOFINAS, G. P., FOLKE, C. & CHAPIN, M. C. 2009. *Principles of ecosystem stewardship: resilience-based natural resource management in a changing world*. Springer Science & Business Media.

CHEN, H., CHANG, Y.-C. & CHEN, K.-C. 2014. Integrated wetland management: an analysis with group model building based on system dynamics model. *Journal of environmental management* 146:309–319.

CHEPKWONY, R., VAN BOMMEL, S. & VAN LANGEVELDE, F. 2018. Citizen science for development: Potential role of mobile phones in information sharing on ticks and tick-borne diseases in Laikipia, Kenya. *NJAS-Wageningen Journal of Life Sciences* 86:123–135.

CHEPKWONY, R., CASTAGNA, C., HEITKÖNIG, I., VAN BOMMEL, S. & VAN LANGEVELDE, F. 2020. Associations between monthly rainfall and mortality in cattle due to East Coast fever, anaplasmosis and babesiosis. *Parasitology*:1–9. Cambridge University Press.

CIESLIK, K. J., LEEUWIS, C., DEWULF, A., LIE, R., WERNERS, S. E., VAN WESSEL, M., FEINDT, P. & STRUIK, P. C. 2018. Addressing socio-ecological development challenges in the digital age: Exploring the potential of Environmental Virtual Observatories for Connective Action (EVOCA). *NJAS-Wageningen Journal of Life Sciences* 86:2–11.

CLEAVELAND, S., LAURENSON, M. K. & TAYLOR, L. H. 2001. Diseases of humans and their domestic mammals: pathogen characteristics, host range and the risk of emergence. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 356:991–999.

CLEMENT, E. P. 2014. Using normalized Bayesian information criterion (BIC) to improve Box-Jenkins model building. *American Journal of Mathematics and Statistics* 4:214–221.

CRADDOCK, S. & HINCHLIFFE, S. 2015. One world, one health? Social science engagements with the one health agenda.

CRANE, W., SANDWITH, T., MCGREGOR, E. & YOUNGE, A. 2009. Where conservation and community coincide: a human rights approach to conservation and development in the Cape Floristic Region, South Africa. *Rights-based approaches: exploring issues and opportunities for conservation. Center for International Forestry Research (CIFOR) and International Union for the Conservation of Nature (IUCN), Bogor, Indonesia*:141–162.

CUMMING, G. 2002a. Comparing climate and vegetation as limiting factors for species ranges of African ticks. *Ecology* 83:255–268.

CUMMING, G. S. 1999. Host distributions do not limit the species ranges of most African ticks (Acari: Ixodida). *Bulletin of Entomological Research* 89:303–327.

CUMMING, G. S. 2002b. Comparing climate and vegetation as limiting factors for species ranges of African ticks. *Ecology* 83:255–268.

DANTAS-TORRES, F. 2008. The brown dog tick, Rhipicephalus sanguineus (Latreille, 1806)(Acari: Ixodidae): from taxonomy to control. *Veterinary parasitology* 152:173–185.

DANTAS-TORRES, F., CHOMEL, B. B. & OTRANTO, D. 2012. Ticks and tick-borne diseases: a One Health perspective. *Trends in parasitology* 28:437–446.

DANTAS-TORRES, F., CHOMEL, B. B. & OTRANTO, D. 2013. Corrigendum to 'Ticks and tick-borne diseases: a One Health perspective'. *Trends in parasitology* 10:516.

DAVIS, A. & SHARP, J. 2020. Rethinking One Health: emergent human, animal and environmental assemblages. *Social Science & Medicine*:113093. Elsevier.

DE BRUIJN, M. 2009. *Mobile phones: The new talking drums of everyday Africa*. African Books Collective.

DE BRUIJN, M. & VAN DIJK, R. 2012. *The social life of connectivity in Africa*. Springer.

DEGNBOL, T. 1996. The terroir approach to natural resource management: panacea or phantom?. the Malian experience.

DEJENE, S. W., HEITKÖNIG, I. M., PRINS, H. H., LEMMA, F. A., MEKONNEN, D. A., ALEMU, Z. E., KELKAY, T. Z. & DE BOER, W. F. 2016. Risk factors for bovine tuberculosis (bTB) in cattle in Ethiopia. *PloS one* 11:e0159083.

DEY, B. L., PANDIT, A., SAREN, M., BHOWMICK, S. & WOODRUFFE-BURTON, H. 2016. Co-creation of value at the bottom of the pyramid: Analysing Bangladeshi farmers' use of mobile telephony. *Journal of Retailing and Consumer Services* 29:40–48.

DICKINSON, J. L., SHIRK, J., BONTER, D., BONNEY, R., CRAIN, R. L., MARTIN, J., PHILLIPS, T. & PURCELL, K. 2012. The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment* 10:291–297. Wiley Online Library.

DONG, S., WEN, L., LIU, S., ZHANG, X., LASSOIE, J. P., YI, S., LI, X., LI, J. & LI, Y. 2011. Vulnerability of worldwide pastoralism to global changes and interdisciplinary strategies for sustainable pastoralism. *Ecology and Society* 16.

ENTICOTT, G. 2008. The spaces of biosecurity: prescribing and negotiating solutions to bovine tuberculosis. *Environment and Planning A* 40:1568–1582.

ESTRADA-PEÑA, A., ALEXANDER, N. & WINT, G. W. 2016. Perspectives on modelling the distribution of ticks for large areas: so far so good? *Parasites & vectors* 9:1.

ESTRADA-PEÑA, A. & DE LA FUENTE, J. 2014. The ecology of ticks and epidemiology of tick-borne viral diseases. *Antiviral research* 108:104–128.

ESTRADA-PEÑA, A. & SALMAN, M. 2013a. Current limitations in the control and spread of ticks that affect livestock: A review. *Agriculture* 3:221–235.

ESTRADA-PEÑA, A. & SALMAN, M. 2013b. Current limitations in the control and spread of ticks that affect livestock: a review. *Agriculture* 3:221–235.

ETZO, S. & COLLENDER, G. 2010. The mobile phone 'revolution in Africa: rhetoric or reality? *African affairs* 109:659–668.

FAO, I. & UNICEF, W. 2017. The state of food security and nutrition in the world. *Rome, Italy: Food and Agriculture Organization of the United Nations*.

FOX, G. R. 2018. Maasai group ranches, minority land owners, and the political landscape of Laikipia County, Kenya. *Journal of Eastern African Studies* 12:473–493. Taylor & Francis.

FRAME, B. & BROWN, J. 2008. Developing post-normal technologies for sustainability. *Ecological Economics* 65:225–241.

FYUMAGWA, R. D., RUNYORO, V., HORAK, I. G. & HOARE, R. 2007. Ecology and control of ticks as disease vectors in the wildlife of the Ngorongoro Crater, Tanzania. *South African Journal of Wildlife Research* 37:79–90.

GACHOHI, J., SKILTON, R., HANSEN, F., NGUMI, P. & KITALA, P. 2012a. Epidemiology of East Coast fever (Theileria parva infection) in Kenya: past, present and the future. *Parasites & vectors* 5:194.

GACHOHI, J., SKILTON, R., HANSEN, F., NGUMI, P. & KITALA, P. 2012b. Epidemiology of East Coast fever (Theileria parva infection) in Kenya: past, present and the future. *Parasites & vectors* 5:194.

GAUR, A. S. & GAUR, S. S. 2006. *Statistical methods for practice and research: A guide to data analysis using SPSS*. Newbury Park, California: Sage Publications Inc., Newbury Park, California.

GEORGE, D. & MALLERY, P. 2016. *IBM SPSS Statistics 23 step by step: A simple guide and reference*. Routledge.

GHOSH, S., AZHAHIANAMBI, P. & DE LA FUENTE, J. 2006. Control of ticks of ruminants, with special emphasis on livestock farming systems in India:

present and future possibilities for integrated control—a review. *Experimental & applied acarology* 40:49–66.

GOVERNMENT OF KENYA. 2016. Laikipia County Integrated Development Plan (CIDP).

GRAHAM, M. D., ADAMS, W. M. & KAHIRO, G. N. 2012. Mobile phone communication in effective human-elephant–conflict management in Laikipia County, Kenya. *Oryx* 46:137–144.

GRILLO, K. M. 2012. The materiality of mobile pastoralism: ethnoarchaeological perspectives from Samburu, Kenya.

HAKLAY, M. 2010. Extreme Citizen Science. *London Citizen Cyberscience Summit (2-3 September*.

HARDY, C. & LEIBA-O'SULLIVAN, S. 1998. The power behind empowerment: Implications for research and practice. *Human relations* 51:451–483.

HARRISON, A., SCANTLEBURY, M. & MONTGOMERY, W. I. 2010. Body mass and sex-biased parasitism in wood mice Apodemus sylvaticus. *Oikos* 119:1099–1104.

HART, B. L. & HART, L. A. 2018. How mammals stay healthy: the evolution of behaviours to avoid parasites and pathogens. *Philosophical Transactions of the Royal Society B: Biological Sciences* 373:20170205.

HAWLENA, H., ABRAMSKY, Z. & KRASNOV, B. R. 2006. Ectoparasites and age-dependent survival in a desert rodent. *Oecologia* 148:30–39.

HENRICHS, B., OOSTHUIZEN, M. C., TROSKIE, M., GORSICH, E., GONDHALEKAR, C., BEECHLER, B. R., EZENWA, V. O. & JOLLES, A. E. 2016. Within guild co-infections influence parasite community membership: a longitudinal study in African Buffalo. *Journal of Animal Ecology* 85:1025–1034.

HEUER, C., BOEHLE, W., RUTAGWENDA, T., JONGEJAN, F., UNGER, F., KIVARIA, F. M. & OKELLO-ONEN, J. 2004. Endemic stability for Theileria parva infections in Ankole calves of the Ankole ranching scheme, Uganda. *Onderstepoort Journal of Veterinary Research* 71:189–195.

HINCHLIFFE, S. 2015. More than one world, more than one health: Re-configuring interspecies health. *Social Science & Medicine* 129:28–35.

HINCHLIFFE, S., ALLEN, J., LAVAU, S., BINGHAM, N. & CARTER, S. 2013. Biosecurity and the topologies of infected life: from borderlines to borderlands. *Transactions of the Institute of British Geographers* 38:531–543.

HOLLOWAY, L. 2007. Subjecting cows to robots: farming technologies and the making of animal subjects. *Environment and Planning D: Society and Space* 25:1041–1060.

HORAK, I. G., HEYNE, H. & DONKIN, E. F. 2010. Parasites of domestic and wild animals in South Africa: XLVIII. Ticks (Acari: Ixodidae) infesting domestic cats and wild felids in southern Africa. *Onderstepoort Journal of Veterinary Research* 77:01–07.

HOUNKONNOU, D., KOSSOU, D., KUYPER, T. W., LEEUWIS, C., NEDERLOF, E. S., RÖLING, N., SAKYI-DAWSON, O., TRAORÉ, M. & VAN HUIS, A. 2012. An innovation systems approach to institutional change: smallholder development in West Africa. *Agricultural systems* 108:74–83.

HUANG, S.-J. & SHIH, K.-R. 2003. Short-term load forecasting via ARMA model identification including non-Gaussian process considerations. *IEEE Transactions on power systems* 18:673–679.

HUGHES, L. 2005. Malice in Maasailand: The historical roots of current political struggles. *African Affairs* 104:207–224. Oxford University Press.

INGOLD, T. 2011. *Being alive: Essays on movement, knowledge and description*. Taylor & Francis.

JOCHUM, K. A., KLISKEY, A. A., HUNDERTMARK, K. J. & ALESSA, L. 2014. Integrating complexity in the management of human-wildlife encounters. *Global Environmental Change* 26:73–86.

JONES, N. A., SHAW, S., ROSS, H., WITT, K. & PINNER, B. 2016a. The study of human values in understanding and managing social-ecological systems. *Ecology and Society* 21.

JONES, N. A., SHAW, S., ROSS, H., WITT, K. & PINNER, B. 2016b. The study of human values in understanding and managing social-ecological systems. *Ecology and Society* 21.

JONGEJAN, F. & UILENBERG, G. 1994. Ticks and control methods. *Revue scientifique et technique (International Office of Epizootics)* 13:1201–1226.

JONGEJAN, F. & UILENBERG, G. 2004. The global importance of ticks. *Parasitology* 129:S3–S14.

KAMBARAGE, D. M. 1995. East Coast fever as a continued constraint to livestock improvement in Tanzania: a case study. *Tropical Animal Health and Production* 27:145–149.

KANYARI, P. & KAGIRA, J. 2000. The role of parasitic diseases as causes of mortality in cattle in a high potential area of central Kenya: a quantitative analysis. *The Onderstepoort Journal of Veterinary Research* 67:157–161.

KEELING, M. J. & ROHANI, P. 2008. Modelling infectious diseases in humans and animals. *Clinical Infectious Diseases* 47:864–865.

KEESING, F., ALLAN, B. F., YOUNG, T. P. & OSTFELD, R. S. 2013a. Effects of wildlife and cattle on tick abundance in central Kenya. *Ecological Applications* 23:1410–1418.

KEESING, F., ALLAN, B. F., YOUNG, T. P. & OSTFELD, R. S. 2013b. Effects of wildlife and cattle on tick abundance in central Kenya. *Ecological Applications* 23:1410–1418.

KEESING, F., BELDEN, L. K., DASZAK, P., DOBSON, A., HARVELL, C. D., HOLT, R. D., HUDSON, P., JOLLES, A., JONES, K. E. & MITCHELL, C. E. 2010. Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature* 468:647–652.

KEESING, F., HOLT, R. D. & OSTFELD, R. S. 2006. Effects of species diversity on disease risk. *Ecology Letters* 9:485–498.

KEESING, F. & YOUNG, T. P. 2014. Cascading consequences of the loss of large mammals in an African savanna. *BioScience* 64:487–495.

KEMAL, J., TAMERAT, N. & TULUKA, T. 2016. Infestation and Identification of Ixodid Tick in Cattle: The Case of Arbegona District, Southern Ethiopia. *Journal of veterinary medicine* 2016. Hindawi.

KENYA NATIONAL BUREAU OF STATISTICS. 2019, December. Kenya population and housing census 2019 : Distribution of population by socio-economic characteristics, (Vol. IV). Government Printer, Nairobi, Kenya.

KIFFNER, C., STANKO, M., MORAND, S., KHOKHLOVA, I. S., SHENBROT, G. I., LAUDISOIT, A., LEIRS, H., HAWLENA, H. & KRASNOV, B. R. 2013. Sex-biased parasitism is not universal: evidence from rodent–flea associations from three biomes. *Oecologia* 173:1009–1022.

KILELU, C. W. 2013. *Unravelling the role of innovation intermediaries in smallholder agricultural development: case studies from Kenya*. Wageningen UR.

KILELU, C. W., KLERKX, L. & LEEUWIS, C. 2013. Unravelling the role of innovation platforms in supporting co-evolution of innovation: Contributions and tensions in a smallholder dairy development programme. *Agricultural systems* 118:65–77.

KLERKX, L. & LEEUWIS, C. 2008. Balancing multiple interests: Embedding innovation intermediation in the agricultural knowledge infrastructure. *Technovation* 28:364–378.

KLERKX, L., VAN MIERLO, B. & LEEUWIS, C. 2012. Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions. Pp. 457–483 *Farming Systems Research into the 21st century: The new dynamic*. Springer.

KOCAN, K. M., DE LA FUENTE, J., GUGLIELMONE, A. A. & MELÉNDEZ, R. D. 2003. Antigens and alternatives for control of Anaplasma marginale infection in cattle. *Clinical microbiology reviews* 16:698–712.

KOŁODZIEJ-SOBOCIŃSKA, M. 2019. Factors affecting the spread of parasites in populations of wild European terrestrial mammals. *Mammal Research*:1–18.

KWON, H. S. & CHIDAMBARAM, L. 2000. A test of the technology acceptance model: The case of cellular telephone adoption. Pp. 7-pp. IEEE.

LAISSER, E. L. K., CHENYAMBUGA, S. W., MSALYA, G., KIPANYULA, M. J., MDEGELA, R. H., KARIMURIBO, E. D., MWILAWA, A. J. & KUSILUKA, L. J. K. 2015. Knowledge and perception on ticks, tick-borne diseases and indigenous cattle tolerance to East Coast fever in agro-pastoral communities of Lake Zone in Tanzania. *Livestock Research for Rural Development* 27.

LEEUWIS, C. 2004. Fields of conflict and castles in the air. Some thoughts and observations on the role of communication in public sphere innovation processes. *The Journal of Agricultural Education and Extension* 10:63–76.

LEEUWIS, C. 2013. *Communication for rural innovation: rethinking agricultural extension*. John Wiley & Sons.

LEEUWIS, C. & AARTS, N. 2020. Rethinking adoption and diffusion as a collective social process: Towards an interactional perspective. *In: Campos, H, (ed.)(2021). The innovation revolution in agriculture-A roadmap to value creation. Springer Press, Cham, Switzerland*:95–116.

LEEUWIS, C., CIESLIK, K., AARTS, M., DEWULF, A., LUDWIG, F., WERNERS, S. & STRUIK, P. 2018. Reflections on the potential of virtual citizen science platforms to address collective action challenges: lessons and implications for future research. *NJAS-Wageningen Journal of Life Sciences* 86:146–157. Elsevier.

LENGOIBONI, M., BREGT, A. K. & VAN DER MOLEN, P. 2010. Pastoralism within land administration in Kenya—The missing link. *Land Use Policy* 27:579–588.

LESOROGOL, C. K. 2003. Transforming institutions among pastoralists: inequality and land privatization. *American Anthropologist* 105:531–541.

LETAI, J. 2011. Land deals in Kenya: The genesis of land deals in Kenya and its implication on pastoral livelihoods–A case study of Laikipia District, 2011. Pp. 6–8.

LEWIS, D. & MADON, S. 2004. Information systems and nongovernmental development organizations: Advocacy, organizational learning, and accountability. *The information society* 20:117–126.

LWANDE, O. W., PAUL, G. O., CHIYO, P. I., NG'ANG'A, E., OTIENO, V., OBANDA, V. & EVANDER, M. 2015. Spatio-temporal variation in the prevalence of Rift Valley fever: a post-epidemic serum survey in cattle and wildlife in Kenya. *Infection ecology & epidemiology* 5:30106.

MALOO, S. H. 1993. Epidemiological Studies of Vector-Borne Diseases with Consequent Development of Preventive Medicine Programmes for Small-Holder Dairy Farmers in Coastal Kenya. PhD Thesis, The University of Glasgow.

MEDLOCK, J. M., HANSFORD, K. M., BORMANE, A., DERDAKOVA, M., ESTRADA-PEÑA, A., GEORGE, J.-C., GOLOVLJOVA, I., JAENSON, T. G., JENSEN, J.-K. & JENSEN, P. M. 2013. Driving forces for changes in the geographical distribution of Ixodes ricinus ticks in Europe. *Parasites & vectors* 6:1–11.

MILLER, R. L. 2015. Rogers' innovation diffusion theory (1962, 1995). Pp. 261–274 *Information seeking behaviour and technology adoption: Theories and trends*. IGI Global.

MINJAUW, B. & DE CASTRO, J. J. 1999. Host resistance to ticks and tick-borne diseases: its role in integrated control. *Chapter* 7:153–169.

MINJAUW, B. & MCLEOD, A. 2003. Tick-borne diseases and poverty: the impact of ticks and tick-borne diseases on the livelihoods of small-scale and marginal livestock owners in India and eastern and southern Africa. The research report, DFID Animal Health Programme, Centre for Tropical Veterinary Medicine, University of Edinburgh JO - UK.

MIZUTANI, F., MUTHIANI, E., KRISTJANSON, P. & RECKE, H. 2005a. Impact and value of wildlife in pastoral livestock production systems in Kenya: possibilities for healthy ecosystem conservation and livestock development for the poor. *Conservation and development interventions at the wildlife/livestock interface: implications for wildlife, livestock and human health*:121–132.

MIZUTANI, F., MUTHIANI, E., KRISTJANSON, P. & RECKE, H. 2005b. Impact and value of wildlife in pastoral livestock production systems in Kenya: possibilities for healthy ecosystem conservation and livestock development for the poor. *Conservation and development interventions at the wildlife/livestock interface: implications for wildlife, livestock and human health*:121–132.

MORGAN, W. 1963. The white highlands' of Kenya. *The Geographical Journal* 129:140–155.

MUDLIAR, P. & KOONTZ, T. M. 2020. Locating Power in Ostrom's Design Principles: Watershed Management in India and the United States. *Society & Natural Resources*:1–19.

MUGAMBI, J. M., WESONGA, F. D. & NDUNGU, S. G. 2012. Ticks and tick-borne disease control in pastoral and agro-pastoral farming systems in Kenya. *Livestock Research for Rural Development* 24:1–8.

MUGISHA, A., MCLEOD, A., PERCY, R. & KYEWALABYE, E. 2008. Socio-economic factors influencing control of vector-borne diseases in the pastoralist system of south western Uganda. *Tropical animal health and production* 40:287–297. Springer.

MUTAVI, F., AARTS, N., VAN PAASSEN, A., HEITKÖNIG, I. & WIELAND, B. 2018. Techne meets Metis: Knowledge and practices for tick control in Laikipia County, Kenya. *NJAS-Wageningen Journal of Life Sciences* 86:136–145.

MWAMUYE, M. M., KARIUKI, E., OMONDI, D., KABII, J., ODONGO, D., MASIGA, D. & VILLINGER, J. 2016. Occurrence of novel and emergent tick-borne pathogens in a Kenyan biodiversity hotspot. *International Journal of Infectious Diseases*:350.

MWANGI, T. W. 2013. Exploring Kenya's inequality: pulling apart or pooling together? National report. Nairobi, Kenya: Kenya National Bureau of Statistics, Nairobi, Kenya.

NABAVI, E., DANIELL, K. A. & NAJAFI, H. 2017. Boundary matters: the potential of system dynamics to support sustainability? *Journal of Cleaner Production* 140:312–323.

NESS, L. R. 2015. Are We There Yet? Data Saturation in Qualitative Research.

NORVAL, R. A. I., SUTHERST, R. W., KURKI, J., GIBSON, J. D. & KERR, J. D. 1988. The effect of the brown ear-tick *Rhipicephalus appendiculatus* on the growth of Sanga and European breed cattle. *Veterinary Parasitology* 30:149–164.

ODADI, W. O., KARACHI, M. K., ABDULRAZAK, S. A. & YOUNG, T. P. 2011. African wild ungulates compete with or facilitate cattle depending on the season. *Science* 333:1753–1755.

ODADI, W. O., YOUNG, T. P. & OKEYO-OWUOR, J. B. 2007. Effects of wildlife on cattle diets in Laikipia rangeland, Kenya. *Rangeland ecology & management* 60:179–185.

OGDEN, N. H., SWAI, E., BEAUCHAMP, G., KARIMURIBO, E., FITZPATRICK, J. L., BRYANT, M. J., KAMBARAGE, D. & FRENCH, N. P. 2005. Risk factors for tick attachment to smallholder dairy cattle in Tanzania. *Preventive veterinary medicine* 67:157–170.

OKELLO-ONEN, J., TUKAHIRWA, E. M., PERRY, B. D., ROWLANDS, G. J., NAGDA, S. M., MUSISI, G., BODE, E., HEINONEN, R., MWAYI, W. & OPUDA-ASIBO, J. 1999. Population dynamics of ticks on indigenous cattle in a pastoral dry to semi-arid rangeland zone of Uganda. *Experimental & applied acarology* 23:79–88.

OSTFELD, R. S. & KEESING, F. 2000. Biodiversity and disease risk: the case of Lyme disease. *Conservation Biology* 14:722–728.

OSTROM, E. 1990. *Governing the commons: The evolution of institutions for collective action*. Cambridge university press.

OSTROM, E. 2010. Polycentric systems for coping with collective action and global environmental change. *Global environmental change* 20:550–557. Elsevier.

PAINTER, T., SUMBERG, J. & PRICE, T. 1994. Your" Terroir" and My'Action Space': Implications of Differentiation, Mobility and Diversification for the" Approche Terroir" in Sahelian West Africa. *Africa*:447–464.

PARKES, M. W., BIENEN, L., BREILH, J., HSU, L.-N., MCDONALD, M., PATZ, J. A., ROSENTHAL, J. P., SAHANI, M., SLEIGH, A. & WALTNER-TOEWS, D. 2005. All hands on deck: transdisciplinary approaches to emerging infectious disease. *EcoHealth* 2:258–272.

PASCHEN, J.-A. & ISON, R. 2014. Narrative research in climate change adaptation—Exploring a complementary paradigm for research and governance. *Research Policy* 43:1083–1092.

PAVELA, R., CANALE, A., MEHLHORN, H. & BENELLI, G. 2016. Application of ethnobotanical repellents and acaricides in prevention, control and management of livestock ticks: a review. *Research in veterinary science* 109:1–9.

PAZIEWSKA, A., ZWOLIŃSKA, L., HARRIS, P. D., BAJER, A. & SIŃSKI, E. 2010. The utilisation of rodent species by larvae and nymphs of hard ticks (Ixodidae) in two habitats in NE Poland. *Experimental and Applied Acarology* 50:79.

PERRY, B. D. & YOUNG, A. S. 1995. The past and future roles of epidemiology and economics in the control of tick-borne diseases of livestock in Africa: the case of theileriosis. *Preventive Veterinary Medicine* 25:107–120.

PIPANO, E., KRIGEL, Y., MARKOVICS, A. & SHKAP, V. 1992. The effect of oxytetracycline treatment on immunity induced by *Anaplasma centrale*. *Veterinary microbiology* 31:81–87.

PORTER, N. 2016. One Health, Many Species: Towards a multispecies investigation of bird flu. Pp. 138–153 *Humans, Animals and Biopolitics*. Routledge.

POULIN, R. 1993. The disparity between observed and uniform distributions: a new look at parasite aggregation. *International journal for parasitology* 23:937–944.

PROKOPY, L. S., FLORESS, K., KLOTTHOR-WEINKAUF, D. & BAUMGART-GETZ, A. 2008. Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of soil and water conservation* 63:300–311.

RADLEY, D., BROWN, C., BURRIDGE, M., CUNNINGHAM, M., PEIRCE, M. & PURNELL, R. 1974. East Coast fever: quantitative studies of *Theileria parva* in cattle. *Experimental Parasitology* 36:278–287.

RANDOLPH, S. E. 1997. Abiotic and biotic determinants of the seasonal dynamics of the tick Rhipicephalus appendiculatus in South Africa. *Medical and Veterinary Entomology* 11:25–37.

RANDOLPH, S. E. 2004. Tick ecology: processes and patterns behind the epidemiological risk posed by ixodid ticks as vectors. *Parasitology* 129:S37–S65.

RIGINOS, C., PORENSKY, L. M., VEBLEN, K. E., ODADI, W. O., SENSENIG, R. L., KIMUYU, D., KEESING, F., WILKERSON, M. L. & YOUNG, T. P. 2012. Lessons on the relationship between livestock husbandry and biodiversity from the Kenya Long-term Exclosure Experiment (KLEE). *Pastoralism* 2:1–22.

RIGINOS, C. & YOUNG, T. P. 2007. Positive and negative effects of grass, cattle, and wild herbivores on Acacia saplings in an East African savanna. *Oecologia* 153:985–995.

ROBSON, J., PEDERSEN, V., ODEKE, G., KAMYA, E. & BROWN, C. 1977. East Coast fever immunisation trials in Uganda: Field exposure of zebu cattle immunized with three isolates of *Theileria parva*. *Tropical animal health and production* 9:219–231.

ROGERS, D. J. & RANDOLPH, S. E. 2006a. Climate change and vector-borne diseases. *Advances in parasitology* 62:345–381.

ROGERS, D. J. & RANDOLPH, S. E. 2006b. Climate change and vector-borne diseases. *Advances in parasitology* 62:345–381.

ROSS, H. 2012. One Health from a Socio-Ecological Systems Perspective: Enriching Social and Cultural Dimensions. Pp. 217–229 *One Health: The Human-Animal-Environment Interfaces in Emerging Infectious Diseases*. Springer.

ROY, H. E., POCOCK, M. J., PRESTON, C. D., ROY, D. B., SAVAGE, J., TWEDDLE, J. C. & ROBINSON, L. D. 2012. Understanding citizen science and environmental monitoring: final report on behalf of UK Environmental Observation Framework.

SAUNDERS, B., SIM, J., KINGSTONE, T., BAKER, S., WATERFIELD, J., BARTLAM, B., BURROUGHS, H. & JINKS, C. 2018. Saturation in qualitative research: exploring its conceptualization and operationalization. *Quality & quantity* 52:1893–1907.

SCHUT, M., KLERKX, L., RODENBURG, J., KAYEKE, J., HINNOU, L. C., RABOANARIELINA, C. M., ADEGBOLA, P. Y., VAN AST, A. & BASTIAANS, L. 2015. RAAIS: Rapid Appraisal of Agricultural Innovation Systems (Part I). A diagnostic tool for integrated analysis of complex problems and innovation capacity. *Agricultural Systems* 132:1–11.

SCOTT, J. 2016. The social theory of Patrick Geddes. *Journal of Classical Sociology* 16:237–260.

SCOTT, J. C. 1989. Everyday forms of resistance. *The Copenhagen Journal of Asian studies* 4:33–33.

SEEBER, P. A., FRANZ, M., GREENWOOD, A. D. & EAST, M. L. 2019. Life history stage and extrinsic factors affect behavioural time allocation in plains zebras (Equus quagga) in the Serengeti ecosystem. *Behavioural Ecology and Sociobiology* 73:126.

SETTEN, G. 2004. The habitus, the rule and the moral landscape. *Cultural geographies* 11:389–415.

SHAW, I. G. R., ROBBINS, P. F. & JONES III, J. P. 2010. A bug's life and the spatial ontologies of mosquito management. *Annals of the Association of American Geographers* 100:373–392.

SHORTALL, O. & BROWN, K. 2020. Enacting and resisting biosecurity citizenship: More-than-human geographies of enrolment in a disease eradication scheme in Scotland. *Environment and Planning E: Nature and Space*:2514848620923590.

SILVERTOWN, J. 2009. A new dawn for citizen science. *Trends in ecology & evolution* 24:467–471.

SOL, D., JOVANI, R. & TORRES, J. 2003. Parasite mediated mortality and host immune response explain age-related differences in blood parasitism in birds. *Oecologia* 135:542–547.

DE SOUSA, R., LUZ, T., PARREIRA, P., SANTOS-SILVA, M. & BACELLAR, F. 2006. Boutonneuse fever and climate variability. *Annals of the New York Academy of Sciences* 1078:162–169.

STRENGERS, Y. & MALLER, C. 2014. Beyond behaviour change: practical applications of social practice theory in behaviour change programmes. Pp. 77–91 *Social Practices, Intervention and Sustainability*. Routledge.

SUBAK, S. 2003. Effects of climate on variability in Lyme disease incidence in the Northeastern United States. *American Journal of Epidemiology* 157:531–538.

SWAI, E. S., KARIMURIBO, E. D., KAMBARAGE, D. M. & MOSHY, W. E. 2009. A longitudinal study on morbidity and mortality in youngstock smallholder dairy cattle with special reference to tick-borne infections in Tanga region, Tanzania. *Veterinary parasitology* 160:34–42.

SWAI, E. S., KARIMURIBO, E. D., RUGAIMUKAMU, E. A. & KAMBARAGE, D. M. 2006. Factors influencing the distribution of questing ticks and the prevalence estimation of T. parva infection in brown ear ticks in the Tanga region, Tanzania. *Journal of Vector Ecology* 31:224–228.

SWEENEY, L. B. & STERMAN, J. D. 2000. Bathtub dynamics: initial results of systems thinking inventory. *System Dynamics Review: The Journal of the System Dynamics Society* 16:249–286.

TAITI, S. W. 1992. vegetation of Laikipia District, Kenya.

THEILER, A. 1911. Further investigations into anaplasmosis of South African cattle. Pretoria: Government Printer and Stationery Office.

VAN DEN BAN, A. 1963. Cultural change: the basis for increasing agricultural productivity. *International review of community development* 12:67–78.

VANDERWAAL, K., GILBERTSON, M., OKANGA, S., ALLAN, B. F. & CRAFT, M. E. 2017. Seasonality and pathogen transmission in pastoral cattle contact networks. *Royal Society open science* 4:170808.

VUDRIKO, P., OKWEE-ACAI, J., BYARUHANGA, J., TAYEBWA, D. S., OKECH, S. G., TWEYONGYERE, R., WAMPANDE, E. M., OKURUT, A. R. A., MUGABI, K. & MUHINDO, J. B. 2018. Chemical tick control practices in southwestern and northwestern Uganda. *Ticks and tick-borne diseases* 9:945–955.

WALKER, A. R. 2003. *Ticks of domestic animals in Africa: a guide to the identification of species*. Bioscience Reports, Edinburgh.

WALKER, A. R. 2011. Eradication and control of livestock ticks: biological, economic and social perspectives. *Parasitology* 138:945–959.

WALKER, J. G., KLEIN, E. Y. & LEVIN, S. A. 2014a. Disease at the wildlife-livestock interface: acaricide use on domestic cattle does not prevent transmission of a tick-borne pathogen with multiple hosts. *Veterinary parasitology* 199:206–214.

WALKER, J. G., KLEIN, E. Y. & LEVIN, S. A. 2014b. Disease at the wildlife-livestock interface: acaricide use on domestic cattle does not prevent transmission of a tick-borne pathogen with multiple hosts. *Veterinary parasitology* 199:206–214.

WALLACE, H., POLLACK, M. A. & YOUNG, A. R. 2015. *Policy-making in the European Union*. Oxford University Press, USA.

WALLER, R. 2004. 'Clean'and'dirty': Cattle disease and control policy in Colonial Kenya, 1900-40. *Journal of African History*:45–80. JSTOR.

WALLER, R. 2012. Pastoral production in colonial Kenya: lessons from the past? *African Studies Review*:1–27. JSTOR.

WALLER, R. & HOMEWOOD, K. 1997. Elders and experts: contesting veterinary knowledge in a pastoral community. In: A. Cunningham and B. Andrews, eds., Western Medicine as Contested Knowledge. Manchester: Manchester University Press.

WANGDI, K., SINGHASIVANON, P., SILAWAN, T., LAWPOOLSRI, S., WHITE, N. J. & KAEWKUNGWAL, J. 2010. Development of temporal modelling for forecasting and prediction of malaria infections using time-series and ARIMAX analyses: a case study in endemic districts of Bhutan. *Malaria Journal* 9:251.

WAUTERS, E. & MATHIJS, E. 2014. The adoption of farm-level soil conservation practices in developed countries: A meta-analytic review. *International journal of agricultural resources, governance and ecology* 10:78–102.

WESONGA, F. D., ORINDA, G. O., NGAE, G. N. & GROOTENHUIS, J. 2006. Comparative tick counts on game, cattle and sheep on a working game ranch in Kenya. *Trop Anim Health Prod* 38:35–42.

WHATMORE, S. 2013. Earthly powers: Thinking through flooding. *Theory, Culture & Society* 30:33–50.

WHATMORE, S. J. 2009. Mapping knowledge controversies: science, democracy and the redistribution of expertise. *Progress in Human Geography* 33:587–598.

WIESMANN, U., GICHUKI, F. N., KITEME, B. P. & LINIGER, H. 2000. Mitigating conflicts over scarce water resources in the highland-lowland system of Mount Kenya. *Mountain Research and Development* 20:10–15.

WIGGINS, A. & WILBANKS, J. 2019. The rise of citizen science in health and biomedical research. *The American Journal of Bioethics* 19:3–14.

WILCOX, B. A., ECHAUBARD, P., DE GARINE-WICHATITSKY, M. & RAMIREZ, B. 2019. Vector-borne disease and climate change adaptation in African dryland social-ecological systems. *Infectious diseases of poverty* 8:36.

WOLDEHANNA, S. & ZIMICKI, S. 2015. An expanded One Health model: integrating social science and One Health to inform the study of the human-animal interface. *Social science & medicine* 129:87–95.

YANOW, D. 2009. Organizational ethnography and methodological angst: myths and challenges in the field. *Qualitative Research in Organizations and Management: An International Journal* 4:186–199.

YOUNG, A. S., MUTUGI, J. J., KARIUKI, D. P., LAMPARD, D., MARITIM, A. C., NGUMI, P. N., LINYONYI, A., LEITCH, B. L., NDUNGU, S. G. & LESAN, A. C. 1992. Immunisation of cattle against theileriosis in Nakuru District of Kenya by infection and treatment and the introduction of unconventional tick control. *Veterinary parasitology* 42:225–240.

YOUNG, T. P., PALMER, T. M. & GADD, M. E. 2005. Competition and compensation among cattle, zebras, and elephants in a semi-arid savanna in Laikipia, Kenya. *Biological conservation* 122:351–359.

YURCO, K. 2017. Herders and herdsmen: The remaking of pastoral livelihoods in Laikipia, Kenya. *Pastoralism* 7:1–11. SpringerOpen.

ZIEGER, U., CAULDWELL, A. & HORAK, I. G. 1998. Dynamics of free-living ixodid ticks on a game ranch in the Central Province, Zambia. *The Onderstepoort Journal of Veterinary Research* 65:49–59.

ZIEGLER, A., ECHAUBARD, P., LEE, Y., CHUAH, C., WILCOX, B., GRUNDY-WARR, C., SITHITHAWORN, P., PETNEY, T., LAITHEVEWAT, L. & ONG, X. 2016. Untangling the complexity of liver fluke infection and cholangiocarcinoma in NE Thailand through transdisciplinary learning. *EcoHealth* 13:316–327.

ZUUR, A. F., IENO, E. N. & ELPHICK, C. S. 2010. A protocol for data exploration to avoid common statistical problems. *Methods in ecology and evolution* 1:3–14.

## Summary

Tick-borne diseases (TBDs) such as East Coast fever, anaplasmosis and babesiosis and their resultant mortalities are major constraints to livestock production, wildlife conservation and human health with ramifications on livelihoods, especially in the tropical drylands. The control of TBDs in the tropical drylands include pasture spelling, keeping livestock perceived to be TBDs resistant and the use of chemical acaricides. Although the use of acaricides is still the most dominant control practice for the control of TBDs, this approach is constrained by the least understood interactive effects of ecological and social factors. For instance, during the wet season, rainfall is considered a prominent ecological factor that directly or indirectly influences vegetation, host availability and movement, and land-use activities. Social factors include weak information sharing and governance issues in disease management. These uncertainties mirror the struggles that livestock farmers face and the results of this study may be applied to improve the management of TBDs in tropical areas. It is assumed that enhanced information sharing by actors through the adoption and scaling up of innovative technologies such as mobile phones and citizen science could be leveraged for information sharing to address TBDs in the tropical drylands. The interactions between the ecological and social factors influencing TBDs represent a socio-ecological system (SES) problem addressed in this thesis. It is critical to understand how various factors interact to promote the spread of or to impede effective control TBDs in tropical drylands. In this thesis, the central focus is to investigate **the social and ecological factors and their interaction effects on TBDs, and what could be the potential of mobile phones in reporting TBDs in tropical drylands?**

This thesis draws on literature review and empirical data (qualitative and quantitative), applying SES modelling, to explore the interactive effects of the ecological and social factors exacerbating the spread of, or impeding the control practices of TBDs in Laikipia County, Kenya. As a theoretical framework, SES modelling recognises that peoples' behaviour, the environment or the context in which they occur are embedded within larger interactive and overlapping ecological and social systems.

In Chapter 2, I analyzed the existing long-term data on rainfall and cattle mortalities from Olpejeta Conservancy in Laikipia County to determine the associations between rainfall-induced mortalities in Boran cattle. The results

suggested that East Coast fever (ECF) and anaplasmosis were negatively correlated with rainfall, with a lag of 2 and 6 months for ECF and anaplasmosis, respectively. However, Babesiosis could not be correlated to rainfall. This is a new finding identifying the associations between ecological factors and TBDs-induced cattle mortalities.

In Chapter 3, I sampled ticks in wildlife and livestock in both pastoral and commercial ranching areas. As expected, wild herbivores (zebras, rhinos and elephants) had significantly higher tick loads than livestock. The results suggested that animals with poor body conditions had significantly higher tick loads than those with good body conditions, irrespective of the management system. Cattle in transhumant pastoral areas had significantly higher tick loads than those in intensively managed commercial ranches. This study is among the few studies that highlight the importance of considering ecological and social factors influencing TBDs in tropical drylands.

In Chapter 4, I conducted a study aimed at identifying the unknown social factors and their interaction effects and the historical contexts constraining the control of TBDs, including the relationships between farmers, extension officials and actors involved in TBDs management. The results suggested that the control of TBDs in Kenya is a product of the pastoral communities and western-ideologic based veterinary thought with two different logics, sometimes converging but often at odds over fundamental socio-economic conditions perpetuated by the previous colonial regime and the pastoralist logic of herd immunity. Here, the analysis of the interplay of historical *context*, *practices* and *interactions* between TBDs actors reveals the power relations, tensions and contradictions emerging from an attempt to impose a western model of zoonotic disease management in the landscape with different biological outcomes. This new result gives insight into the biopolitics involved in zoonotic diseases management, opening up a discussion on how the dominant socio-political systems could be challenged and transformed into a more resilient one in the face of compounding uncertainties.

In chapter 5, I conducted a study aimed at (i) identifying issues of concern that complicates TBDs management in Kenya, including (ii) the assumption that lack of information by actors complicates the control of TBDs. Furthermore, I sought to clearly understand why and how farmers use mobile phones to address local issues of concern, including TBDs, and (iii) reflect on the implications of these results on the development of citizen science-based platforms for information sharing on TBDs. The results suggested that mobile phones are widely used for various socioeconomic activities: to communicate with family members and friends and to access information on pressing issues of concern such as human (in)security, human-wildlife conflicts and the occurrences of notifiable zoonotic diseases, forming issue-based networks of communication. I concluded that the design of mobile phone-based platforms and citizen science for information sharing on TBDs management should consider the motivation and the underlying socio-political factors influencing the information-sharing culture in an area. Together with chapter 4, the results of this study underscore the importance of diverse information dissemination channels, including farmer-to-farmer communication, radio or television talk shows which could be leveraged in the remote rural areas in the tropical areas characterised by poor communication infrastructure to enhance information sharing for effective control of TBDs.

Together, the four studies in this thesis strongly suggest that in tropical drylands (1) the major issues of concern which cut across the spread and control of TBDs in Laikipia County, Kenya, are related to the interactive effects of ecological and social factors, and (2) these cross-cutting issues impinge on people’s trust, power relations, communication and information sharing, extending into cases of human-wildlife conflicts and human insecurity. Specifically, the control of TBDs is compounded by the interaction effects of environmental (rainfall), biological (age, species, body condition of hosts) and social factors (management systems, socio-economic inequalities between farmers, historical contexts, relationships of TBD actors), representing a socio-ecological system. The results of this study also suggested that to successfully address TBDs, we require a clear understanding of its complexity, rather than reducing it to its most simplistic parts. This study highlights a profound need of addressing TBDs at all levels of the social and political structure while addressing the factors contributing to poor implementation of the control practices of TBDs. This study also highlights that to improve information sharing by actors, then we also need a clear understanding of the trust and relationship issues between farmers, extensionists, acaricide stockists and policy-makers at all levels. Furthermore, this study highlights the importance of co-design of projects including the development and scaling up of innovations such as digital platforms for information sharing to enhance TBDs management and agricultural production.

## Samenvatting

Ziekten die worden overgedragen door teken ('tick-borne diseases' TBD) zoals East Coast fever, anaplasmose en babesiose en de daaruit voortvloeiende sterfte vormen een belangrijke belemmering voor veeteelt, natuurbehoud en menselijke gezondheid. Dit heeft gevolgen voor het levensonderhoud van mensen, vooral in de tropische droge gebieden. De bestrijding van TBD's in de tropische droge gebieden omvat tijdelijk niet gebruiken van weiden, het houden van vee dat als TBD-resistent wordt beschouwd en het gebruik van chemische acariciden. Hoewel het gebruik van acariciden nog steeds de meest dominante praktijk is voor de bestrijding van TBD's, wordt deze aanpak beperkt doordat de interactieve effecten van ecologische en sociale factoren nog niet duidelijk zijn. Zo is bijvoorbeeld tijdens het natte seizoen regenval een prominente ecologische factor die direct of indirect van invloed is op de vegetatie, de beschikbaarheid en bewegingen van de gastheer en landgebruiksactiviteiten. Sociale factoren zijn onder meer de geringe informatie-uitwisseling en zaken met betrekking tot governance bij tekenbeheer. Deze onzekerheden weerspiegelen de worsteling waarmee veehouders worden geconfronteerd. De resultaten van deze studie kunnen worden toegepast om de bestrijding van TBD's in tropische gebieden te verbeteren. Aangenomen wordt dat verbeterde informatie-uitwisseling tussen actoren, door adoptie en opschaling van innovatieve technologieën, zoals mobiele telefoons en 'citizen science', kan worden gebruikt voor bestrijding van TBD's in tropische droge gebieden. De interacties tussen de ecologische en sociale factoren die TBD's beïnvloeden vormen een sociaal-ecologisch systeem (SES). Dit proefschrift behandelt de problemen die worden geassocieerd met dit SES. Het is van cruciaal belang om te begrijpen hoe verschillende factoren op elkaar inwerken die de verspreiding van TBD's in tropische droge gebieden bevorderen of de effectieve controle belemmeren. De kern van dit proefschrift richt zich op het onderzoeken van de sociale en ecologische factoren en hun interactie-effecten op TBD's. Daarnaast richt het onderzoek zich op het potentieel van mobiele telefoons bij het rapporteren van TBD's in tropische droge gebieden.

Dit proefschrift is gebaseerd op literatuuronderzoek en empirische gegevens (kwalitatief en kwantitatief). In dit proefschrift wordt SES-modellering toegepast, om de interactieve effecten van de ecologische en sociale factoren te onderzoeken

die de verspreiding van TBD’s vergroten of de bestrijding van TBD’s bemoeilijken. Het proefschrift richt zich op Laikipia County, Kenia. Als theoretisch kader erkent SES-modellering dat het gedrag van mensen, de omgeving of de context waarin ze voorkomen, zijn ingebed in grotere interactieve en overlappende ecologische en sociale systemen.

In Hoofdstuk 2 heb ik bestaande lange-termijn gegevens over regenval en sterfte van vee van de ‘Olpejeta Conservancy’ in Laikipia County geanalyseerd, om de associaties tussen regen en door TBD veroorzaakte sterfte bij Boran-runderen te bepalen. De resultaten suggereerden dat East Coast fever (ECF) en anaplasmose negatief gecorreleerd waren met regenval, met een vertraging van respectievelijk 2 en 6 maanden voor ECF en anaplasmose. Sterfte door Babesiose kon echter niet worden gecorreleerd aan regenval.

In hoofdstuk 3 heb ik teken bemonsterd van dieren in het wild en vee in zowel landelijke als commerciële veeteeltgebieden. Zoals verwacht hadden wilde herbivoren (zebra's, neushoorns en olifanten) een hogere tekenbelasting dan vee. De resultaten suggereerden dat ongeacht het managementsysteem, dieren met een slechte lichaamsconditie significant hogere tekenbelastingen hebben dan dieren met een goede lichaamsconditie. Runderen in transhumance pastorale gebieden hadden aanzienlijk hogere tekenbelastingen dan die in intensief beheerde commerciële boerderijen. Deze studie is één van de weinige studies die laat zien dat het belangrijk is dat er rekening wordt gehouden met ecologische en sociale factoren die TBD’s beïnvloedden in tropische droge gebieden.

In hoofdstuk 4 heb ik een studie uitgevoerd die gericht was op het identificeren van de onbekende sociale factoren en hun interactie-effecten en de historische contexten die de bestrijding van TBD's beperken, inclusief de relaties tussen boeren, voorlichtingsfunctionarissen en actoren die betrokken zijn bij het bestrijden van TBD's. De resultaten suggereerden dat de bestrijding van TBD's in Kenia een product is van de pastorale gemeenschappen en het op westerse ideologieën gebaseerde veterinaire denken. Het pastorale en het westerse veterinaire denken zijn beide verschillende logica's, die soms convergeren, maar vaak op gespannen voet staan met fundamentele sociaal-economische omstandigheden. Dit werd bestendigd door het vorige koloniale regime en de pastorale logica van kudde-immuniteit. De analyses laten zien dat de poging om een westers model van zoönotisch ziektebeheer op te leggen, een samenspel was van de historische context, praktijk en interacties tussen TBD-actoren. De machtsrelaties, spanningen en tegenstrijdigheden die hieruit voortkwamen hebben geleid tot verschillende resultaten in tekendichtheden. Dit nieuwe resultaat geeft inzicht in de bio-politiek die betrokken is bij het beheer van zoönotische ziekten, en opent een discussie over hoe de dominante sociaal-politieke systemen kunnen worden uitgedaagd en getransformeerd in een veerkrachtiger systeem, met name in het licht van toenemende onzekerheden.

In hoofdstuk 5 heb ik een studie uitgevoerd gericht op (i) het identificeren van onderwerpen die de bestrijding van TBD's in Kenia bemoeilijken. Hierbij is ook gekeken naar (ii) de veronderstelling dat de bestrijding van TBD’s wordt bemoeilijkt door het gebrek aan informatie bij actoren. Verder probeerde ik te begrijpen waarom en hoe boeren mobiele telefoons gebruiken om lokale problemen aan te pakken, waaronder TBD’s. Tevens heb ik (iii) nagedacht over de implicaties van deze resultaten voor de ontwikkeling van op ‘citizen science’ gebaseerde platforms voor het delen van informatie over TBD's. De resultaten suggereerden dat mobiele telefoons op grote schaal worden gebruikt voor verschillende sociaaleconomische activiteiten, bijvoorbeeld, om te communiceren met familieleden en vrienden en om toegang te krijgen tot informatie over dringende problemen, zoals veiligheid, conflicten tussen mens en natuur en het voorkomen van zoönotische ziekten met een meldingsplicht, d.w.z. het vormen van op problemen gebaseerde communicatienetwerken. De resultaten laten zien, dat bij het ontwerp van op mobiele telefoons gebaseerde platforms en ‘citizen science’ voor het delen van informatie over het beheer van TBD's, rekening moet worden gehouden met de motivatie en de onderliggende sociaal-politieke factoren die de cultuur van het delen van informatie in een gebied beïnvloeden. Samen met hoofdstuk 4 onderstrepen de resultaten van deze studie het belang van diverse kanalen voor informatieverspreiding om het delen van informatie te verbeteren, zodat TBD’s effectiever kunnen worden bestreden. De kanalen die kunnen worden gebruikt in de afgelegen plattelandsgebieden in de tropische gebieden met een slechte communicatie-infrastructuur betreffen communicatie van boer tot boer en radio- of televisietalkshows.

De vier studies in dit proefschrift suggereren dat in tropische droge gebieden (1) de belangrijkste problemen die de verspreiding en bestrijding van TBD's in Laikipia County, Kenia belemmeren, sector-overstijgend zijn en verband houden met de interactieve effecten van ecologische en sociale factoren. Aanvullend laten de vier studies zien dat (2) deze sector-overstijgende kwesties het vertrouwen van mensen, machtsverhoudingen, communicatie en informatie-uitwisseling aantasten, en gerelateerd zijn aan conflicten tussen mens en natuur en aan onveiligheid. In het bijzonder wordt de bestrijding van TBD's belemmerd door de interactieve effecten van omgevingsfactoren (regenval), biologische (leeftijd, soort, lichaamsconditie van gastheren) en sociale factoren (managementsysteem, sociaal-economische ongelijkheid tussen boeren, historische context, relaties van TBD-actoren), die een sociaal-ecologisch systeem vertegenwoordigen. De resultaten van deze studie suggereerden ook dat om TBD's met succes aan te pakken, we een duidelijk begrip nodig hebben van de complexiteit ervan, in plaats van het te vereenvoudigen tot simpele onderdelen. Deze studie benadrukt de grote behoefte om TBD's op alle niveaus van de sociale en politieke structuur aan te pakken en tegelijkertijd de factoren aan te pakken die bijdragen aan een slechte implementatie van de bestrijding van TBD's. Deze studie benadrukt ook dat om het delen van informatie door actoren te verbeteren, we tevens een duidelijk begrip nodig hebben van de vertrouwens- en relatieproblemen tussen boeren, voorlichters, acaricide-handelaren en beleidsmakers op alle niveaus. Bovendien benadrukt deze studie het belang van co-creatie van projecten, waaronder de ontwikkeling en opschaling van innovaties, zoals digitale platforms voor het delen van informatie, om de bestrijding van TBD's en de landbouwproductie te verbeteren.

## Affiliations of co-authors

**Frank van Langevelde**, (1) Wageningen University, Wildlife Ecology and Conservation Group, P.O. Box 47, 6700 AA Wageningen, The Netherlands; (2) School of Life Sciences, Westville Campus, University of KwaZulu-Natal, Durban 4000, South Africa

**Carolina Castagna**, Wageningen University, Wildlife Ecology and Conservation Group, P.O. Box 47, 6700 AA Wageningen, The Netherlands

**Ignas Heitkönig**, Wageningen University, Wildlife Ecology and Conservation Group, P.O. Box 47, 6700 AA Wageningen, The Netherlands.

**Severine van Bommel**, (1) The University of Queensland, School of Agriculture and Food Sciences, Gatton QLD 4343, Australia; (2) Wageningen University, Strategic Communications Group, P.O. Box 8130, 6700 EW Wageningen, The Netherlands

## PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises a minimum total of 32 ECTS (= 22 weeks of activities)

**Review of the literature (4.5 ECTS)**

- Drivers of tick & tick-borne disease spread and control in tropical drylands

**Writing of project proposal (4.5 ECTS)**

- Combating tick & tick-borne disease menace in semi-arid areas of Kenya

**Post-graduate courses (10 ECTS)**

- Companion modelling; WASS, the Netherlands (2016)
- One health initiative training course for Laikipia County; Centre for Disease Control, Kenya (2016)
- Research methodology: from topic to the proposal; WASS, the Netherlands (2016)
- Basic statistics; PE&RC, the Netherlands (2016)

**Laboratory training and working visits (4.5 ECTS)**

- Tick identification at ILRI and DVS laboratory; Directorate of Veterinary Service, Kenya (2019)

**Invited review of (unpublished) journal manuscript (2 ECTS)**

- Journal of Dairy and Veterinary sciences-Juniper publishers: a review of some innovative teaching concepts and methods used in the field of veterinary medical education (2018)
- Journal of Dairy and Veterinary sciences-Juniper publishers: comparison of the social and individual behaviour of intact and neutered female domestic dogs, *Canis lupus familiaris*, using video analyses (2018)

**Deficiency, refresh, brush-up courses (6 ECTS)**

- Change, interhuman processes and communication; WASS (2016)

**Competence strengthening/skills courses (6.6 ECTS)**

- Writing propositions; PE&RC (2016)
- PhD Carousel; PE&RC (2016)
- EVOCA Modules; WASS (2016)

- Presenting with impact; In’to languages at Radbound University (2019)
- Scientific writing; In’to languages at Radbound University(2020)

**Scientific integrity / ethics in science activity (0.5 ECTS)**

- Research ethics for social sciences; WASS (2019)

**PE&RC Annual meetings, seminars and the PE&RC weekend (0.9 ECTS)**

- PE&RC Weekend for first years (2016)

**Discussion groups / local seminars / other scientific meetings (6 ECTS)**

- The proposal at the First International EVOCA Workshop; oral presentation; Wageningen, the Netherlands (2016)
- Kenya tick case team presentation at the 3rd EVOCA International Workshop; Accra, Ghana (2017)
- Second International EVOCA Conference; oral presentation; Wageningen, the Netherlands (2018)

**International symposia, workshops and conferences (2.5 ECTS)**

- Large Carnivore Conference; Nairobi, Kenya (2018)
- The Annual Scientific Conference; oral presentation; Kruger, South Park, Republic of South Africa (2019)

**Societally relevant exposure (2 ECTS)**

- Talk and conservation campaign walk at the World Rhino Day at KANU Grounds-Nanyuki, Kenya (2017)
- Talk at the World Environment Day-Tree planting at Thingithu Primary School, Nanyuki Kenya (2018)

**Supervision of BSc/MSc students (3 ECTS)**

- Muna Bilha: potential role of mobile phones in pasture and water management in pastoral areas of Laikipia, Kenya
- Carolina Castagna: Association between rainfall and mortalities due to East Coast fever, *anaplasmosis* and *babesiosis*

**Acknowledgements**

The production of this thesis was made possible due to the scholarship from the Wildlife Ecology and Conservation Group (WEC) in conjunction with the INREF programme "Environmental Virtual Observatories for Connective Action" (EVOCA) of Wageningen University. I would like to pay my special regards to my promotor Professor Frank van Langevelde, co-promotor Dr Severine van Bommel and Dr Ignas Heitkonig for recruiting me to the EVOCA programme. The trio always guided and encouraged me to learn how to write good scientific papers even when the task looked immensely challenging. Without their persistent help, the goal of this project would not have been realized. I wish to give my gratitude to Cieslik Katarzyna of the graduate school Wageningen Social Science (WASS) who was my first contact on my arrival in the Netherlands. I arrived in the Netherlands in February 2016, and it was chilling winter. To me, it was indeed a weather shock since I had never lived in Europe before during the winter. During that period Katarzyna kept encouraging us with her usual phrase "My EVOCA students" despite the challenging first phase of the PhD trajectory. For Katarzyna, it is wholeheartedly appreciated that your great support and advice during the first stages of EVOCA proved monumental towards the success of this study. Other people made this study successful and I want to thank them for their immense contributions towards this study.

I want to particularly single out the late Mr Julius Kimani (former director KWS), for not only granting me study leave but also for encouraging me and extending to me their total support throughout my PhD journey. I also sincerely thank Mr Kitili Mbathi (former KWS-DG) and Brig. John Waweru (current KWS DG) for allowing me to continue with this study to completion. I also wish to single out Mr Michael Kipkeu (DD Devolution and community wildlife service) and Mr Aggrey Maumo and Simon Gitau (former ADs for Mountain Conservation Area) for their assistance in making the necessary clearance for all my PhD study trips both locally and abroad.

The physical and technical support of the Kenya Wildlife Service (KWS) is immensely appreciated. Without their support in providing security during the tense periods of insecurity in Laikipia, this work would not have been possible. I wish to express my deepest gratitude to the commercial and community ranches in Laikipia which supported us in organising fieldwork and focused groups discussions. I also wish to thank James Mathenge, Samuel Mutisya and Alfred Kibungei of Olpejeta Conservancy, and Richard Tonui and Lance Tomilson of Loldaiga Hills Conservancy for always organising tick collections during chemical spraying sessions for cattle. I wish to thank the KWS drivers Samuel Ndungu, Victor Chira and Duncan Wangomi whose assistance was a milestone in the completion of this project.

I am also indebted to other staff from the Wildlife Ecology and Conservation Group (WEC) who were always willing to review my proposal and manuscripts whenever I called upon them and in normal weekly PhD lab meetings and corridor encounters. These sessions enriched and improved my thesis a great deal; to Henjo de Knegt, Tim Hofmeester, Helen Esser- I thank you all. Claudius van de Vijver and Lennart Suselbeek were also instrumental in guiding me to navigate the PhD trajectory that looked almost impossible but eventually was possible. The PE&RC weekend was particularly motivating as it allowed us to share ideas and experiences with the past PhD candidates. They taught us how to circumvent the challenges that come with a PhD study in the many PE&RC meetings, carousels and training sessions they organised.

I also wish to thank Patricia Meijer and Gerda Martin who were always handy in organising my travel back to the Netherlands and provided me with all the assistance I needed and ensured that all my travels, fieldwork went on smoothly. I also wish to thank Inge Ruisch from WASS for playing a similar role at KTI - from providing office space to stationary and answering any query I had on university procedures. Gerda sorted my finances in record time. My travel plans, insurance and registration processes were seamlessly handled by the trio. To all of you, I say kudos.

I sincerely thank the Kenyan community in Wageningen University who made me feel at home away from home; Martin, Faith, Kilelu, Prisca Oria, Hellen, Tabitha Yussuf, Moses Lekishon, Tele, Muna, Emma, Kirina, Sally Migose, Jasper Kiplimo and Joshua Wambugu. The many meet-and-greet sessions, barbeques, exploring the Netherlands and the African night, together made my stay in Wageningen a lot more fun. I am also indebted to other our colleagues; Lorraine Nokuthula, Stratton Hatfield, and Carolina Castagna for their great contributions in preparing one of my manuscripts. I also cherish my corridor mates at Asser Park including Clyde, Joshua, Femke and Marina. Together with Clyde Xibrraku and Lorraine Nokuthula, we occasionally took a walk to the neighboring farms to beat the odds of Coronavirus lockdowns that often involved sitting indoors for too many hours a day.

I wish to also acknowledge the support of my other PhD candidates at WUR comprising the EVOCA digital comrades: Marilyn, Domina, Assefa Elias, Shiferaw, Andy, Emmanuel, Faith, Christopher, Nyamwaya and Mariette.

I also wish to thank my paranymphs: Maria Contesse and Lorraine Nokuthula, for the support their support during my PhD defence.

I also wish to acknowledge the support and great love of my family, my wife, Beatrice; my mother, Esther; and my children; Dennis, Cynthia, Brian and Pryce-Fortune. Their moral support towards and while away both in Kenya and abroad for many months while pursuing this PhD programme would not have been possible without them.

Finally, for those whom I may not have mentioned here but who contributed in one way or another towards the attainment of this academic pursuit, I'm grateful to you all because, without you, this thesis would not have become a reality.

**Curriculum Vitae**

Richard Kiprotich Chepkwony was born on 30th November 1974 in Kericho County, Kenya. He is happily married with four kinds-2 boys and 2 girls. He studied at Chepsir Primary School in Kericho County and Kaplong Boys' High School in Bomet County in the years 1981-1988 and 1989-1992, respectively. In 1998, he obtained a BSc. Degree in Wildlife Management from Moi University in Kenya. 1n the year 2000, he joined Kenya Wildlife Service (KWS) as an assistant research scientist and after 2-years he was re-designated as a management trainee After one year of training in the Kenya Wildlife Service Law Enforcement Academy Manyani and the departments of Wildlife Security, Community Wildlife Service, Park Management and Tourism, he got full-time employment with KWS as a National Park Manager, specialising in rhino monitoring and surveillance. After 9-years he transitioned to a full-time park manager-specialising in community wildlife service, education and outreach. He has since managed various terrestrial National Parks and stations in Kenya for over 10 years, including the Tsavo West, Nairobi and Amboseli National Parks; Kajiado, Laikipia and Narok stations-classified as human-wildlife conflict ‵′hotspots′′ in Kenya. In June 2007, he enrolled for a sandwich summer course in Tropical Biology Associations course in Ecological Research Methods 1 & 2 in savanna ecosystems jointly offered by the Cambridge University in the United Kingdom, the Mpala Research Centre, Laikipia, and the Nature Kenya. In 2009, he enrolled for the MSc. Degree in Wildlife Management at Moi University in Kenya where he graduated in 2012. He has studied various short professional courses such as: Computer and ICT applications for environmental management at the Kenya Institute of Administration (now Kenya school of

Government in 2003); Environmental Education through Nature Conservation and eco-tourism in savanna ecosystems in Tokyo, Shizuoka and Aichi Prefecture (Nagoya), Japan, in 2005; Accredited rhino monitoring and surveillance studies in Africa by the African Rhino specialist group at Nakuru, Kenya; Scene of wildlife crimes, Intelligence and Investigation at the Kenya Wildlife Service Training Institute- Naivasha Kenya in 2003. He has also studied financial, procurement and stores management for non-finance managers in 2010 while at KWS. Moreover, he has studied the application of ‵′SMART′′ technologies for Biodiversity monitoring and Conservation in Arusha, Tanzania and The University of Pretoria, Republic of South Africa (RSA); Ecological Research methods in African savannas at Kruger National Park, RSA; Savanna fire management and command course offered jointly by the KWS and the Brazilian Fire-brigade at the Law Enforcement-Manyani, Kenya; Human-wildlife conflict management tool box in the East and Central African protected areas in 2013. Furthermore, he has attended many scientific conferences and writing workshops in Kenya, Republic of South Africa, Ghana, Tanzania, and in Europe, among others.

He joined Wildlife Ecology and Conservation Group and the Wageningen School of Social Sciences in Wageningen University for a PhD study in 2016 through the Environmental Virtual Observatories for Connective Action (EVOCA) in Infectious diseases, Water and Wildlife management by Wageningen University-development partnership scholarship scheme. His study focussed on the Application of Environmental virtual Observatories using Digital (SMART) Technologies and Innovations for Connective Actions by stakeholders to combat the tick-borne disease at the human, wildlife and livestock interfaces in tropical drylands of Africa. The results of this research culminated in this Thesis. Richard is currently a Senior Manager in the department of Community Wildlife Service and Outreach at the Kenya Wildlife Service managing the Narok County and Mau Forest Complex Joint-Enforcement Unit (JEU). JEU is a multi-agency security enforcement and forest restoration team that is jointly implemented between the Kenya Water Towers; the Ministry of Environment and Natural resources, The Narok County Government, the National Police Service, and the Kenya Wildlife Service.

## Colophon

Cover design by Richard Chepkwony and Trevor Wamisi

The research described in this thesis was financially supported by through the Environmental Virtual Observatories for Connective Action (EVOCA) and Wildlife Ecology and Conservation Group of Wageningen University.

Financial support from Wageningen University for printing of this thesis is gratefully acknowledged.

Layout and print by: ProefschriftMaken (www.proefschriftmaken.nl)