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Assessment of pastoralists' vulnerability to trypanosomiasis and effects of climate on tsetse and trypanosomes distribution in Tanzania's Maasai steppe

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ASSESSMENT OF PASTORALISTS' VULNERABILITY TO TRYPANOSOMIASIS AND EFFECTS OF CLIMATE ON TSETSE AND TRYPANOSOMES DISTRIBUTION IN TANZANIA'S MAASAI STEPPE

Happiness J. Nnko

A dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy in Life Science of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

For decades, pastoralists have had their adaptation strategies that enable them to thrive in harsh environments. However, changing climate and land management regimes, coupled with under-investments in pastoral areas, threaten to overwhelm pastoralists' traditional adaptation methods. This could potentially increase vulnerability of pastoral communities to multiple stressors, including trypanosomiasis. Trypanosomiasis is caused by a parasitic protozoan of *Trypanosoma spp* where tsetse flies are the main vector. Trypanosomiasis is a neglected tropical disease, yet a disease of public health and socio-economic concern. It exacerbates economic hardships due to loss of livestock or through additional costs needed to control and treat the disease. Despite these concerns, information about where and when to expect high burden of tsetse flies and trypanosomes remain limited, and control strategies, if offered, are often ineffective. This study therefore assessed pastoralists' vulnerability to trypanosomiasis, seasonality of tsetse fly abundance, prevalence of trypanosome infections in the vector, and potential impacts of climate change on tsetse fly distribution. The study incorporated social and ecological analytical techniques including ArcGIS 10.4, polymerase chain reaction (PCR) and species distribution modelling (SDM). Emboreet and Loibor-Sireet Wards in Simanjiro district were identified as the most vulnerable locations to trypanosomiasis. Three tsetse fly species (*Glossina m. morsitans, Glossina pallidipes* and *Glossina swynnertoni*) and three trypanosome species (*T.vivax*, *T.congolense* and *T. brucei*) were found in the study area. Tsetse fly relative abundance and trypanosome prevalence peaked in July and October, respectively. Maximum and minimum temperature negatively affected abundance of *G. m. morsitans* and *G. swynnertoni,* respectively. Trypanosome prevalence was negatively correlated with tsetse abundance but positively correlated with temperature. The climate tsetse fly relationships were used in the SDM to show that by the year 2050, the habitable area of *G. m. morsitans*, *G. pallidipes* and *G. swynnertoni* may decrease to 23.13%, 12.9% and 22.8% of current suitable habitat (19 224.58 km^2, 7113.37 km^2 and 32 335.27 km^2), respectively in the study area. These results provide useful information to inform communities, health and livestock development sectors and tsetse fly control units on where and when to expect the highest risk of trypanosomiasis infection in the Maasai Steppe and plan accordingly.

Keywords: Pastoralist, vulnerability, trypanosomiasis, adaptation, tsetse, trypanosome prevalence, seasonality, SDM, Maasai Steppe, Tanzania

DECLARATION

I, Happiness Jackson Nnko, do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award at any other institution.

_ 17. Dec. 2017

Name and signature of candidate **Date**

The above declaration is confirmed

Dr. Anna Estes ______________ **18. 12. 2017**

Name and signature of supervisor **Date**

Prof. Gwakisa, Paul S.

18. Dec 2017

Name and signature of supervisor **Date**

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CERTIFICATION

The undersigned certify that they have read and hereby accept the dissertation titled "***Assessment of pastoralists' vulnerability to trypanosomiasis and effects of climate on tsetse and trypanosomes distribution in Tanzania's Maasai Steppe",*** in fulfillment of the requirements for the Degree of Doctor of Philosophy in Life Science at the Nelson Mandela African Institution of Science and Technology (NM-AIST).

Dr. Anna Estes **18. 12. 2017**

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18. Dec. 2017

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Luka, Eliakim and Kanali, your support and willingness to assist during tsetse fly trapping is treasured.

Sincere appreciation to my husband Amani Kaaya and my whole family for the support they gave me even when they were not asked.

DEDICATION

This work is dedicated to Almighty God, my husband, mother, my late father (May his soul rest in eternal peace) and the entire family.

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LIST OF ABBREVIATIONS

AAT----------------------------African Animal Trypanosomiasis

AIC-----------------------------Akaike's Information Criterion

AUC----------------------------Area under the receiver operating curve

BCC-CSM1-------------------The climate system models from Beijing Climate Center

BIC-----------------------------Bayesian information Criterion

CMIP5-------------------------Coupled Model Inter-comparison Project

DNA----------------------------Deoxyribonucleic acid

ENMTools---------------------Ecological Niche Modelling tools

GCM---------------------------General circulation models

HAT----------------------------Human African Trypanosomiasis

IPCC----------------------------Intergovernmental Panel on Climate Change

NP------------------------------National Park

OR ------------------------------Odds Ratio

PAs-----------------------------Protected Areas

PCR-----------------------------Polymerase chain reaction

RCPs----------------------------Representative Concentration Pathways

SADC---------------------------Southern Africa Development Community

SDM---------------------------- Species distribution modeling

SPM---------------------------- Summary for Policymakers

SRES-----------------------------Special Report Emissions Scenarios

UN-------------------------------United Nations

UNEP---------------------------United Nations Environmental Programme

CHAPTER ONE

INTRODUCTION

1.1 General introduction

This dissertation is based on three data chapters which have been written as original articles. Although published articles are multi-authored, as is common in the field of ecology, all the work presented in this dissertation is original and is my own. Chapter One provides a general introduction and background of the study, research problem and justification, objectives, research questions and conceptual framework. Chapter Two is a detailed assessment of pastoralists’ vulnerability to trypanosomiasis and adaptation strategies. Chapter Three gives details of tsetse fly species abundance and trypanosome prevalence in relation to seasonal variation of climate. Chapter Four is a detailed description of potential impacts of climate change on spatial and temporal distribution of tsetse flies and hotspots of infection. Chapter Five includes a general discussion, conclusions and recommendations.

1.2 Background

1.2.1 Vulnerability to trypanosomiasis

Many definition of vulnerability exists but this study, considers vulnerability as a function of exposure, sensitivity and adaptive capacity which is consistent with the IPCC definition (Intergovernmental Panel for Climate Change [IPCC], 2001). Vulnerability to trypanosomiasis is therefore, viewed as a degree to which a community or system is susceptible to harm/damage, and unable to adapt to damages (Smit and Wandel, 2006) caused by trypanosomiasis. It is determined by level and type of trypanosomiasis risks and exposure factors, sensitivity and an internal adaptive capacity of a health system and the community at large. It is also shaped by continually changing socio-economic factors, suggesting the need to assess vulnerability in context of space and time. Vulnerability assessment focuses on identifying locations and communities that are more at risk of a trypanosomiasis, availability and accessibility of health institutions including human and veterinary health infrastructure. Accordingly, locations that are characterized by high levels of trypanosomiasis stress, inadequate health infrastructure and high dependence on climate sensitive livelihoods options are more vulnerable than others. The reason for this is the fact that trypanosomiasis, especially in pastoral areas is exacerbated by the impact of climate change particularly drought. Drought accelerates scarcity of forage and water, which force people and their herds into trypanosomiasis high risk areas and thus increase the potential for trypanosomiasis transmission. Furthermore, scarcity of forage accelerates loss of immunity and emaciation of livestock which is a main source of livelihood in pastoral communities (Msoffe *et al.,* 2011a). Consequently pastoralists' adaptive capacity in terms of economy and health become jeopardized. This situation coupled with chronic under investment in pastoral areas may lower pastoralists resilience to diseases such as trypanosomiasis and others stressors. To avoid confusion of terminology, this study used trypanosomiasis as an english name for both Animal African Trypanosomiasis (AAT) and Human African Trypanosomiasis (HAT) as recommended by World Health Organization (Ashford, 2001).

1.2.2 Climate change and their impacts on pastoral socio-ecological system

Climate predications show that at least the next nine decades of changing global climate will be characterized by upward trend in temperature (Meehl *et al.,* 2007). These changes are a consequence of global warming caused by anthropogenic activities that have pumped greenhouse gases into the atmosphere at an unprecedented rate over the last 40 years (Parry, 2007; Collier *et al.,* 2008). On average, global temperature is expected to rise by 0.8 - 2.6^{0}C, and by 1.5 - 3^{0}C in Africa, by the year 2050 (United Nation Environmental Programme [UNEP], 2007). Consequences of these changes are felt around the globe, thus reducing debates over whether existence of climate change is real (King, 2004; Leiserowitz, 2005). Some of manifested climate change impacts include but not limited to crop failure and food shortage (Bohle *et al.,* 1994; Parry *et al.,* 2004; Challinor *et al.,* 2010), loss of biodiversity (Lovett *et al.,* 2005) and emergence and re-emergence of vector-borne diseases as a result of expansion and range shift of disease vectors (Githeko *et al.,* 2000; Patz *et al.,* 2005; Rogers and Randolph, 2006). Food insecurity driven mainly by extreme weather events has been predicted to hit the eastern Africa region due to projected changes in climate (Adhikari *et al.,* 2015). In Tanzania, analysis of climate for the past three decades indicated increasing trends of temperature in various parts of the country and already an outcry of crop failure, water scarcity, energy shortage and health issues is accelerating (United Republic of Tanzania

[URT], 2007; Levira, 2009). These were the major motivation for preparation of National Adaptation Programme of Action (NAPA) by the Tanzania government in order to identify and promote activities that address urgent and immediate needs for adapting to the adverse impacts of climate change.

Climate change is also predicted to impact vector borne diseases by altering the suitability of the environment for parasites and vectors (Githeko *et al.,* 2000; Moore *et al.,* 2011). The impact of environmental factors such as climate on vector-pathogens relations is specific to a combination of individual vector-pathogen systems. But, generally, vectors, specifically insects, are poikilothermic and ambient temperature affects their physiology directly, and also affects the parasites in their body. For example the effects of fluctuations of both mean maximum and minimum temperatures has been predicted to accelerated and lower respectively the malaria parasite development. This is to say, the extreme temperatures where range expansions or contractions is likely to occur, transmissions is potentially possible at lower temperatures than currently predicted while fluctuations at higher temperatures has a potential to block the transmission (Paaijmans *et al.,* 2010).

Also, climate influences interactions of vector and pathogens by affecting susceptibility of vector to infections, vectors' ability to fight infections, host preference, feeding frequency and rates of pathogen development and ultimately vector borne disease onset and severity is affected in a complex way (Githeko *et al.,* 2000; Moore *et al.,* 2011; Parham *et al.,* 2015). For instance, it is anticipated that the predicted upward trend in global temperature, together with anthropogenic, biological, and ecological factors will affect vector-borne diseases by not only altering the geographical distribution, but also reproduction and biting rates of disease vectors and incubation periods of pathogens (Gage *et al.,* 2008; Mills *et al.,* 2010). Those changes may compromise human health due to effects on emergence and resurgence of infectious diseases (Patz *et al.,* 2005; Hayes and Gubler, 2006; Moore *et al.,* 2011). Already some vector-borne diseases such as malaria have been reported to emerge in areas previously not favorable, and some are likely to re-emerge in areas previously eliminated (Moore *et al.,* 2011). In Tanzania, malaria has been reported to occur in some parts of East and West Usambara mountains and parts of Kagera region where it was not commonly found in previous years (URT, 2007).

In broad perspective, climate change poses a particular challenge of sustainability of many socio-ecological systems (Goldman and Riosmena, 2013) including pastoral socio-ecological systems. In this study, pastoral socio-ecological system is considered to be a set of essential resources such as natural, cultural and socio-economic whose flow and use is controlled by a coherent combination of ecological and social systems in pastoral areas. Specifically, climate change threatens sustainability of pastoral socio-ecological system by accelerating landscape transformation, natural resources scarcity and cultural related institutions adjustments which may in turn affect communities' traditional livelihoods and consequently create new dimensions of vulnerabilities. In East Africa, for example, climate change is likely to cause frequent and severe droughts (Adhikari *et al.,* 2015) which will likely increase pressure on pastoral land and consequently drive people and their livestock to among others, tsetse fly infested area and thus increase their risks of contracting trypanosomiasis. In Tanzania, recurring droughts coupled with extension of protected areas (PAs) and land conversion for crop farming, for example, are weakening traditional pastoral system mosaics such that landscape, livelihoods and institutions are no longer reciprocally supporting each other (Fratkin, 2001; Goldman and Riosmena, 2013). Subsequently, flexibility in traditional methods of coping with diseases in drought and zoonotic stricken areas is decreasing (Huho *et al.,* 2011; Goldman and Riosmena, 2013; Schmidt and Pearson, 2016). As a result, adaptation to diseases and climate perturbation within and across pastoral communities is likely to increase people's vulnerability to multiple stressors because traditional pastoralism is breaking down (Agrawal, 2008).

Poor and marginalized communities are most vulnerable to climate change impacts and have little capacity to adapt (IPCC, 2001; (United Nations [UN], 2016). In Tanzania, pastoral communities of Maasai Steppe are among the poor and marginalized communities. These communities are marginalized economically and politically (Parkipuny, 1994; Lawson *et al.,* 2014), constrained by ever increasing resource competition (land tenure and water) that has led to degradation and scarcity of forage for livestock in grazing areas (Msoffe *et al.,* 2010), and also proper development policies. Due to the mentioned constraints, Maasai communities of the Maasai Steppe already face many challenges that make it harder for them to adapt to perpetual climate surprises. For example, movement across landscape which used to be a strategy of escaping harsh environment such as drought and zoonotic diseases is now restricted by extension of PAs and recent land conversion for crop farming, consequently resilience to zoonotic diseases has been reduced. Since livestock plays key role in economy of Maasai communities, loss of pastoralists' resilience to diseases such as trypanosomiasis coupled with recent Maasai communities acquired sedentary lifestyle suggest low adaptive capacity to diseases of both livestock and human and thus increased vulnerability to diseases and other perturbations. In totality, climate change impacts are multidimensional and pose multidimensional challenges that increase the vulnerability to multiple stressors and eventually compromised resilience of the pastoral socio-ecological system at large.

In a marginalized community, climate change impacts could make the situation worse for neglected vector-borne diseases, since the risk of their transmission will be exacerbated by impaired health facilities and human migration resulting from projected increases in vulnerability to climate change (Patz *et al.*, 2005). Nonetheless, consequences of climate stress on agricultural and pastoral systems will result in malnourished and less resilient communities, and thus worsen the communities' rate of susceptibility to infections (McMichael, 2004) such as trypanosomiasis. These impacts are likely to persist for a long time as the Intergovernmental Panel on Climate Change (IPCC) have cautioned about the possibility of an increase in temperature from an average of 1.8°C to 4°C in the 21st century compared to an increase of 0.76^0C on average in the pre-industrial period (Parry, 2007) if no strong actions are taken to mitigate global warming. Since greenhouses gases live long in the atmosphere, it is expected that, the planet will continue to warm and impacts of climate change will continue to happen far into the future regardless of the efforts to mitigate climate change in time.

1.2.3 Climate effects on tsetse flies distribution

Tsetse flies belong to the genus *Glossina* that is further subdivided into three subgenera. These subgenera are *Austenina (fusca group)*, *Nemorhin (palpalis group)* and *Glossina (morsitans group)*, and they prefer distinct habitats and ecological settings. *Austenina (fusca group)* are forest dwellers, *Nemorhin (palpalis group)* prefer riverine/wetlands and *Glossina (morsitans group)* prefer open woodland/woodland savanna. Based on the distribution of suitable ecological conditions, *Austenina*, *Nemorhin* and *Glossina* sub-genera are mainly found in Congo, West Africa and East Africa respectively.

Apart from vegetation and host availability, geographical distribution of tsetse fly is highly determined by climate; too hot or too cold climate is unfavorable for their survival. This partly explains why, tsetse flies are not found in southern and northern Africa where is too cold and hot respectively. Also, climate particularly temperature affects tsetse fly development rate and activities and thus seasonal variation of their abundance (Torr and Hargrove, 1999). Specifically, temperature affects tsetse fly rates of larval production and the hatching rate/pupal development rate. Hargrove (1994) observed that the rate of larva production become shorter at lower temperatures and under field condition compared to laboratory estimates. The first larva production may take longer, but production of subsequent larva takes maximum of 12 days at lower temperatures (Hargrove, 2004). Tsetse fly emerge from pupal at a temperature of between 16^0C - 32^0C, the higher the temperature, the shorter the development rate and vice versa (Hargrove, 2004). Tsetse mortality at various stages such as larva abortion, pupal mortality, adult mortality is also influenced by temperature, although other non-natural and natural factors too play part.

Climate change is expected to impact the distribution tsetse fly in Africa, nonetheless, predictions of how the impacts will change tsetse fly distribution do not all agree in terms of geographical extent of the range, but many concludes on range shift. Some have predicted a large range shift of up to 60 %, by the year 2090 (Moore *et al.*, 2011). Rogers and Packer (1993) also predicted overall reduction of suitable range for tsetse flies, but also a spread out of suitable range particularly in high-altitude areas that currently exclude the species due to low temperatures in some parts of East Africa due to climate change in the region. In the SADC region, Hulme (1996) predicted a contraction of *G. m.morsitans* geographic range owing to climate change.

Occurrence of tsetse flies and trypanosomes not only pose public health risks, but also financial threat. For instance, the presence of tsetse flies threatens African livestock sector development and can cost between $600 thousand and $1.3 billion a year (Moore and Messina, 2010) for disease control and treatment.

1.2.4 Climate effects on trypanosomes and trypanosomiasis transmission

Trypanosomes are protozoa of the genus *Trypanosoma*, which are transmitted mainly through bites of infected tsetse flies when sucking blood from hosts. The parasite *Trypanosoma species* go through various developmental stages in tsetse fly and mammalian host (Fig.1).

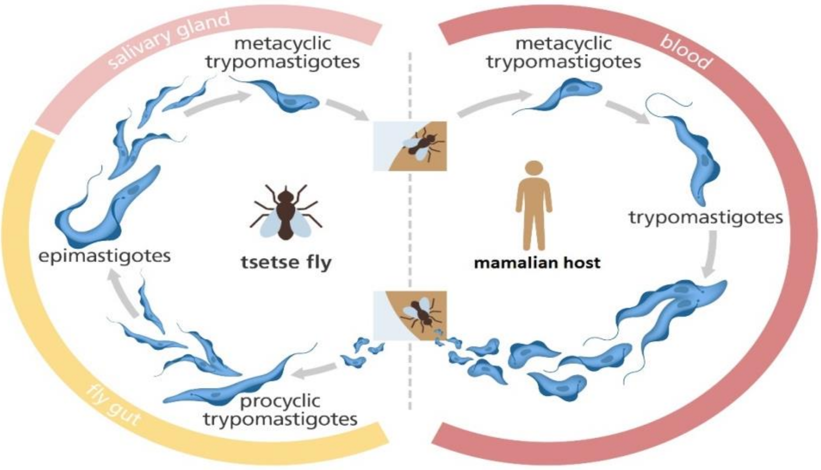

Figure 1: The life cycle of *Trypanosoma species*.

Source: Modified from Genome Research Project, www.yourgenome.org/facts/what-is-african sleeping-sickness.

In tsetse fly, the trypanosome starts by transforming itself from blood stream form to non-infective forms (procyclic) in midgut. The parasite completes its life cycle by transforming into epimastigotes that move from midgut to salivary gland where it changes to infective metacyclic form. The development of trypanosomes from one stage to another in the tsetse fly is regulated by the environmental temperature; the higher the temperature the quicker the transformation process (Akoda *et al.,* 2009). The infection is introduced into skin tissues of the mammalian host during tsetse fly feeding. From the skin tissues the trypanosome enters the lymphatic system and passes into blood stream where it changes into trypomastigotes that travels to other body fluid parts including lymph and spinal fluid and continue binary fusion replication. Trypanosomes transmit trypanosomiasis, a disease of both humans and animals. In animals, the form of the disease is commonly known as nagana or African Animal Trypanosomiasis (AAT), and in human is referred to as sleeping sickness or Human African Trypanosomiasis (HAT). AAT is mainly caused by *Trypanosoma congolense*, *Trypanosoma* *vivax* and *Trypanosoma brucei* subspecies *brucei* (Clarkson, 1976) commonly found in tsetse belt of sub Saharan Africa (Fig 2a) and HAT is caused by *Trypanosoma brucei rhodesiense* (predominant in East Africa) and *Trypanosoma brucei gambiense* (predominant in West Africa) (Fig 2b). At present, trypanosomiasis affects more than 25 sub-Saharan Africa countries, but its distribution has been changing because of factors such as changes in climate where by models have predicted the epidemics to occur when mean temperatures are between 20.78^0C and 26.18^0C (Moore *et al.,* 2011). Other factors that affect the distribution include host availability (wild animals, hereafter referred to as wildlife, livestock and humans), suitable habitat, awareness of the disease, and socio-cultural practices (Moore and Messina, 2010; Simarro *et al.,* 2012; Rutto *et al.,* 2013).

Seasonal variations of climate affect transmission of trypanosomiasis. In particular, seasonal fluctuations of temperature affects tsetse fly abundance, mortality rate, biting rates and trypanosome development rates (Moore *et al.,* 2011). The seasonality may increase pathogen burden and consequently heighten the risk to public health. The reason for this is that seasonal temperature fluctuations may modify interactions between parasites, vectors and hosts by re-synchronizing climate-sensitive development stages. Consequently, parasite transmission dynamics is altered, in part by changing the biology of vectors or parasite infectious stages, behavior of hosts, and immunity to infections (Githeko *et al.,* 2000; Altizer *et al.,* 2006).

Because of the complex interactions of environment, vectors, parasites and hosts approaches to study vulnerability to diseases and how climate affects infectious diseases require a framework that combines and integrates the ecology and role of all climate sensitive parameters of disease transmission, and adaptive capacity of a community but this kind of approach is challenged by large data requirements. Recent work on climate change influences on HAT, for example, incorporated both host and vector parameters to understand the effect of temperature-dependent parameters on R_0 (the basic reproduction number) (Moore *et al.,* 2011). R_0 is defined as the expected number of secondary cases produced by a single infection in a completely susceptible population. However, no studies of this kind had previously been done in the Maasai Steppe. This study therefore sought to identify places most vulnerable to trypanosomiasis, tsetse and trypanosome dynamics with the aim of identifying locations and climatic conditions with increased risks of trypanosomiasis transmission. Uncovering temporal patterns of vector abundance and parasite prevalence in relation to climate parameters provides information useful for understanding local climate effects on tsetse and trypanosomes dynamics, and thus an inference of seasons and areas at risk of disease.

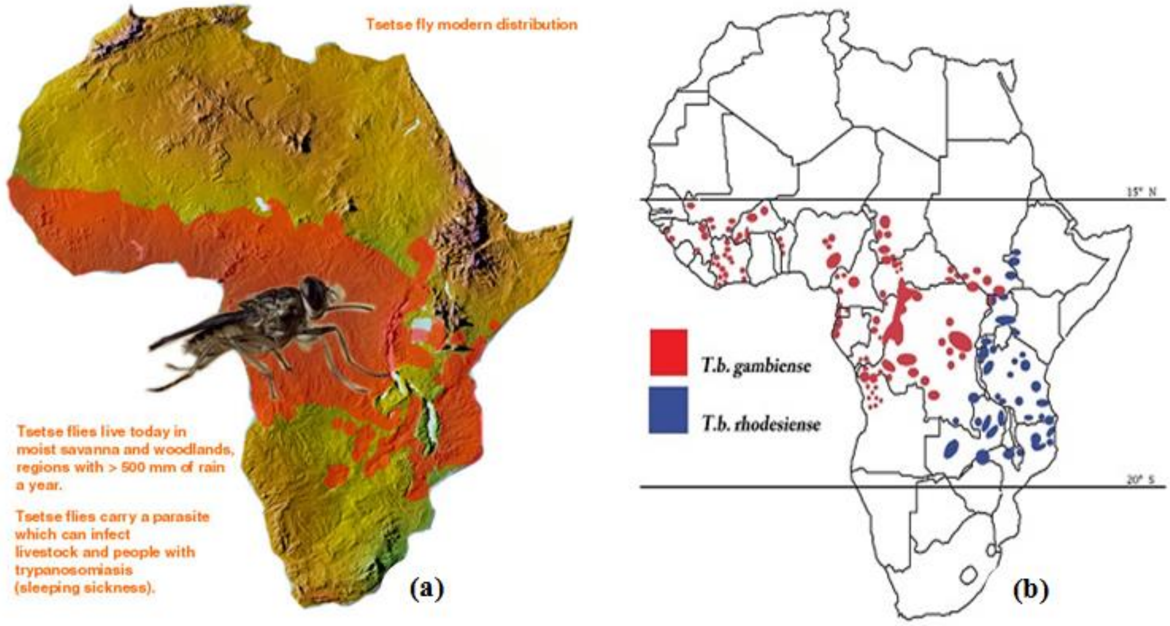

Figure 2: Map of Africa showing tsetse belt and risks areas for; a) AAT and b) H AT.

Source: https://www.acsu.buffalo.edu/~lread/trypanosomiasis.html

1.3 Problem statement

Maasai Steppe is regarded as a high risk area for trypanosomiasis in Tanzania because of high tsetse fly abundance, and extensive interaction between domestic animals, wildlife and human, but the distribution of vectors and infection rates are not clearly known. Although HAT is not always found in many areas where tsetse flies are found possibly due to generally low prevalence of the human-infective trypanosomes (Auty *et al.*, 2012), hospital records confirmed previous presence of HAT in the area (Magugu hospital chief physician personal communication). Climate change in the form of increasing temperature and more variable rainfall is expected to increase interactions between wildlife and livestock, as common grazing and water resources become scarcer (Jack and Kloppers, 2016). This in turn is likely to increase trypanosomiasis transmission risk in Maasai Steppe. Since livestock is regarded as a store of value which plays important roles in economy, nutrition, food security and prestige, exposure to tsetse increases community vulnerability to multiple stressors including trypanosomiasis. The enormous dependency on livestock and recent increasing sedentarization among the previously semi-nomadic pastoralists, coupled with climate variability and a land tenure system that restricts movement could make impacts of climate and trypanosomiasis problem more devastating in the Maasai communities. These communities are also challenged by limited spatial and temporal information on trypanosomiasis risk, which may inhibits both adaptation and vector control strategies.

In the past, Maasai communities used movement across landscape as one of the strategies to cope with challenges of harsh environment, including drought and livestock diseases; their strategies are now constrained by the ever spreading out agricultural fields, expansion of wildlife PAs and stress of changing climate. Series of volatile reactions such as grazing land conversion to agriculture are being practiced to offset some climate change impacts such as food insecurity (Msoffe, 2010; Msoffe *et al.*, 2011a). However, this practice not only pushes livestock into more disease prone areas to seek adequate grazing and water, but it also slowly erodes the sustainability of Maasai culture and their pastoral systems. In addition, family ties are impaired while resource use conflicts are surfacing (Madulu and Kiwasila, 2006) because of grazing land scarcity partly brought by agriculture expansion. Since most perturbations are intertwined, adaptations and control methods require strategies that are rooted in sustainability of the system as a whole to avoid new dimensions of problems that may increase Maasai pastoralist’s vulnerability.

Recent studies on tsetse fly and trypanosomiasis risk have mainly focused on biological aspects of the vector and the protozoa within the Maasai Steppe, and there remains a lack of knowledge about places more vulnerable to trypanosomiasis and climate influence on risk of infection (Malele *et al.*, 2006; Matemba *et al.*, 2010; Salekwa *et al.*, 2014; Muse *et al.*, 2015). This study therefore aimed at understanding where and when trypanosomiasis risk is high and how changes in local climate affect spatial and temporal distribution of tsetse flies and their infection rates.

1.4 Objectives

1.4.1 General objective

The primary objective of this study was to assess pastoralists' vulnerability to trypanosomiasis and the potential effects of climate change on tsetse and trypanosome distribution in the Maasai Steppe of Tanzania. The following are the specific objectives of this study.

1.4.2 Specific objectives

Specific objectives were to;

i. Assess pastoralists' vulnerability to trypanosomiasis and determinants of adaptation strategies in the Maasai Steppe.

ii. Assess abundance of tsetse fly species in relation to seasonal variation of climate in the Maasai Steppe, Tanzania.

iii. Determine trypanosome infections in tsetse flies in relation to seasonal variation of climate in the Maasai Steppe, Tanzania.

iv. Assess potential impacts of climate change on the spatial distribution of tsetse fly species in the Maasai Steppe.

1.5 Research questions

i. What wards in selected parts of the Maasai Steppe (Simanjiro and Monduli districts) are more vulnerable to trypanosomiasis, based on geographical distribution of trypanosomiasis risk factors, and what determines trypanosomiasis adaptations in those areas?

ii. Is seasonal variation of climate associated with tsetse fly abundance and their infection rates?

iii. What are the potential effects of climate change on hotspots of tsetse flies and thus trypanosomiasis?

1.6 Significance of the study

The findings of this study will provide information that can inform stakeholders about the time of the highest burden of tsetse flies and risks associated with trypanosomiasis infection in the Maasai Steppe, where this information is limited or unavailable. Also, the established spatial and temporal patterns of vector and parasites, together with climate relationships, can provide fundamental information needed when developing predictive models of the spatial-temporal dynamics of the relative abundance of individual tsetse fly species and their infection rates.

1.7 Conceptual framework

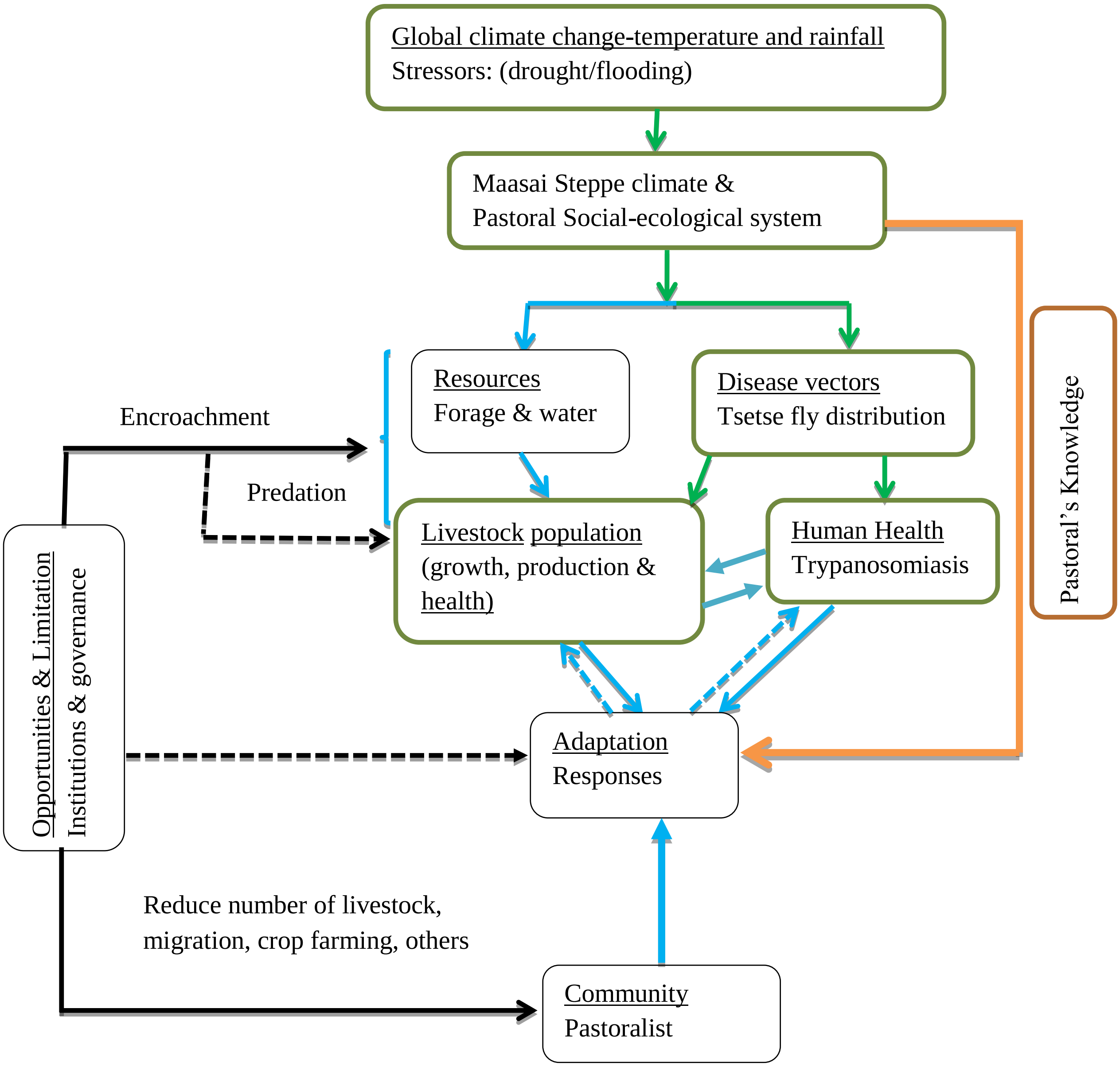

Figure 3: Conceptual framework showing potential impacts of climate change and interactive forces that may influence community vulnerability to trypanosomiasis.

CHAPTER TWO

PASTORALISTS' VULNERABILITY TO TRYPANOSOMIASIS IN THE MAASAI STEPPE[1]

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Abstract

Although pastoral communities of Maasai Steppe have been able to adapt to trypanosomiasis in the past, their traditional strategies are now constrained by changes in climate and land regimes that affect their ability to move with their herds and continually shape the communities' vulnerability to trypanosomiasis. Despite these constraints, information on communities' vulnerability and adaptive capacity to trypanosomiasis is limited. A cross-sectional study was therefore set in Simanjiro and Monduli districts, which are part of Maasai Steppe to establish pastoralists' vulnerability to trypanosomiasis and determinants of adaptation. A weighted overlay approach in ArcGIS 10.4 was used to analyze vulnerability levels while binomial and multinomial logistic regressions in R 3.3.2 were used to analyze the determinants of adaptation. It was revealed that Simanjiro district was most vulnerable to trypanosomiasis. Majority (87.5%, n = 136) of the respondents were aware of

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trypanosomiasis in animals and 7.4% (n = 136) knew about sleeping sickness. Reported impacts of trypanosomiasis were low milk production (95.6%, n = 136), death of livestock (96.8%, n = 136) and emaciation of animals (99.9%, n = 136). Crop farming was the most frequently reported adaptation strategy (66%, n = 136). At 95% confidence interval, accessibility to livestock extension services (β = 7.62, SE = 3.07, df = 126, p = 0.013), years of livestock keeping experience (β = 6.08, SE = 1.8, df = 126, p = 0.0009), number of cattle owned (β = 5.80, SE = 2.67, df = 126, p=0.029) and membership in associations (β = -4.31, SE = 1.71, df = 126, p = 0.011) had a significant impact on the probability of adapting to trypanosomiasis.

Keywords: Pastoralists, vulnerability, trypanosomiasis, determinants, adaptation, strategies

2.1 Introduction

Trypanosomiasis is a vector-borne parasitic disease of both humans and animals and one among the list of neglected tropical diseases. In animals, the form of the disease is commonly known as nagana or African Animal Trypanosomiasis (AAT), and the human form is referred to as sleeping sickness or Human African Trypanosomiasis (HAT). Although both forms of the disease are transmitted by bites of infected tsetse flies (*Glossina* genus), protozoan parasite *Trypanosoma brucei rhodesiense* (predominant in East Africa) and *Trypanosoma brucei gambiense* (predominant in West Africa) cause HAT while *Trypanosoma congolense, Trypanosoma vivax* and *Trypanosoma brucei* subspecies *brucei* are the leading causes of AAT (Clarkson, 1976). While AAT is characterized by loss of body condition, development of anaemia and death if untreated (Murray and Dexter, 1988; Magona *et al*., 2003), HAT is characterized by fever, severe headache, disruption of the sleep cycle, coma and death if not treated (Smith *et al.,* 1998). Apart from trypanosomes and tsetse flies, other risk factors for these diseases include availability of reservoir hosts (wild animals hereafter referred to as wildlife, livestock and humans), awareness and socio-cultural practices (Rutto *et al.,* 2013). At present trypanosomiasis affects more than 25 sub Saharan African countries but its distribution has been changing because of factors, such as changes in climate and land cover (Moore and Messina, 2010; Simarro *et al.,* 2012). In East Africa, climate change is likely to cause frequent and severe droughts which will increase pressure on land and consequently drive people to tsetse fly infested areas. Recurring droughts and extension of agriculture and wildlife protected areas (PAs) for instance, are already reducing pastoralists' grazing lands. Since rain is patchy, the challenge of enough resources to maintain livestock productivity and density is overwhelming as movement across landscape is restricted by presence of agriculture fields and wildlife PAs (Nelson, 2012). Poor and marginalized communities have little capacity to adapt to this situation and thus become most vulnerable to climate change impacts (IPCC, 2001; UN, 2016) and their consequences.

By definition, adaptation is an adjustment of a community or an individual in order to respond to actual and/or expected effects with the aim of moderating harm (Smith *et al.,* 2009). In this study adaptation was considered to be any adjustment done by pastoralists in their traditional livelihoods option for at least 10 years in response to effects of trypanosomiasis in order to moderate harm and /or exploit opportunities brought by this disease. Adaptation depends on adaptive capacity of communities or individuals in which adaptive capacity is the ability to cope with impacts of stressors (Füssel, 2007). The adaptive capacity is influenced by socio-economic factors such as education, social services, household size, wealth and social networks (Deressa *et al.,* 2009). Adaptation to trypanosomiasis therefore depends on pastoralists' awareness, knowledge, experience, wealth/resources and institutions that accelerate access to information and aid mobilization of the resources. The lower the adaptive capacity the higher the vulnerability of a community or individual. To lower vulnerability, adaptation strategies must be in line with sustainability of pastoral systems (Magnan, 2014), where pastoralists continue to keep up their livestock productivity, access resources such as pasture and water, and preserve their traditions (Fratkin and Mearns, 2003). This is necessary particularly in dryland pastoral areas where substitution of pastoralism with other inflexible system such as agriculture is constrained by water scarcity, irrigation infrastructure under investment and uncertainty in rain fed agriculture (Fratkin and Mearns, 2003; IFAD, 2009; Lankester and Davis, 2016; Lind *et al.*, 2016). Vulnerability is defined as a degree to which a community or socio-ecological systems are prone to, and unable to adapt to harmful impacts from stressors such as diseases and /or climate change (Smit and Wandel, 2006). It is determined by exposure to risk factors and sensitivity and adaptive capacity of a community/individual or a system at large. The Intergovernmental Panel for Climate Change (IPCC) defines vulnerability as a function of exposure, sensitivity and adaptive capacity and can be summarized as $V = (AD - (E+S))$ where V = vulnerability, E = exposure, S = sensitivity and AD = adaptive capacity. For a community to be resilient, adaptive capacity has to be greater than exposure and sensitivity combined (Smit *et al.,* 2001; Smith *et al.,* 2001; Brooks *et al.,* 2005; Tesso *et al.,* 2012).

In Tanzania, trypanosomiasis is a disease of public health and socio-economic concern as it causes considerable human suffering and mortality if untreated (Kibona *et al.,* 2002). This disease threatens health and economy of approximately four million people and costs the livestock sector over eight million USD per annum (Malele, 2011). The Tanzania Maasai Steppe (area extending from southern Kenya to northern Tanzania with savannah vegetation and occupied mainly by Maasai pastoralists) is considered high risk trypanosomiasis areas in the country because of high tsetse fly abundance, and extensive interaction between domestic animals, wildlife (the main reservoir of the disease) and humans. It should however be noted that, sleeping sickness is not always found in many areas where tsetse flies are found, possibly due to often low prevalence of the human-infective trypanosomes (Auty *et al.*, 2012). Climate change in the form of increasing temperature and more variable rainfall is expected to increase interaction between wildlife and livestock, as common grazing and water resources become scarcer (Jack and Kloppers, 2016). This in turn is likely to increase both AAT and HAT risk.

In the past, Maasai communities used movement across landscapes as one of the strategies to cope with multiple perturbations such as animal diseases and drought; their strategies are now constrained by current expansion of agriculture, wildlife PAs and stress of changing climate and variability. Households have undertaken responses to the constraints they face, such as converting land to crop production, that deviate from traditional cultural practices (Msoffe, 2010; Msoffe *et al.*, 2011a). Consequently, not only that this practice pushes livestock into more disease prone areas, but also it slowly erodes the sustainability of the Maasai culture and their pastoral system. In addition, social ties are impaired while resource use conflicts are surfacing (Madulu and Kiwasila, 2006). Since most perturbations are not independent, adaptations require strategies that are rooted in sustainability of the system as a whole to avoid new dimension of problems that may increase and vulnerability.

Several previous studies have examined diversification of livelihoods, land use changes, and abundance of tsetse flies and prevalence of trypanosomes in the Maasai Steppe (Msoffe, 2010; Msoffe *et al.*, 2011a, b; Goldman and Riosmena, 2013; Salekwa *et al.*, 2014; Simwango, 2016; Nnko *et al.*, 2017). However, none of these studies have assessed community's vulnerability to trypanosomiasis and determinants of adaptation strategies in this area. To fill this gap, this study attempted to answer the following questions: (a) what wards in Simanjiro and Monduli districts are more vulnerable to trypanosomiasis, based on geographical distribution of trypanosomiasis risk factors? (b) In the most vulnerable places, are pastoralists aware of both human and animal trypanosomiasis? (c) What were the trypanosomiasis impacts and adaptation strategies in the most vulnerable wards? and (d) what factors determined communities' adaptation strategies in the most vulnerable places?.

2.2 Methodology

2.2.1 Study area

Research was conducted between 2014 and 2015 in two administrative districts in Tanzania, Monduli and Simanjiro, located between 4° 47' 15" S and 36° 53' 54" E (Fig.4). These districts are found in Savannah of Northern Tanzania. The area is famous for diverse and abundant wildlife population especially large ungulates. The vegetation of the area varies with landscape, with grassland savannah dominated by Commiphora, Acacia and allied genera of shrubby forms is a main characteristic. Simanjiro and Monduli districts cover an area of 19 941 and 6419 square kilometers and have human population size of 178 693 and 185 237, respectively (National Bureau of Statistics [NBS] and Office of Chief Government Statistician [OCGS], 2013). Literacy rate is 45% for Monduli district (Monduli District Council [DC], 2015) and 44.2% for Simanjiro district (Simanjiro District Council [DC], 2015). The land in these two districts is mixed of communal grazing land, PAs and individual pieces of land. The climate is semi-arid with rainfall from 350 to 500 mm per annum and maximum temperature between 25 and 30 °C. The mainstay of income generation in the two districts is livestock keeping, with increasing land conversion for farming and small scale mining activities in Simanjiro (Mccabe *et al.*, 2010; Msoffe *et al.,* 2011b), whereas in Monduli in addition to livestock keeping, there is also large scale agriculture and ranches. The expansion of agriculture in these areas is accelerating encroachment to PAs where tsetse flies are abundant and risk of trypanosomes infection is high. This is supported by Simwango (2016) who reported over 17% trypanosome prevalence in cattle from four villages bordering these PAs.

2.2.2 Study design

The study was a cross sectional (both descriptive and analytical) with two hierarchical levels; 23 wards and four villages (Fig. 4). At the ward level, the aim was to understand the places more vulnerable to trypanosomiasis and at the village level; the aim was to understand pastoralists' knowledge of trypanosomiasis, its impacts and community adaptation strategies. These villages; Emboreet in Emboreet ward, Loibor-Sireet and Kimotorok in Loibor-Sireet ward (Simanjro district) and Oltukai in Esilalei ward (Monduli district) were purposively selected based on their proximity to PAs and trypanosomiasis vulnerability level.

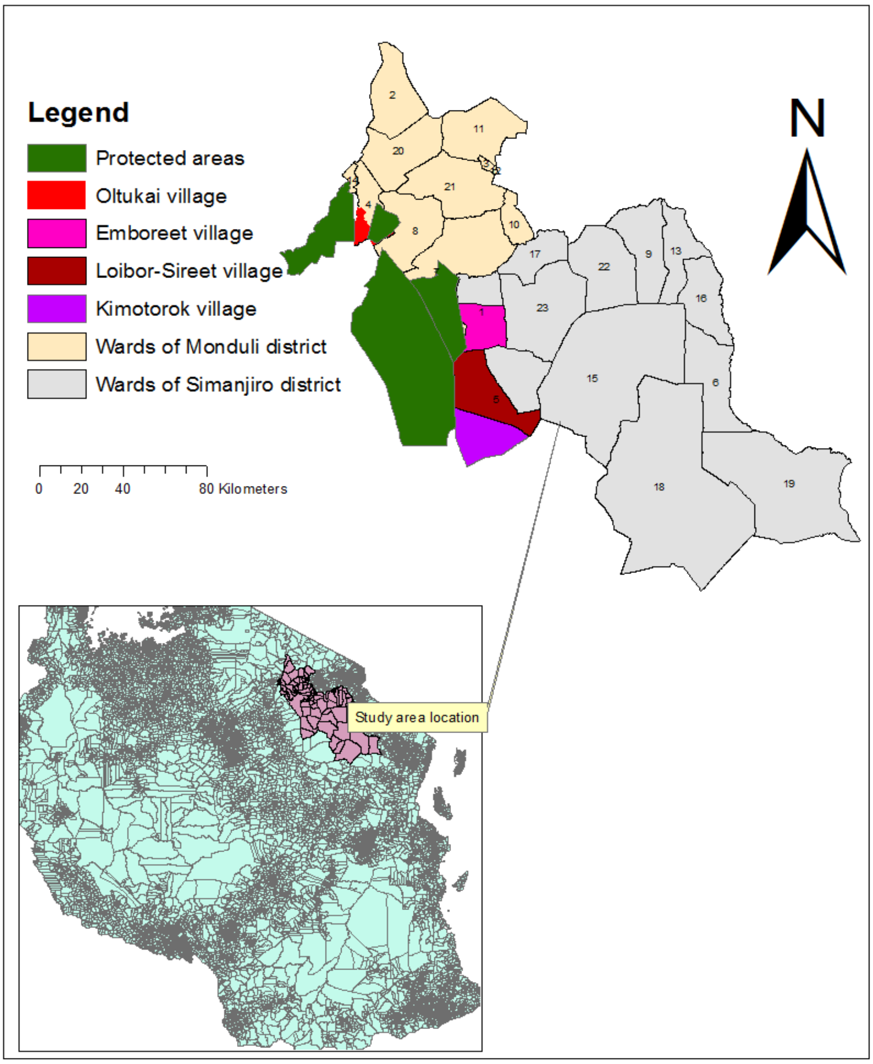


Figure 4: Map of Simanjiro and Monduli districts showing location of study wards and villages.

Note: Wards are labeled as follows: 1 = Emboreet, 2 = Engaruka, 3 = Engutoto, 4 = Esilalei, 5 = Loibor-Siret, 6 = Loiborsoit, 7 = Lolkisale, 8 = Makuyini, 9 = Meserani, 10 = Moita, 11 = Monduli Juu, 12 = Monduli Urban, 13 = Msitu wa Tembo, 14 = Mto wa Mbu, 15 = Naberera, 16 = Ngorika, 17 = Oljoro No.5, 18 = Orkesment, 19 = Ruvu Remit, 20 = Selela, 21 = Sepeko, 22 = Shambarai, 23 = Terrat. The four study villages within those wards are indicated as bright colored polygons and shown on the legend. The insert is the map of Tanzania showing location of study districts.

2.3 Data collection

2.3.1 Vulnerability assessment data

Health vulnerability assessment procedures described by Manangan *et al.* (2015), were followed to capture data for vulnerability assessment. Briefly, an exhaustive literature search was conducted to identify trypanosomiasis risk factors such as abundance of tsetse flies and wild animals, number of reported AAT and HAT cases (Gondwe *et al.*, 2009; Malele *et al.*, 2011a, b) to represent trypanosomiasis vulnerability exposure/risk factors. Secondly, this information was confirmed at ward-level, where a checklist was prepared and district officers responsible for tsetse control, wildlife, health and livestock sectors were asked to qualitatively rank abundance of tsetse flies, wildlife (large mammals and ostrich), HAT and AAT incidences by using scores of 0, 1, 2 and 3 to represent absent, low, average and high, respectively (appendix 1). The task was carried out at specific department and the participant work on group to agree on the scores in ranking exercise. Selection of participants was based on their role related to trypanosomiasis. Before beginning of the ranking exercise, participants received an explanation on how to rank based on the presence or absence of each risk factor. Subsequently, information on human population size was collected at ward level to cover for sensitivity, while literacy rate, availability of human and veterinary health infrastructures were recorded to cover for adaptive capacity (Kanj and Mitic, 2009). Estimate of human population size, literacy rate and number of health facilities were extracted from Tanzania population census of 2012 (NBS and OCGS, 2013). Since qualitative estimate rankings were not directly comparable to quantitative estimates, a further step of constructing indices based on the functional relationship to vulnerability was performed to allow use of two metrics in mapping vulnerability. The vulnerability assessment data were then combined into Geographical Information System (GIS) to generate trypanosomiasis vulnerability maps.

2.3.2 Trypanosomiasis knowledge, impacts and adaptation data

Male and female respondents were purposively identified from Maasai pastoralist households headed by individuals aged ≥ 30 years. Thirty was considered a reasonable age for respondents to have experienced impacts of AAT and adjusted some of their traditional livelihood option. From the pool of households that met the study criteria, respondents were randomly (simple random) selected to include at least 30 respondents from each village (Hogg *et al.,* 2015). Respondents were visited at their households for interviews and only those who consented were interviewed. In total, 136 respondents were interviewed. Structured interviews were used to gather information on AAT impacts, adaptation strategies and socio-economic factors that might have influenced household's decision on adaptation (appendix 2). Semi-structured questions were used as a triangulation method to clarify some information from the structured questions (Crosswell, 2003; Creswell *et al.,* 2007; Hayes *et al.,* 2013). Maasai speaking survey enumerators were trained on questionnaires survey and involved in conducting interviews together with research team and Both Maa and Swahili were used whenever necessary.

2.4 Data analysis

Variables which were ranked as negative (HAT incidences and presence of veterinary health infrastructures) in all wards were removed from the analysis. The index approach was used to understand trypanosomiasis vulnerability levels between wards and a numerical scale was calculated from abundance of tsetse flies, wild animals, AAT incidences, human population size, literacy rate and presence of human health infrastructures. Because index is not a direct measure of probability but rather an explanation of some of the trypanosomiasis burdens in the study area, the calculated scale was used to compare vulnerability in different wards and group them as less or more vulnerable. All factors were arranged in a matrix and normalized using functional relationship (International Crops Research Institute for the Semi-Arid Tropics [ICRISAT], 2000; Nations and Singer, 2006). The normalized indices ranging from 0 - 1 for each risk factor in a respective ward were imported into ArcGIS 10.4 (ESRI, 2016) and mapped using the equal interval method whereby for the purpose of this study, index values of 0.25, 0.5, 0.75 and 1 represented least, medium, high and most vulnerable places, respectively. These index scores were displayed on a continuous color ramp, where yellow to deep brown indicated least to most vulnerable. In order to capture location variability within a risk factor layer, the data from each layer were reclassified and assigned weighting values according to increasing risk. A weighting overlay domain approach in ArcGIS was used to combine all six layers. Based on judgement of ten experts comprised of tsetse and trypanosomiasis researchers, district livestock officers and tsetse control officers, influence of

27%, 23%, 17%, 15%, 10% and 8% was set for abundance of tsetse flies, wildlife, human population size, trypanosomiasis problem, health infrastructures and literacy rate, respectively. A checklist of relative contribution of these risk factors to existence of trypanosomiasis (appendix 3) was prepared and the average score was used to gage the influence of each risk factor based on expert knowledge. After weighting all data layers, a composite vulnerability index was created by overlaying each layer and adding up the values that overlapped.

Data from the village-level household interviews were descriptively analyzed using SPSS version 21. Binomial and multinomial logistic regression was performed in R (R Core Team, 2016) to examine factors influencing households' AAT adaptation decisions. A Generalized Linear Model of family binomial with the logit function was used for binomial regression while the mlogit function was used for multinomial logistic regression. A response variable for the binomial model was adaptation where the outcome were adapting and not adapting. In a multinomial model, response variable was choice of adaptation strategy while, arming, wedge labor, sell of livestock and not adapting were outcome of choice of adaptation strategy. Explanatory variable/factors considered in these analyses were level of education attained, household size, access to extension services, experience in livestock keeping, number of cattle owned, land area owned, membership in social associations, access to loans, access to markets and tsetse abundance in grazing area. All explanatory variables were selected on the basis of previous studies on factors influencing adaptation and perception in agro-pastoralists and pastoralists communities, particularly on the impacts related to climate change (Deressa, 2009; Silvestri *et al.*, 2012). Numbers of model were run and the one that performed better than random/base was considered. The model that included all nine predictor variables performed the best. A brief description of the explanatory variables used in the binomial and multinomial logit model is provided in appendix 4. These factors were categorically grouped and used as independent variables in the models. They were all dummy variables taking the value of 1 for yes and 0 for no. Semi-structured data were sorted according to themes and analyzed manually through a template approach (Thomas, 2006).

The multinomial model specifications were;

The dependent variable was the adaptation status (1 = not adapting; 2 = subsistence farming; 3 = sell livestock; 4 = wage labor). Letting Z j (j = 1,2,3) be the probabilities of a respondents being in each adaptation strategy and assuming that j = 1 is the reference category, the multinomial logit model showing the relative probabilities of being in the three adaptation categories as a linear function of X_{ki} for the i^{th} household (Greene, 2003), is estimated as:

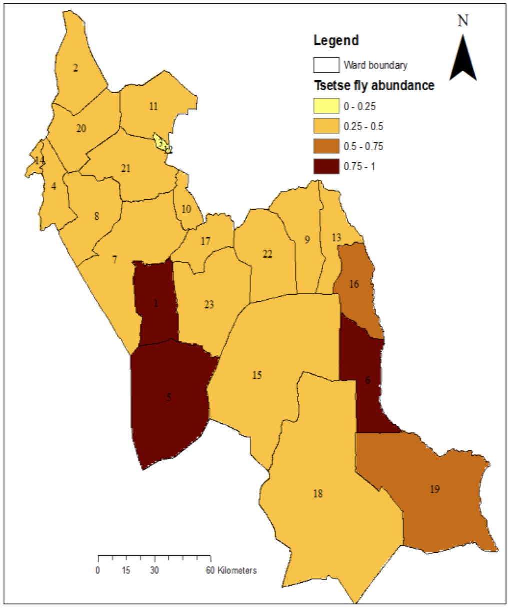
$$\ln\left(\frac{Z_j}{Z_1}\right) = \log\left(\frac{Z_j}{Z_1}\right) = \beta_{0j} + \beta_{1j} \times_{1i} + \cdots \beta_{kj} \times_{ki} + \cup_{ji}$$

For j = 2, 3 and i = 1, 2...n respondents where: ln = the natural logarithm (or $\log_e$); Z_1 = the probability of the respondents being in the reference category (Not adapting); Z_2 = the probability that respondents practicing subsistence farming; Z_3 = the probability that the respondents are adapting by selling livestock; Z_4 = the probability that the respondents practice wage labor, β_{kj} are the multinomial coefficients to be estimated and, X_{ki} is the k^{th} explanatory variable explaining the i^{th} respondents.

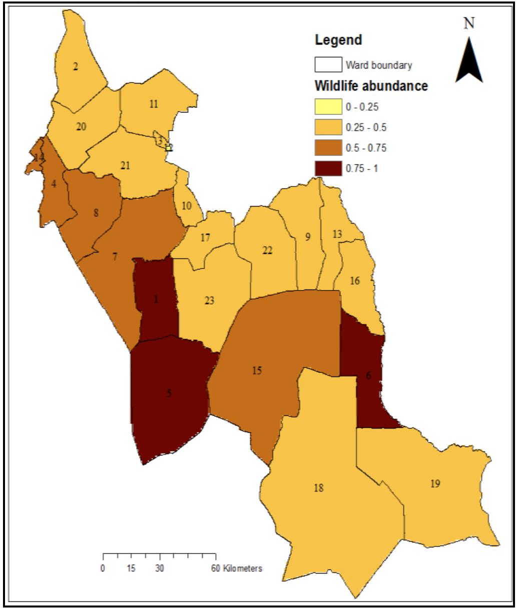
2.5 Results

2.5.1 Vulnerability to trypanosomiasis

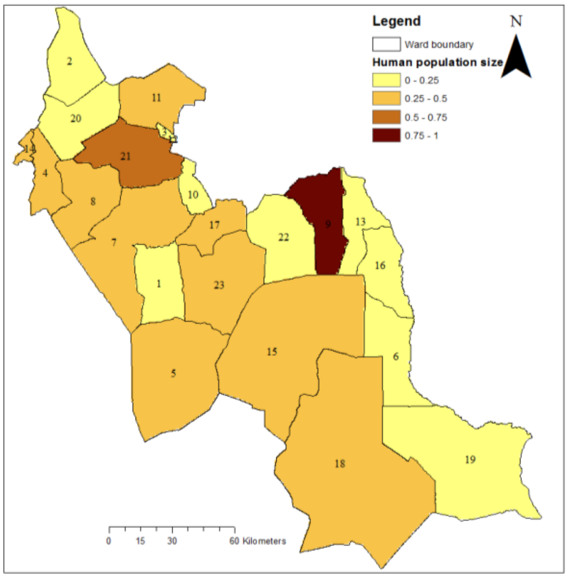
Emboreet, Loibor-Sireet and Loiborsoit wards indicated high abundance of tsetse flies and wildlife while Engutoto and Monduli Urban had low abundance of tsetse flies and wildlife (Fig. 5a, b). Mererani ward was highly populated compared to other wards (Fig. 5c). High number of cases of AAT was reported for Emboreet, Engaruka, Esilalei, Loibor-Sireet, Mto wa Mbu, Seleala and Terat wards (Fig. 5d). The highest levels of illiteracy were reported for Loibor-Sireet and Naberera wards, followed by Emboreet, Oljoro No. 5 and Ngorika (Fig. 5e). Engutoto, Esilalei, Monduli Urban, Mto wa Mbu, Oljoro No.5, Selela and Shambarai reported to have fewer health facilities compared to other wards (Fig. 5f).



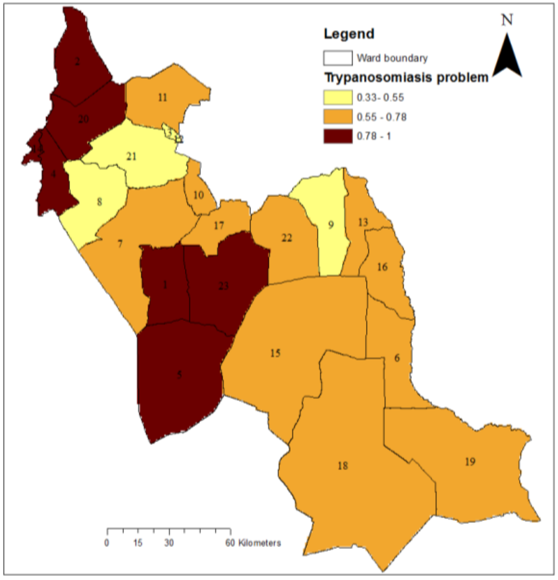
(a) Tsetse fly abundance



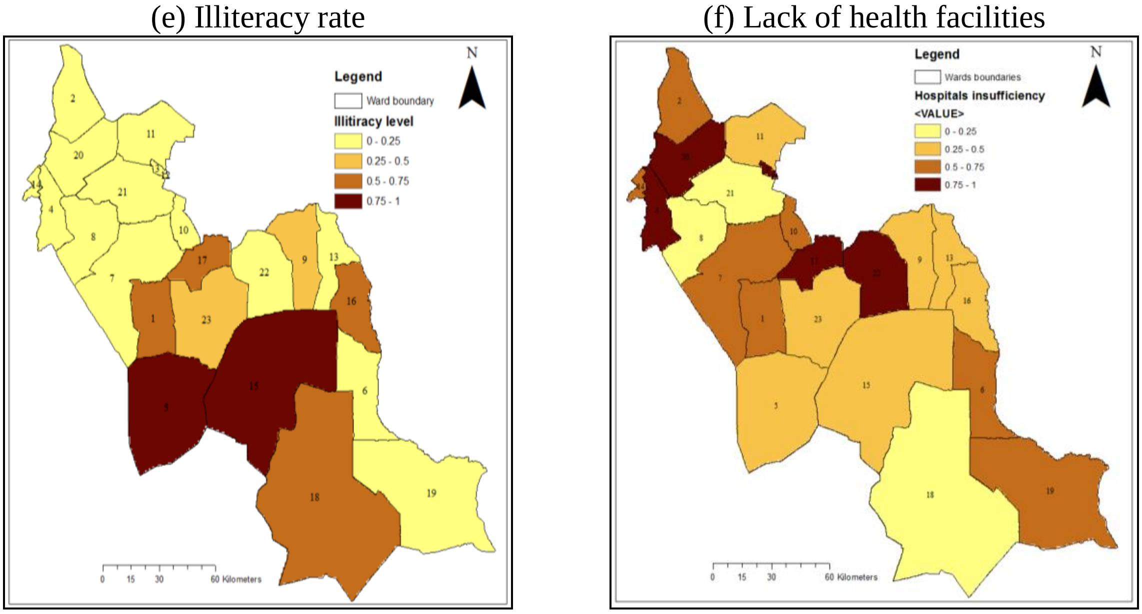
(b) Wildlife abundance



(c) Human population size



(d) Animal trypanosomiasis


(e) Illiteracy rate

(f) Lack of health facilities

Figure 5 a-f: Spatial distribution of factors affecting vulnerability to trypanosomiasis in Simanjiro and Monduli districts.

Combining the various measuments of vulnerability by overlaying figures 5a to 5f revealed that Emboreet and Loibor-Sireet wards in Simanjiro district were most vulnerable to trypanosomiasis while Engutoto and Monduli Urban were least vulnerable compared to other wards (Fig. 6).

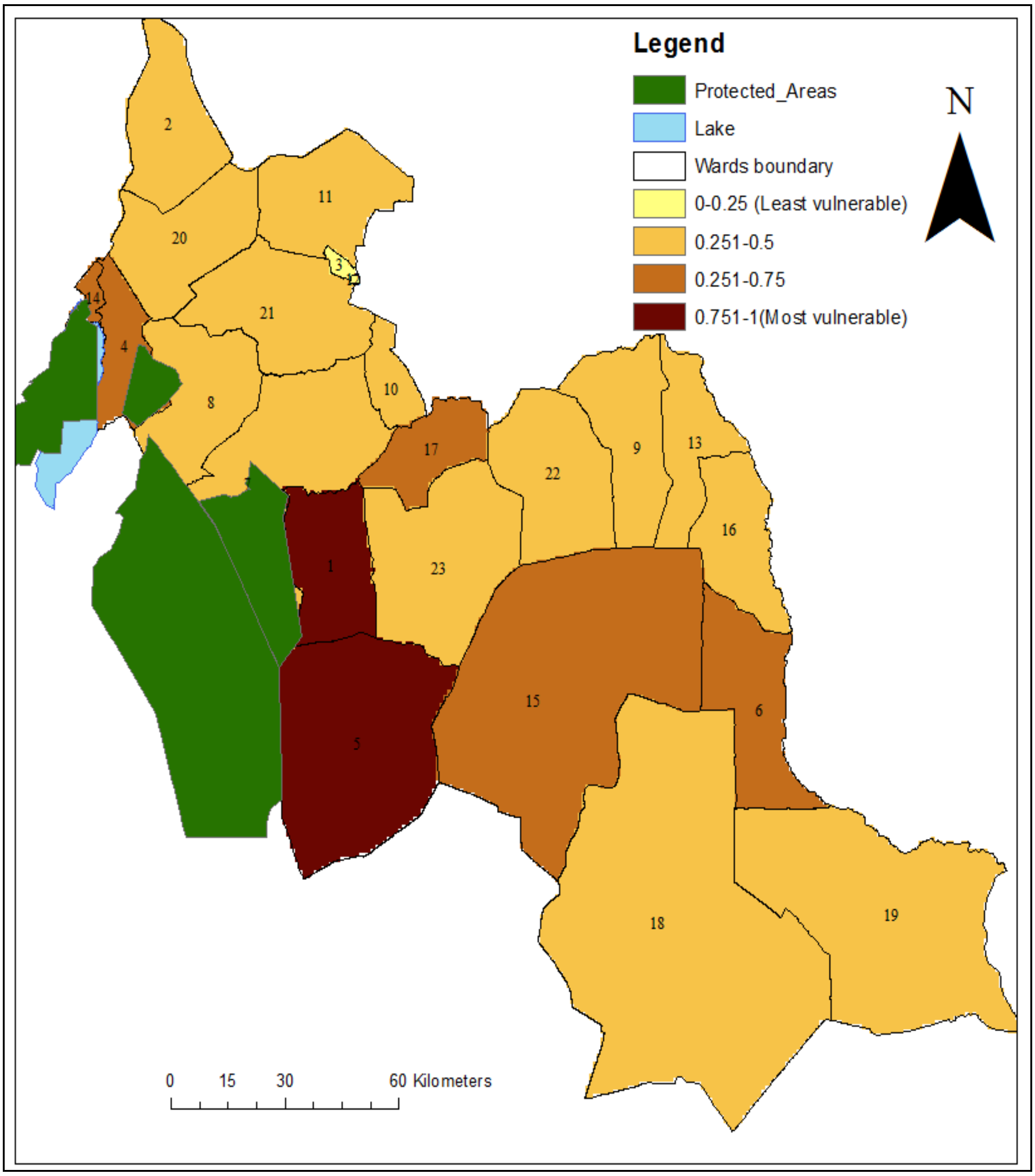


Figure 6: Spatial distribution of trypanosomiasis composite vulnerability index score in Simanjiro and Monduli districts.

2.5.2 Pastoralists' knowledge/awareness of trypanosomiasis

Awareness of existence of AAT in the areas was high (87.5%, n = 136) but low for HAT (7.4% n = 136). All respondents who were aware of AAT reported that their livestock had previously contracted trypanosomiasis and they could tell its clinical signs in cattle (100%, n = 119). It was revealed that 72.1% (n = 136) of respondents graze their herds in areas between the villages and wildlife reserves and 96.3 % (n = 136) of respondents reported presence of tsetse flies on the grazing fields and all of them correctly identified tsetse fly photos among various insects. From surveys, it was revealed that AAT was considered a year round problem, but high risk of contraction was reported to occur during dry months (July – October, with highest risk in August; Fig. 7). The majority (78.7%) of respondents had no access to early warning information that could help them plan when to move their herds in advance.

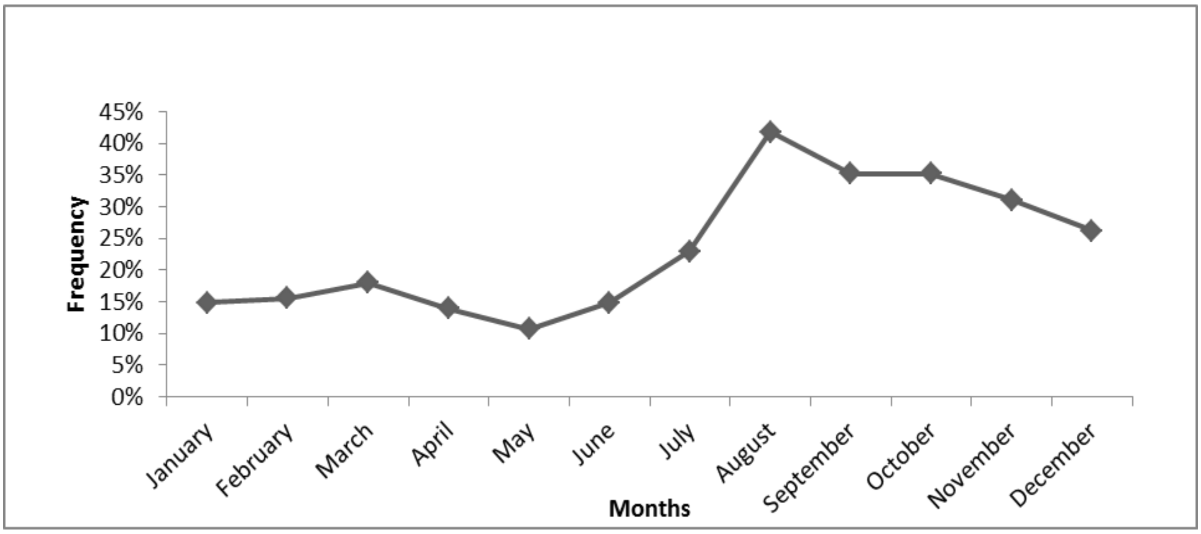


Figure 7: Perceived risk of trypanosomiasis in the study area, by month, for all four villages in which interviews were conducted.

2.5.3 Trypanosomiasis impacts and adaptation strategies

Reported impacts of trypanosomiasis included low milk production (95.6%, n = 136), death of livestock (96.8%, n = 136) and emaciation of animals (99.9%, n = 136). Crop farming was reported as an AAT adaptation strategy by 66% of 136 respondents, followed by waged labor and sales of livestock (Fig. 8). However, 13% (n = 136) of respondents reported to fail to adapt to impacts of AAT because of lack of clear information on AAT which was reported by 53% of respondents (n = 17) followed by uncertainty of weather/drought recurrence (35%, n = 17) and inadequate grazing land (12%, n = 17). From unstructured data, it was revealed that majority of respondents who did not adapt tried subsistence crop farming but failed due to unpredictable rainfall.

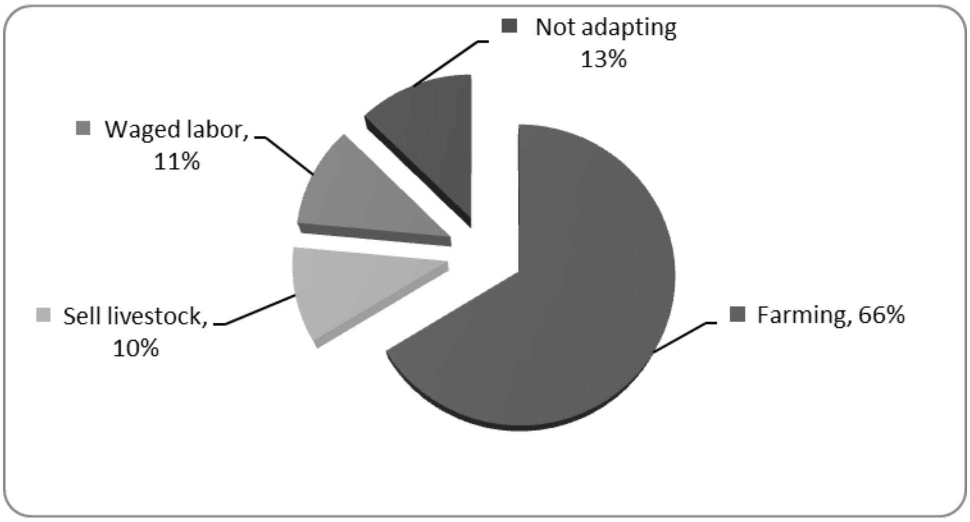


Figure 8: Pastoralists’ strategies for adaptation to trypanosomiasis in Simanjiro and Monduli districts.

2.5.4 Determinants of pastoralists’ choice of adaptation strategy

Household characteristics, wealth, institutional and social network factors that were used in binomial and multinomial logistic regressions and their marginal percent are summarized in Table 1.

Table 1: Marginal percentage of the independent variables used in the binomial and multinomial logit trypanosomiasis adaptation models.

	Independent variable	Response/outcome	n	%
Household characteristic	Education level	Never attended school	94	69.1%
		Primary education and above	42	30.9%
	Size of the household	<=10 people	50	36.8%
		>10 people	86	63.2%
	Livestock keeping experience	<=10 years	40	29.4%
		>10 years	96	70.6%
	Closeness to market	No	41	30.1%
		Yes	95	69.9%
	Tsetse abundance in grazing area	Not abundant	25	18.4
		Abundant	111	81.6
Wealth factors	Number of cattle owned	< = 100	100	73.5%
		>100	36	26.5%
	Land size owned	< = 20 ha	85	62.5%
		> 20 ha	51	37.5%
Institutional factors	Access to livestock extension services	No	54	39.7%
		Yes	82	60.3%
	Access to loan	No	107	78.7%
		Yes	29	21.3%
Social networks factors	A member of an association	No	100	73.5%
		Yes	36	26.5%

The logistic regression model containing all 10 predictor variables had the best fit; (likelihood ratio test statistic $\chi^2 = 81.9$ with p-value <0.0001). At a 95% confidence interval (CI), accessibility to livestock extension services ($\beta = 7.61$, SE = 3.28, df = 135, p = 0.02), years of livestock keeping experience ($\beta = 6.17$, SE = 1.95, df = 135, p = 0.001), number of cattle owned ($\beta = 5.85$, SE = 2.70, df = 135, p = 0.03) and membership in associations ($\beta = -4.11$, SE = 1.79, df = 135, p = 0.02) had a significant impact on the probability of adapting to AAT (Table 2).

Table 2: Contribution of different variables in the universal logistic regression model predicting likelihood of adaptation to trypanosomiasis, in which the variables with p-values indicated in bold text significantly, improved the likelihood of adaptation.

Explanatory variable	***Coeff* ± *SE***	***P***	***Exp(B)*** ***(Odds Ratio)***
Education: Primary and above	4.61 ± 2.9	0.12	9.99E+01
Household's size: >10 people	1.16 ± 1.4	0.42	3.18E+00
Access to livestock extension services: Yes	7.61 ± 3.3	**0.02**	2.02E+03
Livestock keeping experience: > 10	6.17 ± 2.0	**0.002**	4.79E+02
Number of cattle owned: >100	5.85 ± 2.7	**0.03**	3.48E+02
Land size owned : >20ha	1.71 ± 1.5	0.26	5.53E+00
Membership in association: Yes	-4.11 ± 1.8	**0.02**	1.64E-02
Access to loan: Yes	-0.29 ± 2.3	0.90	7.46E-01
Close to the market: Yes	2.39 ± 1.6	0.13	1.09E+01
Tsetse abundance in grazing areas: Abundant	0.95 ± 1.3	0.48	2.59E+00

The four adaptation options; crop farming, waged labor, selling livestock and no adaptation were used as dependent variables in a multinomial logit model. No adaptation was set as a base category for comparison purposes. The model containing all 10 predictors was statistically significant with $\chi^2 = 98.82$, p-value <0.0001, and explained 51% (McFadden R^2: 0.51) of the variance in choice of the adaptation strategy.

At the 95% CI, of the 10 predictors in the multinomial model, four predictors; accessibility to livestock extension services, livestock keeping experience, cattle ownership and membership in associations consistently proved to be significant predictors of the choice of adaptation strategy.

Education, on the other hand, was only a significant predictor of the probability of selling livestock as an adaptation strategy (Table 3).

Table 3: Parameter estimates of the variables in the multinomial logit trypanosomiasis adaptation strategies model, in which the variables with p-values indicated in bold text significantly, predicted the likelihood of choosing the indicated adaptation strategy.

Adaptation strategy	**Explanatory variable**	***Coeff ± SE***	***P***	***Exp(B) (Odds Ratio)***
Farming	Education: Primary and above	4.51 ± 2.87	0.1176	9.08E+01
	Household's size: >10 people	1.65 ± 1.45	0.256	5.22E+00
	Access to livestock extension services: Yes	7.79 ± 3.42	**0.023**	2.41E+03
	Livestock keeping experience: > 10	6.16 ± 1.96	**0.002**	4.73E+02
	Number of cattle owned: >100	6.02 ± 2.73	**0.027**	4.11E+02
	Land size owned : >20ha	1.86 ± 1.54	0.228	6.43E+00
	Membership in association: Yes	-4.26± 1.81	**0.019**	1.41E-02
	Access to loan: Yes	-0.10± .368	0.965	9.02E-01
	Close to the market: Yes	2.31 ± 1.59	0.147	1.01E+01
	Tsetse abundance in grazing areas: Abundant	0.80 ± 1.36	0.557	2.22E+00
Selling of livestock	Education: Primary and above	5.32 ± 2.93	**0.070**	2.04E+02
	Household's size: >10 people	0.87 ± 1.59	0.581	42.39E+00
	Access to livestock extension service: Yes	9.78 ±3.58	**0.006**	1.77E+04
	Livestock keeping experience: > 10	6.79 ± 2.10	**0.001**	8.92E+02
	Number of cattle owned: >100	6.17 ± 2.81	**0.028**	4.76E+02
	Land size owned : >20ha	1.61 ± 1.67	0.33	5.00E+00
	Membership in association: Yes	-4.01± .958	**0.039**	1.81E-02
	Access to loan: Yes	-1.97± 2.63	0.453	1.39E-02
	Close to the market: Yes	2.67 ± 1.75	0.128	1.44E+01
	Tsetse abundance in grazing areas: Abundant	1.69 ± 1.76	0.337	3.40E+00
Waged labor	Education: Primary and above	4.94 ± 2.91	0.090	1.39E+02
	Household's size: >10 people	-0.51 ± 1.5	0.743	6.03E-01
	Access to livestock extension services: Yes	7.43 ± 3.46	**0.032**	1.68E+03
	Livestock keeping experience: > 10	6.52 ± 2.09	**0.002**	6.76E+02
	Number of cattle owned: >100	6.05 ± 2.78	**0.029**	4.23E+02
	Land size owned : >20ha	1.23 ± 1.62	0.449	3.43+00
	Membership in association: Yes	-3.81± 1.88	**0.043**	2.22E-02
	Access to loan: Yes	-1.99± 2.61	0.446	1.37E-01
	Close to the market: Yes	2.89 ± 1.73	0.094	1.79E+01
	Tsetse abundance in grazing areas: Abundant	1.04 ± 1.51	0.490	2.84E+00

Notes: Base category= Not adapting and Number of observations = 136

2.6 Discussion

This study reports areas that are most vulnerable to trypanosomiasis, knowledge/awareness of trypanosomiasis, impacts of trypanosomiasis and adaptation strategies in those areas. High levels of vulnerability to trypanosomiasis in Emboreet and Loibor-Sireet wards were the result of the reported high abundance of tsetse flies, wildlife, high frequency of AAT cases and low adaptive capacity in terms of health facilities and literacy rate where 55% and 56% of population in Monduli and Simanjiro, respectively are illiterate (Monduli DC, 2015; Simanjiro DC, 2015). Although reporting of trypanosomiasis cases was based on clinical signs without laboratory confirmation, our results provide an indication of areas burdened with this disease. While high abundance of tsetse flies is likely due to proximity to PAs bordering these two wards; low literacy rates and insufficient human health infrastructures may be linked to general low school enrolment and high dropout due to Maasai culture (Temba *et al.,* 2013; Gimbo *et al.,* 2015) as well as underinvestment in marginalized pastoral communities (Parkipuny, 1994; Kirkbride and Grahn, 2008; Nassef *et al.,* 2009). In addition, expert judgement indicated that abundance of tsetse flies and wildlife contributes to persistence of trypanosomiasis in these areas. This is consistent to the findings that persistence of trypanosomiasis largely depends on availability of both tsetse flies and hosts (Geiger *et al.,* 2015). High incidence of AAT in these areas was also supported by local practices reported by respondents, whereby cattle are normally grazed in wildlife-livestock interface areas what increases the likelihood of tsetse bites by infected flies and hence disease (Malele, 2011). Other factors such as emergent agriculture, decreased grazing land and increased climate variability also push livestock into tsetse infested areas and thus increase risk of contracting trypanosomiasis as well as increasing vulnerability to the less adaptive part of Maasai community.

High awareness of AAT among pastoralists is consistent with the endemicity of AAT in the Maasai steppe but also due to the important role livestock plays in the livelihood of Maasai community. The finding of this study also conforms to earlier studies in Kenya and Tanzania which reported superiority of Maasai pastoralists' knowledge on various livestock diseases including trypanosomiasis (Jacob *et al.,* 2004; Chengula *et al.,* 2013). On the other hand, low awareness of HAT could be due to rarity of reported cases of sleeping sickness, because of the generally lower prevalence of this form of the disease (Auty *et al.*, 2012). Inadequacy of diagnostic facilities in the study area is another factor which contributes to misdiagnosis of sleeping sickness and often being treated as other febrile illnesses.

Results of impacts of trypanosomiasis reported in this study are also similar to other studies conducted in Morogoro, Tanzania and Ethiopia (Nonga and Kambarage, 2009; Chani *et al.*, 2013). Since Maasai pastoralists' income and nutrition heavily rely on livestock keeping, impacts of AAT including decreased milk production, death of livestock and emaciation of animals which consequently hinder access to markets may cause economic disruption and food insecurity among individuals. Furthermore, amplification of existing stress of trypanosomiasis and other animal diseases due to inability to meet production inputs may expose pastoralists' to multiple stressors and thus increase their vulnerability.

Farming as an option to curb the effect of trypanosomiasis was the most common adaptation strategy among respondents. Use of this method could be attributed to availability of land for farming. Although farming is the preferred adaptation strategy, other studies have shown how frequent crops in this area fail (Barbara and Fouad, 1995; Nassef *et al.*, 2009; Msoffe *et al.*, 2011b) and that often people who supplement with agriculture end up worse off than those who don't because of wastage of resources committed to agriculture. To a large extent, converting grazing land for farming particularly for rain fed agriculture may put pastoralists' investments at jeopardy. Resorting to wage labor as an adaptation strategy for pastoral communities may be linked to consumption pressure which forces households to divert their labor force, as a means of increasing their resilience. However, knowing how to access information on available waged labor opportunities may be a challenge to Maasai pastoral communities in which 69% of respondents had never attended school. It is expected that illiterates may have narrow opportunities for diversifying sources of income which could enhance their resilience. Sale of livestock was the least preferred adaptation strategy probably because livestock is a symbol of wealth and pride to Maasai people. However, unwillingness to sell livestock, coupled with decreased grazing land and increased drought means that by the time they finally decide to sell cattle, many have died or their value has severely decreased due to starvation, what reduces their resistance to disease, and also contributes to increased vulnerability for the pastoralists. The adaptation strategies such as subsistence farming, wage labor reported in this study are similar to strategies reported in Ngorongoro district, Tanzania (Fratkin, 2001; Galvin *et al.,* 2004) as well as the pastoral systems of Kenya and Ethiopia (Huho *et al.,* 2011; Schmidt and Pearson, 2016).

Adaptation constraints reported among Maasai pastoralists in this study are also related to poverty. Adaptation to AAT can be costly, and could require pastoralists to sell livestock to buy farm inputs and meet other basic needs. Pastoralists with limited resources to sell are therefore even more vulnerable to impacts of the disease. While uncertainty of weather could be linked to lack of an early warning system, lack of grazing land is attributed to increase in human population and associated agricultural conversion, which can force livestock into tsetse fly prone areas, thus increasing their vulnerability to trypanosomiasis (Reid *et al.,* 2000; Msoffe *et al.,* 2011a, b; Wamwiri and Changasi, 2016).

Respondents' decision to adapt and their adaptation strategy was influenced by socio-economic factors related to household characteristics, institutional capacity, social networks and wealth. For example; relative to no adaptations, the odds of farming, selling livestock and waged labor increased with every additional unit of access to livestock extension services, years of livestock keeping experience and number of cattle owned. Extension services, for instances are among the institutional factors that increase access to information that can help community to make informed decisions on adaptation strategies thus increasing adaptive capacity of a communities and individuals (Agrawal, 2008; Deressa, 2009). Several years of livestock keeping experience may imply accumulation of knowledge that can be used to avoid various stresses. As expected (Tesso *et al.,* 2012), the likelihood of choosing any of the three adaptation strategies was positively associated with number of livestock owned. This is partly because Maasai people consider livestock as a store of value which plays an important role in their economy. Education attained also influenced the likelihood of respondents selling livestock as an adaptation strategy. The reason for this could be the fact that higher level of education is associated with greater access to information on market accessibility, livestock diseases and services which can support informed decisions and lower vulnerability to diseases (Kanj and Mitic, 2009). Contrary to the expectation that social networks would exert a positive influence on adaptation (Agrawal, 2008); and the fact that Maasai community is known to be a communal community; membership in associations was negatively associated with adaptation. We suspect that there might be limited number of associations and organizations in the area which render large number of individual participation and consequently negative association with adaptation.

These findings indicate that individuals with no access to extension services, few years of experience in livestock keeping, few livestock and low education attainment are less likely to adapt, meaning they have low adaptive capacity and thus likely to be vulnerable to trypanosomiasis. These factors have likewise been reported to be important predictors of vulnerability and adaptive capacity in other studies (Smit and Wandel, 2006; Deressa, 2009; Tesso *et al.,* 2012; Ebi *et al.,* 2013; Haynes *et al.,* 2014).

2.7 Conclusion

Levels of vulnerability to trypanosomiasis in Simanjiro and Monduli districts have been highlighted. Although awareness of AAT among pastoralists was high, adaptive capacity in terms of household characteristics and institutions that aid adaptation to trypanosomiasis through easy access to information were low and thus increasing individuals vulnerability to trypanosomiasis impacts. Farming was most practiced adaptation strategy; yet, it pushes livestock into tsetse infested areas due to reduced grazing lands and thus increases potential for trypanosomiasis transmission. Vulnerability to trypanosomiasis is further exacerbated by multiple stressors, including frequent drought. This indicates the need for a multi-sectoral approach in developing fit for purpose sustainable adaptation strategies that will eventually increase communities’ resilience and livelihood security.

2.8 Ethic statement

Ethical approval was obtained from Medical Research Coordinating Committee of the Tanzanian National Institute for Medical Research (NIMR/HQ/R.8c/Vol.11/428). Participation in this study was on a voluntary basis. Written informed consent was sought from all study participants prior to their enrollment in the study.

2.9 Limitation of the study

This study included few trypanosomiasis risk factors in the vulnerability analysis due to relatively rare availability of massive data and complexity of quantifying the trypanosomiasis risk factors.

CHAPTER THREE

SEASONAL VARIATION OF TSETSE FLY SPECIES ABUNDANCE AND PREVALENCE OF TRYPANOSOMES IN THE MAASAI STEPPE, TANZANIA[2]

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Abstract

Tsetse flies, the vectors of trypanosomiasis, represent a threat to public health and economy in sub-Saharan Africa. Despite these concerns, information on temporal and spatial dynamics of tsetse flies and trypanosomes remain limited and may be a reason that control strategies are less effective. The current study assessed the temporal variation of the relative abundance of tsetse fly species and trypanosome prevalence in relation to climate variability in the Maasai Steppe of Tanzania between 2014 and 2015. Tsetse flies were captured using odor baited Epsilon traps deployed in ten sites selected through random subsampling of the major vegetation types in the area. Fly species were identified morphologically and trypanosome species classified using PCR. The climate dataset was acquired from the African Flood and Drought Monitor repository. Three species of tsetse flies were identified namely: *G. swynnertoni* (70.8%), *G. m. morsitans* (23.4%), and *G.pallidipes* (5.8%). All species showed monthly changes in abundance with most of the flies collected in July. The relative abundance of *G.m. morsitans* and *G. swynnertoni* was negatively correlated with maximum and minimum temperature, respectively. Three trypanosome species detected were recorded: *T. vivax* (82.1%), *T. brucei* (8.93%), and *T. congolense* (3.57%). The peak of trypanosome

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infections in the flies was found in October and as three months after the tsetse abundance peak. The prevalence was negatively correlated with tsetse abundance.

A strong positive relationship was found between trypanosome prevalence and temperature. In conclusion, we find that trypanosome prevalence is dependent on fly availability and temperature drives both tsetse fly relative abundance and trypanosome prevalence.

Keywords: *Glossina*, species, seasonality, abundance, Maasai Steppe, Tanzania

3.1 Introduction

The distribution and abundance of vectors is determined by the interplay of three factors: suitable climatic conditions, habitat for development and the availability of hosts for food. These factors are not independent, since changes in climate not only directly affect the conditions for vector development but also indirectly alter vegetation cover and the movement of the hosts (Jones *et al.,* 2007; Gage *et al.,* 2008; Reisen *et al.,* 2008; Mills *et al.,* 2010; Moore and Messina, 2010; Parham and Michael, 2010; Srimath-Tirumula-Peddinti *et al.,* 2015). Of the different aspects of climate, temperature has been shown to influence the growth and proliferation of trypanosomes within the tsetse fly vector (Walshe *et al.,* 2009). There are multiple approaches that can be used to examine the effects of climate variation on vector distribution and parasite developments (Moore *et al.,* 2011; Vale and Hargrove, 2015). In this paper we examine the within-year fluctuations in temperature and rainfall in the Maasai Steppe of Tanzania and how these are associated with changes in relative abundance of three *Glossina* species and the prevalence of trypanosomes within them, which in turn affects the likelihood of cattle and humans becoming infected with trypanosomiasis.

The general consensus among infectious disease ecologists is that changes in climate alter the distribution of many infectious diseases (Patz *et al.,* 2003; Gray *et al.,* 2009; Moore *et al.,* 2011; Huynen and Martens, 2013). Climate envelope models have been used to examine the distribution of vectors, as well as calculation of vector vital rates, including transmission rates (Epstein, 2001; Anderson *et al.,* 2004; Rödder *et al.,* 2008; Bouyer *et al.,* 2013). Correlations between climatic variables and abundance have also been used to examine the impact of changes in climate on vector borne diseases (Githeko *et al.,* 2000; Lafferty, 2009; Moore *et al.,* 2011; Paaijmans *et al.,* 2012; Mordecai *et al.,* 2013). Both average climatic conditions and day to day variation in temperature are known to be important for vector and parasites development (Hargrove, 2004; Patz *et al.,* 2005; Terblanche *et al.,* 2008; Kleynhans and Terblanche, 2011; Lukaw *et al.,* 2014). For these reasons, studies involved in monitoring abundance and prevalence of vectors and pathogens, coupled with records of location and climate, have been used to provide insights that can assist in describing the relationship between climate variation and vector and pathogens dynamics, and thus an inference of seasons and areas at risk of disease.

Tsetse fly species have been recorded in more than three quarters of the Tanzania rangelands with high abundance in wildlife protected areas and adjacent zones (Lucas *et al.,* 2001; Malele *et al.,* 2011a). These flies are vectors for both human and animal African trypanosomiasis, and play a significant role in compromising the health of people, livestock and economic development (Malele, 2011). Currently, trypanosomiasis threatens the livestock sector in Tanzania, which accounts for about 4.7% of the National GDP and 13% of the Agricultural GDP (Tumbo *et al.,* 2011). The infection also threatens more than four million rural Tanzanians including the Maasai communities (Malele *et al.,* 2006; Malele *et al.,* 2011b). Maasai communities are particularly vulnerable to negative impacts of trypanosomiasis since their economic status and nutrition are highly tied to livestock production. These communities are also challenged by current land tenure, climate change and a number of other livestock infections. In addition, information on trypanosomiasis risk in Maasai areas is limited, and this compromises vector control programs.

Recent studies on tsetse fly and trypanosomiasis risks have mainly focused on biological aspects of the vector and the protozoa within the Maasai Steppe, and there remains a lack of knowledge about climate and its influence on risk of infection (Malele *et al.,* 2006; Sindato *et al.,* 2008; Matemba *et al.,* 2010; Malele *et al.,* 2011a; Mramba *et al.,* 2013; Salekwa *et al.,* 2014; Muse *et al.,* 2015). Therefore, this study was carried out in the Masaai Steppe of Tanzania and addressed the following questions: (a) Do tsetse fly abundance and trypanosome prevalence vary between months? (b) Is seasonal variation of climate associated with tsetse fly abundance and pathogen prevalence? (c) Does tsetse fly abundance influence trypanosome prevalence?

3.2 Methodology

The tsetse fly sampling was undertaken in Emboreet village in the Simanjiro District, part of the Tanzanian Maasai Steppe located between 4° 47' 15" S and 36° 53' 54" E (Fig. 8). The area is semi-arid, characterized by grassland savanna with *Acacia* woodlands, *Commiphora* species, scattered baobab (*Adansonia digitata*) and sausage (*Kigelia africana*) trees. The area is inhabited by the Maasai people who herd livestock and co-exist and share pasture with free-ranging wild ungulate species. Surface water is scarce and seasonal availability determines the movement and presence of livestock and the wild animals. Economic activities by the Maasai focus primarily on livestock and more recently agricultural production (McCabe *et al.*, 2010). Eco-tourism is important in this part of Tanzania and there are several national parks (NP) including Tarangire and Lake Manyara NP.

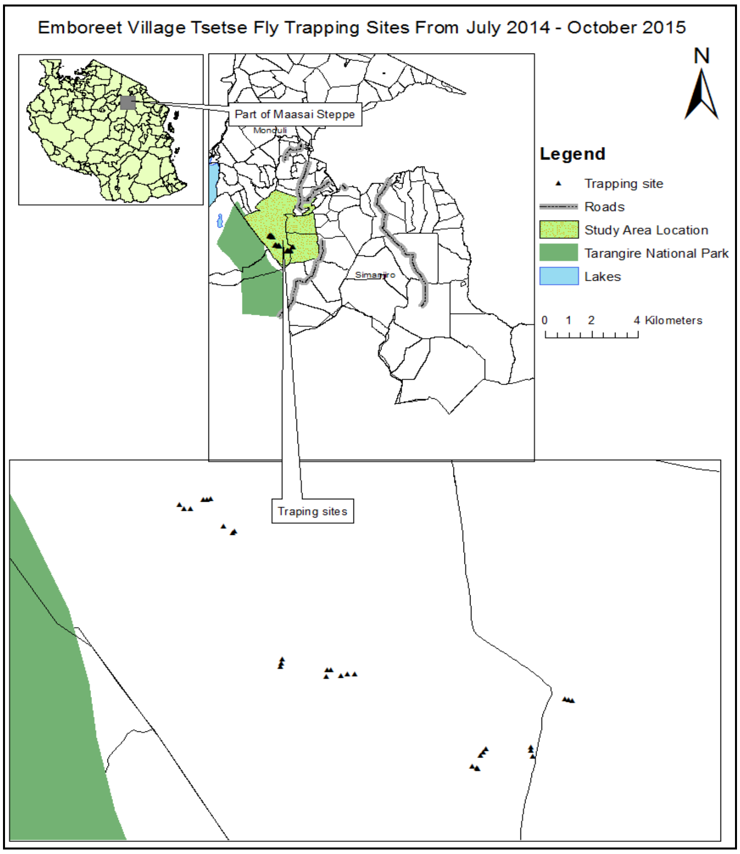

Figure 9: Location of tsetse fly trapping sites within Emboreet village lands bordering Tarangire NP, Tanzania.

3.2.1 Tsetse fly abundance, trypanosome prevalence and climate data collection

Temporal abundance of tsetse flies was estimated by monthly sampling for a period of 15 months in 2014 - 2015 in the village of Emboreet, which borders Tarangire National Park (Fig. 9). Sites were selected through stratified random subsampling of the identified four (riverine, open woodland, grassland and ecotone) major vegetation types in the area (Bouyer *et al.*, 2010). At least one site was chosen in each vegetation type. A total of ten sites were identified and three epsilon traps were deployed at each site and located at least 200 m apart (Malele *et al.*, 2011a). At each trap, the grass vegetation was cut to ground level and the legs of the trap greased to avoid ants consuming caught flies. Each trap was baited with an attractant made from acetone, phenols and octanol (Hargrove *et al.,* 1995). Traps were checked and emptied every 24 hours for six days each month, at which time the number of individuals for each tsetse species within each trap was recorded, along with the GPS (global positioning system) location. Tsetse flies were identified using training manuals published by the Food and Agricultural Organization (Pollock, 1982) and identification was confirmed with a qualified entomologist from the Vector and Vector-Borne Diseases Research Institute located in Tanga, Tanzania. After six days, the traps were removed from the site and deployed again for sampling the following month.

Collected flies were preserved individually in eppendorf tubes filled with absolute ethanol. DNA was extracted from individual flies in the laboratory using Ammonium Acetate Precipitation protocol (Bruford *et al.*, 1998). A total of 2927 tsetse flies DNA was extracted. All DNA samples were stored at -20^{0}C until further analysis. Trypanosome species were identified by using polymerase chain reaction (PCR) undertaken on fly-specific pools (Ferreira *et al.,* 2008; Malele *et al.,* 2013). Each pool was prepared by mixing 10 individual DNA samples in equal volumes. Positive pools of DNA samples were further studied to identify the individual flies that were infected in order to establish prevalence of trypanosome species within each tsetse species. Total volume of 15µl containing 7.5µl Dream Taq master mix, 200nM of forward and reverse primers and 3.9µl of nuclease free water was used during the PCR amplification process where the ITS1 gene was targeted. Positive reference DNA (*T. vivax, T. brucei* and *T.congolense* savannah) and negative (nucleated free water) controls were included in each set of experiments. Tubes were incubated at 94°C for 3 minutes in an initial denaturation step, followed by 30 cycles of 94^{0}C for 30 seconds, 55^{0}C for 30 seconds, 70^{0}C for 30 seconds and 72^{0}C for 10 minutes. A final recycling was processed at 94^{0}C for 10 minutes, 35 cycles of 94^{0}C for 1 minute, 68^{0}C for 1 minute and 72^{0}C for 60 seconds and lastly by 72^{0}C for 10 minutes. The PCR products were separated on 2 % GR green stained agarose gels and positive results were identified based on PCR product size corresponding to 300bp for *T. vivax,* 400bp for *T. brucei* and 700bp for *T.congolense* savannah. *T. brucei* positive samples were further tested using SRA gene amplification primers in order to identify human infective trypanosomes. Detailed primer sequences and cycling conditions followed in this study is described in Radwanska *et al.* (2002) and Njiru *et al.* (2005).

Climate data were acquired from the African Flood and Drought Monitor repository which provides satellite gridded data at spatial and temporal resolution of 0.25^0 at daily intervals, (http://stream.princeton.edu/AWCM/WEBPAGE/interface.php?locale=en). Daily, maximum and minimum temperature and total precipitation for the year 2014 and 2015 were acquired and used to characterize the weather of the study area. After acquisition, data were checked for quality before used in the analysis. These data have limitations of spatial resolution since the trapping sites fall into only two grids of satellite climatic data. Availability of local station data on the ground or alternative high resolution data for the study area is poor and/or limited.

3.3 Data analysis

Tsetse fly and trypanosomes 15 moth data were lumped for some months that had records for year 2014 and 2015 so as to understand seasonal pattern tsetse fly abundance and trypanosome prevalence variation. The relationships between climate and tsetse fly abundance or trypanosome prevalence, and also between tsetse flies and trypanosomes, were examined using linear mixed effect models (LME) fixed with maximum likelihood with the *'lme4'* package in the statistical program R (v. 3.24) (Baayen *et al.*, 2008). Where possible, the contribution of independent variables with quadratic or exponential functions, as well as two-way interactions with other independent variables, was also examined. Sampling site and occasionally habitat (where it improved the model results) were included as a random factor to take into account between-site variability and the re-sampling of the same site over the months. The following mathematical notation was used;

$$\boldsymbol{Z} = \times \boldsymbol{\beta} + \boldsymbol{W\gamma} + \boldsymbol{\varepsilon}$$

In R, the formula was presented as; Model= lme (Z ~ X + W), data, method = “ML”

Where Z is a response variables (observed number of tsetse fly species or trypanosome prevalence); X also termed as explanatory variables is a matrix for fixed effects relating observation Z (maximum and minimum temperature, month and number of tsetse fly irrespective of species) β is column vector of the fixed-effects; W is the matrix for the random effects (site and habitat) relating observation Z to γ; γ is a vector of the random effects; and ε is a column vector of the residuals, that part of Z that is not explained by the model, Xβ+Wγ (Rabe-Hesketh and Skrondal, 2008). This model was opted because most of ecological data are not entirely independent, such that, use of linear model would violet the assumption of variable independency. This method allows the modeling of correlated data while maintaining a normal distribution of errors (Crawley, 2007). Independent variables (i.e., fixed effects) are unknown constants to be estimated from the data while random variables (here included as a random effect of the fixed effect intercepts) govern the variance-covariance structure of the response variable. The minimum parsimonious model was considered and presented in our results. To examine the effect of time lag in relative abundance of tsetse fly species on prevalence, cross correlation analysis was implemented and a delay of up to three months was examined using the *'astsa'* package in R (Rao, 2001).

3.4 Results

While the goal of this study was to examine the seasonality in the relative abundance of tsetse flies and their infection rate, a preliminary analysis was performed to investigate the role of habitat in the temporal variation of fly catches. Analysis confirmed that habitat significantly affected changes in total fly abundance at the monthly level (appendix 5). Given that the resolution of our climatic data covered the habitat selected in our study sites, and considering that the role of habitat on tsetse dynamics has been addressed in a study complementing the current work (Ngonyoka *et al.*, 2017), my analyses were performed combining the habitat together and using the sampling site as a random factor in the analysis to take into account spatial variability in fly trapping and trypanosome prevalence.

During the study period the lowest temperature was recorded in July and the highest in February. Rainfall was relatively variable between months, with the maximum amount of rainfall recorded in April and the minimum in September (Fig. 10).

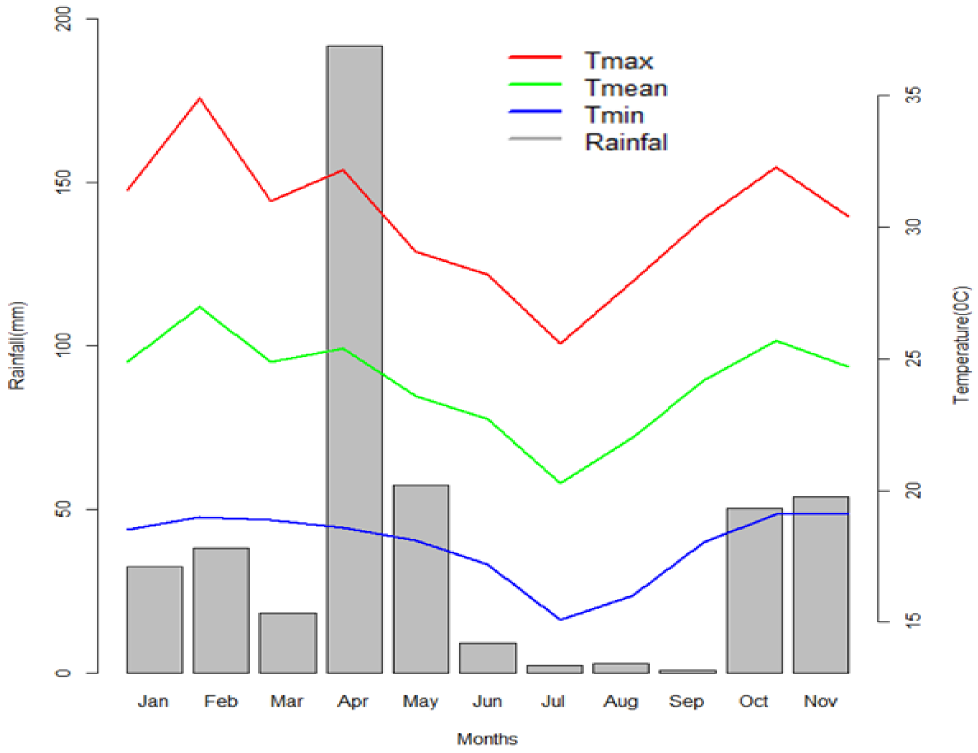

Figure 10: Monthly variation in total rainfall, and mean, maximum and minimum temperature at Emboreet village during the study period.

3.4.1 Temporal dynamics of tsetse fly relative abundance

A total of 3000 tsetse flies, comprising three savanna *Glossina* species, were caught during the 15 months of trapping. *G. swynnertoni* (70.8%) was the most abundant species followed by *G.m.morsitans* (23.4%) and at lowest value, *G.pallidipes* (5.8%). Temporal changes in abundance were recorded in all three species. *G.swynnertoni* abundance peaked in July, followed by September and then March, while *G.m.morsitans* and *G.pallidipes* exhibited two peaks each: *G.m.morsitans* peaked in July and March, whereas *G.pallidipes* peaked in November and July (Fig. 11). Differences in abundance of tsetse species were significant for a number of months (Table 4).

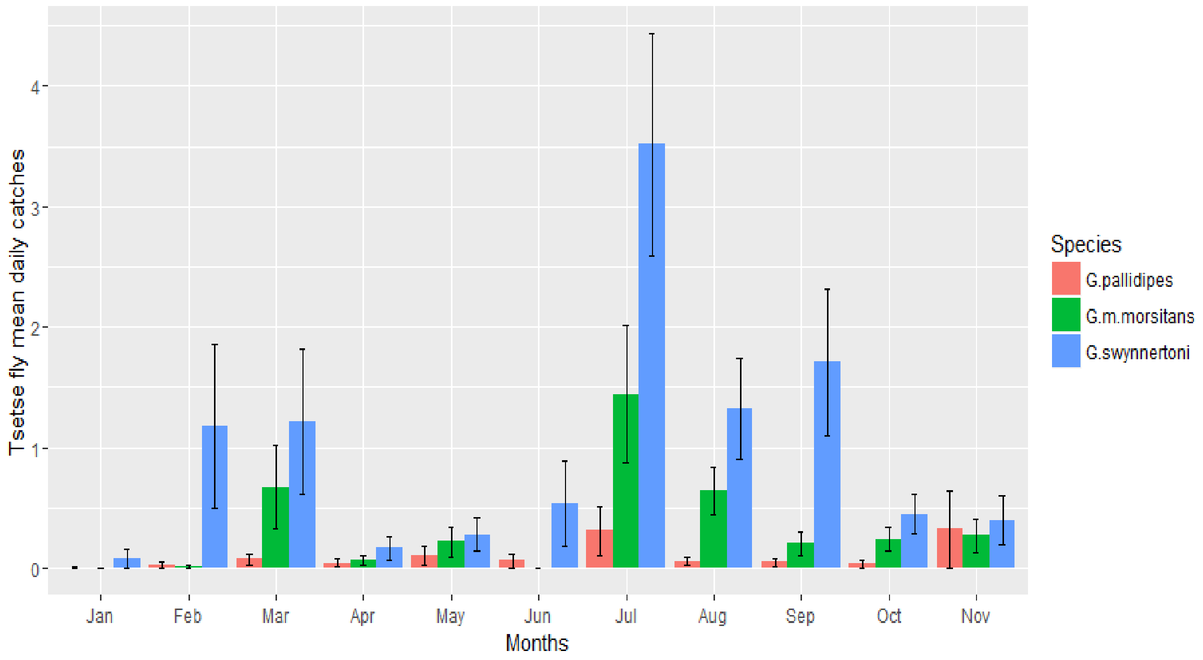

Figure 11: Seasonal variation in tsetse fly species relative abundance, showing the mean daily catches as observed at Emboreet village during the study period.

Table 4: Linear mixed effect models with the relative abundance of tsetse fly species as response and months as explanatory variables; all months are compared to the intercept *January.

MONTH	***G.pallidipes***			***G.m.morsitans***			***G.swynnertoni***		
	Coef ± SE	***Df***	***P***	***Coef ± SE***	***Df***	***P***	***Coef ± SE***	***Df***	***P***
***Intercept*	0.004 ±.02	2236	***0.84***	0.00001±.07	2236	***1***	0.04 ±.14	2236	***0.79***
February	0.009 ±.02	2236	***0.62***	0.007±.35	2236	***0.8***	0.21 ±.05	2236	***<0.001***
March	0.043 ±.02	2236	***<0.05***	0.19 ±.35	2236	***<0.001***	0.24 ±.05	2236	***<0.001***
April	0.023 ±.02	2236	***0.26***	0.04 ±.35	2236	***0.22***	0.05 ±.05	2236	***0.29***
May	0.042 ±.02	2236	***0.04***	0.105 ±.35	2236	***<0.01***	0.09 ±.05	2236	***0.058***
June	0.012 ±.02	2236	***0.52***	0 ±.35	2236	***1***	0.11 ±.05	2236	***<0.05***
July	0.147 ±.02	2236	***<.0.001***	0.448 ±.04	2236	***<0.001***	0.83 ±.05	2236	***<0.001***
August	0.033 ±.02	2236	***0.07***	0.263 ±.03	2236	***<0.001***	0.33 ±.04	2236	***<0.001***
September	0.031 ±.02	2236	***0.08***	0.075 ±.03	2236	***<0.05***	0.31 ±.04	2236	***<0.001***
October	0.015 ±.02	2236	***0.38***	0.106 ±.03	2236	***<0.001***	0.13 ±.04	2236	***<0.01***
November	0.024 ±.02	2236	***0.25***	0.114 ±.04	2236	***<0.01***	0.09 ±.05	2236	***0.083***
Random Factor: Site	**0.040**			**0.204**			**0.440**		
AIC value	**-1031.20**			**1490.000**			**2799.000**		

3.4.2 Climate - setse fly relative abundance relationships

A negative relationship was found between relative abundance of *G.m.morsitans* and maximum temperature and between *G.swynnertoni* and the minimum temperature, while relative abundance of *G.pallidipes* showed no associations with any of the temperature variables (Table 5).

Table 5: Linear mixed effect model between tsetse fly species and maximum and minimum temperature; *Intercept; *G.m.morsitans* **Intercept; *G.swynnertoni*.

G.m.morsitans				***G.swynnertoni***			
	Coef± SE	***Df***	***P***		***Coef± SE***	***Df***	***P***
*Intercept	21.2 ± **3.6**	481	0.0000	**Intercept	6.32 ± **8.2**	481	0.4
Tmax	-7 ± **2.0**	481	0.0004	**Tmax**	7.9 ± **4.5**	481	0.08
Tmin	1.2 ± **2.0**	481	0.5554	**Tmin**	-10.8 ± **4.5**	481	0.02
Random effect: Site	**0.79**			***Random effect: Site***	**2.5**		
AIC value	**2266.17**			***AIC value***	**3075.9**		

3.4.3 Temporal dynamics of trypanosomes prevalence

A total of 2927 tsetse flies were sent to laboratory for analyzing infection rate and the summary report is appended as appendix 6 in the appendix section. Most of the tsetse fly infections were from *T.vivax* (82.1%), with proportionately fewer from *T. brucei* (8.93 %) and *T.congolense* (3.57%). Co-infections with *T.vivax* and *T.brucei* were the most common (3.57%) while *T. vivax-T.congolense* and *T. vivax-T.brucei-T.congolense* were rare and only 0.89% each. Further analysis of *T. brucei* positive flies found no human infective species, specifically *T. brucei rhodensiense*. The highest upper and interquartile values of trypanosome prevalence were recorded in October, while lowest quartiles and interquartiles of prevalence were recorded in January. These results suggest that October consistently scored the highest prevalence and January the lowest compared to the other months (Fig. 12). In general, prevalence of trypanosomes increased from January to November with some monthly fluctuations, but only the peak in October was significant (Table 6).

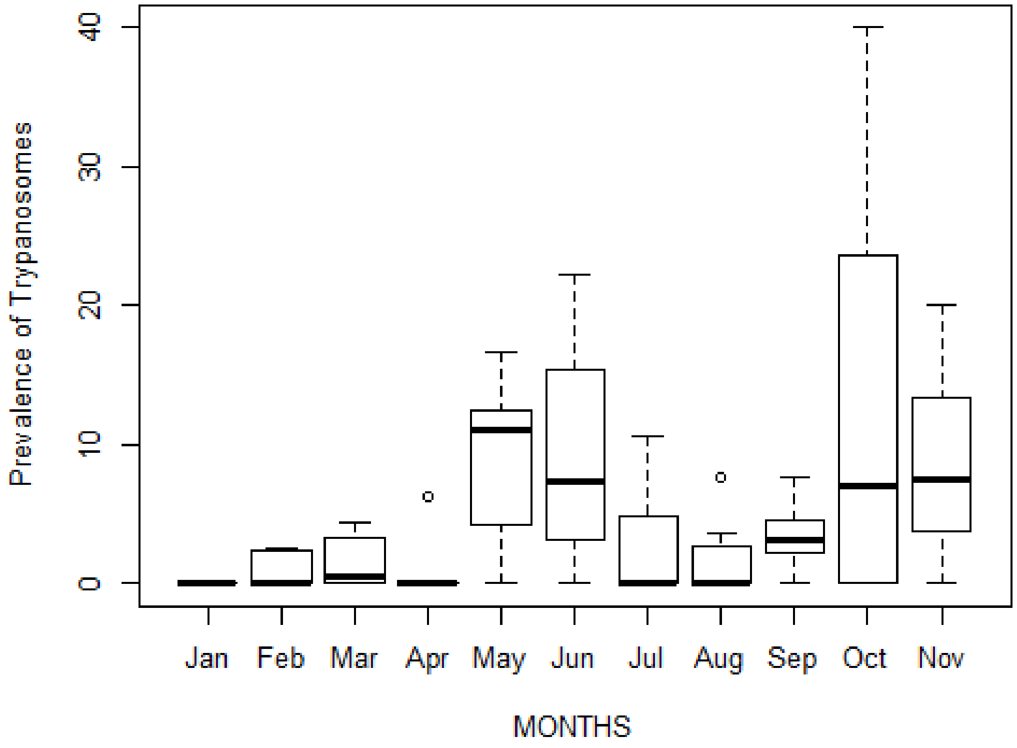

Figure 12: Monthly variation in trypanosome prevalence as observed at Emboreet village during the study period. The 25%, 50% and 75% quantiles and maximum and minimum values are reported.

Table 6: Linear mixed effect models between trypanosome prevalence (species combined) and months; all months are compared to the intercept *January.

MONTH	***Prevalence***		
	Coef* ± *SE	***Df***	***P***
***Intercept**	0.00 ± 4.8	63	***1***
February	0.83 ± 5.6	63	***0.9***
March	1.44 ± 5.6	63	***0.8***
April	1.25 ± 5.7	63	***0.8***
May	9.22 ± 5.6	63	***0.1***
June	9.26 ± 5.9	63	***0.1***
July	2.73 ± 5.2	63	***0.6***
August	1.49 ± 5.2	63	***0.8***
September	3.52 ± 5.2	63	***0.5***
October	12.20 ± 5.2	63	***0.05***
November	8.68 ± 5.7	63	***0.1***
Random Factor: Habitat	**0.0003**		
AIC value	**554.9**		

3.4.4 Relationship between climate and prevalence of trypanosomes

Following previous work, this paper initial prediction was that trypanosome prevalence would rise with temperature, reach a peak and then decline (Cross and Manning, 1973). Accordingly, we found that trypanosome prevalence increased with rising maximum temperatures from 26^0C to 31^0C, and declined beyond a maximum temperature of 31^0C (Fig. 12). This trend was significantly described by a positive relationship of prevalence with maximum temperature (β = 23.14, SE = 9.07, df = 37, p = 0.0150) and quadratic terms (β = -0.37, SE = 0.15, df = 37, p = 0.0177).

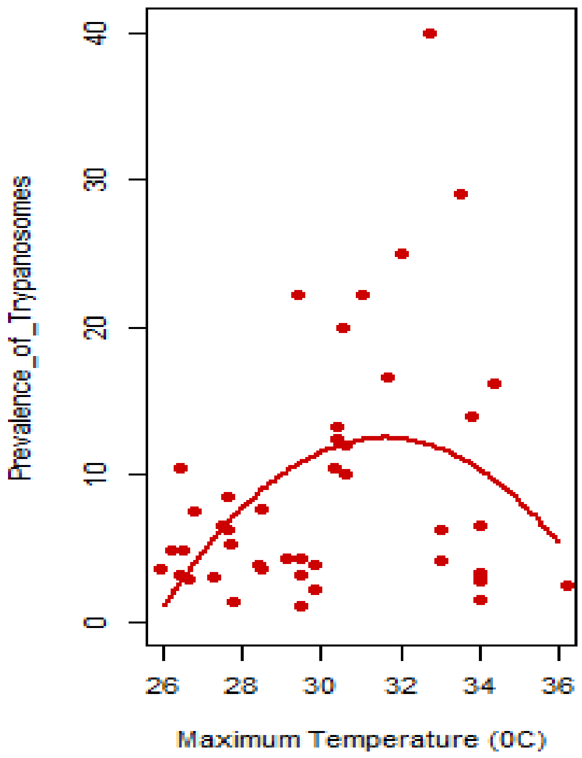

Figure 13: Variation of trypanosome prevalence in relation to maximum temperature recorded at Emboreet village during the study period. Points represent prevalence of trypanosomes recorded at different temperatures and the line represents the best fit quadratic model.

3.3.5 Relationship between prevalence of trypanosomes and relative abundance of tsetse flies

The peak in trypanosome prevalence lagged 3 months behind the July peak in tsetse fly abundance (Fig.11, 12) but this lag effect was not statistically significant. A negative relationship was found between trypanosome prevalence and tsetse fly abundance suggesting that high prevalence is related to low fly abundance (Fig. 13). In general, it was observed that an increase in one unit of tsetse fly abundance reduces prevalence of trypanosomes (β = -7.66, SE = 1.23, df = 38, p = ***0.001***).

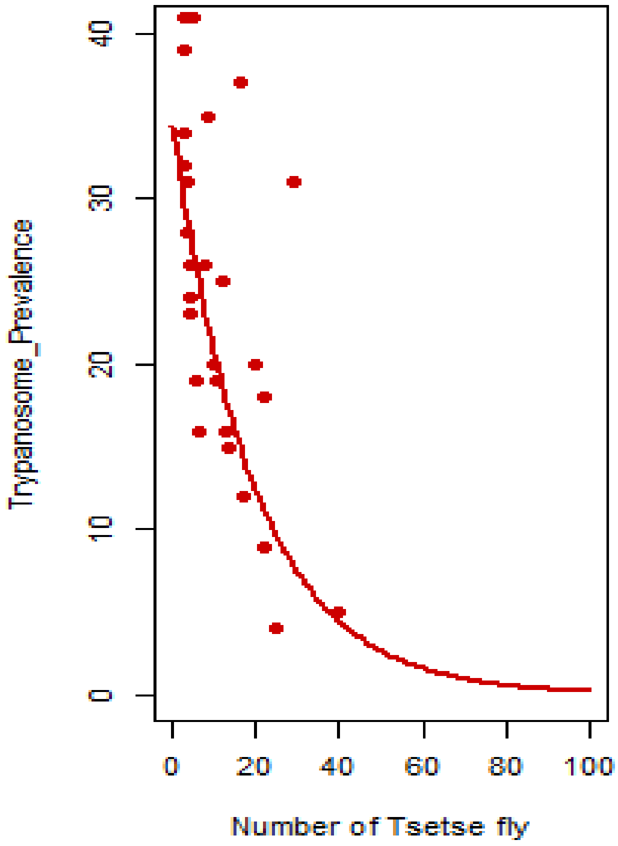

Figure 14: Relationship between trypanosome prevalence and tsetse fly relative abundance as observed at Emboreet village during study period. Points are prevalence of trypanosomes relative abundance in tsetse and the line represents the best exponential model fit.

3.5 Discussion

The relationship between seasonal variation of climate and tsetse fly abundance or trypanosome prevalence in the Maasai Steppe of Tanzania has not received adequate attention. Yet this area has abundant wildlife reservoir hosts of zoonotic diseases, it is also heavily used by livestock and can be a potential hot spot for infectious diseases of human concern, including the neglected tropical disease, trypanosomiasis. In order to fill this gap in knowledge, the current study addressed this concern by performing a longitudinal sampling at Emboreet village in 2014 - 2015.

This study identified *G. swynnertoni* and *T.vivax* as the most dominant tsetse fly and trypanosome species, respectively. The study has clearly shown temporal variation in relative abundance of different species of tsetse flies that appeared to be mainly associated with a negative effect of minimum and maximum temperature. Furthermore, we have shown temporal variations of trypanosome prevalence that was significantly affected by maximum temperature. It was revealed that trypanosome prevalence peaked three months after the peak in tsetse fly relative abundance, however, a negative exponential relationship was found between tsetse fly relative abundance and trypanosome prevalence, where lower tsetse abundance is associated with higher prevalence of trypanosomes.

The relatively large number of *G.swynnertoni* reported in this study confirms the findings by Sindato *et al.* (2007) and Salekwa *et al.* (2014) who also reported dominance of G.*swynnertoni* in the same area. Dominance of this species may suggest that even though the other two species, *G. pallidipes* and *G.m.morsitans,* can pose potential risk as vectors for trypanosomiasis, *G. swynnertoni* could still be the most important species in driving the epidemiology of infection in the area. Predominance of *T.vivax* was expected since it is known to be a widely distributed species due to both mechanical and cyclical transmissions (Dagnachew and Bezie, 2015). Predominance of *T.vivax* around the Maasai Steppe has also been reported in other studies (Adams *et al.,* 2010; Swai and Kaaya, 2012). Okoh *et al.* (2012) also found predominance of *T.vivax* from investigation carried out in one of the national parks of Nigeria. Since persistence of *T.vivax* requires only one fly and three to four animal hosts (Rogers, 1988), presence of numerous wild ungulates and cattle in the study area further support the dominance of *T. vivax*. Further analysis of *T. brucei* positive samples did not indicate presence of human infective trypanosomes; however, these negative results should not support the notion that the Masaai Steppe is a sleeping sickness free zone. The lack of positive cases may be attributed to the fact that human infective trypanosomes are usually at low prevalence and often not captured in relatively low sample size. Auty *et al.* (2012) reported similar finding in a study carried out in Serengeti NP. Nonetheless, there is also a chance for false negative results since this study did not run confirmatory test for false negative which is based availability of enough genetic material. Although amount of DNA was quantified by using spectrophotometry to meet protocol requirement, running another single gene copy PCR alongside the SRA PCR would have cleared the doubt *(*Picozzi *et al.,* 2008). When genetic material available for reaction is enough, it is expected that, the phospholipase C gene (GPI-PLC), a single copy gene found within *T. brucei* savanna will be positively amplified (Mensa-Wilmot *et al.,* 1990).

Tsetse fly relative abundance was greatest in July, whereas relatively low catches were recorded in January. In general, the months with high catches corresponded to a dry period. At this time of the year, adult tsetse flies rely entirely on available host blood (Hargrove, 2004) and they appear to be well adapted to this dry environment. It is possible that the concentration of available animals around resources like water and food offers good opportunities to overcome the extreme dry climate while allowing the reproductive life cycle of the fly to continue. Indeed, in the dry months of the Maasai Steppe, wild animals and livestock congregate and feed on bushes where food and protection are available and tsetse flies have access to the hosts for blood. Since there is a frequent interaction between vectors and hosts, this period can pose a high risk for animal trypanosomiasis. The presence of relatively high abundance of flies during the dry seasons has also been reported (Sindato *et al.,* 2007; Lukaw *et al.,* 2014). However, it is also possible that flies are more mobile during dry months and, thus, while the catch increases, the actual abundance might remain un-changed. Similarly, the availability of hosts may also increase during this period, as a consequence of resource driven animal movements, and when the hosts move through the trapping areas, the catch rate increases. In addition, this observation may have been influenced by the fact that only hungry flies would enter the trap while the fed traps prefer resting under the shade. Also, epsilon trap mostly used in trapping savannah tsetse fly species (morsitans group) might have introduced biases in data since the savannah group is attracted to bigger traps. For these reasons the recorded variation in abundance does not necessarily reflect the abundance in the entire area but it gives an understanding of what to expect in different seasons within this area.

There was no strong relationship between climate parameters and *G.pallidipes,* but a significant negative relationship between minimum temperature and *G.swynnertoni* and maximum temperature with *G.m.morsitans* was observed. The weak relationship between *G.pallidipes* and climate parameters could be associated with the ability of this species to thrive at low abundance in different areas and under mild climatic conditions (Pollock, 1982).

Also the low sample size of *G. pallidipes* could have influenced these results. The siginificant negative relationship of *G.swynnertoni* and *G.m.morsitans* relative abundance with minimum and maximum temperature could be partly because both low and high temperatures reduce the activity of the flies. At cold temperatures, fly activity falls and then again at high temperatures as the flies seek refuges and are more likely to enter the traps (Torr and Hargrove, 1999; Terblanche *et al.*, 2007). The observed disparities among the tsetse fly species and the climatic variables raises the questions of whether *G.swynnertoni* tolerance is greater to high temperatures and *G.m.morsitans* tolerance is greater to lower temperatures, however this study did not have data or published work to test this hypothesis. Overall, these findings were counter to my expectation of temperature being a robust predictor of tsetse fly species abundance (Rogers *et al.*, 1996; Moore *et al.*, 2011; Vale and Hargrove, 2015). Part of the weak signal observed could be associated with the low spatial resolution of the satellite climate data that lacked to provide microclimate changes and variation during the trapping sessions.

The presence of trypanosomes throughout the year could be associated with three factors: first, the year-round presence of wild animals as "trypanosome reservoirs" in areas close to the park; second, the evidence that adult tsetse flies feed entirely on host blood, which allows the chance of year round trypanosomes circulation in the area; thirdly, adult tsetse flies appear to thrive well through much of the variation in weather conditions and thus there is a risk of transmission throughout the year (Hargrove, 2004). The high trypanosome prevalence recorded in October was contrary to our expectation and the findings of previous studies in the same area (Sindato *et al.*, 2007). Possible reasons for this observation could be the fact that October coincides with a period of short rains (Fig. 10) when hosts, both livestock and wild ungulates, are numerous and widely spread allowing high rates of contact between hosts and vectors.

The strong correlation between maximum temperature and trypanosomes prevalence reported in this study confirms the relationship between environmental temperature and trypanosome development (Walshe *et al.*, 2009). Environmental temperature regulates the switching of the trypanosomes from the bloodstream form that has entered the fly and their multiplication in the tsetse fly midgut (procyclic form) before proceeding to salivary gland ready to infect a host (Akoda *et al.,* 2009). It appears from *in-vitro* experiments that the process of differentiation of trypanosomes from the blood stream form to the procyclic form initiates and continues the multiplication when temperature is between 27^0C / 26^0C to 37^0C (Brown *et al.,* 1973; Bienen *et al.,* 1980; Milne *et al.,* 1998; Li *et al.,* 2003). Other laboratory experiments concluded 25°C to 28°C as the optimum temperature for growth of trypanosomes but slow growth occurs up to 37 °C (Cross and Manning, 1973). Generally, high temperature shorten the duration of trypanosome development cycles within the tsetse fly (Moore *et al.,* 2011). This study reported infections between 26^0C to 36^0C and with the highest infection rates at around 31^0C. There could be two reasons for this observation; first, there is the rapid differentiation and proliferation of trypanosome species at temperature between 26^0C and 37^0C as suggested by laboratory studies; the second, nutritional stress could affect these patterns where high temperatures induced quick digestion of blood meals in the tsetse fly leading to more frequent feeding events, and hence increased risk of infection. Other exo-endogenous factors might also play an important role, such as quality of blood source, type of tsetse fly midgut enzymes, and quality of parasite surface coat, though they were beyond the scope of this study (Kubi *et al.*, 2006; Akoda *et al.,* 2009; Geiger *et al.,* 2015).

Peaks in trypanosome prevalence lagged behind tsetse fly abundance peaks and confirmed previous findings by others (Rogers, 1988). This observation may be partly because tsetse flies catch infections from hosts, and I suspect the flies to be susceptible to low immunity during low fly abundance and vice versa, but we did not have data to test this. Inverse relationship between tsetse fly relative abundance and their infection rates was relatively similar to reported paradox where low tsetse fly abundance resulted to a serious trypanosomiasis in animals and vice versa. This situation is probably attributed to the fact that high proportion of tsetse flies is resistant to trypanosomiasis infections and thus they do not develop mature infections. For this reason infection is aggregated in only susceptible part of tsetse population (Kubi *et al.*, 2005). Since tsetse fly infection rates depends on prevalence of trypanosomes in the vertebrate host populations, the observed general inverse relationship between tsetse fly relative abundance and trypanosomes prevalence implies that there is a risk of trypanosomiasis infection by vertebrate hosts regardless of tsetse fly abundance. Nonetheless, very low vector abundance lowers the prevalence as shown in January, indicating that a threshold of tsetse fly abundance is important for trypanosome infections to occur.

In summary, this study highlights seasonal patterns of tsetse fly burden and trypanosome prevalence. This information can inform stakeholders on months in which there is the highest risk of trypanosomiasis infection in the Maasai Steppe, where this information is limited or unavailable. Also, the established temporal patterns of vector and parasites together with climate relationships can provide fundamental information needed when developing predictive models of the temporal dynamics of tsetse fly species relative abundance and their infection rates. Nonetheless, it is important to recognize the possible role of other factors associated with changes in climate and how they may affect trypanosomiasis dynamics. Furthermore, the experimentation of *G.swynnertoni* and *G.m.morsitans* thermal tolerance under field conditions is recommended in order to explain the variation of temperature effects to this species reported in this study.

3.6 Acknowledgements

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3.7 Limitation of the study

Climate data used in this study have limitations of spatial resolution since the trapping sites fall into only two grids of satellite climatic data. There were no local station data on-the-ground or alternative high resolution data for the study area and this is somehow a limitation of this study.

CHAPTER FOUR

PREDICTED IMPACTS OF CLIMATE CHANGE ON SPATIAL AND TEMPORAL DISTRIBUTION OF TSETSE FLY SPECIES IN THE MAASAI STEPPE[3]

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Abstract

Tsetse flies are the main vectors for trypanosomiasis, a debilitating and fatal disease to livestock (African Animal Trypanosomiasis - AAT) and humans (Human African Trypanosomiasis - HAT) if not treated. Although climate is an important determinant of tsetse fly occurrence, few predictions have been made concerning likely climate change effects on tsetse fly distribution and the disease they transmit. Existing prediction such as the impact of climate change on tsetse fly distribution in Eastern Africa and SADC region are too coarse in scale to be useful in understanding and predicting vector and disease dynamics at the local scales necessary to design and implement mitigation strategies. This study therefore used MaxEnt (Maximum Entropy) species distribution modelling (SDM) and ecological niche modeling tools to estimate the potential distribution of *G. m. morsitans, G. pallidipes* and *G.swynnertoni* in the Maasai Steppe of Tanzania, based on unique occurrence records of each species (n = 32, 59 and 29 respectively), current and future climate, and altitude. Future prediction scenarios indicated that by the year 2050, the habitable area of *Glossina m. morsitans, Glossina pallidipes and Glossina swynnertoni* may decrease by up to 23.13%, 12.9% and 22.8% of current suitable habitat (19 225 km^2, 7113 km^2 and 32 335 km^2), respectively.

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This information can serve as a useful predictor of potential trypanosomiasis hotspots. Distribution maps generated by this study can be used as guides by tsetse fly control managers, health and livestock officers to set priorities for surveys and surveillance programs.

Keywords: *Climate change, Maasai Steppe, tsetse fly, MaxEnt, SDM,*

4.1 Introduction

The increase of greenhouse gases in the atmosphere is widely agreed to be the main cause of increasing global temperatures. Climate change predictions show an upward trend in temperature for at least the next nine decades (Meehl *et al.,* 2007). However, there is uncertainty in climate predictions, with different climate models predicting different magnitudes of warming. It is often therefore instructive to consider a suite of predictions which give a range of possible climate outcomes. On average, therefore, global temperature is expected to rise by 0.8 - 2.6^{0}C, and by 1.5 - 3^{0}C in Africa by the year 2050 (UNEP, 2007). Such increases may seriously affect species distributions and influence changes in ecosystem function and structure. In particular, rises in temperature can force species to expand or contract their geographical distribution and consequently alter their associations with their environment and other species. The influence of climate change on species distribution is supported by evidence from fossil records (Davis and Shaw, 2001) and observed trends from the twentieth to twenty first centuries on species range shifts. Already it has been estimated that a change in 1^{0}C will lead to range shifts of 160 km of ecological zone on earth (Thuiller, 2007; Thuiller *et al.,* 2008). The implication is that if the globe will warm by 4^{0}C by the year 2100, the flora and fauna of the north pole will move about 600 km northward, or 600 m higher in the altitude, to remain within their thermal tolerances. Already some species of butterflies in Europe have been reported to shift further north or to higher altitudes as those zones become habitable (Konvicka *et al.,* 2003; Franco *et al.,* 2006; Hickling *et al.,* 2006).

Predicted increases in temperature are likewise expected to transform, vector-borne disease dynamics by either altering the vector's and pathogen's geographical distribution, or development and mortality rates (Gage *et al.,* 2008; Mills *et al.,* 2010). Trypanosomiasis, which is transmitted by bites of infected tsetse flies, is an example of a vector-borne disease that is expected to be affected by changes in climate (Cook, 1992; Moore *et al.,* 2011). Protozoa of the *Trypanosoma* genus that cause human sleeping sickness and nagana in animals, develop and multiply in tsetse flies and are injected into mammalian hosts when infected flies feed on them. At present, distribution of tsetse flies is confined to sub-Saharan Africa and is determined by climate, vegetation and hosts. Climate variables, and temperature in particular, is regarded as a major driver as it influences all others factors that determine tsetse occurrence. The transmission of trypanosomiasis is a function of tsetse fly competence, and the ecology and behavior of available hosts. This leads to spatial variation of disease burden depending on the distribution of biotopes necessary for tsetse flies to thrive. For this reason, mapping the occurrence of the vector tsetse fly is a useful predictor of trypanosomiasis distributions, and can help predict areas with high risk of transmission.

In many parts of sub-Saharan Africa, trypanosomiasis remains a debilitating and fatal disease to livestock and humans if not treated. For instance, trypanosomiasis in livestock causes loss of over 4 billion USD due to 70% reduction of cattle density, 50% reduction in diary and meat sales, 20% reduction in calving rates, and 20% increases in calf mortality in Sub-Saharan Africa (Swallow, 1999). In Tanzania, over 65% of rangeland savannah ecosystems are infested with tsetse flies (Malele *et al.*, 2011b), exposing at least 4 million people in rural communities to the risk of contracting sleeping sickness, and leading to USD 8 million loss due to low livestock productivity induced by nagana (Sindato *et al.*, 2008; Malele *et al.*, 2011b; Daffa *et al.*, 2013). Trends in climate, land use and associated socioeconomic transformation are expected to evoke modification of these rangelands, and hence tsetse distribution. However, empirical evidence to support this phenomenon is lacking in the country. In addition, information that could aid planning for future preparedness is rare to find in the country and absent at local scales. For example, in the Maasai Steppe in northern Tanzania, knowledge of current and future spatial-temporal distribution of tsetse flies is not publicly available, and often based on old data. Furthermore, there is no information on how predicted changes in climate will alter the distribution of trypanosomiasis vectors, which is a gap this study aimed to address. Because resources for controlling tsetse and trypanosomiasis are generally scarce, understanding potential impacts of climate on tsetse fly distribution in space and time is essential for informing coherent strategies for vector and disease control.

A number of scientific approaches have been used to understand the potential impacts of climate on spatial and temporal distribution of disease vectors. Some of the approaches include climate envelope models and correlations between climatic variables and vectors (Rogers and Packer, 1993; Baker *et al*., 2000; Githeko *et al.*, 2000; Watling *et al.*, 2012). Climate envelopes are species distribution models that use climate data to define climate suitability for species to occur (Watling *et al.*, 2013). Specifically, climate envelope models relies on statistical correlations between species distributions points and their associated climate parameters to define a species' envelope of tolerance around existing ranges thereby delineating a ‘climate envelope’ within which species occur (Baker *et al.,* 2000; Watling *et al.,* 2013). This study draws on the general definition of climate envelopes in which models are built using climate variables to define areas that have suitable climate for tsetse fly species. Compared to mechanistic models, climate envelope models do not incorporate data other than occurrence and environmental related data; so they do not predict fitness variation across climate gradients (Kearney *et al.,* 2009).

There have been some studies that examine the risk of trypanosomiasis and tsetse fly burden in parts of Maasai Steppe, the most recent of which are associated with this work (Malele *et al.,* 2006; Sindato, *et al.,* 2007; Malele *et al.,* 2011a; Salekwa *et al.,* 2014; Nnko *et al.,* 2017). However, none of them has established the future distribution of tsetse flies and disease risk under the influence of climate change. To fill this gap in knowledge, the central question of this study is, what is the potential impact of climate change on the distribution of common *Glossina* species found in the Tanzanian Maasai Steppe? Specifically this paper asked; based on suitable climate, (a) What is the current distribution of common *Glossina* species in the Maasai Steppe? (b) How is this distribution related to climate variables? and (c) How might the distributions for these three tsetse fly species change as the result of climate change? This study used climate envelope models to model tsetse fly species distribution based on current climate under which they have been observed, and predicts the future distribution to understand how distribution and disease risk might change in the Maasai Steppe under future climate scenarios. This information may help livestock keepers, tsetse fly control managers, livestock development mangers, health departments and other agencies to allocate scarce resources in preventing trypanosomiasis by implementing more targeted interventions. This study also may form a basis for a large national scale prediction of future trypanosomiasis risk areas.

4.2 Methodology

4.2.1 Study area

The study was carried out in the Maasai Steppe ecosystem in northern Tanzania.

Geographically this area is located between 1.5 to 5° South latitude and 35 to 37° East Longitude (Fig. 15). It covers an area of more than 60 000 km^2 with a population of over 600 000 people, mainly practicing pastoralism and agro-pastoralism. The region is semi-arid, receiving 200 - 600 mm of rainfall per annum in two peaks. Rainfall patterns dictate movement of pastoralists and their herds and wildlife in search for water and pastures. Movement in search of these common resources increases the likelihood of disease transmission between domestic animals, people and wildlife. The main economic activities in the area are livestock keeping, subsistence and mechanized agriculture. Tourism also provides income to some communities since there are number of different form of protected areas such as national parks, conservancies hunting areas and tourism concessions on village lands located within the Maasai Steppe (Kshatriya *et al.*, 2007). Increasing conversion to agriculture in the study area reduces the available land for livestock to graze and consequently pushes people and their livestock into areas infested with tsetse flies, thus increasing the potential for disease transmission to livestock and humans.

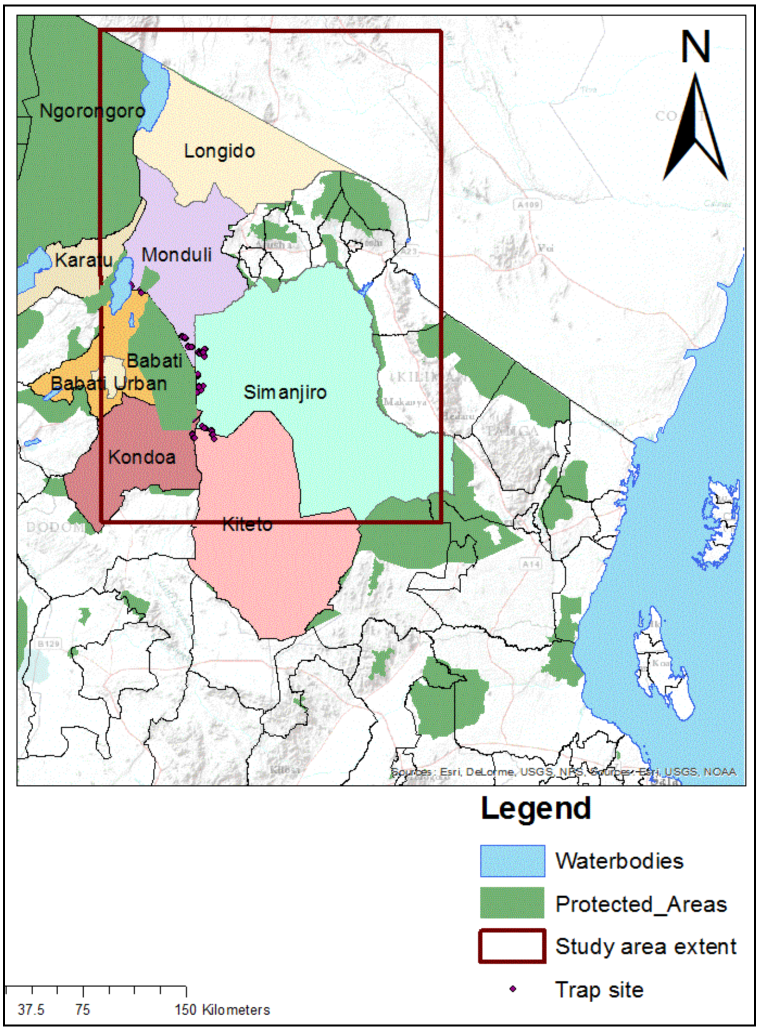


Figure 15: Map of the study area showing the main districts (Kiteto, Longido, Monduli and Simanjiro) forming the Maasai Steppe.

4.3 Data collection

4.3.1 Species occurrence data

This study targeted three savannah *Glossina* species *G. m.morsitans, G.pallidipes and G.swynnertoni*, commonly found in the Maasai Steppe. *Glossina* species abundance data were collected through entomological field surveys carried out once in the dry season and once in the wet season, where trap was left on site for six days and emptied every 24 hours. A total of 99 baited epsilon traps (Hargrove *et al.*, 1995) were placed in four villages near protected areas in Simanjiro and Monduli districts. Traps were deployed in November 2014 and May 2015 at a distance of at least 200 m apart (Hargrove *et al.,* 1995; Malele *et al.,* 2011a) in stratified random subsampling of the major vegetation types (Bouyer *et al.*, 2010). At each trapping site, numbers of tsetse flies caught as well as GPS (Global Positioning System) locations were recorded. The collected abundance data was converted to presence data for each of the GPS locations, yielding a total of 32, 59 and 29 unique occurrence points for *G.m.morsitans, G. pallidipes* and *G. swynnertoni,* respectively, after eliminating duplicate records resulted from multiple entries for a particular season. Duplicate records were removed using ecological niche modelling tools (ENMTools) software version 1.4.3 (Warren *et al.,* 2010). The occurrence data were used with climatic predictor variables in the maximum entropy machine-learning algorithm, MaxEnt v 3.3.3k (Phillips *et al.,* 2006), to create climate envelope models for the different tsetse species. MaxEnt is a kind of species distribution model developed to work with presence-only data, and has been widely used in modelling and mapping species distributions (Elith *et al.,* 2011), including to predict the probability of occurrence of species across space and time in areas that have not been sampled.

4.3.2 Background data

MaxEnt identifies environmental features that are important in determining species' distributions by comparing the conditional density of the features at known presence sites, with a random background sample of features from across the landscape (Elith *at al.,* 2011). In an ideal world, the landscape from which background data are generated includes all environmental characteristics which might affect species occurrence. Also, there are suggestions that the selection of background points should be restricted to areas which are accessible via dispersal when setting an extent from which background data are drawn (Merow *et al.,* 2013). Although restricting background sampling avoids biasing the model, it should be handled carefully because the process can accidentally reduce the species niche and consequently lead to incorrect characterization of environments where species occur and eventually incorrect estimates of potential distribution (Merow *et al.,* 2013). Since dispersal of tsetse flies is very dependent on availability of suitable hosts, and the study area is home to numerous hosts (wildlife and livestock), the study assumed that all districts of Maasai Steppe were potential for attracting tsetse flies. For this reason, background data were sampled from the whole study area (Phillips *et al.*, 2009; Peterson *et al.*, 2011; Bradley, 2016).

4.3.3 Climate layers

Predictive models of tsetse species distribution were made using the occurrence data and current climate variables (Table 7). The initial candidate layers considered in the model were elevation, precipitation of the wettest month (April), mean maximum temperature of the warmest month (February), mean maximum temperature of the driest month (September) and mean minimum temperature of the coldest month (July). Both maximum and minimum temperature affects tsetse fly activity patterns and plays an important role in determining the development of tsetse flies at each life stage (Hargrove, 2001; Hargrove, 2004). Since tsetse flies rely entirely on blood meals, no information is known on effects of precipitation on tsetse fly species except reports that indicate fluctuation of abundance during rainy season (Van Den Bossche and De Deken 2002; Sindato *et al.*, 2007; Lukaw *et al.*, 2014). However, it is thought that rainfall, apart from maintaining vegetation and humidity for tsetse fly to thrive, it also affects tsetse fly species indirectly by causing local flooding which may drown pupae that are buried in loose soil (Pollock, 1982) and so it was included in predictor variables. Elevation, which is a proxy for temperature, was also used as a predictor variable in order to gain insight regarding the potential altitude limit for tsetse fly species.

Models created using current climate variables were mapped on to future climate layers to understand how changing climate might influence tsetse distribution and thereby trypanosomiasis risk. For the future climate projection scenario (year 2050), this study used 833.33m resolution Coupled Model Inter-comparison Project (CMIP5) global circulation model (GCM). General Circulation Models (GCM) are detailed grid-based simulations of weather that use atmospheric physics to predict events over time (hourly, daily and even longer periods of time). Of recently the GCMs have become popular and more reliable as the knowledge of physics of the atmosphere and computational capacity of computers increases. Normally, the GCM experiments apply forcing and CO_2 (carbon dioxide emissions added to the atmosphere through human activities such as burning fossil fuels, farming etc) is considered a primary variable. Levels of expected carbon emissions are referred to as emission scenario and so each scenario is grounded on a number of assumptions such as choices world community might make regarding steps to minimize carbon emissions (IPCC SRES, 2000). Already the IPCC (Intergovernmental Panel on Climate Change) has developed and used sets of socio-economic based scenarios (such as the ones documented in the Special Report on Emissions Scenarios (IPCC SRES, 2000) that represent the possible carbon emissions to the atmosphere for the next 100 years. Of lately, a set of scenario, termed representative concentration pathways (RCP) have been established in order to provide a range of possible futures for the progression of atmospheric composition (Moss *et al.,* 2010). Unlike socio-economic based scenarios, RCPs are largely based on different scenarios of atmospheric radiative forcing. Four RCPs have been defined; low scenario (RCP 2.6), two intermediate (RCP 4.5 and RCP 6) and the highest (RCP 8.5). The number indicates the equivalent top of the tropopause change in radiative forcing in the year 2100 (Jack and Kloppers, 2016). Of the many possible GCMs to use, CMIP5 was chosen because the CMIP5 models are relatively more advanced (fine-tuned) and they use RCP scenario compared to previous GCMs that were used in the IPCC’s Fourth Assessment Report (AR 4) or other earlier report that were released in or before 2010. In particular, BCC-CSM1-1model was used and the RCP 4.5 was selected for this study. The BCC-CSM1-1 (The climate system models from Beijing Climate Center) was chosen for this analysis because it’s among the models that have been suggested to capture the key processes relevant to our study area (Jack and Kloppers, 2016). Although there is uncertainty associated with any future climate scenario, these data provide reasonable predictions that can be useful for planning.

Table 7: Candidate covariates used in initial model runs and the unbolded ones used in the best performing MaxEnt models.

Variable	Type	Units	Resolution	source
Precipitation of the wettest month (April)	Continuous	ml	833.33m	http://www.worldclim.org
Mean maximum temperature of the warmest month (Feb)	Continuous	^{0}C*10	833.33m	http://www.worldclim.org
Mean minimum temperature of the coolest month (July)	Continuous	^{0}C*10	833.33m	http://www.worldclim.org
Altitude/elevation	Continuous	msl	833.33m	http://www.worldclim.org
Mean maximum temperature of the driest month (September)	**Continuous**	**^{0}C*10**	**833.33m**	**http://www.worldclim.org**

4.4 Modelling procedures

In order to minimize the use of correlated variables that may mask contribution of individual variables and cause difficulties in results interpretation (Elith *et al.,* 2011; Hijmans and Elith, 2013), pairwise collinearity tests of predictor variables was performed using ENMTool 1.4.3 (Phillips *et al.,* 2006; Warren *et al.,* 2010). Temperature variables and altitude were highly correlated but mean minimum and maximum temperature of coldest and warmest month respectively were maintained because of their high biological relevance to tsetse fly species (Hargrove, 2004). Altitude was also maintained so as to gain insights regarding the elevation limits of tsetse fly species distribution. Mean maximum temperature of the driest month was omitted from analysis because of the relatively lower knowledge of biological values of dryness to tsetse fly. For any specific species and spatial dataset, models could potentially be improved by individually adjusting climate predictors or by choosing from a wider array of climatic predictors (Hijmans *et al.,* 2005; Hijmans and Graham, 2006). However, for consistency between species and distribution datasets, in this study the same climate predictors for current and future projection were used (Bakkenes *et al.,* 2002; Kutywayo *et al.,* 2013; West *et al.,* 2015).

For each tsetse fly species, this study used maximum entropy method to model the probability of species occurrence based on species specific occurrence point (Phillips *et al.,* 2006). Sample bias file was excluded in the model with the assumption that tsetse flies are likely to be present in large part of the study area due to widely spread of hosts (Msoffe *et al.,* 2011b; Daffa *et al.,* 2013). Because there were more than 15 occurrence points, MaxeEnt was run using linear, quadratic and hinge features (Bateman *et al.,* 2012). The model was set to run with 500 iterations and 10 replicates with default parameters regularization and the jackknife estimates (measure of variable influence).

4.5 Model assessment

Four variables were included in MaxEnt along with the *G. morsitans, G. pallidipes and G. swynnertoni* occurrence data. An initial SDM was run in MaxEnt (one run; raw output setting) to acquire lambda values used in ENMTools v.1.4. 3 (Warren *et al.,* 2010) to calculate Akaike's Information Criterion (both AICc and AIC) and Bayesian information

Criterion (BIC) (Anderson and Burnham, 2002) for a model fit with four, three and two variables, respectively (Table 8). This method selects the fitted approximating model (the most parsimonious model). The model that was most parsimonious in this study (lowest AIC, AICc, BIC and high area under the receiver operating curve (AUC) value) had all four variables: precipitation of the wettest month, mean maximum temperature of the warmest month, mean minimum temperature of the coldest month and altitude. The best model for each species was validated using 10 fold cross validation, with the averages of 10 model runs representing the final output. Model performance as well as the contribution of predictor variables were assessed by using AUC and variable importance was assessed using the relative gain contribution of each variable and jackknife tests compared using AUC, test gain and regularized training gain. Marginal and single variable response curve were used to depict the relationship between different tsetse fly species and predictor variables. Final outputs included predictive maps of the probability of tsetse species presence based on climate suitability.

4.6 Results

4.6.1 Model selection

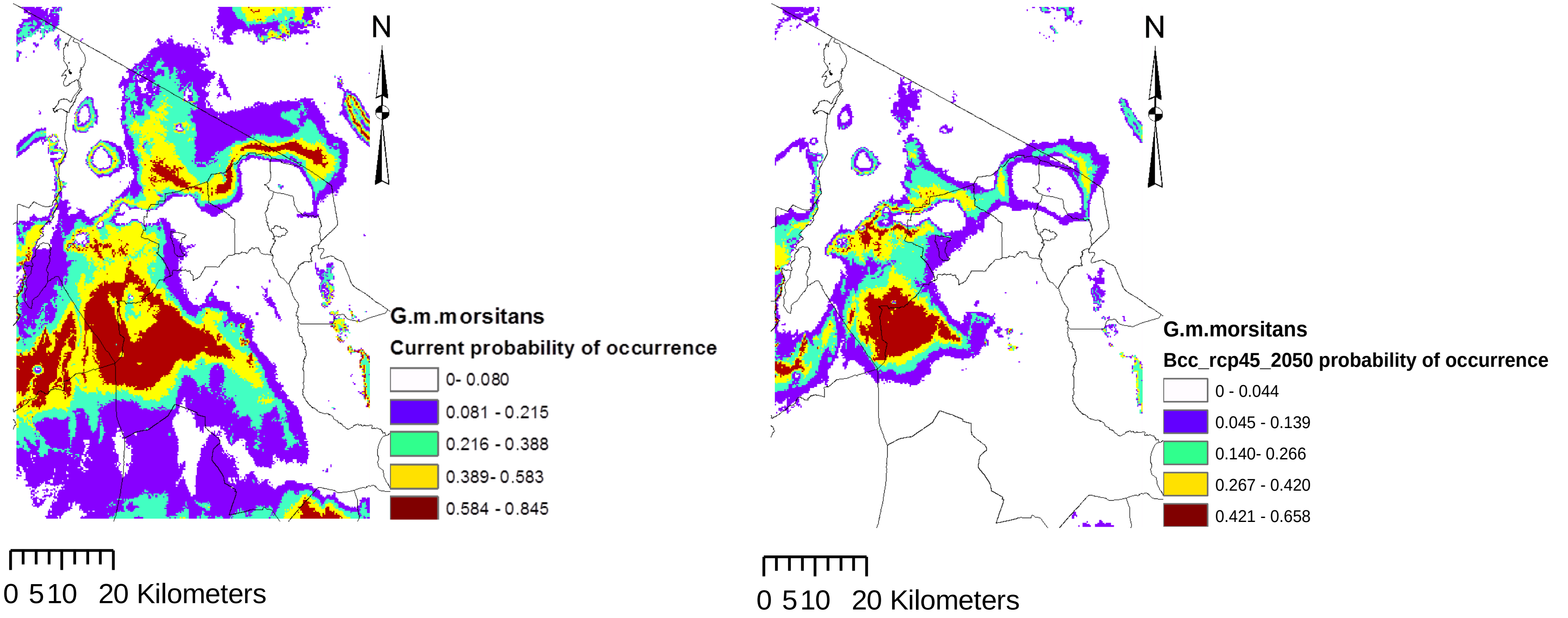
The distribution models for each tsetse fly species performed better than base/random (AUC>0.5). The model that included all four predictor variables performed the best (Table 8), and the results presented in all subsequent sections are based on that model.

Table 8: Model performance based on AUC, AIC, AICc and BIC values for tsetse fly species occurrence and different combinations of the environmental variables.

Species	*Model assessment*	*Tmax of warmest month Tmin of coldest month*	*Precipitation of the wettest month Tmax of warmest month Tmin of coldest month*	*Altitude Precipitation of the wettest month Tmax of warmest month Tmin of coldest month*
G.m.morsitans	***AUC***	0.850	0.902	0.938
	AIC	702.78	667.27	625.79
	AICc	709.04	680.47	642.21
	BIC	714.51	683.39	643.38
G. pallidipes	***AUC***	0.818	0.919	0.959
	AIC	1302.59	1198.26	1108.75
	AICc	1304.79	1202.85	1115.54
	BIC	1317.13	1219.04	1133.68
G.swynnertoni	***AUC***	0.840	0.854	0.899
	AIC	624.99	614.66	576.83
	AICc	630.32	626.88	601.09
	BIC	634.56	628.33	594.60

4.6.2 Variable contribution and climate suitability map for *G. m morsitans*

Altitude accounted for more than one third (35.1%) of the variation in climate suitability model for *G. m. morsitans* occurrence, followed by precipitation of the wettest month (32.1%), maximum temperature of the warmest month (22.3%), and minimum temperature of the coldest month (10.6%). Based on 10 percentile training presence logistic threshold (10% minimum threshold), the model showed that current suitable climate for *G.m.morsitans* covers 32% (19 225 km^2) of the entire Maasai Steppe (≈ 60 000 km^2) and in the future (year 2050) the model indicated the suitable area will shrink to 7.4% (4447.34 km^2) of the current suitable area in the Maasai Steppe (Fig. 16a, b).



a) Current climate suitability map for *G.m.morsitatns*

b) 2050 Climate suitability map for *G.m.morsitatns* based on RCP 4.5

Figure 16: Current and future (2050) climate suitability maps for the best performing model with the *G.m.morsitans* occurrence data, and all 4 environmental variables: elevation, precipitation of the wettest month (April), mean maximum temperature of the warmest month (February), and mean minimum temperature of the coldest month (July).

Variable response curves indicated that the probability of occurrence of *G.m.morsitans* drops off dramatically above 1000 m of altitude when all variables are included in the model (Fig. 17, Column A (i)), but a very peaked response to altitude ≈ 1200 msl and almost no probability of occurrence above 2500 msl when that is the only variable considered (Fig. 17, Column B (i)). Marginal and single variable response curves were however similar for precipitation of the wettest month, showing a preference (probability of presence ≥ 0.6) for precipitation between 140-230 mm per month, and almost no chance of occurrence below 100 mm/month or above 350 mm/month (Fig. 17 column A (ii) and B (ii)). The probability of occurrence of *G.m.morsitans* drops off dramatically above 28^0C maximum temperature when all variables are included in the model (Fig. 17, Column A (iii)), but, a peaked response to maximum temperature of ≈ 28^0C for the mean maximum temperature of the warmest month, and almost no chance of occurrence below 15^0C or above 32^0C maximum temperature (Fig. 17, Column B (iii)) when used as the only variable. The probability of occurrence of *G.m.morsitans* drops off dramatically above 14^0C minimum temperature when all variables are included in the model (Fig. 17, Column A (iv)), but, a very peaked response to minimum temperature of ≈ 13^0C for the mean minimum temperature of the coldest month and almost no chance of occurrence below 0^0C or above 16^0C minimum temperature when used as the only variable (Fig. 17, Column B (iv)).

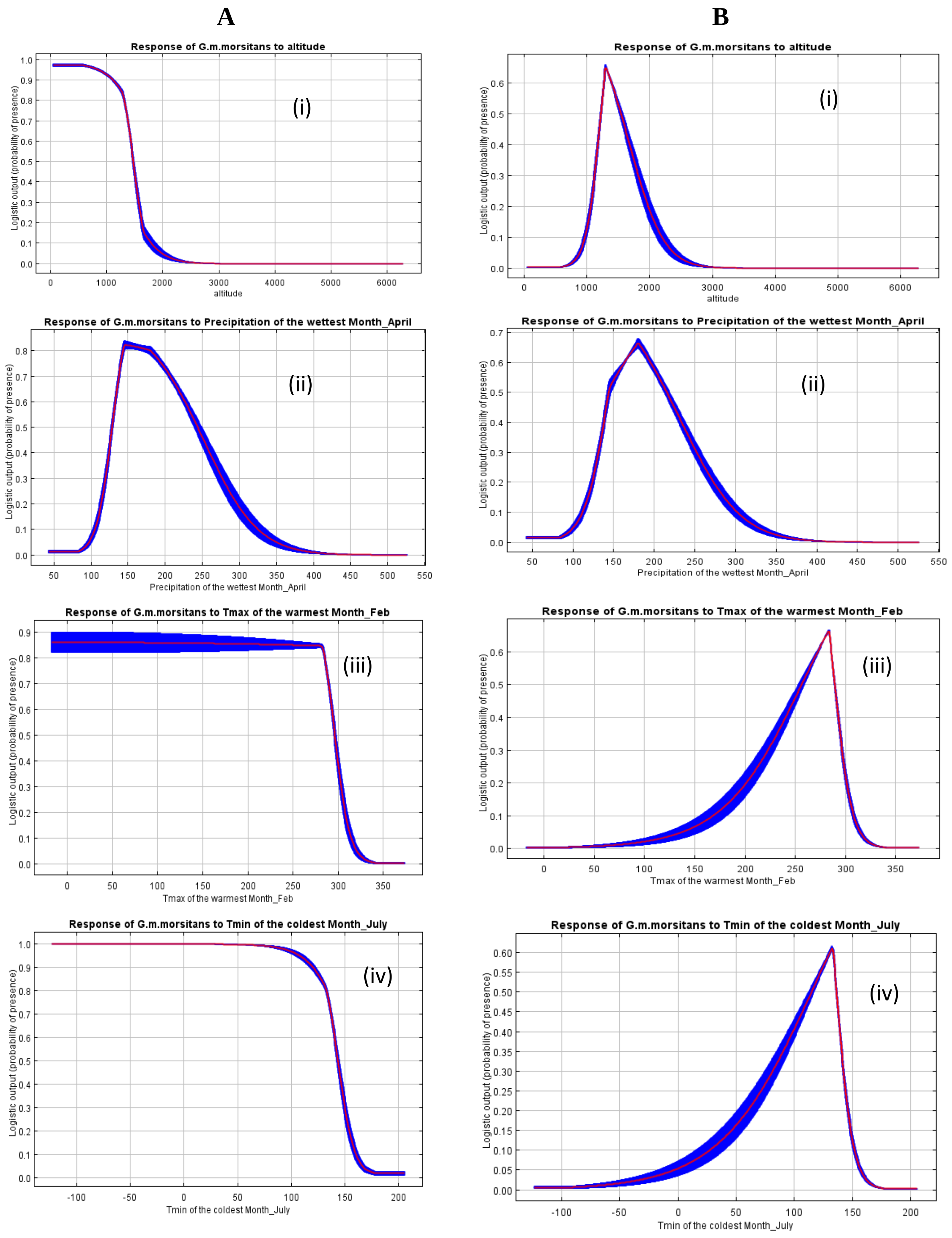


Figure 17: Column A shows marginal response curves and Column B single variable response curves for the best performing model with *G.m.morsitans* occurrence data. Temperature is reported in ^{0}C * 10.

Although altitude accounted for over one third of variation in climate suitability model for *G. m. morsitans* occurrence, maximum temperature of the warmest month provided the best fit to the training model when used in isolation; therefore, it appears to have the most useful information. Precipitation of the wettest month appeared to have most information that is not captured by other variables and thus decreases the gain the most when omitted. Maximum temperature of the warmest month also indicated the best fit to the *G. m. morsitans* test data and best predicted the distribution of the test data as indicated in the jackknife of AUC (Fig. 18).

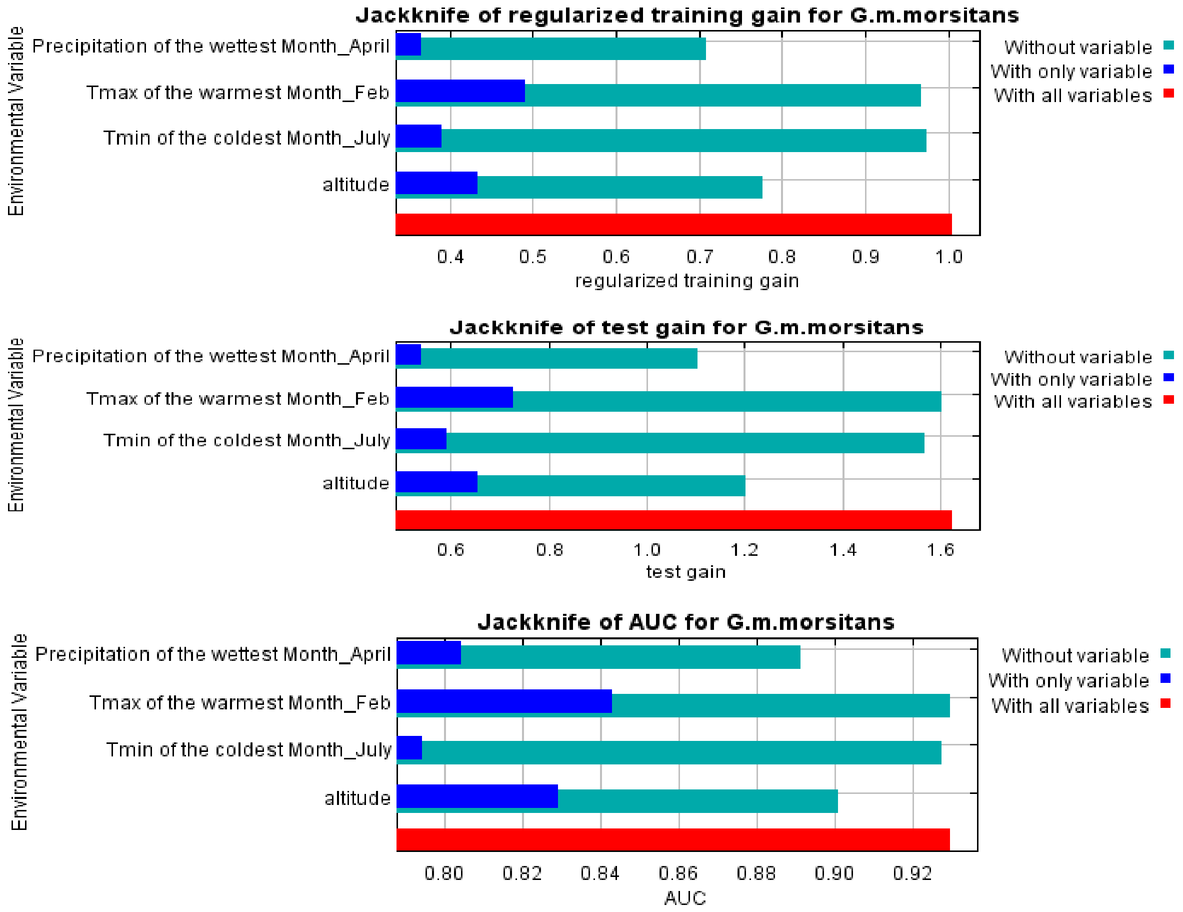
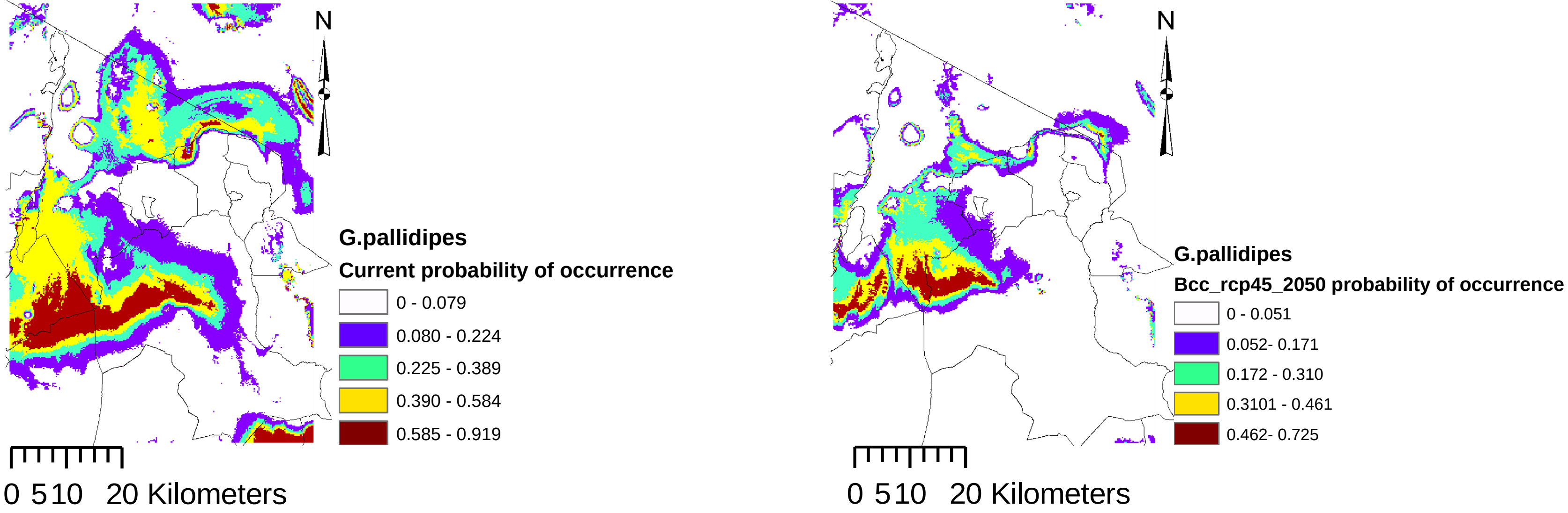


Figure 18: Jackknife estimates of variable importance for the best-performing model for *G.m.morsitans*. Variable performance is assessed via the variables’ impact to training and test gain (top and middle) and AUC (bottom).

4.6.3 Variable contribution and climate suitability map for *G. pallidipes*

Precipitation of the wettest month accounted for more than two thirds (60.4%) of the variation in climate suitability, followed by altitude (23%) and maximum temperature of the warmest month (16.6%). Based on 10 percentile training presence logistic threshold, the model showed that current suitable climate for *G.pallidipes* covers 11% (7113 km^2) of the Maasai Steppe and by 2050, the model indicated only 918 km^2 with suitable climate for this species (Fig. 19a, b).



a) Current climate suitability map for *G.pallidipes*

b) 2050 Climate suitability map for *G.pallidipes* based on RCP 4.5

Figure 19: Current and midcentury (2050) climate suitability map for the best performing model with the *G.pallidipes* occurrence data, including all 4 variables**.**

Variable response curves indicated that the probability of occurrence of *G.pallidipes* drops off dramatically above 1000 m of altitude when all variables are included in the model (Fig. 20, Column A (i)), but a very peaked response to altitude ≈ 1200 msl and almost no probability of occurrence above 3000 msl when that is the only variable considered (Fig. 20, Column B (i)). Marginal and single variable response curves were similar for precipitation of the wettest month, showing a preference (probability of presence ≥ 0.6) for precipitation between 140-180 ml per month, and almost no chance of occurrence below 120 mm/month or above 330 mm/month (Fig. 20 column A (ii) and B (ii)). The probability of occurrence of *G.pallidipes* drops off dramatically above 28^0C maximum temperature when all variables are included in the model (Fig. 20, Column A (iii)), but, a peaked response to maximum temperature of ≈ 28^0C for the mean maximum temperature of the warmest month, and almost no chance of occurrence below 10^0C or above 34^0C maximum temperature (Fig. 20, Column B (iii)) when used as the only variable. The probability of occurrence of *G.pallidipes* drops off dramatically above 10^0C minimum temperature when all variables are included in the model (Fig. 20, Column A (iv)), but, a very peaked response to minimum temperature of ≈ 13^0C for the mean minimum temperature of the coldest month and almost no chance of occurrence below -5^0C or above 17^0C minimum temperature when used as the only variable (Fig. 20, Column B (iv)).

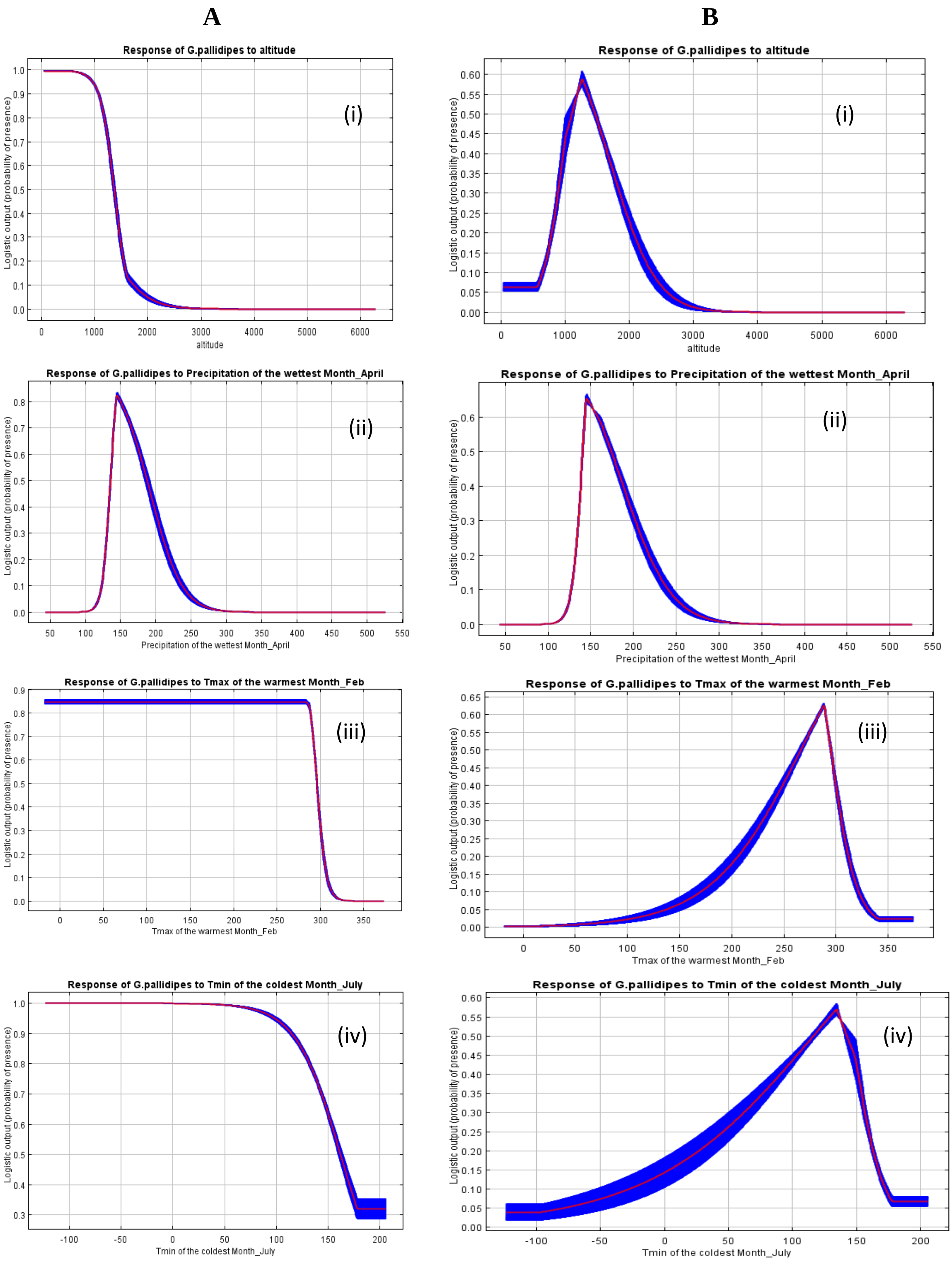


Figure 20: Column A is marginal response curves and Column B is single variable response curves for the best performing model with *G.pallidipes* occurrence data. Temperature is reported in ^{0}C * 10.

Precipitation of the wettest month provided the best fit to the training data when used in isolation. This variable also appears to have the most information that is not present in the other variables, as it decreases the gain the most when it is omitted. Yet, precipitation of the wettest month indicated the best fit to the test data and best predicted the distribution of the *G. pallidipes* test data as indicated in the jackknife of AUC (Fig. 21).

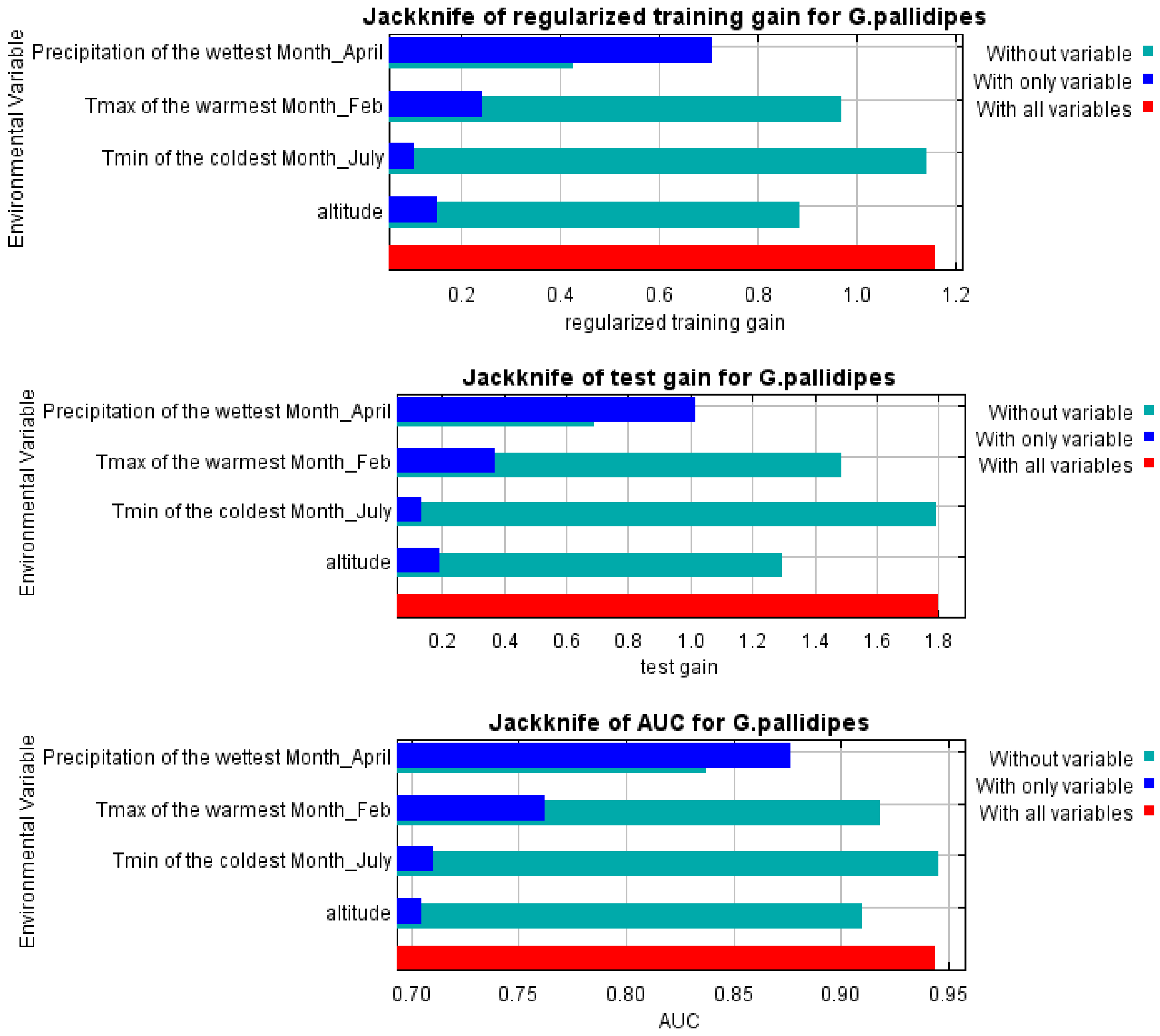
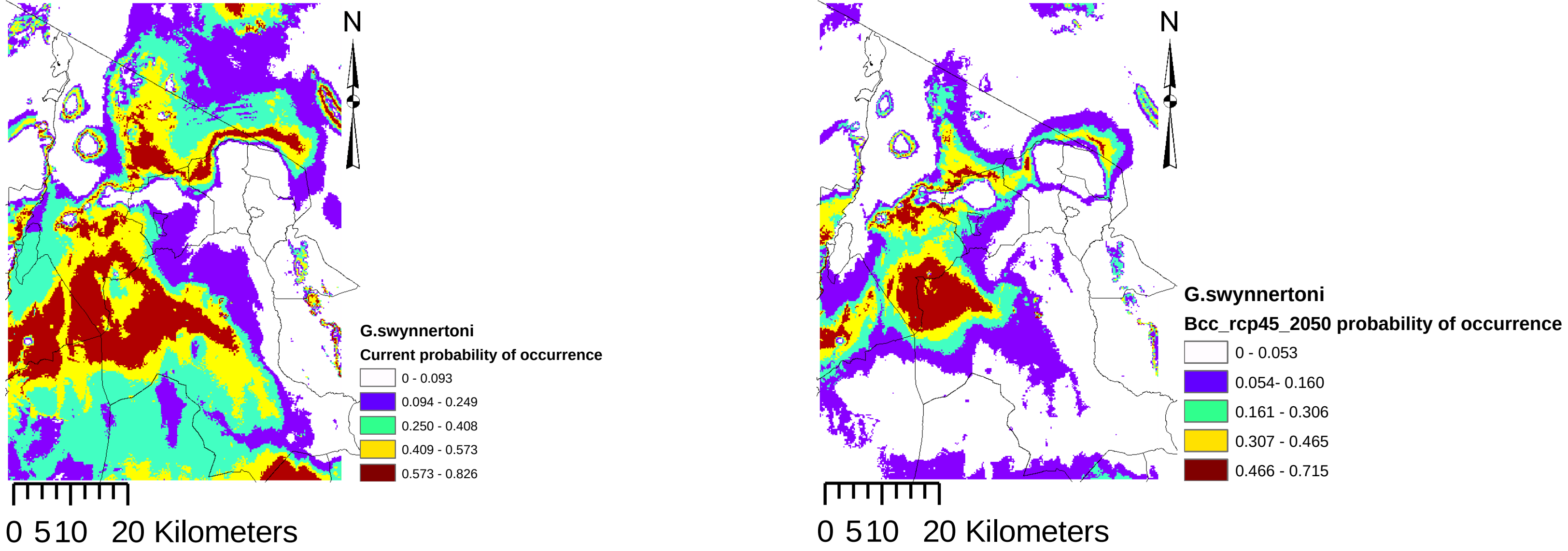


Figure 21: Jackknife estimates of variable importance for the best-performing model for *G. pallidipes*. Variable performance is assessed with training and test gain (top and middle) and AUC (bottom).

4.6.4 Variable contribution and climate suitability map for *G. swynnertoni*

Altitude contributed almost a half (47.5%) of the variation in climate suitability for *G. swynnertoni* occurrence, followed by precipitation of the wettest month (27.4%), minimum temperature of the coldest month (22%), and maximum temperature of the warmest month (3.1%). Based on 10 percentile training presence logistic threshold, it was revealed that, current suitable climate for *G. swynnertoni* covers 32 335 km^2, but is predicted to shrink to 7374 km^2 by the year 2050 (Fig. 22a, b).



a) Current climate suitability map for *G.swynnertoni*

b) 2050 climate suitability map for *G.swynnertoni* based on RCP 4.5

Figure 22: Current and midcentury (2050) climate suitability maps for *G. swynnertoni*, for the model including all four predictor variables

Variable response curves indicated that the probability of occurrence of *G.swynnertoni* drops off dramatically above 1000 m of altitude when all variables are included in the model (Fig. 23, Column A (i)), but a very peaked response to altitude ≈ 1300msl and almost no probability of occurrence above 2500 msl when that is the only variable considered (Fig. 23, Column B (i)). Variable response curves indicated that the probability of occurrence of *G.swynnertoni* drops off dramatically above 140 ml of rainfall when all variables are included in the model (Fig. 23, Column A (ii)), but a very peaked response to precipitation ≈ 160 ml for the precipitation of the wettest month and almost no probability of occurrence above 400 ml/month or below 90 ml/month when that is the only variable considered (Fig. 23, Column B (ii)). The probability of occurrence of *G.swynnertoni* drops off dramatically above 28^0C maximum temperature when all variables are included in the model (Fig. 23, Column A (iii)), but, a peaked response to maximum temperature of ≈ 28^0C for the mean maximum temperature of the warmest month, and almost no chance of occurrence below 10^0C or above 34^0C maximum temperature when used as the only variable (Fig. 23, Column B (iii)). The probability of occurrence of *G.swynnertoni* drops off dramatically above 14^0C minimum temperature when all variables are included in the model (Fig. 23, Column A (iv)), but, a very peaked response to minimum temperature of ≈ 14^0C for the mean minimum temperature of the coldest month and almost no chance of occurrence below 0^0C or above 16^0C minimum temperature when used as the only variable (Fig. 23, Column B (iv)).

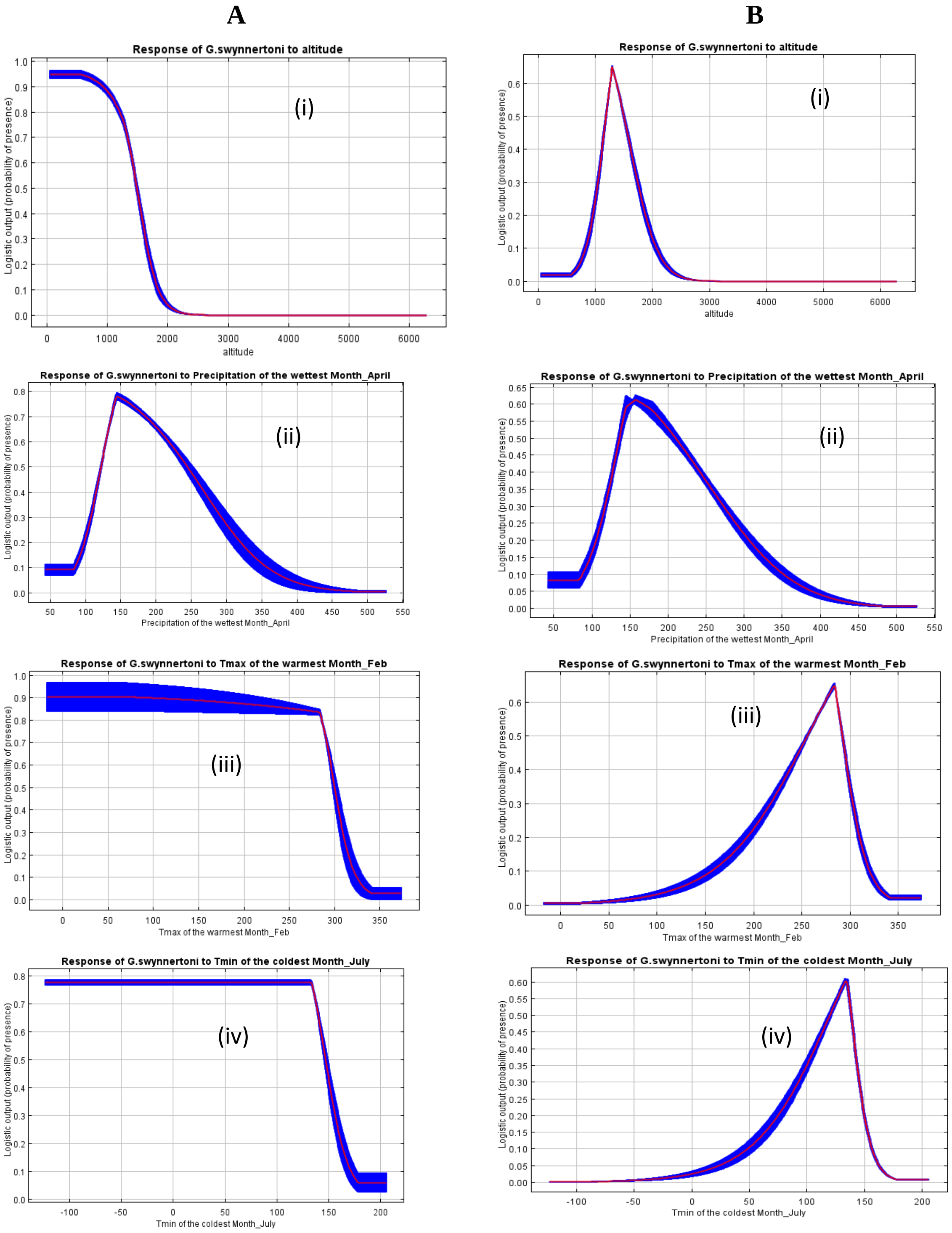


Figure 23: Column A is marginal response curves and Column B is single variable response curves for the best performing model with G.*swynnertoni* occurrence data. Temperature is reported in ^{0}C * 10.

The best fit to the *G.swynnertoni* training data was provided by altitude when used by itself. Altitude indicated the best fit to the test data and best predicted the distribution of the *G swynnertoni* test data as indicated in the jackknife of AUC. Also, omission of this variable decreases the gain the most, meaning altitude had most information that is not present in other variables (Fig. 24).

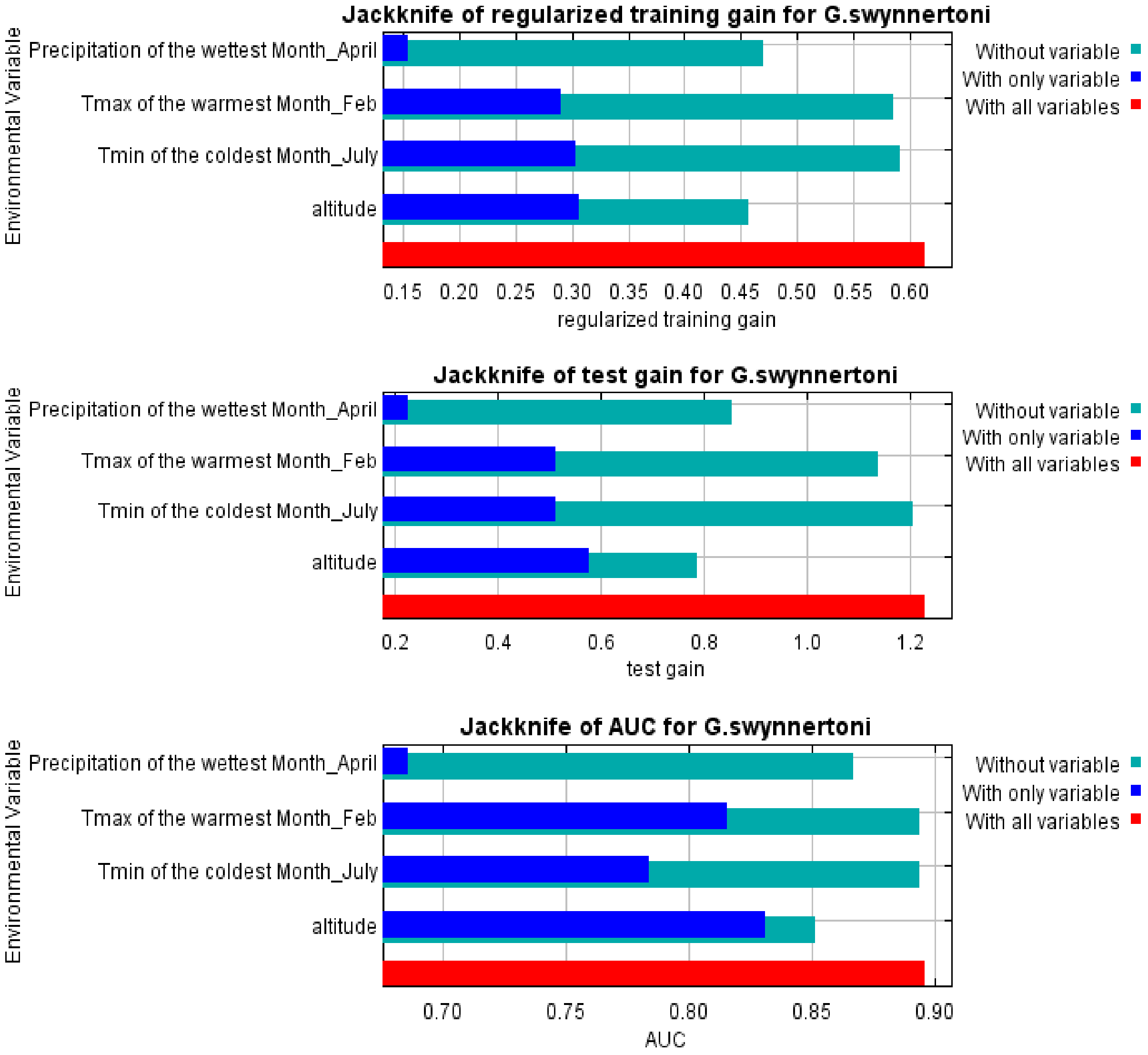


Figure 24: Jackknife estimates of variable importance for the best-performing model for *G. swynnertoni*. Variable performance is assessed with training and test gain (top and middle) and AUC (bottom)

4.7 Discussion

This study used MaxEnt species distribution modelling to understand the influence of climate variables on tsetse fly species occurrence, and make predictions about future distribution based on predictive climate models. The models yielded current and future potential habitat distribution maps for *G.m.morsitans, G.pallidipes and G. swynnertoni*, and predicted an overall reduction in the area of the Maasai Steppe that will be suitable for the *Glossina* species, with relatively smaller areas becoming more suitable. Compared to current conditions, in the year 2050, area with suitable climate will decline to 23.13%, 12.9% and 22.8% of current suitable area for *G. m. morsitans*, *G.pallidipes* and *G.swynnertoni,* respectively. These findings complement the Rogers and Packer (1993) suggestion that change in climate in some parts of East Africa would result in overall reduction of suitable range for tsetse flies, but also a spread out of suitable range particularly in high-altitude areas that currently exclude the species due to low temperatures. Hulme (1996) also predicted a contraction of *G. m.morsitans* geographic range owing to climate change expected to affect SADC region. The reason for this can be found in the variable response curves, which indicate thresholds of suitability, as in the *G. m.morsitans, G.pallidipes* and *G. swynnertoni* responses to most significant climatic variables mean minimum and maximum temperature. Specifically 34^0C mean maximum temperature of the warmest month appeared to be the maximum temperature upper threshold while 17^0C mean minimum temperature of the coldest month appeared to be a maximum lower threshold for all three tsetse fly species. Therefore the range reduction across the Maasai Steppe can be attributed to future climates exceeding these thresholds. This finding is supported by other studies that predict that, by mid of the century, maximum temperature will rise by 1.7^0C in the Maasai Steppe (Jack and Kloppers, 2016). Furthermore, the existence of temperature thresholds that influence tsetse distribution and abundance has been showed in other studies from the Maasai Steppe, based on intensive longitudinal sampling over smaller geographic areas (Nnko *et al.,* 2017).

The distribution of *Glossina species* has been explained in previous studies primarily by climate (Rogers and Randolph, 1986; Rogers *et al.*, 1996; Hargrove, 2001; Hargrove, 2004; Moore and Messina, 2010; Albert *et al.,* 2015). *G.m.morsitans, G. pallidipes* and *G.swynnertoni* are groups of tsetse flies whose relative abundance tends to decrease with high temperature. My model forecasts climate suitable habitat for all three tsetse fly species will shrink in the Maasai Steppe by 2050 under RCP 4.5, suggesting populations of these species may crash or may respond to increasing maximum temperatures by moving upward in elevation. In fact, the models predicted a suitable altitude for *G.m.morsitans*, *G.pallidipes* and *G. swynnertoni* from around 1000 msl currently observed, to around 2500 m, 3000 m and 2500 m elevation, respectively, indicating these species may become problematic in subalpine ecosystems of the study area if other ecological requirements for these species will be met in those habitats.

The importance of the four variables that were selected through our parsimony analysis to the ecology of the three *Glossina* species indicates the importance of careful scrutiny of available environmental data for a study site of interest. Although there was variation in variable contribution to specific species model, mean maximum temperature of the warmest month and mean minimum temperature for the coldest month indicated similar response curve. Specifically, mean maximum temperature of the warmest month, and mean minimum temperature of the coldest month have relevant ecological importance to the distribution of tsetse fly species. For example, the logistic probability response curves indicated higher maximum temperature of the warmest month and higher minimum temperature of the coldest month decreases likelihood of all three *Glossina* species occurrence, likely because, both low and high temperatures affect development of all three tsetse species at various life stages (Hargrove, 2001). Effects of hotter and colder environments on various developmental stages of tsetse fly species has also been reported (Torr and Hargrove, 1999; Terblanche *et al.,* 2008).

Logistic probability response curves indicated higher precipitation during the wettest month decreases the likelihood of occurrence of the three *Glossina* species considered in this study. Generally, no record is known on direct effect of rainfall on tsetse fly, but, it is thought that high rainfall may affect tsetse fly species indirectly by causing local flooding which may drown many pupae that are buried in loose soil, leading to population declines and thus low probability of occurrence. Rainfall also play important role in maintain vegetation and humidity for tsetse fly to thrive (Pollock, 1982).

Although responses to this variable indicated similar trend in all three species, the importance of the variable in models for the different species varied dramatically. For example, precipitation of wettest month contributing over two thirds (60.4%) of the relative gain to the *G. pallidipes* model and also providing the best fit to the model, indicating that the species can respond differently to the climate variables. In particular, precipitation in the wettest month may be more important to the distribution of *G. pallidipes* owing to the species' ecology. *G. pallidipes* is strongly associated with wetter riverine habitats, and so relatively hydrophilic, unlike *G.m.morsitans* and *G. swynnertoni.* Also *G. pallidipes*' ability to thrive at low relative abundance in different areas and under mild climatic conditions (Pollock, 1982) influences their occurrence.

In all three tsetse fly species models, altitude had a relatively high contribution to the model gain, but did not necessarily provide the best fit to the training model. For example, altitude contributed 35.1% of relative gain to the *G.m.morsitans* model and 23% for *G. pallidipes* respectively. However, the best fit to the training models for these two species were provided by mean maximum temperature of the warmest month and precipitation of the wettest month. This may be because temperature and rainfall have more biological relevance to tsetse flies compared to altitude. Although altitude indicated high contribution (47.5%) to the *G. swynnertoni* model and also had the best fit, it should however be noted that all occurrence points were obtained at a relatively lower altitudes and this might have influenced the results. Nevertheless, all *Glossina* species responded similarly to altitude, with response curves for all species indicating low preference for higher altitude. This is because higher altitudes are characterized by lower temperature that affects tsetse fly development (Hargrove, 2004). Furthermore, because altitude is a proxy for temperature and the two variables are correlated, it is possible that including altitude in the model could have masked the contribution of variables with greater biological relevance (Elith *et al.,* 2011). However, because relationships between tsetse flies and temperature are well-established (Hargrove, 1980; Rogers, 1988; Hargrove, 2001; Hargrove, 2004; Terblanche *et al.*, 2008), altitude was included in the models in order to gain insight into how tsetse fly species are likely to expand their range to higher elevations under future increases in temperature.

Extrapolated over larger areas, my findings could indicate either decreases in suitable tsetse climate or a shift in geographical range. Likewise, predictions of climate impacts of tsetse distribution in Africa do not all agree. Rogers and Packer (1993) suggested that change in climate in some parts of East Africa would result in a spreading out of suitable range for tsetse flies particularly in high-altitude areas that currently exclude the species due to low temperatures, but also there is a chance of range contraction of tsetse flies in some location. Other reports have suggested a decline in the distributional range of tsetse species owing to climate change. For example, under various future climate change scenarios for instances, *G. morsitans* in southern Africa is expected to experience a contraction of its geographic range due to decrease in suitable temperature (Hulme, 1996). Furthermore, it should be noted that climate variables are not likely to be the sole predictors of future tsetse distribution. Other factors such as host availability and suitable habitat will also influence where tsetse are found, but are more difficult to model into the future. Distribution maps based on relationships with climate variables can therefore be considered to be maximum potential distributions.

Tsetse fly occurrence poses public health challenges and exacerbates economic hardships due to the investment an individual and community needs to make to control tsetse flies and treat the diseases they transmit (HAT and AAT). Since climate is one of the dominant factors that determines tsetse fly occurrence, and the resources for controlling tsetse and trypanosomiasis are scarce, understanding how the changes in climate at local scale affects the spatial and temporal distribution of tsetse fly species is critical in identifying the most likely vulnerable places, and better targeting limited resources. The SDM used in this study provides useful information for public health and livestock development stakeholders to plan for future potential climates effects across space and time. Although the findings of this study are based on only a single GCM model, BCC-CSM1-1 from CMIP5 is expected to have better predictive capacity because it uses RCP and at a relatively finer resolution of about 1km. The fact that these findings agree with previous findings reported by Rogers and Randolph (1993) and Hulme (1996) that used relatively older GCM version, increase the confidence that climate is more likely to push distribution of tsetse flies into new areas, while removing it from others. For this reason, maps produced by this study can improve the efficiency and lower the cost of future surveys. Also, the methods employed by this study can be adopted to generate high resolution species distribution maps under current and future climate scenarios for larger areas and for other vectors that pose threats to both public health and economic development. Tsetse fly control managers can incorporate the maps created from these models into integrated pest management regimes, and further tailor them based on what is already known about Maasai Steppe. Finally, maps such as these may be displayed to the public to increase awareness of climate change implications in the Maasai Steppe and other areas that are tsetse infested.

4.8 Limitation of the study

In order to broaden understanding of future trypanosomiasis dynamics, addition of tsetse fly physiology, biology data aspects of hosts and vegetation in prediction is important; however availability of this massive and complex data was a limitation of this study.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 General discussion

This chapter summarizes all the findings from previous chapter and generally discusses the implications of those findings for the study area.

5.1.1 Pastoralists' vulnerability to trypanosomiasis and adaptation strategies

Trypanosomiasis has long been a significant problem of pastoralists of the Maasai Steppe, and the problem is exacerbated by changes in climate and land use patterns. The burden of this disease may exaggerate poverty amongst the Maasai communities who recently adopted more sedentary lifestyles. Although the problem affects large parts of the Maasai Steppe, some locations are more vulnerable than others due to uneven geographical distribution of trypanosomiasis risk factors and adaptive capacity of individuals and communities. Because resources for controlling tsetse and trypanosomiasis are generally scarce, being able to target the places most vulnerable to trypanosomiasis is imperative. Understanding the potential impacts of climate on tsetse fly distribution in space and time is one way to achieve this and facilitate planning of coherent strategies for vector and disease control relative to existing risks. The aims of this study were therefore (i) to assess pastoralists' vulnerability and adaptation strategies to trypanosomiasis, (ii) to examine seasonal variation of tsetse fly species abundance and their infection rates, and (iii) to use climate data to predict current and future hotspots of trypanosomiasis vectors. This study established that levels of vulnerability to trypanosomiasis were higher in wards situated closer to wildlife protected areas and most of these wards (Emboreet, Loibor-Sireet and Terrat) were found in Simanjiro district. The most commonly-cited impacts of trypanosomiasis were low milk production (95.6%, n = 136), death of livestock (96.8%, n = 136) and body emaciation of animals (99.9%, n = 136). Supplementing pastoralism with crop farming was the most popular adaptation strategy (66%, n = 136). Assessment of temporal dynamics of tsetse flies and trypanosomes revealed that drier months were generally more risky and thus associated with higher risks of trypanosomiasis transmission than others. This study also established that more than half of the Maasai Steppe area has conducive climate for tsetse fly species to thrive, but by the year

2050 this range will shrink because of unfavorable climate primarily associated with increasing temperature.

High levels of vulnerability to trypanosomiasis in some wards in Simanjiro and Monduli districts is supported by Simwango (2016) who reported high trypanosome prevalence in tsetse flies and cattle in these wards. Also, most respondents graze their cattle in wildlife-livestock interface areas which increases the likelihood of being bitten by tsetse flies that have fed on infected hosts, and therefore risks of contracting the disease (Malele, 2011). These findings imply that the most vulnerable wards are in the areas that have less capacity to adapt to trypanosomiasis while they are more exposed to trypanosomiasis risk factors. For this reason, any interventions that intend to improve the community resilience to trypanosomiasis in these districts may consider improving adaptive capacity such as human and veterinary health infrastructures, literacy rate.

On the hand, reported impacts of trypanosomiasis in the Maasai Steppe conform to findings in Ethiopia and Morogoro, Tanzania (Nonga and Kambarage, 2009; Chani *et al.,* 2013). These impacts has potential to exaggerate existing stress of trypanosomiasis and other animal diseases due to the fact that, pastoralists meet most of their need through livestock and thus any impacts that lead to inability to meet production inputs expose pastoralists' to multiple stressors and thus increase their vulnerability.

Since livestock play an important role in the livelihood of Maasai pastoralists and trypanosomiasis is endemic in the Maasai Steppe, high pastoralist awareness of animal African trypanosomiasis was expected. Jacob *et al.* (2004) and Chengula *et al.* (2013) also reported high Maasai pastoralists' knowledge on various livestock diseases including trypanosomiasis. This implies that the local knowledge can be integrated in the understanding of the trypanosomiasis dynamics and thus in tailor made fit for purpose control programs and interventions. This study revealed that respondents' decision to adapt to animal African trypanosomiasis and the choice of adaptation strategy was influenced by socio-economic factors such as level of education attained, availability of livestock extension services, years of experiences in livestock keeping and number of livestock owned. For this reason, improvement of all these factors has a potential to increase adaptive capacity of a community and thus lower vulnerability to trypanosomiasis and other stressors. Although association indicated negative relationship with adaptation decision and choice of adaptation strategy, encouragement and facilitation of social networks may improve adaptation through easy flow of information for the Maasai is a communal community.

Farming was the most popular trypanosomiasis adaptation strategy and is practiced at the expense of reducing livestock grazing areas, which can increase the potential for trypanosomiasis transmission by forcing pastoralists to graze their cattle closer to protected areas. Although farming is the preferred adaptation strategy amongst respondents in this study, crops often fail in large parts of Maasai Steppe due to shortage of rainfall and low soil nutrients (Barbara and Fouad, 1995; Nassef *et al.,* 2009; Msoffe *et al.*, 2011b). This implies that, converting grazing land for agriculture may actually increase poverty and lower pastoralists' adaptive capacity to cope with trypanosomiasis, thus increasing their vulnerability to various stressors and thus worsen livelihoods situation of the pastoralists. Moreover, other adaptation methods including wage labor and livestock selling is relatively new to Maasai culture and thus may expose them to new dimensions of vulnerability. In addition, low literacy rates represented by 69%, (n = 136) of respondents who never attended school is expected to narrow opportunities for diversifying sources of income. On the other hand, sale of livestock is contrary to the Maasai cultural practice of accumulating wealth in terms of number of livestock (Fratkin, 2001; Galvin *et al.,* 2004), and thus may accelerate cultural transformation, which could lead to new dimensions of vulnerability.

5.1.2 Climate influences on tsetse abundance and trypanosomes prevalence

In addition to identifying multiple social and ecological factors that contribute to trypanosomiasis vulnerability, this study delved deeper into one of these factors; vector abundance. In particular, the study identified three species of tsetse flies throughout the study area: *G. m. morsitans, G. pallidipes and G. swynnertoni*. All three species indicated seasonal variation in their relative abundance that also appeared to be mainly associated with a negative effect of minimum and maximum temperature, though a disparity was observed between species. *G.swynnertoni* was the most dominant species and this finding conformed to those of Sindato *et al.* (2007) and Salekwa *et al.* (2014) who also reported dominance of G.*swynnertoni* in the same area. Dominance of this species may possibly suggest importance of *G. swynnertoni* in driving the epidemiology of infection in the study area, although the contribution of other species cannot be underestimated. In general, the highest catches corresponded with dry season. Relatively high abundance during dry season was also reported by Lukaw *et al.* (2014) and Sindato *et al.* (2007). During the dry season, host density may increase in certain areas with important water and grazing resources that facilitate easy access to blood meals. It’s good to point out that flies are more mobile during dry months and, thus while the catch increases, the actual abundance might remain un-changed. Equally, the frequent movement of hosts close to traps in search of pastures during dry season may have influenced the catches. For these reasons, the recorded variation in catches may not be an accurate reflection of actual abundance, but does offer insight into temporal and spatial trends in relative abundance. Nonetheless, the risk of animal trypanosomiasis transmission increases in dry season likely because interactions between vectors and hosts increase as forage and water became scarcer. These results imply that pastoralists may plan their control activities based on the season when the burden is higher, and thus practice wise allocation of scarce resources.

The reported negative relations of maximum and minimum temperature with *G.m.morsitans* and *G.swynnertoni,* respectively was expected (Hargrove, 2004) and could be attributed to the fact that both high and low temperatures lower tsetse fly activity (Torr and Hargrove, 1999; Terblanche *et al.*, 2007). *G.swynnertoni* and *G.m.morsitans* relative abundance patterns indicated different behaviour towards temperature in the different species, and, this raised the question whether, the former is more tolerant to high temperatures and the latter to lower temperatures. However there were no data from the field or published work to test these hypotheses. Nonetheless, this work has indicated the importance ot fluctuations of daily maximum and minimum temperatures influence on tsetse fly species relative abundance unlike many other studies that have based on mean temperature alone. It is expected that these findings may improve as the finer scale climate data become available for Maasai Steppe.

The observed year-round presence of trypanosomes in the vector could be due to several factors. First, resident wildlife hosts are present in the study area throughout the year; second, because adult tsetse flies feed entirely on host blood, trypanosomes are in continuous circulation in the area; and third is the fact that adult tsetse flies thrive through much of the variation in weather conditions, thus allowing risk of transmission throughout the year (Hargrove, 2004). The highest trypanosome prevalence peak lagged behind the peak of tsetse fly abundance was somehow expected (Rogers, 1988). This is partly because tsetse flies catch infections from hosts and we suspect the flies to be susceptible to low immunity during low fly abundance and vice versa, but there were no data to test this. The fact that trypanosome peak coincides with short rains which suggest widely spread of water and grasses and thus hosts (wildlife and livestock), it is likely that tsetse flies become stressed when searching for blood meal in hosts that are avoiding dense bushes and thus become less immune to trypanosomes infections, but this remains speculation as the data to prove this hypothesis were lacking. In addition, the positive temperature and trypanosome prevalence relationship was expected (Walshe *et al.,* 2009). Since tsetse fly is a poikilothermic insect, this relationship implies that, the environmental temperature is vital for trypanosomes to develop to infectious stage inside the tsetse fly. This is supported by Akoda *et al.* (2009) who reported environmental temperature as a requirement for a tsetse fly to develop mature infections. In general, hot temperatures quicken growth of trypanosome populations as it shortens the duration of the trypanosome development cycle in the tsetse fly (Moore *et al.,* 2011). In fact, this study showed that trypanosomes were not present below 26°C or above 36°C. This implies that the bound temperatures for trypanosome development can be estimated under field conditions, and the information can be used to predict when infection rate is high and the control measures can be strengthened during such periods.

5.1.3 Potential impacts of climate change on tsetse fly distribution

Assessment of potential impacts of climate change revealed that by the year 2050, area with suitable climate for tsetse fly species will decline to 23.13%, 12.9% and 22.8% of current suitable area for *G.m.morsitans*, *G.pallidipes* and *G.swynnertoni,* respectively. Reduction in suitable area for tsetse in response to climate has also been reported in East and southern Africa (Rogers and Packer, 1993; Hulme, 1996). Although overall tsetse fly range in the Maasai Steppe is predicted to shrink, tsetse flies will also likely invade new areas such as higher altitudes which were previously un-colonized due to unfavorable climate. Nonetheless, there are uncertainties associated with models derived from climate predictions, yet, these findings and previous ones indicate that there will be range shifts of tsetse fly species associated with changes in climate. For this reasons, there is a need for stakeholders to enact proactive plans so as to avoid caught up in surprises especially in areas indicating new potential risk areas for tsetse fly infestations.

5.2 Conclusions

In conclusion, tsetse fly and trypanosome occurrence poses a public health challenge and exacerbates economic hardships due to the investment an individual may need to incur for controlling and treatment of HAT and AAT. Identifying areas that are more vulnerable to this disease is a prerequisite for wise resource allocations to combat the risk of disease. Understanding temporal and spatial variation in trypanosomiasis high risk areas is equally important for planning control measures. This study have highlighted levels of vulnerability to trypanosomiasis and identified factors that are likely to reduce vulnerability. Improvement of education, extension services, keeping more livestock, and enhanced knowledge would increase adaptive capacity of the community and lower the vulnerability to trypanosomiasis. Furthermore, encouragement and facilitation of social networks in the study area may improve adaptation through easy flow of information since Maasai is a communal community. This study also highlights seasonal patterns of tsetse fly burden and trypanosome prevalence. In addition, this study predicted current and midcentury hotspots of infection based on vector distribution change. This information can inform communities on planning their cattle movement; health departments, livestock development departments and tsetse fly control units plan and carry out location specific intervention and wise allocation of scarce resources.

5.3 General recommendations

Based on the findings of this study, several important recommendations can be made to help reduce vulnerability in targeted communities.

i. Given that resources for controlling trypanosomiasis are scarce, this study recommends the use of vulnerability maps to target the most vulnerable areas so as to lessen the disease burden where adaptive capacity is low.

ii. Although this study did not identify any cases of human-infective trypanosomes (*T. brucei rhodesiense*), the fact that there is continuous presence of other trypanosome species indicates the importance of raising awareness of HAT among Maasai communities. Other studies have shown that HAT typically exists at very low prevalence (Auty *et al.,* 2012), and increased awareness of HAT is necessary to prevent the community and associated health services from being taken by surprise in case of an outbreak. Awareness of HAT could be improved by ensuring accessible and accurate diagnostic facilities along with improving local communities' knowledge on how HAT differs from other febrile diseases.

iii. Given the observed temporal patterns of tsetse and trypanosomes in the most vulnerable areas in the Maasai Steppe, this study recommends utilization of these patterns by local community in planning livestock grazing patterns so as to lower the community and livestock risks of being infected by trypanosomes.

iv. Although the predictive maps of vector distribution based on climate factors indicate an overall shrinkage of tsetse range in the Steppe by the year 2050, these predictions also indicate that some areas that are not currently suitable will become suitable. It is therefore prudent to advise communities to enact proactive plans to lower the risk of trypanosomiasis in these areas.

5.4 Recommendations for further study:

i. This study included only those trypanosomiasis risk factors in the vulnerability analysis for which I could reliably get sufficient data. However, other risk factors could be included with future studies aimed at measuring these factors quantitatively. However, complexity of quantifying the risk factors should be expected.

ii. Employ finer-resolution climate data in species models that encompass microclimate variables in establishing tsetse fly species and climate relationships.

iii. Incorporate tsetse physiology and additional aspects of tsetse ecology in predictive models to get a broader understanding of future trypanosomiasis dynamics

iv. Since hosts and vegetation are also important determinants of tsetse fly occurrence, and are also affected by climate change, incorporation of these parameters in modelling climate change impacts on tsetse fly distribution is necessary, although very complex.

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APPENDICES

Appendix 1: Checklist for District (*health, environment, disaster/emergency preparedness, livestock and tsetse fly control*) officials

1. Do you have records/history of Trypanosomiasis (HAT and AAT) in this area? **Yes [ ] No [ ]** If Yes please answer the following; (*Request for the reported cases, years and the location*)
2. What is the current burden of Trypanosomiasis? In terms of;
   Geographical distribution………………………Incidences…………Population at risk…………………
3. Do you have a facility to diagnose HAT in this area (doctors, functioning lab, and technicians)? **Yes [ ] No [ ]** If Yes, please answer the following;
4. Mention those centers/hospitals
   ……………………………………………………………………………………………
5. Do you have a program to educate community on Trypanosomiasis? **Yes [ ] No [ ],** If yes, please answer the following?
6. What is its management structure?
   ……
   ……………………………………………………………………
7. In order to identify and treat vector borne disease like Trypanosomiasis, do you have a working integrated vector management (*Please refer the table below*)

Program	Yes	No
a). educational programs for individuals/communities/ health-care workers		
b). Environmental programs		

8. Do you have surveillance and monitoring programs for Trypanosomiasis? Yes [ ] No [ ]
9. What is its management structure ?(please describe the structure on the back of this paper)
10. At present do you have capacity to address the risk of Trypanosomiasis? (Human resources, infrastructure, funds?) Yes [ ] No [ ] If yes, please explain a bit on the capacity.
    ……
    ……
    …………
11. **Based on knowledge and experience in the the wards in your district, how do you rank the following? ((To be filled by wildlife, tsetse control, veterinary/livestock and health officers)**

Sno.	**Ward**	**Wildlife abundance by wildlife officers**	**Tsetse abundance, filled by tsetse officers**	**Incidences of AAT, be filled by Veterinary officers**	**Incidences of HAT, to be filled by health officers**
		0= absent, 1= few, 2=average, 3=abundant	**0= absent, 1= few, 2=average, 3=abundant**	**0= absent, 1= few, 2=average, 3=many**	**0= absent, 1= few, 2=average, 3=many**
1	**Emboreet**				
2	**Engaruka**				
3	**Engutoto**				
4	**Esilalei**				

5	**Loibor-Siret**				
6	**Loiborsoit**				
7	**Lolkisale**				
8	**Makuyini**				
9	**Meserani**				
10	**Moita**				
11	**Monduli Juu**				
12	**Monduli Urban**				
13	**Msitu wa Tembo**				
14	**Mto wa Mbu**				
15	**Naberera,**				
16	**Ngorika**				
17	**Oljoro No.5**				
18	**Orkesment**				
19	**Ruvu Remit**				
20	**Selela**				
21	**Sepeko**				
22	**Shambarai**				
23	**Terrat**				

Demographic issues

12. Do you have a functionally early warning system in place? Yes [ ] No [ ]
13. Do you have access to current & future health related climate risks information? Yes [ ]No [ ]

21. Do you have any question you would like to ask me?
………
Thank you very much for your time.

Appendix 2: General pastoral social ecological system vulnerability to trypanosomiasis (animal and human Trypanosomiasis)

District : _____________Village Name : _________________Sub-village Name : __________________Location :
X______________Y________________

A: Social Vulnerability

A: Demographic Information

1: Gender	2: Marital status	3: Ethnicity	4: Education	5: Occupation	6: Origin of the house hold	7: If immigrant, you moved from which village? Where were you borne?	8: Household size
						from________ Borne_______	

<u>Code:</u> Gender: 1=Male 2=Female; Marital status: 1=Married 2=Divorced 3=Widow Education: 1 = Never went to school; 2 = Primary education; Origin of household: 1= Native (Born in this village?); 2 = Immigrant, Household size: 1= ≤10 people; 2= ≥ 10 people

10. Which age set do you belong? *(Tick the age set which fits your age in the table below)(Since this is a retrospective study the idea is to interview head of the households who are >= 30 years old, so nyangulo (young age set is left out)*

Age set	*Korianga*	*Irrikidotu*	*Nyangusi*	*Seuri*	*Ilindareto*
√					
#					
# of dependent<18 &≥65					

B: Awaress of trypanosomiasis

1. **Would you please tell us if you are aware of trypanosomiasis? (***Tick the one which fits your answer)*
   a). In animal [ ] YES, [ ] NO.
   b). In Human [ ] YES, [ ] NO.
   c). Is there any member of your family was diagnosed with HAT in the past? [ ] YES, [ ] NO.

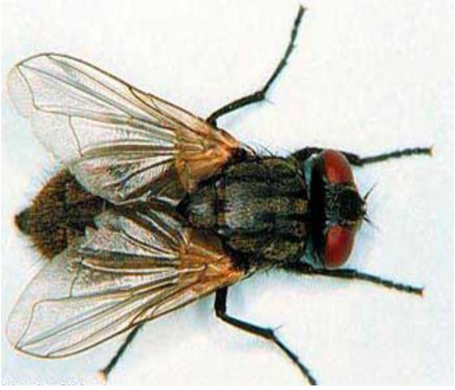
2. Did your livestock have previously contracted trypanosomiasis? **(***Tick the one which fits your answer)*
   [ ] YES, [ ] NO.
3. Could you tell the sign if you animal contract trypanosomiasis? **(***Tick the one which fits your answer)*
   [ ] YES, [ ] NO. If yes, please continue no. 4
4. Would you please list down at least three symptoms in animals that you relate with animal trypanosomiasis.
   a). ____
   b). ____
   c). ____
5. Where do you graze your livestock for over 50% of a year?
   a). In the villages just close to settlement ( )
   b) In the village land between settlement and close to protected areas border ( )
   c). Inside the protected area (rarely though) ( )
   d). Never in the protected areas ( )

6. Do you normally encounter tsetse fly on areas where you graze livestock? **(***Tick the one which fits your answer)*
[ ] YES, [ ] NO.

7. If you are presented with various insect photos, can you Identify tsetse fly? **(***Tick the one which fits your answer)*
[ ] YES, [ ] NO. If yes, please continue no. 8

8. Given the photo of various insects below, would you please identify which insect is tsetse fly? (*Tick the one which fits your answer)*(***Insect Card is presented separately- Enumerators please tick if the choice is correct or wrong***), Correct choice ( ), incorrect choice ( )

Tsetse Identification Card

	
	
	**No idea?**

9. Based on your experience on animal trypanosomiasis and a table below, please indicate a month when trypanosomiasis is likely to affect your livestock. (Indicate with a ** months that has high risk of animal contracting trypanosomiasis.

Month	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***

√ there is risk												
** risk is high												

10. Do you have a traditional/conventional early system to warn you when risk is expected to be high or otherwise? **Yes** [ ] **No** [ ] **I don't know** [ ]. If yes please answer 10b and 10c

10b. Do you normally make uses early warning system knowledge in your production activities? **Yes** [ ] **No at all** [ ]

10c. Can you please explain a bit about the available early warning system works, especially (traditional) (emergency of insects, *flowering of certain plants, wild animal movement, birds call sign*?

………
………
………
………
……………………………………………………......

C: Trypanosomiasis impacts and adaptation strategies (perception)

11. What would you consider the effects of animal trypanosomiasis in your community? (*you may √ more than one choice*)
a). low milk production ( )
b). death of livestock ( )
c). loss of animal condition (thin and unhealthy) ( )
d). Disease transmission to family member ( )
e). others (*please specify*)
……
……
……………………......

12. Please tell us how your household was once affected by animal trypanosomiasis, (*what problems you experienced at an household level*)?
....
....
....
....

13. What have you been doing to counterbalance the effects trypanosomiasis at your household? (You can only √ one that most describe your major adaptation you have been practicing). *If your choice in a, please continue number 14 and 15.*
a). Not doing anything ( )
b). Practice subsistence farming ( )
c). Do wage labor ( )
d). Sell livestock ( )
e). Others (*please specify)*

14. Would you please mention at please one reason as to what are the constraint's for you to adapt?
……
……
……
……………..

15. Have you tried any coping strategy and fail in the past? **(***Tick the one which fits your answer)*
[ ] YES, [ ] NO. If yes, please continue no. 16

16. Would you please mention at least one coping strategy you tried out and fail in the past?
……
……………………………………………………………………

17. At present in this area, there is (please refer to the table below);

a). *place where I can easily access and or gain knowledge on*	**Yes [√]**	**No [√]**	**Unsure[√]**
i). climate risks (droughts, floods etc)			
ii). Modern livestock keeping methods			
iii) Traditional livestock keeping methods			
iv). Conventional Health improvement methods			
v) Traditional Health improvement methods			
b). *Social groups and Networks (Partly covered in General questionnaire)*			
i). Active women saving group			
ii). Active livestock base organization			
iii). Active farmers base organization			
iv). I am a member any of some of the above organization			
v). You have been keeping livestock for ≥ 10 years now			
c). Infrastructure			
i). Health center where many diseases in our area can be diagnosed			
ii). You have access to livestock extension services and livestock diseases prevention			
iii) Access to market			
iv). Boreholes for watering livestock			
v). There are irrigation schemes			
d). Natural resources available			
i). Reliable (*Can be used throughout the year*) natural water ponds			
ii). Reliable (*available throughout the year*) land for grazing			
iii). Available land for cultivation			
e). Financial/economic			
i). You have more than one source of income			
ii). You have ≥ 100 cattle			
iii). You own ≥ 20 ha of land			
iv). You have access to micro-loan in case of disasters			

D: Current Situation of the area which may increase vulnerability to trypanosomiasis

18. Do you agree or disagree with the following statement.

Compared to the last 20 years	**Yes[√]**	**No[√]**	**Unsure[√]**
a). Size of grazing land is shrinking due to conversion to farm land			
b). Human wildlife interaction is increasing			
c). New diseases are coming in our community			
d). More villagers are engaging into agriculture			
e). Size of herds per household is decreasing			
f). Availability of quality pastures is becoming a problem			
g). Peoples are more sedentary/ there has been less mobility			
h). Markets for livestock and livestock products is growing			
i). Spread of tsetse flies has expanded in recent years			
j).My livestock graze in tsetse fly infested areas longer period than before			

E: Economic/Livelihood option

21. What is your economic activity? You can tick [√] more than one category of livelihood

Livelihood Option	**Experience (Years you have been doing this)**
a. *Livestock only*	
b. *Farming only*	
c. *Livestock and Farming*	
d. *Business*	
e. *Tourism*	
f. *Mining*	
g. *Employed (please mention where)*	
h. Others... (specify)	

If you keep livestock and/or you are farming, kindly answer the following questions;

19a. How many acres set aside for grazing? **≤ 20** [ ], **> 20** [ ], **≤50** [ ] **None** [ ] **don't know [ ]**

19b). If you have set aside your own area for grazing please tell us when you started? Nyerere regime [ ],Mwinyi regime[ ],Mkapa regime[ ], Kikwete regime[ ]

20. Kindly fill the table below; *Note; If you sell livestock, please use code for Reasons of selling)* ***S****=****S****urplus,* ***D****= to change* ***D****iet,* ***F****= school* ***F****ees for kids,* ***P****=Farm* ***P****reparation,* ***CT****=****C****attle* ***T****reatment and* ***PT****=* ***P****eople* ***T****reatment*

Type of livestock you	Breed	Their number? ≤ **20** [ ], **about 50** **[ ], > 50<200 [**	What Product you	Do you sell livestock	Months that you sell more	Reasons for selling *(use*
i). Cattle						
ii). Sheep						
iii). Goat						
iv). Kuku						
v). Donkey						

21a). Do you have your own bore hole/water point for your livestock? **Yes** [ ] **No** [ ]. If no, please answer the following 2 questions

21b) How far do you go to water your livestock? Km______________

21c) How far do you go to get water for home consumption? Km______________

22. If you practice farming, kindly fill the table below; *Note; Number of bags for consumption should target what is enough for entire season/before the next harvest and for Reasons of selling use this code)* ***S****=****S****urplus,* ***D****= to change* ***D****iet,* ***F****= school* ***F****ees for kids,* ***P****=Farm* ***P****reparation,* ***CT****=****C****attle* ***T****reatment and* ***PT****=* ***P****eople* ***T****reatment*

Type of crops that you grow	Where do you get seed	Harvest/acre(gunia/bags)	# of Bags 4 consumption	# of Bags 4 sale	Month you sell	Reasons for selling *(use the code)*	# of bags reserved 4 food in next year
i). Maize							
ii). Beans							
iii). Sunflower							

32: If you increase you yield would you be willing to decrease number of your livestock?
....

Appendix 3: Expert judgment on the weight/ or influence of identified trypanosomiasis risk factor

1. Institutions-------------------------------------- (please tick (√) what correspond to your answer.

a). Vector and Vector-Borne Diseases Research Institute (VVBDR)located in Tanga

b). Monduli Discrict Councel

c). Simanjiro Disctrict Councel

2. Would you please tick (√) the department underwhich you work.

a). Livestock development

b). Health

c). research/VVBDRI

3. Based on the fact that trypanosomiasis risk factors differ in terms of contribution to occurrence and persistence of Human and Animal trypanosomiasis, I am therefore requesting your expert judgment on the weight/ or influence of each factor (in the table below) out of 100% (What is your perception on how big is the influence of each factor).

NB. I know there are other important trypanosomiasis risk factors but we could not get their quantitative or qualitative estimate and so we chose the present factors because we could get qualitative estimate (wildlife abundance, tsetse abundance, trypanosomiasis prevalence) at ward level. The estimates of the remaining factors were quantitatively estimates from Tanzania Census 2012.

No.	***Trypanosomiasis risk factor***	***Percentage***
1	Wildlife presence	
2	Tsetse Presence	
3	Trypanosomiasis Prevalence	
4	Human population/density	
5	Literacy rate	
6	Available health facilities	

Appendix 4: Variables used in the binomial and multinomial logit model to explain adaptation decision

Sno.	***Explanatory variable***	***Explanation of the cut ff point***
1	Education level	Dichotomous; 1 if individual has at least primary education and 0 otherwise
2	Size of the household	Dichotomous; 1 if individual has household size
3	Livestock keeping experience	Dichotomous; 1 if individual has >10 years' experience and 0 otherwise
4	Tsetse abundance in grazing areas	Dichotomous; 1 if individual graze in tsetse abundant areas and 0 otherwise
5	Closeness to market	Dichotomous; 1 if individual is close to the market and 0 otherwise
6	Number of cattle owned	Dichotomous; 1 if individual has >100cattle and 0 otherwise
7	Land size owned	Dichotomous; 1 if individual has >20 acres and 0 otherwise
8	Access to livestock extension services	Dichotomous; 1 if individual has access to livestock extension services and 0 otherwise
9	Access to loan	Dichotomous; 1 if individual had access to loan and 0 otherwise
10	A member of an association	Dichotomous; 1 if individual was a member of association and 0 otherwise

Appendix 5: Table showing results from Linear mixed effect models between the relative abundance of tsetse flies as dependent variables and month/season*habitat as independent/explanatory variables.

MONTH*habitat	***Number of tsetse fly***		
	Coef ± SE	***Df***	***P***
*Intercept	1.314 ±.13	2242	***0***
Month	0.1 ±.011	2242	***0***
Open woodland	-1.196 ±.15	6	***0.0002***
Riverine	-1.218 ±.16	6	***0.0002***
Swamp	-1.356 ±.17	6	***0.0002***
Month*woodland	-0.057±.012	2242	***0***
Month*riverine	-0.071±.013	2242	***0***
Month*swampy	0.025 ±.014	2242	***0.0793***
Random Factor: Site	**0.11**		
AIC value	**3706.253**		
SEASON*habitat			
**Intercept	-2.162 ±.119	2234	***0***
Long rain	-0.941 ±.100	2234	***0***
Short Dry	-0.606 ±.087	2234	***0***
Short Rain	-0.888 ±.100	2234	***0***
Open woodland	-1.859 ±.133	6	***0***
Riverine	-2.101 ±.138	6	***0***
Swamp	-1.791 ±.146	6	***0***
Long rain*open woodland	0.699 ±.112	2234	***0***
Short Dry* open woodland	0.384 ±.097	2234	***0.0001***
Short Rain* open woodland	0.682 ±.112	2234	***0***
Long rain*riverine	1.007 ±.117	2234	***0***
Short Dry* riverine	0.626 ±.102	2234	***0***
Short Rain* riverine	0.850 ±.123	2234	***0***
Long rain*swamp	0.579 ±.124	2234	***0***
Short Dry* swamp	0.300 ±.107	2234	***0.0053***
Short Rain* swamp	0.792 ±.140	2234	***0***
Random Factor: Site	**0.107**		
AIC value	**3566.889**		

All months and seasons are compared to the intercept *Ecotone ** Dry season respectively

Appendix 6: Table showing number of tsetse fly screened for trypanosome infections

Month	Year	Ntsetse	Screend Tsetse flies	Infected Tsetse flies
1	2015	15	15	0
2	2015	218	204	2
3	2015	352	352	7
4	2015	51	51	2
5	2015	107	106	8
6	2015	105	102	10
8	2015	257	256	0
9	2015	339	339	10
10	2015	122	121	0
11	2015	Not included in the analysis		
7	2014	651	649	15
8	2014	270	258	10
9	2014	280	279	16
10	2014	98	98	34
11	2014	135	97	12
Total		3000	2927	126