**UNIVERSITY OF NAIROBI**

# MODELING OF THE IMPACT OF CLIMATE CHANGE ON HERBIVORES DISTRIBUTION IN THE SAVANNA ECOSYSTEMS, A CASE STUDY OF AMBOSELI ECOSYSTEM, KAJIADO COUNTY, KENYA

**BY**

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**Reg. No: I85/90781/2013**

**A thesis submitted in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy in the Institute of Climate Change and Adaptation of the University of Nairobi**

**November 2021**

## PLAGIARISM STATEMENT

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# DECLARATION

I hereby declare that this thesis, titled "Modeling of the Impact of Climate Change on Herbivore Distribution in the Amboseli Ecosystem, Kajiado Kenya." is my original work and has not been submitted for a degree in any other University.

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## DEDICATION

I dedicate this thesis to my husband, George Gabriel Obhai, our children Ronny Kray, Natalie Nyasamu, Gene George, Alisha Elma and Kayla Nayelie. And my parents; Hezborn Aduma and Florence Aduma, and my late Father-In-Law Gabriel Ondiala (RIP). Thanks for your inspiration and prayers during my study period. Thanks to my grandmother Dorcas Iminza who saw my potential and continuously encouraged me to pursue my studies relentlessly (RIP). You are the greatest hero in my life.

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AES | Amboseli Ecosystem |
| ACC | African Conservation Centre |
| AIC | Akaike Information Criterion |
| ATE | Amboseli Trust for Elephants |
| ANP | Amboseli National Park |
| ASALs | Arid and Semi-Arid Lands |
| AWF | African Wildlife Foundation |
| CHIRPS | Climate Hazards Group InfraRed Precipitation with Station |
| CHIRTS | Climate Hazards Group InfraRed Temperature with Station |
| CORDEX | Coordinated Regional Downscaling Experiment |
| COP | Conference of Parties |
| DRSRS | Directorate of Resource Surveys and Remote Sensing |
| ENSO | El Niño Southern Oscillation |
| GCM | Global climate Models |
| GHG | Greenhouse gas |
| GIS | Geographical Information System |
| GPS | Geographical Positioning System. |
| HEC | Human-Elephant Conflict. |
| IPCC | Intergovernmental Panel on Climate Change |
| IUCN | International Union for Conservation of Nature |
| JJAS | June-July-August-September |
| KWS | Kenya Wildlife Service |
| ICPAC | Intergovernmental Authority on Development Climate Prediction and Applications Centre |
| IFAW | International Fund for Animal Welfare |
| IGAD | Intergovernmental Authority for Development |
| KMD | Kenya Meteorological Department |
| MAM | March-April-May |
| MPI-ESM-LR | Max Planck Institute for Meteorology |
| MEMR | Ministry of Environment and Mineral Resources |

| | |
|---|---|
| OND | October-November-December |
| TAMSAT | Tropical Applications of Meteorology using Satellite and ground-based observations |
| UNFCC | United Nations Framework Convention on Climate Change. |
| WCRP | World Climate Research Program |
| WMO | World Meteorological Organization |
| WWF | World Wildlife Fund |
| SES | Socio-Ecological Systems. |
| PDO | Pacific Decadal Oscillation |
| RCA4 | Rossby Center Regional Atmospheric Model |
| RCPs | Representative Concentration Pathways\ |
| RCM | Regional Climate Models |

# ABSTRACT

For years, conservationists have been captivated by the existence of many species of large herbivores in grasslands and savannas. However, climate changes manifested through increasing land temperatures and changing rainfall regimes increasingly threaten the distribution of large herbivores. There is a developing understanding of the significance of including environmental change scenarios in management planning and actions, yet this is lacking in numerous frameworks. The main objective of this study was to investigate the potential impact of climate change and variability on herbivore distribution in the Amboseli ecosystem. Trends of rainfall and temperature were examined based on historical Climate Hazards Group InfraRed Precipitation with Station (CHIRPs) and Climate Hazards Group Infrared Temperature with Station (CHIRTs) data for 1960 - 2014 and the period 2006-2100 for the projections. The projections data were from the regional climate models from the Coordinated Regional Downscaling Experiment (CORDEX). Analysis of long-term annual and seasonal rainfall trends and temperature were done using quadratic and linear trend analysis. The range maps of herbivores were developed from aerial censuses conducted in the study area from 1977 to 2014. Future distributions were done based on temperature thresholds for each of the fifteen species for the 2030s, 2050s, and 2070s. The results show that the annual and seasonal rainfall declined slightly between 1960 and 2014. On the contrary, the annual minimum temperatures increased by 1.23 °C and the maximum by 0.79 °C. There was a variation in projected rainfall with RCP 2.6, indicating a decline for the four seasons and a marginal increase in annual and October-November-December (OND) with decreases in the March-April-May (MAM) and June-July-August-September (JJAS) for RCP 4.5 and 8.5. Projected maximum and minimum temperature for RCP 2.6 show increments of less than 1°C, while for RCP 4.5, the maximum range is between 0.57 °C and 1.85 °C, and the minimum is between 0.51 °C to 1.98 °C. RCP 8.5 indicated the most significant increment in maximum temperature between 1.11°C and 4.34 °C and a minimum temperature between 1.34 °C and 5.26 °C for the 2030s, 2050s, and 2070s. Range analysis showed that the increasing temperatures would lead to a contraction in the range size of most herbivores. According to the findings, 3 out of 15 species will lose more than half of their range by the 2030s, 5 out of 15 by the 2050s, and 4 out of 15 by the 2070s under RCP 2.6. According to the RCP 4.5 climate change scenario, three species would lose more than half of their range by 2030, and five will lose more than half by 2050 and 2070. Finally, based on the RCP 8.5 scenario, five species will lose 50% of their range in the 2030s, seven species in the 2050s, and ten species in the 2070s. The level of range loss varied by species, but it was most severe for water-dependent species such as buffalo, Thomson's gazelle, waterbuck, and wildebeest. The elephant, gerenuk, hartebeest, lesser kudu, and oryx, on the other hand, are anticipated to maintain the majority of their range in all RCP scenarios. Further investigation into the relationship between elephant population and rainfall revealed a robust linear relationship between the elephant population and OND's historical seasonal rainfall over 13 years. Under RCP 2.6 and 4.5, annual rainfall increased marginally, but RCP 8.5 indicated a significant rise. The Amboseli ecosystem's anticipated elephant population was influenced by rainfall fluctuation. The elephant population increased by 2455 and 2814 elephants in RCPs 2.6 and 4.5, respectively, whereas RCP 8.5 recorded an average of 3348 elephants. The community's perspectives were determined through a survey, key informant interviews, and stakeholder’s forums. The results show that there is a relationship between the modelled climate and the observations from the locals. Through participatory mapping, it is evident that changes in community livelihoods and human activities are blocking the corridors used by herbivores, further affecting their adaptation to the changing climate. Coupled with the projected range contractions, this scenario raises severe worries about the future of wildlife in Kenya's savannah. As a result, the wildlife sector must adopt climate policies and strategies that consider future climatic scenarios.

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# CHAPTER 1 : INTRODUCTION

## 1.1 General Background

Climate change is a direct driver that is increasingly exacerbating the impact of other drivers on wildlife and human well-being. It creates extra pressure on ecosystems, their biodiversity, and the goods and services they provide. In the last 50 years, extreme weather events such as fires, floods, and droughts have become more frequent and increased intensity (Biju Kumar and Ravinesh, 2017). These changes have contributed to widespread impacts in many aspects of biodiversity, including species distribution, phenology, population dynamics, community structure and ecosystem function (IPBES, 2019). Thus, understanding the environmental elements governing animal movement and distribution is critical for theoretical and practical applications (Nathan *et al*., 2008).

Thuiller *et al*. (2018) affirm that climate change influences species range size and distributions across spatial scales at an unprecedented rate. Range size is a fundamental characteristic of a species movement pattern, and it determines the survival of a species in any given habitat (Borger *et al.,* 2008). The species home range is the "area traversed by the species in its normal food-gathering activities, mating, and caring for the young" (Burt, 1943). The term herbivores, in this case, refers to wild animals that are adapted to eat primarily plant matter (Abraham, 2006). Climate change, therefore, affects the savanna habitats where herbivores have been coexisting with humans for years (Barrios *et al.,* 2018).

Ecosystems are directly affected by climate change through seasonal variations in precipitation and temperature, which affect the quality of ecosystems and, subsequently, habitat and the abundance of herbivores distribution (Kupika *et al*., 2018). The world temperatures have risen by around 0.6°C since 1950, and this trend is expected to continue, with global surface temperatures expected to increase by 3.7°C by the end of the century (IPCC, 2014; World Bank, 2013). Thus, it is indisputable that warming is one of the most prevalent environmental changes that ecosystems are experiencing worldwide. High temperatures affect rainfall which drives large herbivore population dynamics of savanna (Coe *et al.,* 1976; East 1984; Ogutu and Owen-Smith, 2005; Ogutu *et al.,* 2008; Western, 1975). Research has shown that rainfall is critical for producing plant biomass and the concentration of nutrients, promoting breeding and survival rates of the herbivores (Bartzke *et al*., 2018). There is a variation in the way continents of the world are experiencing climatic changes, and Africa is expected to experience more devastating impacts. This is because the current threat of habitat degradation, land-use change or fragmentation, and rapid population increase interact nonlinearly with climate change, causing negative consequences to be more significant than projected in the continent (Midgley *et al.*, 2002; Sonwa *et a*l., 2017). For example, temperatures are projected to increase more rapidly in Africa than in other continents ( Hulme *et al*., 2001; Niang *et al*., 2014; Worldbank, 2013) because of its geographic position and a significant portion of the land is arid and semi-arid (Knaepen *et al*., 2015; Ngigi *et al*., 2016).

As a result, the gravity of droughts is expected to increase, exacerbating the impacts on the availability of forage, which will, in turn, impact reproduction among herbivores (Koons *et al*., 2012). Scientific literature also states that there is medium confidence that habitats such as the African savannas may already have faced some impacts due to global climate change (IPCC, 2014). This shift will increase demand for natural resources, leading to land-use changes and unsustainable species utilization. Furthermore, these changes put a lot of strain on biodiversity and environmental services. Hence, it is necessary to examine the interlinkages between climate change, herbivore distribution and livelihoods, and the threats posed to these components by climate change.

Studies in the eastern Africa savannas have reported a rise in temperatures within the recent decades (Niang *et al*., 2014; Ogutu *et al*., 2013; Ogutu *et al*., 2012; Ogutu *et al*., 2016), but the recent changes in rainfall seem profound and generally erratic (Niang *et al*., 2014). Projected changes in temperatures are likely to have adverse effects on the migration (Pennycuick, 1975) and dispersal (Young and Van Aarde, 2010) of herbivores in the savannas. High temperatures and drought lead to an increase in mortality rates in herbivores, resulting in a decline in their population (Hillmann and Hillman,1977). This has been witnessed in the Serengeti national park, which has recorded drought-related deaths. Furthermore, past studies have also revealed that three-quarters of the wildebeests (*Connochaetes taurinus)* population die due to undernutrition resulting from depressed rainfall that affects the food supply (Mduma *et al*., 1999). For instance, the droughts of 2010 in Amboseli reduced the wildebeest population from 16,290 animals to 2375 animals (Msoffe *et al*., 2019; Western, 2010). As projected by the Intergovernmental Panel on Climate Change (IPCC, 2014), this pattern is expected to continue because all emission scenarios predict an increase in the surface temperature during the 21st century (Hayhoe *et al*., 2017).

The changes in population density are detrimental because the local communities residing next to protected areas depend on herbivores to generate income, mainly through conservation and tourism (Okello *et al*., 2014). Additionally, climatic changes alter the range and distribution patterns of species and can change migratory routes of species that track seasonal changes in vegetation like herbivores, which may also increase conflicts with humans, particularly in areas where rainfall is low (Thirgood *et al*., 2004). Even though impacts of climate change are being witnessed in global ecosystems, there is a lack of knowledge on how the ecosystem will respond to species loss induced by climate change. Therefore, this study considers the connection between climate change and species distribution in savanna ecosystems of East Africa.

Extreme climatic events have long posed a significant risk to regions in Kenya. These events have contributed to the listing of Kenya among the world communities as one of the countries prone to perennial disaster (Parry *et al*., 2012). Of particular concern are hazards of floods and droughts, which have been responsible for considerable loss of life and negatively affecting the nationwide economy (Parry *et al*., 2012). These occurrences are linked to a significant rise in temperatures in recent decades combined with rainfall decline. Rainfall amounts in Kenya have declined since 1960 (Coe and Stern, 2011; Ogutu *et al.*, 2016), while temperatures have increased by 1°C over the last 50 years (GoK, 2009; Ogutu *et al.*, 2016). Available climatic models indicate that by 2020s, there will be a warming of about 1°C, which will increase to 4°C by 2100 (Parry *et al.*, 2012).

A recent analysis of climate change at a national level by Funk *et al.* (2010) predicts an overall reduction within the mean annual rainfall in the study area. The same study also projects wetter than usual conditions for the October to December season. Inversely, the long rains from March to May have become progressively erratic in different country locations. Therefore, they cannot be relied upon for their impact on the herbivores distribution (Parry *et al*., 2012). Ogutu and Owen-Smith (2003) found that rainfall and temperature extremes influence the declines in the population of herbivores in the savanna.

Given that water stress and rising temperatures would severely influence herbivore survival in the savanna ecosystem, a better knowledge of their dynamics is required to support successful herbivore conservation efforts under changing climatic (Bartzke *et al.*, 2018). The conservationists, therefore, need to plan for the future of the herbivores' behaviour based on past and future climate projections. This knowledge interaction of climate change behaviour and its contribution to the conduct of the herbivores distribution is critical for the future survival of the herbivores in the face of increasingly hostile climatic conditions.

Kenya's National Wildlife Strategy 2030 (Ministry of Tourism and Wildlife, 2018) envisions this. It emphasizes potential and novel approaches to tackling developing wildlife concerns in Kenya while ensuring that benefits accrue to the millions of Kenyans who sustain wildlife on their property. The Strategy presents a transformative vision for wildlife conservation by 2030 and a clear set of five (5) year priority targets and tactics centred on four essential pillars: resilient ecosystems, engagement of all Kenyans, evidence-based decision making, and sustainability and governance.

This research is based on the first pillar (Resilient Ecosystems), which addresses ecosystem and species prioritizing, planning, and conservation. This pillar focuses on a complete assessment of ecosystem and species state and conservation goals, establishing frameworks for integrated planning, and effective coordination and implementation of the country's species protection and wildlife security. It includes reducing human-wildlife conflict and promoting coexistence (ibid). Several wildlife sanctuaries, notably the Amboseli, face these challenges (Ogutu *et al*., 2014; Okello *et al*., 2014; Western *et al*., 2015).

The Amboseli ecosystem is a semi-arid, open grassland area in southern Kenya, which has experienced wide-ranging modifications in habitat and climate since the early 1960s (Western, 1975). Results of a past study show a rise in temperatures and a decrease in annual and March-April-May (MAM) seasonal rainfall (Altmann *et al*., 2002). The Amboseli National Park (ANP) and its dispersal areas have been the focus of several long term ecological (Western, 1973; Western *et al*., 2015), behavioural (Altmann *et al*., 2002; Moss, 2001), and social science studies

(Campbell, 1999; Howe *et al*., 2013; Kioko and Okello, 2010; Okello *et al*., 2014). The development of the allometric models in the last three decades has explained the diet and selective feeding of the herbivores (Demment *et al.*, 1985; Illius and Gordon, 1992; Mduma *et al.*, 1999; Mose *et al*., 2013).

The models provide a theoretical basis for explaining the seasonal movements of herbivore species with changing pasture abundance and quality. Although most of the studies have recognized the effects of human species in the ecosystem, more emphasis on the role of climate change as an additional stressor is lacking. Herbivores move seasonally in the park, group ranches, community wildlife sanctuaries, and other dispersal areas within the 8000 $km^2$ Amboseli ecosystem (Douglas-Hamilton *et al.*, 2005; Kioko *et al.*, 2006; Western, 1975, 1982; Western and Maitumo, 2004). However, construction activities around the park have caused fragmentation of herbivore habitats, reduced dispersion areas, and restricted the free movement of herbivores (Moss *et al*., 2011; Okello *et al.*, 2009; Western, 1973b).

Prospects for free movement are becoming restricted when they may be crucial to cope with the broader climatic variability resulting from worldwide warming. Conflict with the humans and their livestock will be severe around the few water sources remaining during the dry season. These deteriorating conditions will challenge the effective conservation of herbivores within and beyond the confines of protected areas. There is, therefore, a clear need for climate change experts to develop climate-based predictive models for use by conservationists in the future management of Herbivores. Currently, such models do not exist, and conservationists continue to manage herbivores and other wildlife as if climate change does not affect them, while available literature indicates the converse.

The primary objective of this research is to model the impact of climate change on the movement of the herbivores in the Amboseli ecosystem to bridge the gap of knowledge between conservationists and climate change scientists. It is assumed that this understanding of the herbivores and other wildlife will lead to better management as the situations continue to change. Fifteen large herbivore species were studied. They include four migratory types such as the wildebeest, zebra, Thomson’s gazelle, eland, one dispersal type (the elephant), and ten resident species (the buffalo, gerenuk, giraffe, Grant's gazelle, hartebeest, impala, Lesser Kudu, oryx, warthog, and waterbuck). The 15 species were selected based on the availability of consistent data from the aerial census conducted between1977 and 2016.

The elephant is one of the keystone species that is categorized as endangered. Other herbivores in the ecosystem depend upon the elephant, such that if it is isolated from the ecosystem, drastic changes in the population dynamics will occur (Western and Lindsay, 1984; Western and Maitumo, 2004; Wijngaarden, 1985). It is well known that elephants and fires facilitate the transformation of woodland and bushes into grasslands (which causes multiple stable states), making the grazers and some browsers flourish (Dublin *et al*., 1990; Wijngaarden, 1985). In Amboseli, the elephant performs a vital role in modifying the landscape and the vegetation. For these reasons, the elephant is investigated further as a single species to establish the relationship between rainfall and its population.

### 1.2 Problem Statement

Knowledge of herbivore distribution and population dynamics equips conservationists with better management strategies leading to harmonious co-existence between humans and herbivores in the ecosystem. This peaceful co-existence boosts herbivore numbers in the ecosystem, promotes tourism activities, and improves the livelihoods of the surrounding communities. However, climate change impacts could threaten this ecosystem balance, which is likely to alter the geographical distribution and population of herbivores in Amboseli. Many studies on herbivore conservation are available, but very few studies integrate climate change projections in the plans, management, and conservation strategies.

Conservationists appreciate the fact that herbivore distribution is changing. However, they lack information on how this relates to climate change, such as variability and seasonality in rainfall and increasing temperatures. Lack of first-hand information on the future range size and distribution of herbivores in the ecosystem is a challenge to proper conservation strategies of the species. A gap currently exists between the difficulties experienced by conservationists and local communities concerning herbivore conservation issues on the one side and climate change scientists on the other. This is because climate scientists and conservation scientists have not been working together to understand the current environmental changes in the ecosystem.

Therefore, conservationists can’t know the future herbivore distribution patterns and the available range to advise the communities at the local level appropriately. This research, therefore, seeks to respond to local level challenges relating to herbivore survival and the community livelihoods as a foundational problem in the ecosystem. These challenges are coupled with the global agenda and are drivers for change in the domains of herbivore conservation. This gap of knowledge requires an integrated approach to rangeland conservation and climate science. Currently, available literature indicates that such studies have not been conducted in Amboseli, and the dichotomy between conservationists and climate scientists persist. There is a need for such a study to develop projected climate models for better management of both herbivores and their environment.

### 1.3 Research Questions

The discussions presented above indicate a lack of a climate change projection and analysis that can assist in bridging the knowledge of the conservationists and the climate science team. According to these issues, the following research questions are addressed.

1. Are there significant changes in historical climate trends in the Amboseli ecosystem?
2. Is there any relationship between herbivores distribution in the Amboseli ecosystem and the trends observed above?
3. What are the trends in climate change scenarios in the Amboseli ecosystem?
4. What are the probable impacts of projected changes in climate on the distribution and range of large herbivores in the Amboseli?
5. How will the impact of climate change on herbivores in the Amboseli ecosystem affect the community's livelihoods?

### 1.4 Objectives

The main objective of this study is to investigate the impact of climate change on herbivore distribution patterns in the Amboseli ecosystem. To achieve this objective, the following specific objectives were explored:

1. To characterize historical climate trends in the Amboseli ecosystem.

2. To determine the relationship between historical herbivore distribution and climate in the Amboseli ecosystem.
3. To characterize trends in the projected climate change scenarios in the Amboseli ecosystem
4. To determine the potential impacts of projected climate change on the distribution of herbivores in the Amboseli Ecosystem.
5. To investigate how the livelihoods of the local communities are affected by climate impacts on herbivores in the Amboseli ecosystem.

### 1.5 Justification and Significance of the Research

Researchers have tried to grasp the link between natural processes and anthropogenic factors and how they influence nature; however, climate change is predicted to extend the complexity of biological systems and how they respond. It is not clear how wildlife, hydrological processes, and ecosystems should adapt to the impacts of climate change. The greater Amboseli ecosystem faces threats from land-use change, land privatization, land fragmentation, overgrazing, and potential climate change impacts. The ecosystem goods and services, such as sustaining high biodiversity and cultural value of its landscape, are likely to be compromised and eventually lost if no mechanisms are instituted to slow down ecosystem degradation and loss in the wake of climate change. It is, therefore, essential to carry out a careful assessment of the impact of both historical and future projected climate scenarios.

Adaptive planning, integrated modelling, and joint responsibility by all stakeholders impacted by ecosystem change are needed to address the intricate ecosystem and design appropriate management and policy interventions. Therefore, projecting seasonal to interannual climate change information, impact monitoring, and adaptation strategies could improve biodiversity conservation planning and management. It is, therefore, essential to gauge the spatial and time-based changes in the ecosystem about climate and wildlife dynamics, especially the large herbivores. This information is critical in understanding the sensitivity of herbivores and locals to climatic stressors and building the capacity of local community decision-makers. Globally, Amboseli is known for its elephant population. Furthermore, a lot has been studied on its impact on the landscape. Still, it faces challenges from an increase in the human population, loss of herbivore ranges from the expansion of agriculture, drought, and poaching.

Conserving large herbivores like the African elephant (*Loxodonta Africana*) is a critical and complex task due to its role in the natural world, conservation status, and relationship with people. The changing human demographics, agriculture, developments, land subdivision, accompanied by climate change, are bound to exacerbate human herbivore conflicts, especially around protected areas. Understanding the shifts in herbivore distribution patterns and institutional adaptation strategies are vital in conservation planning. Amboseli has been selected because it is one of the most iconic parks in Kenya (Okello *et al*., 2001) and is a top earner among the country's parks (Bulte *et al*., 2008) and also a hotspot of biodiversity in Kenya (UNDP, 2018).

The combination of wildlife viewing, biodiversity hot spot, cultural experience, and an extraordinary view of Mt Kilimanjaro, makes Amboseli a unique and highly desirable tourist destination. The diversity of the Amboseli environment is well-known. In the ecosystem large groups of wild mammals are spotted quickly during wildlife viewing by tourists. (Okello *et al* ., 2008). It is also primarily known for its elephants. It is the world's lengthiest study site of elephants. It forms an incomparable body of knowledge on African elephants' life- history and behaviour with intimate details of each elephant (Moss 2001). Land fragmentation, land-use change, increased agriculture, and climate change all pose threats to these species. Furthermore, very little is known on rainfall and temperature trends and projected climate in many savanna ecosystems of Africa.

These are essential elements in managing wildlife resources. Hence, it is of great consequence to study the historical and projected climate trends and later relate them to the possible changes in the distribution of elephants and other large herbivores. The findings and implications of this study will be valuable in appreciating climate change's impact on the Amboseli ecology. Adaptation and mitigation measures needed to address the changing climate within the area will also refer to these findings. Finally, the methodology could also expand the study to key wildlife areas in Kenya and the entire region.

### 1.6 Scope and Limitations

The scope of this thesis lies within the applied scientific disciplinary areas of climate and ecological sciences. Further, this thesis is primarily set in a conservational context in the southern rangelands of Kenya. However, the whole of Kajiado County is considered mainly in terms of range distribution. The work of this thesis was bookended between 2014 and 2017. Any developments since January 2018 are not included, except for the most recent crucial developments for the synthesis. Impacts of climate on the selected herbivore species were analyzed with maximum temperature thresholds of each species. Rainfall was used in the analysis of the elephant population only. This research focuses mainly on conceptual tools and data technologies but less on the theories stemming from social sciences and environmental sciences.

During the field survey, the greatest challenge was the terrain in Amboseli, which is difficult because of accessibility and vastness. It, therefore, restricted the movements of the field assistants since they had to rely on one land cruiser because hiring more than one was too expensive. The problem was solved using motorcycles in some areas and personal cars in other areas of accessibility. The selected regions, therefore, included Kuku, Imbirikani Olgulului, and Kimana ranches. Lengism and Rombo ranches were not covered in the field survey. Time constraints were a limiting factor preventing the study of the entire Amboseli ecosystem. The study area selected included the Amboseli National Park and key dispersal areas of herbivores surrounding the park.

Cultural limitations and language barriers were also a challenge in conducting the surveys. This was overcome by training research assistants from the local community to conduct the survey and translate the questionnaires to the local dialect. Interpreters were also used to perform some key informant interviews. In the study, both men and women were interviewed in the survey. The study was limited by the kind of data under consideration.  The aerial surveys point data used was inadequate compared to if elephant movement data from collared elephants were used. Acquiring collared data for elephants to map their movement was a big challenge.

Limitations on the observed climate data were challenging, with very few meteorological stations operating within the study area. This was overcome by using data from Isara Range station, Mashuru Dispensary, Olkelunyiet - the Parks headquarters, and Amboseli Baboon Research Camp.

The data were obtained from the Kenya Meteorological Department (KMD) archives and Amboseli Baboon Research Camp. In addition, the spatial analysis of the rainfall data was not done in comparison with the species distributions. The study did not focus on land use land cover change since other studies like Western *et al.*, 2015 have examined the same, and we inferred the findings. There was only one stakeholder forum held at the end of the study due to financial constraints.

## 1.7 Organization of Study

The thesis is organized into nine chapters based on the five specific objectives towards achieving the overall objective, as seen in Figure 1.1.

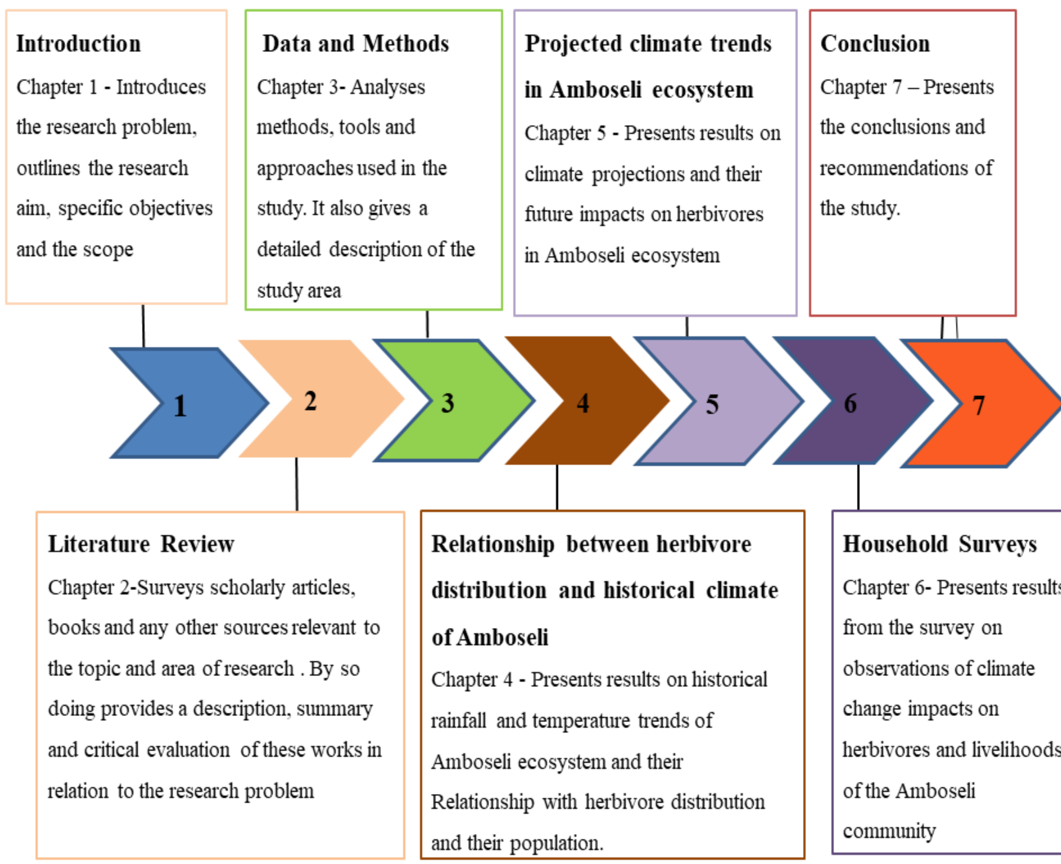



Figure 1.1: Organization of the Thesis Chapters

# CHAPTER 2 : LITERATURE REVIEW

## 2.0 Introduction

In this chapter, the literature relevant to this study is reviewed. The documentation includes past studies on climate and herbivore distribution and its associated impacts on livelihoods and climate change globally, regionally, nationally in Kenya and Amboseli.

## 2.1 Climate Change

Global environmental change, especially global climate change due to anthropogenic activities, has had a significant effect on the functioning of the physical and social systems of the earth (IPCC, 2007). The IPCC (2007) defines climate change as "the state of the climate that can be identified using changes in the mean or variation of its properties, which persists for an extended period (typically decades or longer)." Natural processes within the earth/atmosphere system or human-related factors that lead to continued anthropogenic modifications in the atmosphere or land use may result in climate change (IPCC, 2007). In Article 1 of the United Nations Framework Convention on Climate Change (UNFCCC), climate change is defined as "a change of climate that is attributed directly or indirectly to human activity." Therefore, the UNFCC differentiates between climate change attributed to human activities, altering the components of the atmosphere and climate variability caused by natural causes. This study adheres to the UNFCCCs definition of climate change.

Three sets of factors control the trajectory of climate over the 21st century. They include; "(i) the energy imbalance already built into the system as a result of past forcing by greenhouse gases (GHGs) and other changes (Hansen *et al*., 2005), (ii) the inherent sensitivity of the climate system to anthropogenic forcing (Rohling *et al*., 2012), including atmospheric, carbon cycle, and other feedbacks (Meehl *et al*., 2007); and (iii) the magnitude of future forcings, such as by GHGs and aerosols not yet released" (Moss *et al*.,2010). Analyzing observed patterns and geological records that offer essential insights explains the first two factors. Nevertheless,uncertainty regarding the pace and trajectory of potential emissions necessitates experimental research that can account for possible limits, responses, and non-linear effects. Climate simulations can investigate various futures since such operations cannot be performed on an international framework.

In climate research, socio-economic and emission scenarios provide realistic descriptions of how the future may evolve in various variables such as socio-economic change, technological change, energy and land use, and greenhouse gas and air pollution emissions. Currently, climate forcings are provided by "Representative Concentration Pathways (RCPs), a set of four new pathways developed for the climate modelling community as a basis for long-term and near term modelling experiments." The word "*representative*" implies that each of the RCPs represents a more extensive set of scenarios in the literature. The RCPs as a whole should be compatible with the complete range of emissions scenarios now accessible in the scientific literature, both with and without climate policy."

The words "*concentration pathway*" are intended to stress that "these RCPs are not the final new, fully integrated scenarios (i.e. they are not a complete package of socio-economic, emission and climate projections), but instead are internally consistent sets of projections of the components of radiative forcing that are used in subsequent phases." The use of the word *"concentration"* instead of *"emissions"* also emphasizes that concentrations are used as the primary product of the RCPs, designed as input to climate models(Van Vuuren *et al*., 2011). In summary, RCPs characterize the utmost important features of possible alternative futures and are designed to align with physical, demographic, economic, and social constraints (Moss *et al*., 2010; van Vuuren *et al*., 2011).

The Intergovernmental Panel on Climate Change (IPCC) adopted the RCP greenhouse gas concentration trajectory for its fifth Assessment Report (AR5) in 2014, which substitutes the Special Report on Emissions Scenarios (SRES) projections published in 2000. Climate modelling and research make use of four pathways that describe possible different climate futures. The paths chosen depend on how much greenhouse gases will be released in the coming years. Therefore, as part of the parallel phase, climate modellers will use the time series of future concentrations and emissions of greenhouse gases and air pollutants, as well as land-use change, from the four RCPs to run new climate model experiments and generate new climate scenarios.

The four pathways include; RCP2.6, RCP4.5, RCP6, and RCP8.5. "Each RCP reaches a different level of anthropogenic radiative forcing in 2100, ranging from 2.6 W/ $m^2$ for RCP2.6 to 8.5 W/ $m^2$ for RCP8.5." RCP4.5 and RCP6 are intermediate pathways. Like the Special Report on pollution

Scenarios (SRES) (Nakicenovic and Swart, 2000) and other earlier scenarios, RCPs are not envisioned as forecasts and probabilities or other expectation indicators. Natural ecosystems and human societies face various risks from Anthropogenic greenhouse gas emissions because they drive global climate change and ocean acidification (Meinshausen *et al*., 2011). The impacts of these threats can be intense and are increasingly being witnessed currently (Bellard *et al*., 2014). Already, the world is exposed to a significantly heated climate, with possibilities of further warming in the long run unless carbon emissions pathways change substantially (IPCC, 2014). As a result, the 2018 International Panel on Climate Change (IPCC) Special Report on 1.5°C warns that "allowing the planet to warm beyond 1.5°C would lead to climate change effects, including droughts, storms, heatwaves, and rising sea levels, which are detrimental to humans and biodiversity (Hoegh-Guldberg *et al*.,2018)."

In Africa, climate change influences and also affects ecosystems and biodiversity (Thomas *et al*., 2004). Global warming and human stresses, in their various forms, are expected to be the principal drivers of biodiversity at all levels (Parmesan, 2006). One-fifth of all known mammalian, bird, and plant species, along with one-sixth of all herpetological species, are found in Africa. (Preston and Seigfried, 1995). The species featured can be located in a range of ecosystems around the world, including grasslands, rain forests, coastal ecosystems, marine and freshwater habitats, swamps, and mountain ecosystems.

Climate change has worsened the previously daunting challenges that Africa's biodiversity has faced. This is attributed to two important issues: first, the habitats of different species are getting smaller now than they were previously and can only support a small population, leading in less genetic diversity and adaptive capability. This affects adaptation capacity to changing environmental conditions because the ability of species to adapt depends on their evolutionary potential (Sintayehu, 2018). Secondly, species' habitats are more fragmented than they were previously, thus affecting the movement and distribution of species since they are unable to roam around as freely as they once could in response to climate-related threats. For example, climate change has modified the regional distributions of east African species and habitats substantially. Current rates of species movement will have to be much higher than rates throughout postglacial times in order to adapt to changing climates. (Sintayehu, 2018).

The climate in East Africa is growing more and more unpredictable. Extreme weather events and catastrophes such as drought and flood conditions, are predicted to become more common and severe due to climate change (Field *et al.*, 2014). East Africa is expected to warm by 2 degrees Celsius, with increased extreme rainfall occurrences (IPCC 2014). People's responses to resource unpredictability are predicted to vary as a result of climate change. Pastoralists will most likely need to design alternative risk mitigation and ways of coping due to these climate shifts.

## 2.2 Rainfall and Temperature as Climate Variables

In determining the climatic condition of a region, rainfall and temperature parameters play a crucial role. Global rainfall patterns associated with changing temperatures are a growing cause of concern that are becoming vital indicators for climate change (Jonathan and Suvarna, 2017). Rain is a significant component of the water cycle, and changes in its amount affect stream flows and water demands due to changes in the hydrological cycle pattern (Jain and Kumar, 2012). Rainfall patterns and rates over an area are subject to the ambient and global water evaporation and, to a great extent, on altitude, latitude, and humidity (Jonathan and Suvarna, 2017).

Variations in extreme annual, seasonal, and daily rainfall events are attributed to inter-annual and inter-decadal phenomena such as El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD)" (Morgan *et al.*, 2013). "ENSO is the dominant variability mode of Sea-Surface Temperature (SST) within the tropical pacific. It develops via positive feedback between the ocean and atmosphere, also called Bjerknes feedback (Zheng, 2019). The intrinsic mode of the Bjerknes feedback is the IOD (Webster *et al*., 1999). ENSO influences the worldwide climate through atmospheric and oceanic teleconnections, resulting in enormous environmental and socio-economic impacts (McPhaden *et al*., 2006).

Past studies of historical trends in East African precipitation show a decline in the annual (Giannini *et al*., 2008; Rogelj *et al*., 2012;), wet season (Funk *et al*., 2008; Lyon and Dewitt, 2012; Williams and Funk, 2010) and dry season rains (Rowell *et al*., 2015) in latest decades. Severe droughts were experienced in Eastern and Southern Africa between 1970 to 2006 (Funk *et al*., 2008). La Niña occurrences, which periodically follow extreme El Niño events (Prudhomme *et al*., 2014), characterise severe drying in East Africa (Hastenrath *et al*., 2007). In the negative phases of the Indian Ocean Dipole, the region experienced declines in rainfall (Owiti *et al*., 2008). For instance, the East African drought of 2005-2006 was related to extreme negative Indian Ocean Dipole and La Niña conditions.

On the contrary, climate simulations predict El Niño Southern Oscillation (ENSO) intensification and a more regular occurrence of the Indian Ocean Dipole positive phase (Cai *et al*., 2009; Dore, 2005) with increasing temperatures. However, proof for the intensification of the ENSO phenomenon is still contentious (Collins *et al.*, 2010; Fedorov and Philander, 2000). Such conditions enable moisture transfer from the Indian Ocean to East Africa by weakening westerly winds (Saji *et al*., 1999; Webster *et al*.,1999). The process results in more extreme humid seasons and floods. Such occurrences of climate change are likely to increase negative consequences for ecosystems, biodiversity, and people.

Climate change and variability pose a challenge in how to identify, ascertain, and quantify rainfall trends. It is even more complicated to determine their implications on biodiversity to formulate adaptation measures through appropriate strategies for resource management. Observations of historical climate at the global or continental scale are helpful for planning at local and regional levels (Barsugli *et al*., 2012). Amboseli ecosystem has been investigated for trends in temperature and rainfall by many studies. For instance, Altmann *et al*. (2002) looked at temperature and rainfall analysis from 1976 to 2000 using data from the Oltukai African Baboon Camp station. According to this study, daily temperatures increased significantly throughout this period, at a magnitude higher than that attributed to global warming. On the other hand, annual rainfall varied more than four times, yet it did not exhibit any directional or other regular patterns of variability over the same 25-year period. A recent analysis by Ogutu *et al*. (2016) between 1960 and 2014 analyzing rainfall in Kajiado County presented clear "evidence of quasi-periodic oscillation in the annual rainfall component and a general decline in rainfall."

**2.3 Climate Models**

Several Coupled Model Intercomparison Projects (CMIPs) have generated an immense amount of global climate model (GCM) results over the years, which help assess possible changes in future climate (Meehl *et al*., 2007). However, the GCMs work on coarse horizontal resolution meaning that local topographic features comprising land-sea distribution, vegetation, and terrain altitude are depicted with little details. Some essential atmospheric processes, consisting of mid-latitude and tropical drivers, are inaccurately characterized, while the finer-scale occurrences are not resolved. Regional climate models (RCMs) come in handy to fill this gap. Regional climate models (RCMs), also known as regional dynamic downscaling, are vital for providing a high-resolution climate in a limited area.

An RCM is typically nested in a very coarse resolution global data set (e.g., reanalysis or a GCM) over some region of interest and driven at the boundaries by the coarse resolution data. The RCM simulates the nested domain's climate system, considering the finer scale regional and local forcings (Lennard *et al*., 2018). The crucial assumption in regional modelling is that large scale climate data are used to force (‘drive’) an RCM over a limited area (Vautard *et al*., 2018). As many of the effects of global climate change are likely to occur at regional and local scales, high-resolution climate simulations are also chosen to model possible future regional climates realistically. These scenarios are generally produced by dynamical or statistical downscaling world climate model simulations (Rummukainen, 2010). Furthermore, RCMs simulate synoptic and mesoscale processes better when operated in a limited area domain and at a higher horizontal resolution (Armstrong *et al*., 2019; Bale *et al*., 2002).

Consequently, RCMs are proposed to generate information on scales closer to where actionable information is needed, thus providing critical input to climate impact studies (Rummukainen, 2010). They are, therefore, crucial in formulating policies in response to impacts related to the changing climate at local levels like the Eastern Africa region. Regional models are increasingly being used in various impact studies due to the high computational costs associated with high-resolution GCMs. The World Climate Research Program introduced the Coordinated Regional Climate Downscaling Experiment (CORDEX) program, which aims to generate high-resolution regional climate projections (Endris *et al*., 2013). These projections help evaluate the potential impacts of climate change at regional scales (Nikulin *et al*., 2012).

The four primary goals of the CORDEX program are: “to use downscaling to improve the understanding of regional/local climate phenomena and their variability and changes; to assess and enhance regional climate downscaling models and techniques; to generate coordinated sets of regional downscaled projections worldwide; and to promote communication and knowledge exchange with users of regional climate information (Lennard *et al*., 2018).” Africa has been classified as a region of primary concern because it has the least adaptive capacity and generally lacks RCMs. In addition to their area of interest, regional modeling centers were asked to give downscaled datasets for the African region in research aimed at the continent. (Nikulin *et al.*, 2012). “Following the CORDEX experimental and data output protocols, 12 RCMs and 15 CMIP5 GCMs were downscaled to a horizontal grid resolution of 0.44 degrees over the African domain”.

The fifteen CMIP5 models are subsamples of the CMIP5 ensemble and consist of three RCPs (2.6, 4.5, and 8.5) (Lennard *et al*., 2018). More evidence about the CORDEX GCM-RCM matrix for Africa is accessible in Nikulin et *al.* (2018). The CORDEX RCMs in modelling the current rainfall characteristics over the East African region has also been studied by Endris *et al.* (2013). Endris *et al*. (2013) assessed the capacity of 10 CORDEX RCMs to model the characteristics of rainfall patterns in Eastern Africa. The results show that most RCMs simulate the key elements of rainfall climatology over the three sub-regions and replicate most recorded regional responses to El Niño–Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) forcings.

Together, the analysis reveals significant biases in individual models depending on the season and sub-region, although the ensemble average is in better agreement with observation than individual models. In general, the analyses “show that the mean of the multimodel ensemble adequately simulates Eastern Africa’s rainfall and can, therefore, be used to assess potential climate forecasts for the region.” Specific studies were done in Uganda and Tanzania (Kisembe, 2019; Luhunga *et al*., 2016), Lake Victoria Basin (Olaka *et al.,* 2019), and Ngorongoro Conservation Area (Moehlman *et al*., 2020) and have affirmed the potential use of CORDEX RCMs in simulating rainfall and temperature in the individual countries and application in resource management.

**2.4 Climate Change Scenarios**

A significant number of universal climate change scenarios have been produced in the Fifth Coupled Model Intercomparison Project (CMIP5) (Taylor *et al*., 2012). The Intergovernmental Panel on Climate Change's Fifth Assessment Report (AR5) makes substantial use of these scenarios (IPCC, 2013). CMIP5 models are more complex, better represent external forcing, and run at a higher resolution than those used in the preceding Intercomparison Project (CMIP3). Scenarios for the future in CMIP3 and CMIP5 are remarkably similar (Knutti and Sedlácekˇ, 2014), confirming that scientists can still have confidence in the results. Climate change scenarios are built on assumptions of the future and will be uncertain per se. Several forces influence future climate, the most critical being greenhouse gases, aerosols, and changes in the land surface. Different forcing components work on different spatial scales and can be both warming and cooling. The relative importance of scenario uncertainty grows over time.

As part of the CORDEX effort, the Rossby Centre regional climate model (RCA4) (Strandberg *et al.*, 2014) is used to downscale different GCMs at 12.5 km or 50 km resolution. Nine GCMs have been downscaled using RCA4, making it the highest compared to what has been downscaled with any other RCM to date. Furthermore, the RCA4 ensemble is unique in its sampling of the uncertainty related to the choice of GCM. The RCA4 simulations cover the period 1961-2100, making it possible to validate historical climate's performance and explore likely future climate change from short, medium, and long-term time perspectives under different scenarios. The RCA4 model was developed as a transferable model, implying that it can be applied to any domain worldwide without retuning. The model is efficient and user friendly; no preprocessing is needed to run RCA4 since all data used for simulation are read from global databases. These data sets form a unique resource that could be used in assessing the potential impacts of climate changes on biodiversity (Baker *et al*., 2015; Moehlman *et al*., 2020; Opere *et al*., 2019; Raymond *et al.*, 2019).

## 2.5 Biodiversity Conservation and Climate Change

When combined with other global change factors, including habitat destruction, fragmentation, and exotic species invasion, climate change poses a severe danger to biodiversity (Ehrlich and Pringle, 2009). Research shows that climate change is emerging as the ultimate threat to biodiversity worldwide in the coming years (IPCC, 2019). For example, worldwide, wildlife populations are declining in significant parts of their historic spatial territories. These unprecedented biodiversity declines are attributed to the rising human population, changes in land use, biodiversity overexploitation, invasive species, and threats related to climate change (IPBES, 2019). Conservation and management policies that best maintain biodiversity under climate change must be established appropriately to stop biodiversity loss in the long run. Various efforts to improve the impacts have been mainly challenging (Ceballos *et al*., 2017; Pimm *et al*., 2014). This is occurring despite conservationists' adoption of a variety of tactics to slow the loss, including, but not limited to, gazetting protected areas, conducting diversity and population censuses, analyzing animal behaviour, and unravelling physiological factors that drive individual species fitness (Pullin., 2002; Madliger *et al.*, 2016).

Climate change has caused several of the world's greatest herbivores' ranges to collapse due to temperature and rainfall variations (Morrison *et al.*, 2007; Sanjayan *et al.,* 2012). This is detrimental to savanna ecosystems because large herbivores serve as ecological engineers by transforming the surrounding vegetation structure and species composition (Owen-Smith, 1988). Rainfall and quality surface water availability in the African savannas impact the growth of fine vegetation and collective species-specific biomass levels of large herbivores (Moehlman *et al*., 2020). Therefore, it is crucial to ascertain the future impact of rainfall and temperature variation on significant herbivore population dynamics as a new threat and the contributions of other factors.

Identifying the most robust and effective conservation measures for the future is thus heavily reliant on accurate, and spatially detailed forecasts of climate change's expected effects on biodiversity. Predicting biodiversity's response to climate change has proven to be a highly active area of study. (e.g., Dawson *et al*., 2011; Pereira *et al.*, 2010; Salamin *et al.*, 2010). Climate predictions play a part in informing decision-makers and scientists about impending future risks. They also provide ways of augmenting and attributing biological changes to climate change. Still, they support developing practical methods to reduce the effects of climate change on biodiversity (Parmesan *et al*., 2013; Pereira *et al.*, 2010). In conservation and management applications, descriptive models on space utilization based on home ranges are useful. (Kie *et al.,* 2010). However, ecologists' ultimate goal is to comprehend the processes that result in these patterns. Understanding the processes that drive movement and distribution is necessary for solving complex environmental issues like predicting how animals will react to habitat loss and global warming.

In savanna ecosystems of Africa, species distribution is governed by the availability of forage which varies based on periodic variations in rainfall (Sankaran *et al*., 2010) and temperature

(Kandalam and Samireddypalle, 2015). These disparities are expected to have compounding effects on countless species since the intensity and swiftness of such changes have been unique within the past millions of years (Diffenbaugh and Field, 2013). As climate changes, most species are likely to be subjected to climatic environments that surpass their physiological tolerance. Due to this exposure, animals will experience physiological stress (Huey *et al*., 2012), reduced level of fitness (Bozinovic *et al*., 2011; Kearney *et al*., 2009; Oswald *et al*., 2011), or the threat of being extinct (Sinervo *et al.*, 2010).

Ogutu *et al*. (2016) report massive declines of wildlife in Kenya based on climate change stresses. Their study shows that about 68% of the wildlife has disappeared from Kenyan rangelands between 1977 and 2016. The decline was lowest in Burchell' zebra at 30% and highest in the Giraffe at 88%. The declines occurred both inside the parks and in the dispersal areas. Increased human population, land fragmentation, changes in land use and land cover, infrastructural developments, poaching, climate variability and change, infectious disease outbreaks, and competition with livestock for space, water, and pasture were factors in these decreases (Craigie *et al*., 2010; Ogutu *et al*., 2016; Said *et al*., 2016; Western *et al*., 2009).

**2.6 Impacts of Climate Change on Herbivores**

There is an urgent need to identify and protect species impacted by frequent extreme weather patterns resulting from global warming. Rising temperatures and CO2 levels as a result of global climate change have direct implications on herbivores (Adler *et al.*, 2009; Dawson *et al.*, 2011; Sintayehu, 2018). Changes in the hydrologic cycle (evaporation and precipitation), an increase in the volume and scope of extreme weather events, and more frequent fires that damage ecosystems are all possible indirect repercussions of these direct consequences. Shifts in geographical ranges and species distribution, as well as richness, migratory patterns, and the frequency and severity of pest and disease infestations, are all examples of how these changes can impact biodiversity.

Past studies show a direct link between weather, particularly extreme conditions, and species' reproductive success. The impacts are manifested directly through rainfall, droughts, and heatwaves (Gandiwa, 2016; Owen-smith, 1990; Ogutu *et al*., 2015; Ogutu *et al*., 2014) or indirectly via food availability (Coe *et al*., 1976; Dublin *et al*., 2015; Mduma *et al*., 1999; Ogutu *et al*., 2015). Rainfall is a key climatic factor affecting herbivore population dynamics in African savannas (Dublin and Ogutu, 2015; Ogutu *et al.*, 2008), aggregate population biomass (Coe *et al*., 1976; East. 1984), recruitment dynamics (Ogutu *et al*., 2011), phenology, synchrony and prolificacy of calving (Dublin and Ogutu, 2015; Ogutu *et al.*, 2010, 2014), seasonal dispersal and migration of large herbivores (Holdo *et al*., 2009; Hopcraft *et al*., 2014). Rainfall has been shown to impact the availability of good feed and the performance of large herbivore populations in numerous studies, particularly during the dry season (Mduma and Sinclair 1999; Ogutu and Owen-Smith, 2003).

Herbivore population dynamics and density are influenced by rainfall fluctuations characterized by life-history features and strategies (Moehlman *et al*., 2020). In African savannas, extreme food shortages during severe droughts are frequently associated with enormous die-offs of grazing ungulates. For example, the severe drought of 1993–94 killed ~14 448 (40%) of 36 119 buffalo (Metzger *et al.*, 2010) and a quarter of a million of 1.5 million wildebeest (Mduma and Sinclair 1999) in the Serengeti National Park. Likewise, the 1999–2000 drought, which was also extreme and widespread, killed 1500 buffaloes plus virtually all buffalo calves under nine months old in the Ngorongoro Crater (Estes *et al*., 2006).

On the other hand, extreme rainfall that results in floods within the savannas could also negatively impact animals if huge regions get waterlogged. Furthermore, heavy rain increases grass growth and depletes plant nutrients, reducing the nutritional level of herbivore food. (Moehlman *et al*., 2020). Rainfall during the summer months may have a direct impact on the retention of some green fodder during this key period when starvation sets in. Weakened animals may also become more vulnerable to predation. The dynamics of the rangelands are driven primarily by rain received during the dry season. Rainfall in the times of drought could also have indirect effects by influencing the dependence of animals on water points where lions lurk.

In addition, changes in weather patterns impose natural limits on the distributions of many herbivores (Smith *et al*., 2018). In temperate areas, it’s evident that species are shifting their ranges along with temperature gradients (Cahill *et al*., 2012; Gaston and Curnutt,1998; Parmesan *et al.*, 1999). There are speculations that there could be changes in herbivores distributions in African savanna (Bale *et al.*, 2002). Understanding distribution patterns in African savannas requires careful analyses since savanna herbivores create a range based on the availability of forage driven by rainfall.

There are limited studies on the consequences of varying precipitation and temperature models on herbivores, and little is also published about the direct effects of increasing temperatures patterns on herbivores. Although much can be deduced, exceptionally high temperatures lead to increased mortality in herbivores (Bale *et al*., 2002; Ogutu *et al*., 2016). Existing studies indicate that the unequivocal impacts of temperature tend to be substantial and more important than any other element (Bale *et al*., 2002; Sala *et al.*, 2000) because high temperatures make some habitats inhabited by herbivores unsuitable (Smith *et al*., 2018). Ogutu and Owen-Smith (2005) linked overall decreases among less popular ungulate populations in Kruger National Park (KNP) after 1986 to exceedingly inadequate rain in the dry season months. These researchers found that the temperature conditions increased by about 0.4ºC at the time of the population decline.

Continuously warmer conditions increase plant respiration and thus cause faster loss of green foliage to the detriment of forage quality. NDVI Statistical models support this position; sustained high temperatures would have decreased rainfall efficiency because warmer conditions contribute to faster evaporation of soil moisture (Pareek, 2017). The effects and costs of 1.5 degrees celsius of worldwide warming will be far more than expected, keeping in line with a comprehensive assessment issued by the Intergovernmental Panel on Climate Change (Hoegh-Guldberg *et al*., 2018). The report states that: "climate-related risks rely on the speed, peak, and duration of warming. Collectively, they're more extensive if heating exceeds 1.5°C before returning to the same level by 2100 than if warming gradually stabilizes at 1.5°C, especially if the maximum temperature is about 2°C (high confidence).

Some impacts, such as the loss of ecosystems, may be long-lasting or irreversible. The projected global warming of 1.5°C is expected to cause damage of over half of the climatically determined geographic range in nearly 105,000 species studied, according to IPCC report 2018. Among them are 9.6% of insects, 8% of plants, and 4% of vertebrates. The number increases to 18% of insects, 16% of plants, and 8% of vertebrates for global warming of 2°C (medium confidence)" (Nullis, 2018). Impacts associated with other biodiversity-related risks such as forest fires and the spread of invasive species are lower at 1.5°C than at 2°C of global warming (high confidence) (Nullis, 2018).

## 2.7 Elephant's Response to Rainfall Patterns and Water Availability

In their research, Bohrer *et al*. (2014) and Ngene *et al*. (2009) discovered that elephants respond to large and small rainfall events by migrating and would mainly occupy low elevation areas when vegetation activity is high and retreat to higher elevations forested areas when vegetation senesced. There is a replication of the same scenario in Amboseli, where elephants occupy low altitude dispersal areas in wet seasons such as the Amboseli National park and the surrounding group ranches but migrate to Chyulu hills in the dry season. Vegetation heterogeneity and patch size have also emerged as strong predictors of the presence of elephants in savannah ecosystems (Pittiglio *et al.*, 2012). Elephant's movement and habitat utilization in the dry season are restricted by water availability in the savanna plains of Africa (Chamaillé-Jammes *et al*., 2007; Ngene *et al.*, 2009). In a typical natural environment where human influence is minimal, elephants are known to spend a considerable amount of time near the water sources during dry seasons (Chamaillé-Jammes *et al*., 2013).

Elephants are bulk- feeders, consuming a daily average of approximately 7% of their body weight (Gara, 2014). Therefore, elephants need to balance between foraging in landscapes far from water sources where forage quality and quantity are reasonably high and travelling long distances to meet their water requirements. In habitats such as the Amboseli ecosystem, where pastoralists and elephants co-existed, dry season competition for water is typical. This results in increased human-elephant conflict around water sources. This kind of scenario is also replicated for the other large herbivores. A lack of understanding of these underlying forces and their causes threatens the adequate protection of elephants and other herbivores, and it may escalate human-wildlife conflicts (Bohrer *et al*., 2014). Therefore, the protection and management of elephants and different herbivores habitats in the African savanna needs a proper understanding of their distribution in the ecosystem and how they respond to climatic changes.

## 2.8 Connectivity between Protected Areas and Dispersal Areas

A ‘wildlife corridor’ is a locality within the environment that operates as a passageway to connect wild species through dispersal and migration processes. These corridors are often vegetation-based habitats that facilitate movement while providing less predation risk than migrating through open lands (Burkart *et al.*, 2015). Wildlife corridors vary in size, shape, length, and composition and are likely to lessen the consequences of climate change through habitat connectivity (Beier and Noss, 1998; Ojwang *et al.*, 2017). Climate change can modify the latitude of the routes, change migration time, and in some circumstances, overcrowd the corridors as more species migrate away from territories transformed by warming (Mazaris *et al*., 2013). Protected areas worldwide are rapidly becoming ecological islands because of a severe decrease in connectivity with dispersal areas (Newmark, 1996; Ojwang *et al*., 2017). “Land conversion, artificial barriers, hunting, and the transfer of diseases from domestic animals and humans to wildlife play a key role in connectivity.” Still, Population pressure, economic progress, poor governance, and poverty are the primary drivers of protected area isolation in Africa (Newmark, 2008).

The Amboseli and Chyulu Hills National Parks are tiny and cannot support high populations of herbivores (Okello and Kiringe, 2004). As a result, numerous herbivores are present outside of the protected areas (Western *et al.*, 2009). “Since the parks are not fenced, animals including the migratory or wide-ranging wildebeest (*Connochaetes taurinus*), elephant, buffalo, zebra (*burchelli*) and Thomson’s gazelles (*Eudorcas thomsoni*) move seasonally between the parks, group ranches, community wildlife sanctuaries, and other dispersal areas within 8000 $km^2$ of the Amboseli ecosystem” (Western, 1975, 1982; Western and Maitumo, 2004). The animals gather in the areas designated as protected, notably Amboseli National Park in the dry season, which contains permanent swamps fed by Mt Kilimanjaro melting ice and runoff, as well as various wetlands and riverine habitats.

When water and forage are widely available during the rainy season, the animals disperse into the surrounding pastoral ranches (Andere, 1981; Mworia *et al*., 2008; Western, 1975). The large grazers within the parks inhabit areas of high grass cover or biomass. In contrast, Within pastoral ranches, small herbivores occupy zones with shorter grasses and biomass. (Mworia *et al*., 2008). The pastures of the Amboseli community group ranches are important wildlife spreading grounds and migration routes for a variety of herbivorous animals. (Ntiati, 2002; Okello and D'Amour, 2008) The protected areas will be isolated and insularized without these ranches, resulting in increased competition for precious resources within their bounds. Two of the most critical herbivore dispersal areas and migration corridors are the Olgulului Ololorashi Group Ranch (1232 $km^2$) and Kimana Group Ranch (297.9 $km^2$) (Kioko and Okello, 2010). Since herbivores migrate through large areas between different ecosystems, evolving land use and ownership changes have significant consequences for herbivore conservation (Burkepile *et al.*, 2013). They move in search of free surface water (Jachmann and Croes, 1991) and reproductive demands (Stokke and Du Toit, 2002). Identifying important corridors and related management problems in Amboseli is crucial for immediate conservation action.

**2.9 Impacts of Human Activities on Habitat of Herbivores**

Savanna ecosystems across Africa have been threatened by accelerated land-use change resulting from an increasing human population (Ellis and Galvin, 1994; Sala *et al.*, 2000). The entire ecosystem is adversely affected by impacts on key resource areas resulting from land-use change. For instance, Kenya continues to experience significant challenges in conserving wildlife because of its enormous wildlife diversity and the increasing human population. According to Kenyan government censuses, the Kajiado County's human population increased tenfold from 85,903 in 1969 to 406,054 in 1999 to 687,312 in 2009. The County's population is growing at over 4% per year, above the 3.1 per cent national average (Campbell and Lusch, 2003; Ntiati, 2002). Urbanization, intensification of land use, and rising subsistence and commercial agriculture, all supported by Mt. Kilimanjaro's runoff, are linked to demographic shifts. Poaching, infrastructure, and human-wildlife conflicts are all issues that need to be addressed (Kioko and Okello, 2010; Mworia *et al*., 2008; Okello *et al.*, 2009).

Activities like land fragmentation are a threat to biodiversity because it disrupts the dispersal of organisms (Said *et al.,* 2016). As a result, the capability of species to survive and keep healthy within the fragmented landscape mainly depends on their ability to move and disperse across degraded areas with poor resource conditions (Boudjemadi *et al.*, 1999). Herbivores in Kajiado face harmful impacts from land tenure shifts, subsequent land subdivision, settlements expansions, agriculture, fences, and infrastructure creation (Said *et al*., 2016).

Settlements increased from under 1000 in 1973 to over 10000 in 2000 in the Amboseli ecosystem. Areas with a higher settlement or arable potential, which are also the ideal settings for herbivores, saw a higher rate of increase. (Western and Nightingale, 2004; Western and Dunne, 1979). There was an increase in land under cultivation in Kajiado from below 400 $Km^2$ in 1989 to over 900 $Km^2$ by 1994 (Kioko and Okello, 2010). Currently, broad strips of grasslands and wetlands used by herbivores as dry-season concentration and wet-season dispersal are under cultivation. The areas affected most are those on the slopes of Mt. Kilimanjaro, where over 200 $km^2$ is under rain-fed agriculture (Okello, 2005; Ogutu *et al.*, 2014). Several studies have monitored the seasonal movements of these species in and out of the park (Esikuri, 1998; Kioko and Okello, 2006; Kioko and Okello, 2010; Moss *et al*., 2011; Western, 1975). Moss *et al*.(2011) reported that many herbivore species in Amboseli spend nearly 80% of their time outside the park.

## 2.10 Community Perceptions Towards Herbivores

The communities that live adjacent to protected areas interact with the herbivores daily, and their opinions are based on their past and current experiences. Large herbivores like the elephants are well-known for crop destruction apart from injuries and death to the locals. Sitati *et al.* (2005) examined the proneness of cultivated farms to crop raids by the elephants. The study discovered no uniformity in the spread of the raiding activities within zones of dispute because of differences in geographical factors (Kaelo, 2007) or the efforts of farmers' to defend their fields. In Kenya, retaliatory killings of elephants by the local communities are also a common occurrence (Western *et al.*, 2015). For example, in Laikipia, human-elephant conflicts have increased, especially after the subdivision of the ranches in the south of the county leading to loss of lives, destruction of crops, infrastructure, and compromising physical safety (Blair *et al*., 2018).

In Africa, for instance, current conservation policies prohibit local communities from using traditional methods to reduce conflicts. For example, government officials' drastic security measures are used to protect threatened species like elephants because the local community is perceived as a threat to the animals (Schauer, 2015). There are concerns from rural communities living with elephants in Africa that they are being overlooked by conservation authorities interested more in the welfare of animals than people. As a result, they impose protected area regulations that restrict the community from accessing critical resources such as grazing pastures (Kamau and Pickard, 1998). Past studies have shown that African conservation policies ignore the feelings of the local communities and assume that they are passive actors who should naturally support conservation policies imposed on them (Lee and Graham, 2006).

Several studies have shown that material benefits to the local community encourage positive attitudes towards herbivores, especially elephants, although the communities still suffer from elephant attacks (Gillingham and Lee, 1999; Infield and Namara, 2001). Despite extensive research being done on human herbivores conflict in Amboseli (Moses *et al*., 2016; Okello *et al.*, 2014; Sitati *et al*., 2014; Kagwa, 2011), there has been little effort in exploring the link between attitudes towards these animals and the changing climate in the Amboseli ecosystem. And still, how this might increase impacts on local communities in the future is not clear. Therefore, there is a need to project the changes in climate and its potential effects on wildlife distribution and how this might increase impacts on local communities in the future. Therefore, there is a need to project climate changes and their potential effects on wildlife distribution.

## 2.11 Trans-disciplinary Research Approach

Trans-disciplinary science has been defined as “a broad interdisciplinary research that advocates the integration of natural sciences, social sciences and the humanities, and the involvement in multiple stakeholders from all aspects of society” (Klein, 2004). It has a significant focus on addressing complex societal concerns by applying different knowledge sources (Balsiger, 2004). It has been demonstrated that traditional disciplinary research methods cannot handle complex interdependent challenges not limited to specific sectors or disciplines. (Klein, 2008). Conservation–related issues include a broad spectrum of topics, processes, and solutions, with ecosystems and social networks intricately linked (Allen *et al*., 2011). Many ecologists are now adopting a system dynamics approach to social-ecological systems, thresholds, feedbacks, and emergent traits like adaptability. (Folke *et al*., 2005). Despite anthropogenic change, conservation biology continues efforts to protect biodiversity, environmental structure, and ecological processes. Conservation's capacity has dramatically improved, and its convergence with human-centred fields like psychology, political sociology, and economics has become an intriguing and rapidly moving frontier.

Climate change, and its possible consequences on biodiversity's future, is the new problem (Bellard *et al*., 2012). Solutions to this problem require integrating various sources of knowledge to address it successfully. Scientific methods must be entrenched in a specific context, and multisectoral interactions must be used to match the most suitable approaches and tools to concerns to increase applicability (Ostrom, 1999). Scientific information can be transformed into real-life accomplishment using participatory processes or paying attention to salience, reliability, and acceptability (Cash *et al*., 2003). New understandings built out of a multidirectional knowledge exchange that considers the involvement of all members (including scientists), which results in better livelihoods through discussion based on the scientific approach, is vital. The effects of climate change on herbivore populations were projected using a combination of ecology, conservation biology, local people's perspectives, and climate change in this study.

The Framework within which actions must be taken for transformation exists within precise social and institutional backgrounds. The main goal of adaptation is to support experts and legislators to make accurate decisions to help them get past the intricacy of management-by-policy interfaces from better knowledge and enhanced perception. A higher revolutionary amendment is needed if, as an example, the present performance of a system is already marginal and more sensitive to a stressor like climate variability and global climate change. Trans-disciplinary research mainly aims to link awareness of science and decision-making processes (Lawrence and Després, 2004). The approach acknowledges that scientists have no monopoly on Knowledge (Albrecht *et al*., 1998) but aim to explain today's world by unifying information from both academic and non-academic viewpoints (Ramadier, 2004).

Generally, there is a gap in knowledge and understanding of herbivore distribution, climate science and climate unpredictability in the Amboseli ecosystem. The lack of firsthand information on herbivore range size and distribution in the ecosystem makes adequate conservation efforts for the species complex. Up until recently, there were also gaps in the availability of information on climate change in Amboseli. The availability of a long record of climate data is required for effective adaptation and mitigation methods. This study adds to the existing data on Amboseli's rainfall and temperature. Its goal is to provide scientifically sound information on the effects of climate change on herbivore distribution patterns. The information gathered in this study will help to develop effective, efficient, and equitable policies, strategies, and methods for herbivore control in the Amboseli ecosystem.

# CHAPTER 3 : DATA AND METHODS

## 3.1 Study area

### *3.1.1 Location*

The Amboseli habitat is located in southern Kenya between 36° 52' 48 E and 37° 55' 12 E, and 2° 00' 00 to 3° 12' 36 S. The area spans 5700 km2 in Tanzania, between the Chyulu Hills and Tsavo West National Parks, south of Mt Kilimanjaro (Fig 3.1). In terms of organizational setting, the Amboseli ecosystem comprises Amboseli National Park (ANP; 392 km2), Chyulu West Game Conservation Area (245km2), and the surrounding communally-owned Maasai group ranches. These group ranches cover about 5063 $km^2$ of Kajiado County and form essential dispersal areas for wildlife during the dry season (Groom and Western, 2013; Ogutu *et al.*, 2014; Okello and Kioko, 2010).

Outside of the park, there are important wildlife habitats. To the north, the Lengesim Group Ranch provides herbivores with wet season foraging places. On the other hand, Kuku and Mbirikani group ranches provide important migratory corridor connections to the Chyulu and Tsavo West ecosystems, respectively (Ojwang’ *et al.*, 2017). The Kimana group ranch in the southeast is critical where animals use most marshes as water sources. The Olgulului-Ololorashi group ranch covers 90 per cent of Amboseli National Park's 1232 square kilometres, making it an essential dispersing region for herbivores throughout the year.

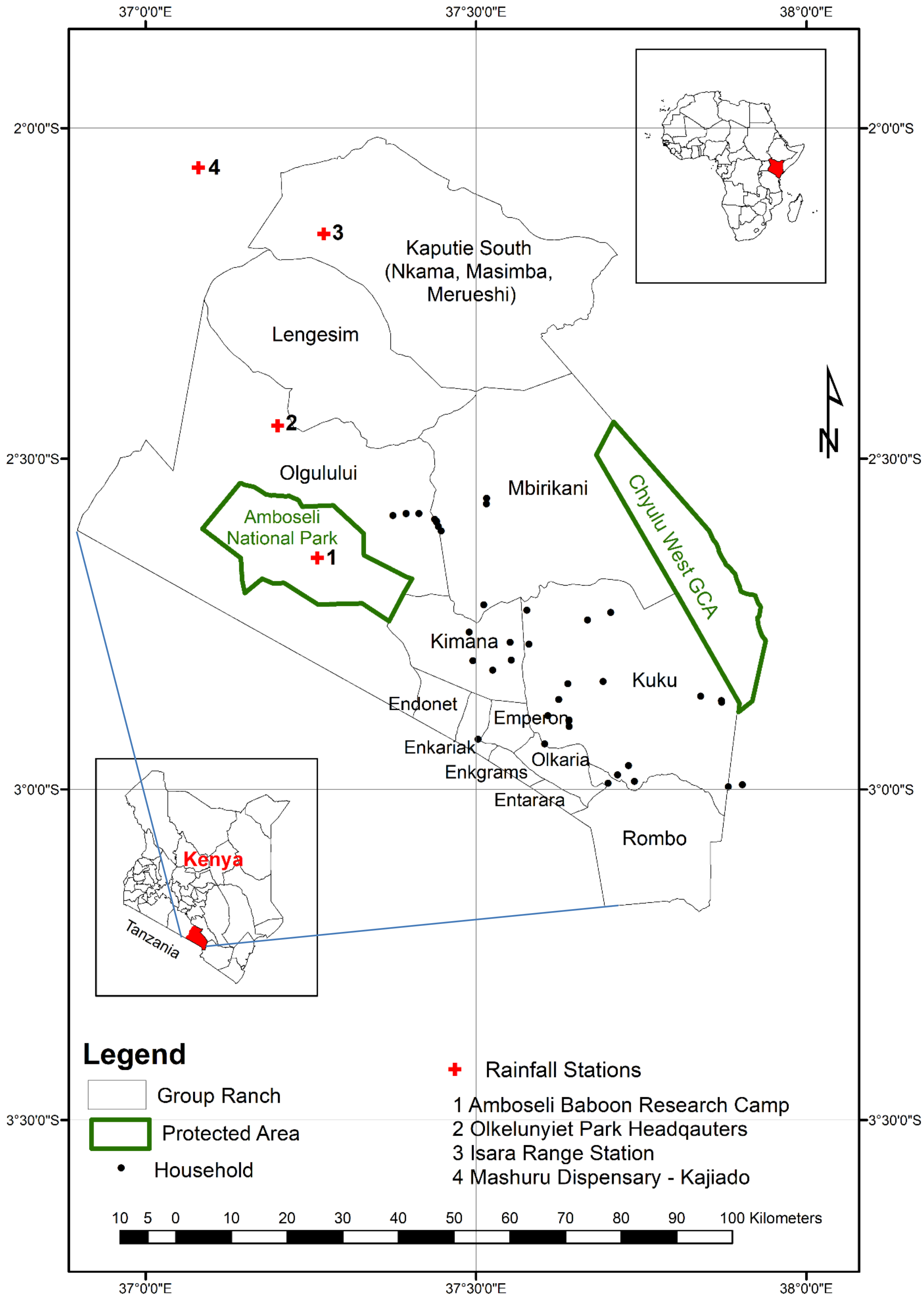



Figure 3.1: Map Showing Location of Study Area and Field Survey Points

### *3.1.2 Amboseli Biodiversity.*

The Amboseli habitat is located in southern Kenya, near the Tanzanian border. Basement plains, saline plains with freshwater swamps, Kilimanjaro's volcanic slopes and semi-arid vegetation make up the ecosystem. Even though the Amboseli habitat is semi-arid, it supports a diverse range of herbivores that carnivores such as lions, leopards, cheetahs, hyenas, jackals, and civets rely on (Stakeholders Amboseli Ecosystem, 2009). Amboseli is a vital wildlife conservation region in Kenya because of its diverse herbivore population. In their study in Amboseli, Muchiru et al. (2009) concluded that the disruption induced by ever-changing nomadic activities causes concentrated nutrient and plant variety hotspots in savanna habitats that remain unique from the surrounding savannas for several years or decades.

Elephants are the main reason for the Amboseli ecosystem's popularity. There are currently over 1400 elephants in the area. These creatures have considerably impacted the region's ecology, particularly in the Amboseli National Park's environs (Western, 2007). The Amboseli elephants have been the subject of one of Africa's most comprehensive elephant studies (Moss *et al*., 2012). Elephants respond to tourists by allowing tourists to get up close and personal with them. They also draw a lot of interest from wildlife researchers (Stakeholders Amboseli Ecosystem, 2009). Because free-ranging large animals constitute the main attraction of foreign tourism in Kenya, there appears to be a link between herbivores (especially large mammals) and tourist interest (Okello, 2005). As a result, efficient management of Kenya's protected areas is required to assure the continued survival of the wildlife on which the tourism economy depends.

### *3.1.3 Climate*

The long-term monthly rains of Amboseli show a bimodal pattern of rainfall with two wet seasons and two dry spells throughout the year. The months of October, November, and December (OND) receive more rain than March, April and May (MAM) (Figure 3.2). The rainfall pattern exhibited in Amboseli is unique and deviates from other parts of the country that receive rainfall in the MAM season. The trend is similar to the one witnessed in Kitui and Machakos, where the OND season is the main rainy and cropping season. The Amboseli habitat is located on the leeward slope of Mt Kilimanjaro, making it one of Kenya's driest areas. However, subsurface streams from Mt

Kilimanjaro well up in a succession of lush swamps during the dry season, providing water and feed for animals.

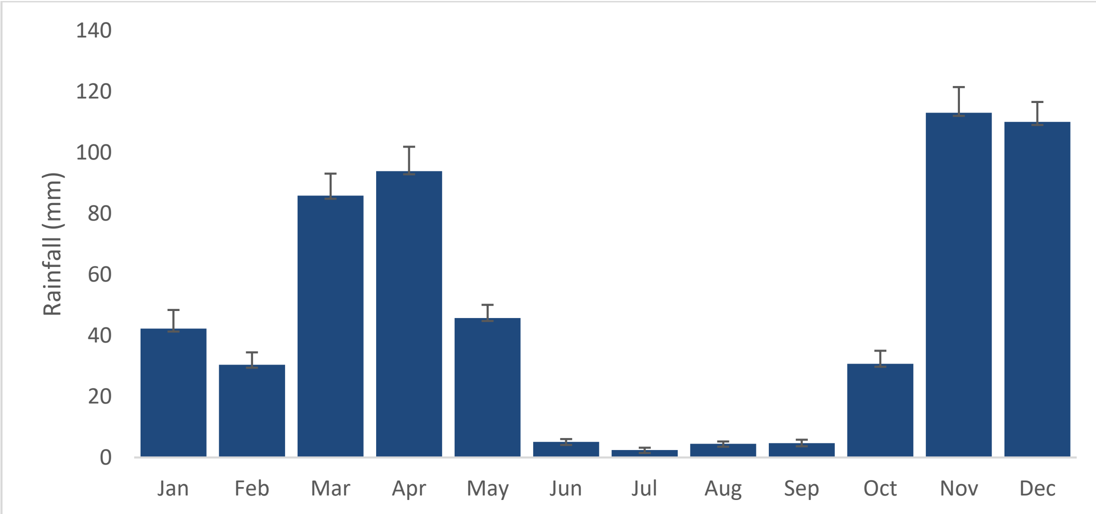



Figure 3.2: Trends in mean monthly Seasonal distribution of rainfall in mm (bars represent the standard error) Source: Aduma *et al.*, 2018

### *3.1.4 Land use and land cover*

Pastoralism is the key land use in the Amboseli ecosystem. Pastoralists customarily depend on animal husbandry for their livelihoods. Pastoralists are affected by the variations in the distribution of rains and evolving arid climatic conditions in which plant growth is seasonal. (Wayumba, 2015). Pastoralists shift their livestock to the mountains or well-watered pastures in the dry seasons and move back to take advantage of the new and more delicious pastures when the rains fall on the rangelands (Wayumba, 2015).

The Amboseli ecosystem comprises mainly Acacia woodlands, open grass plains, swamps, and marshlands (Boone *et al*., 2005). Within the park, woodlands are declining while bushlands, scrublands, grasslands, and wetlands are expanding, as witnessed in the past half a century (Western, 2007). The change in vegetation is attributed to an increasing elephant population destroying woodlands (Western, 2007; Western and Maitumo, 2004) and hindering their recovery, creating open grasslands dominated by grazing herbivores. However, the elephant's movements are blocked due to human activities, allowing woodlands to rejuvenate faster outside the park (Western *et al*., 2009). Subsequently, the modified open grasslands in the park attract livestock to move into the park. In contrast, the transformed woodlands outside attract elephants to move into the dispersal areas outside the park.

In other parts around Loitokitok and the slopes of Mt Kilimanjaro, Woodland is declining partly because of intense human activities. These activities included; clearing natural vegetation to create room for agriculture (Reid *et al*. 2004), and construction of villages and fences using thorn-bushes, wood fuel, and charcoal burning (Okello and Kioko, 2010; Western and Maitumo, 2004). These activities are gradually destroying wildlife habitats and diversity, and have partially blocked migration corridors (Ojwang *et al*., 2017).

### *3.1.5 Land Tenure and Settlement*

Amboseli Ecosystem is dominated by pastoralism as the critical land-use style. This type of communal property regime is essential because it gives pastoralists the right to access pastures and grazing lands. However, these free movements suffered a setback due to the introduction of major land reforms in Kenya, where large parts of communal land are now adjudicated first to group ranches and later to individual private property (Moiko *et al.*, 2019; Mwangi *et al*., 2006; Rutten, 1992).

In Kenya, land laws have changed, resulting in community lands becoming commercial and legal titles becoming securities. (Moiko *et al.*, 2019). Due to the subdivision of group ranches, the tenure of community-owned land is increasingly shifting from group ranch to individual private property. As a result, the Maasai are settling down and controlling livestock on their plots of land, leasing or selling property to settler farmers who have not previously coexisted with animals (Groom and Western, 2013; Kimani and Pickard, 1998; Western *et al*., 2009). The animals' distribution is restricted by the fences of the small individual parcels. As a result, livestock overgrazes the area, degrading the soil and making the landscape appear uniform. (Bulte *et al*., 2006a; Said *et al*., 2019). Herbivores and livestock populations have been adversely affected by cultivation, land tenure changes, and settlements expansion. By 2017, land in Kajiado County had fragmented into private individual ownership (64 per cent), group ranches (20 per cent), protected areas (4 per cent), Magadi Soda Company extended concessions (4 per cent), and transitioned from group ranch to private ownership (8percent). Galaty and Munei (1998) go on to say that the disintegration of group ranches has hurt Kajiado's rangeland management.

According to Western *et al*., 2009, locations best adapted for herbivore grazing and with better arable potential are experiencing a faster pace of settlement growth. The area of land under cultivation has increased, particularly in Eastern Kajiado (Okello and Kioko, 2010). Many grasslands and wetlands areas that animals utilized as dispersal places in the dry and wet seasons, particularly Mt. Kilimanjaro's foothills are presently under rain-fed agriculture. These changes in land use harm the animals in the ecosystem because their seasonal movements to water points, foraging, and breeding grounds are under threat due to blocked migratory corridors (Fynn *et al*., 2016; Okello and D'Amour, 2008; Okello and Kioko, 2010). For that reason, the animals spend more time close to limited available water sources (Western and Gichohi, 1994), heightening the degradation of the habitat and the danger of disease transmission (Western and Maitumo, 2004). During periods of drought, both herbivores and livestock become vulnerable and are devastated by the harsh conditions due to reduced mobility and the inability to access distant pastures (Western and Nightingale, 2004).

### *3.1.6 Livelihoods and Socio-economic vulnerabilities*

For generations, the Maasai have been the primary occupants of the Amboseli ecosystem, with pastoralism as their primary source of income (Rutten, 1992). The main activity on community land is animal grazing, medicinal herbs, building materials, firewood, and tourism. Tourism has been a source of income for the community for many years. However, landowners are currently disgruntled with the tourism industry's profits, which are modest and unequally distributed (Okello *et al.*, 2011). Increasing the human population's challenging economic times and changing climate have resulted in crop farming and leasing of land to large scale farmers in swampy areas (Campbell *et al.*, 2005). Change in land ownership regime in Kajiado has resulted in the community selling land and, in return, has led some into poverty (Galaty, 2013; Moiko *et al*., 2019; Rutten, 1992).

Transformations in land use and land cover threaten the survival of herbivores as land parcels are continuously being subdivided into small units fragmenting the ecosystem and affecting the range size of herbivores (Western *et al.*, 2009). This scenario is increasing conflicts between humans and animals, especially elephants that raid crops from small farms. The Kimana group ranch has been fragmented into 60-acre portions, and some private landowners have fenced their properties, preventing animals from freely moving across the ecosystem. Fences also result in migratory herbivores shifting their routes (Whyte and Joubert, 1988). The fencing of private properties and conservancies in the National Park areas hinders the free movement of the herbivores and even domestic animals (Ojwang *et al*., 2017). For instance, in the Maasai Mara, it has been observed that most herbivores and other animals get entangled into the electric fences as they try to retrace their migration routes. Consequently, most animals die out of exhaustion or become easy targets for poachers.

## 3.2 Conceptual Framework

Attaining natural conservation goals necessitates dealing with "wicked" issues. The complexity and dynamism of the social-ecological systems in which they are embedded are the sources of these intractable challenges. To effectively address these issues, conservationists are increasingly turning to transdisciplinary systems thinking and assessment. This offers philosophies, concepts, methods, tools, and approaches that have shown effectiveness in various sectors. The Social-Ecological Framework in Figure 3.3 incorporates one of the most theoretically important new models in conservation biology. It provides a list of variables that could interact and influence outcomes in the social-ecological systems (Ostrom, 2007, 2009; Poteete *et al*., 2010).

A lengthy history of empirical research on the commons, institutions, and collective action has aided the framework's development (e.g. Agrawal, 2001; Anderies *et al.*, 2004; Meinzen-Dick *et al*., 2002; Ostrom, 1990; Poteete *et al.*, 2010). The framework enables scientists to enhance a universal language that cuts across social and ecological disciplines. It also analyzes ways in which connections amongst various factors affect outcomes. A framework like this could assist future researchers in overcoming the sustainability of a social-ecological system by facilitating a diagnostic approach. Detecting the cause of negative results for natural and human systems using a well-known framework and possible amendments improves the understanding of complex systems. Because there hasn't been much done, it gives a comparison and contrast framework of various programs and, eventually, more established policy proposals.

People depend on ecosystems in many ways. Given the increasing demand for ecosystem-derived products and the growing human population, this reliance frequently necessitates changing or managing ecosystems to improve ecological goods and services (Cumming *et al.*, 2015). Four prevalent general features of social interventions include simplification, reduction in natural variability, fragmentation, and loss of infectious tendencies, as well as the imposition of stringent limits (Turner *et al*., 2001). “People can reduce habitat diversity, harvest animals or plants, alter disturbance patterns, and seek to regulate natural populations within pre-defined limits or create fences that restrict mobility and population expansion”. These alterations have an impact on the ecosystem's stability and resilience.

Forest loss, land degradation, pest outbreaks, extinction of particular species, and habitat loss are examples of how the ecosystem responds to human intervention and use. In his discussion, Cumming *et al*. (2015) stated that because the system is ubiquitous, the disruption is uncommon, and the reactions are varied, management mediations are frequently very confusing. As a result, even when there is a great deal of uncertainty about how the system will react. (Williams, 2011), action is required time and again, and unpredictable results might produce crises or generate new needs and expectations in the human socio-ecological order. People altering ecosystems can thus trigger some feedback loops that start with intentional governance as well as other actions and loop back through the ecological and socioeconomic system to maintain contro (Cumming *et al*., 2015). (Figure. 3.3).

The ecosystem products and services provided to and from SESs and social-ecological responses and exchanges varies with scale (Birge *et al*., 2016). As time and space expand, so does our ability to regulate ecosystems. Nonetheless, the variety of ecosystem resources accessible for management is increasing, generating a tension in which expanding range diminishes management capacity while increasing the need for it. Protected areas are essential for conservation, and they must grow in a way that is environmentally, economically, and politically sustainable (Cumming *et al*., 2017). SES's findings contribute to a more refined and appropriate approach to managing protected areas and a comprehensive framework for contrasting and comparing conservation strengths and weaknesses (Xiong *et al.*, 2009).

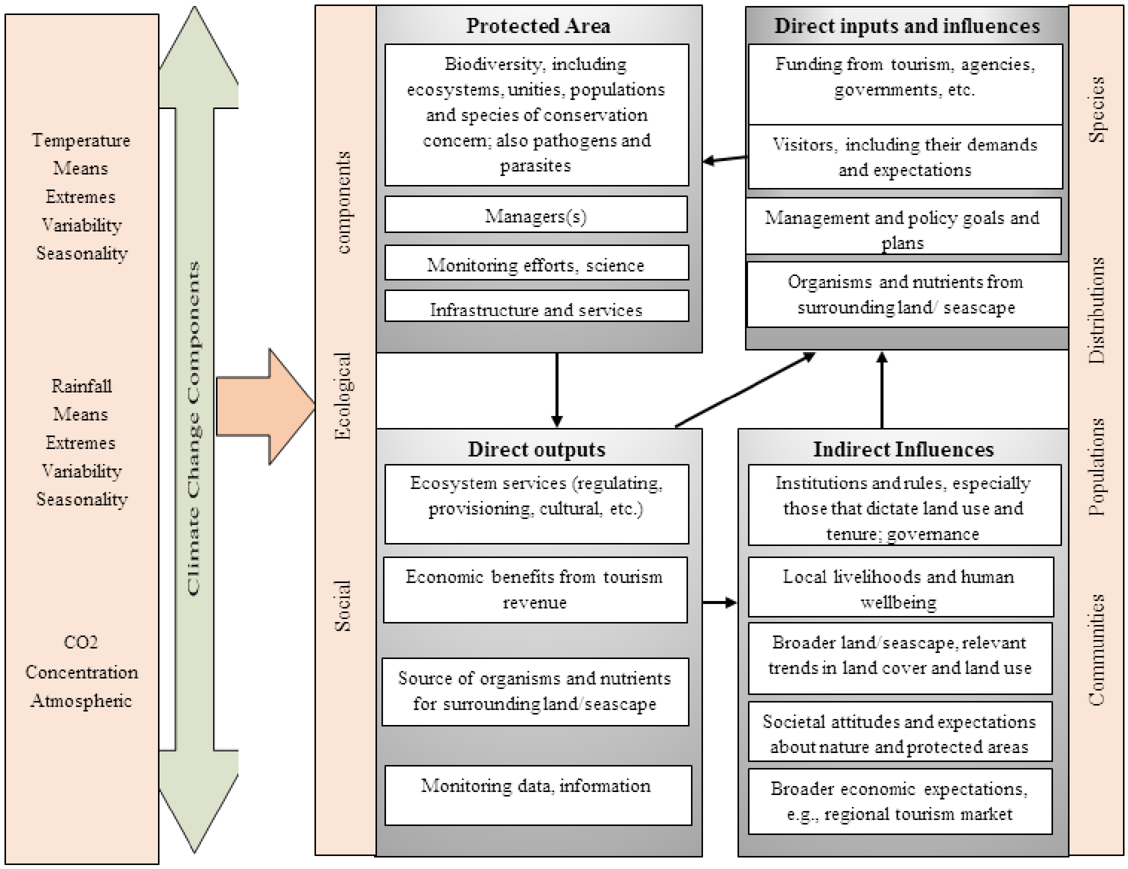



Figure 3.3: A systems perspective on social-ecological feedbacks in protected area management. In addition to interactions and feedback within protected areas, their direct outputs have added effects that influence their internal dynamics and future outcomes. Adapted and modified from (Source: Cumming *et al.*, 2017)

### 3.3 Research Data

This section provides a comprehensive discussion on the data sets used in this study, including climate (historical and projected), wildlife (spatial and temporal), and field survey data.

### *3.3.1 Climate Data*

The climate data consisted of observed rainfall data from 4 rainfall stations within the study area (Figure 3.1), gridded rainfall and temperature blended satellite and ground data, and projected precipitation and temperature from Regional Climate Models.

#### *3.3.1.1 Observed Rainfall Data*

Generally, Amboseli has few meteorological observation stations, which are not at suitable temporal and spatial resolution ideal for climate analysis. The majority of meteorological stations in the area are not operational, and those that are have some data missing. Four stations were used to conduct a climate study using observed rain gauge data from 1960 to 2014. Isara Range Station, Mashuru Dispensary, Olkelunyiet - Parks Headquarters, and Amboseli Baboon Research Camp were studied.

The Kenya Meteorological Department (KMD) and Amboseli Baboon Research Camp were the sources of this data. The stations were chosen for their data extent, proximity to the study area, and the reliability of observations with few missing data gaps. Figure 3.1 shows the geographical locations of the stations. These data sets assisted in verifying the use of the gridded rainfall and temperature data as proxies.

#### *3.3.1.2 Gridded Rainfall and Temperature Data*

The data included monthly temperature and rainfall records for the period 1960 to 2014. Due to limitations in getting station observed data spread uniformly throughout Amboseli, supplemental gridded observation/satellite blended "Climate Hazards Group Infrared Precipitation with Station (CHIRPS) data were used for rainfall (https://www.nature.com/articles/sdata201566). The data was sourced from the University of California, Santa Barbara (UCSB) Climate Hazard Group (CHG) through the IGAD Climate Prediction and Applications Centre (ICPAC). CHIRPS is a global dataset (50° S -50° N, 180° E -180° W), with a spatial resolution of 0.05°, and running from 1960 to 2014 (Funk *et al*., 2015)." It merges the Climate Hazards Center's Precipitation Climatology (https://www.chc.ucsb.edu/data/chpclim), 0.05 resolution satellite imagery and in-situ station data.

The study extracted the gridded monthly temperature data datasets from the Climate Hazard Group (CHG, 2019). The temperature data was derived from NASA's GIS Surface Temperature Analysis (GISTEMP) and was collected at a spatial resolution of 2.0-degree latitude x 2.0-degree longitude (GISTEMP Team, 2017). The data used was for the period between 1960 and 2014. It was also sourced from the University of California, Santa Barbara (UCSB) Climate Hazard Group (CHG) through the IGAD Climate Prediction and Applications Centre (ICPAC). The average monthly temperature data for the Amboseli was extracted using GeoCLIM software. Details on GeoCLIM can be found at http://chg-wiki.geog.ucsb.edu/wiki/GeoCLIM.

#### *3.3.2 Climate Change Scenarios Based on RCP 2.6, 4.5 and 8.5*

The future climate data used in this analysis is from the Rossby Center Regional Atmospheric Model (RCA4). This model was selected based on a survey by Endris *et al*. (2015). The Rossby Centre is the World Climate Research Program (WCRP) recommended by Regional Climate Model (RCM) for downscaling phase 5 Coupled Model Intercomparison Project (CMIP5) under the Coordinated Regional Downscaling Experiment (CORDEX) initiatives (Nikulin *et al*., 2012). "The CORDEX program is a project by the World Climate Research Program (WCRP) of the World Meteorological Organization (WMO) that offers the prospect for a better framework in creating high-resolution regional climate projections for impact assessment studies".

The RCA4 has gone through physical and technical changes with a significant level of analysis within the CMIP5 ensemble, implying that it can illustrate uncertainties and robustness in future climate changes. It also has the added advantage of high resolution (Jacob *et al.*, 2014). With a horizontal grid spacing of 0.44 degrees, the model integrates into the CORDEX-Africa domain, resulting in a 50 by a 50-kilometre grid (Endris *et al., 2015;* Nikulin *et al.*, 2012). The data covered the period 2006 to 2100 and was obtained through ICPAC.

The three Representative Concentration Pathways used in this study give various possibilities of rainfall and temperature changes based on global initiatives to limit gaseous emissions. RCP 2.6 stands for an optimistic projection characterized by low-level emissions resulting in a decrease in the concentration of greenhouse gases in the atmosphere. RCP 4.5 represents the medium emission scenario where international communities limit emissions with the limited implementation of climate change policies. RCP 8.5 scenario denotes a pessimistic projection with high levels of concentrations of gases emitted; this scenario assumes no implementation of climate change policies, the so-called business as usual scenario. Recent biodiversity studies on various species have used either two or three scenarios (Moehlman *et al*., 2020; Newbold, 2018; Wang *et al*., 2019).

#### *3.3.3 Wildlife Data*

The data on large herbivores and elephants was sourced from the Directorate of Resource Surveys and Remote Sensing (DRSRS) and covered 1977 to 2014.

##### *3.3.3.1 Herbivores Data*

The DRSRS has used the same sampling strategy for aerial surveys in Kenya's rangelands since 1977 to track the population and distribution patterns of wildlife and livestock. Aerial sample surveys were used to test the accuracy of population estimates several times and found to be between 71 and 83 per cent or higher (De Leeuw *et al.*, 1998; Ottichilo and Sinange, 1985; Ottichilo *et al.*, 2001; Peden *et al*., 1979). The aerial census is conducted using large winged Partenavia aircraft equipped with a Global Navigation System (GNS), Global Positioning System (GPS), intercom, and radar altimeters. A pilot crew, two rear-seat observers (RSO), and one front seat observer (FSO) are carried on every flight. The RSO is in charge of the animal counts, while the FSO aids in navigation, crew coordination and documents general environmental parameters. The ecosystem was mapped out along transects in an east-west direction and spaced at 5km intervals. The methods and survey parameters are described fully in Norton-Griffiths (1978) and documented in Grundblatt *et al*. (1995), De Leeuw *et al*. (1998), and Ogutu *et al*. (2016).

For flight planning, 1:50.000 topographic sheets were utilized, and all transects followed the Universal Transverse Mercator (UTM) projection method. Each transect was divided into equal sample subunits, and average flying speed and height were maintained during surveys. “A calibrated survey strip width was defined by rods mounted on the aircraft and by window markings. Only animals observed within the survey strip were recorded during the survey. All visual observations by RSO of animals within the survey strip were recorded using tape recorders during the investigation.” A photo was also taken for herds greater than ten animals, then processed and interpreted for herbivore species.

#### ***3.3.3.2 Species studied***

This study investigates fifteen species based on the available census data, information reliability, and size differences. All the herbivore species studied were species larger than Dikdik. Counts included in the research are from 16 censuses conducted in the ecosystem as point localities (x, y). These counts were aggregated to the 5km by 5 km grid. Eight censuses were conducted in the long rains season (March-April-May), six in the short rains season (October-November-December), and two in the short dry season (January-February). These surveys covered the whole of Kajiado. For Amboseli, a masked area was generated, and the data for the area was extracted. A re-run of the Jolly statistics is employed to calculate the population of the 15 species for all the 16 surveys.

The 15 species were classified into migratory, resident, and dispersal species. “Wildebeest (*Connochaetes taurinus*), Burchell’s zebra (*Equus burchelli),* Thomson’s gazelle (*Gazella thomsoni*), eland (*Taurotragus oryx)* were categorized as migratory species. The elephant (*Loxodonta africana*) was classified as a dispersal species because it wanders seasonally but does not engage in regular seasonal migrations (Bhola *et al.*, 2012). Resident herbivores investigated were ten in number and included; the warthog (*Phacochoerus africanus*), Coke’s hartebeest (*Alcelaphus buselaphus cokeii*), impala (*Aepyceros melampus*), Grant’s gazelle (*Gazella granti*), gerenuk (*Litocranius walleri*), waterbuck (*Kobus ellipsiprymnus*), buffalo (*Syncerus caffer*), oryx (*Oryx gazella*), lesser kudu (*Tragelaphus imberbis*) and giraffe (*Giraffa camelopardalis*)*.”* Table 3.1 lists species with scientific names, weights, and guilds based on movements and diet.

Table 3.1: Functional groupings of species by body mass, resident, and dietary guild (modified from Bhola *et al*., 2012; Coe *et al.*, 1976).

| Common name | Scientific name | Mass (kg) | Resident guild | Dietary guild |
|---|---|---|---|---|
| Wildebeest | *Connochaetes taurinus* | 120 | Migratory | Grazer |
| Burchell's zebra | *Equus burchelli* | 200 | Migratory | Grazer |
| Thomson's gazelle | *Gazella thomsoni* | 15 | Migratory | Grazer |
| Eland | *Taurotragus oryx* | 350 | Migratory | Mixed feeder |
| Elephant | *Loxodonta africana* | 5,500 | Dispersal | Mixed feeder |
| Buffalo | *Syncerus caffer* | 700 | Resident | Grazer |
| Gerenuk | *Litocranius walleri* | 49 | Resident | Browser |
| Giraffe | *Giraffa camelopardalis* | 1,250 | Resident | Browser |
| Grant's gazelle | *Gazella granti* | 50 | Resident | Mixed feeder |
| Hartebeest | *Alcelaphus buselaphus cokeii* | 125 | Resident | Grazer |
| Impala | *Aepyceros melampus* | 40 | Resident | Mixed feeder |
| Lesser Kudu | *Tragelaphus imberbis* | 90 | Resident | Browser |
| Oryx | *Oryx gazelle* | 210 | Resident | Mixed feeder |
| Warthog | *Phacochoerus africanus* | 45 | Resident | Grazer |
| Waterbuck | *Kobus ellipsiprymnus* | 160 | Resident | Grazer |

This study focused further on the African Elephants (*Loxodonta africana*), which are outstanding ecological architects who modify and recreate ecosystems as they search for resources that they desire within the environment (Pringle, 2008; Ripple *et al*., 2015). This was due to their increasing population, which shapes habitat structure and function in a changing climate, a central research theme for conservationists in the Amboseli ecosystem.

### 3.4 Social Study of the Perception of the Local Community

The case study approach was employed to obtain data for this study. This method collects, organizes, interprets, and presents detailed descriptive information regarding specific things or cases narratively. The case could be about an individual, a family, a neighborhood, a team, a class, a school, an organization, a program, or anything else. A social or natural event could be the focus of a case study. This data collection method is commonly used in sociology, anthropology, psychology, education, and medicine, and it has several applications in performance technology. This strategy provides a wide range of possible observations that might lead to a deeper understanding of factors, problems, and issues. Data can be acquired using various methods, but surveys, interviews, and stakeholder forums were used in this case. Structured questionnaires were designed, and face-to-face interviews with key stakeholders were conducted.

#### *3.4.1 Identification of Stakeholders*

Stakeholders are people and organizations directly or indirectly involved in decision-making and are affected by an action or policy (Sterling *et al.*, 2017). An inclusive mechanism involving stakeholders is essential for practical and self-governing reasons (Sterling *et al*., 2017). Incorporating stakeholder feedback into the strategic planning of a program might be advantageous in terms of providing real - time feedback and building consensus beforea new policy, strategy, or action goes into force (Vogler *et al*., 2017). As a result, the process is more collaborative, and unnecessary conflict is avoided. A stakeholder analysis was utilized to identify participants in the stakeholders' forum in this study.

A stakeholder grid was used to visualize the relative influence (on one axis) and level of interest— either positive or negative— (on the other axis) of each stakeholder group. It also assisted in visualizing which stakeholders share similar goals or have similar interests.

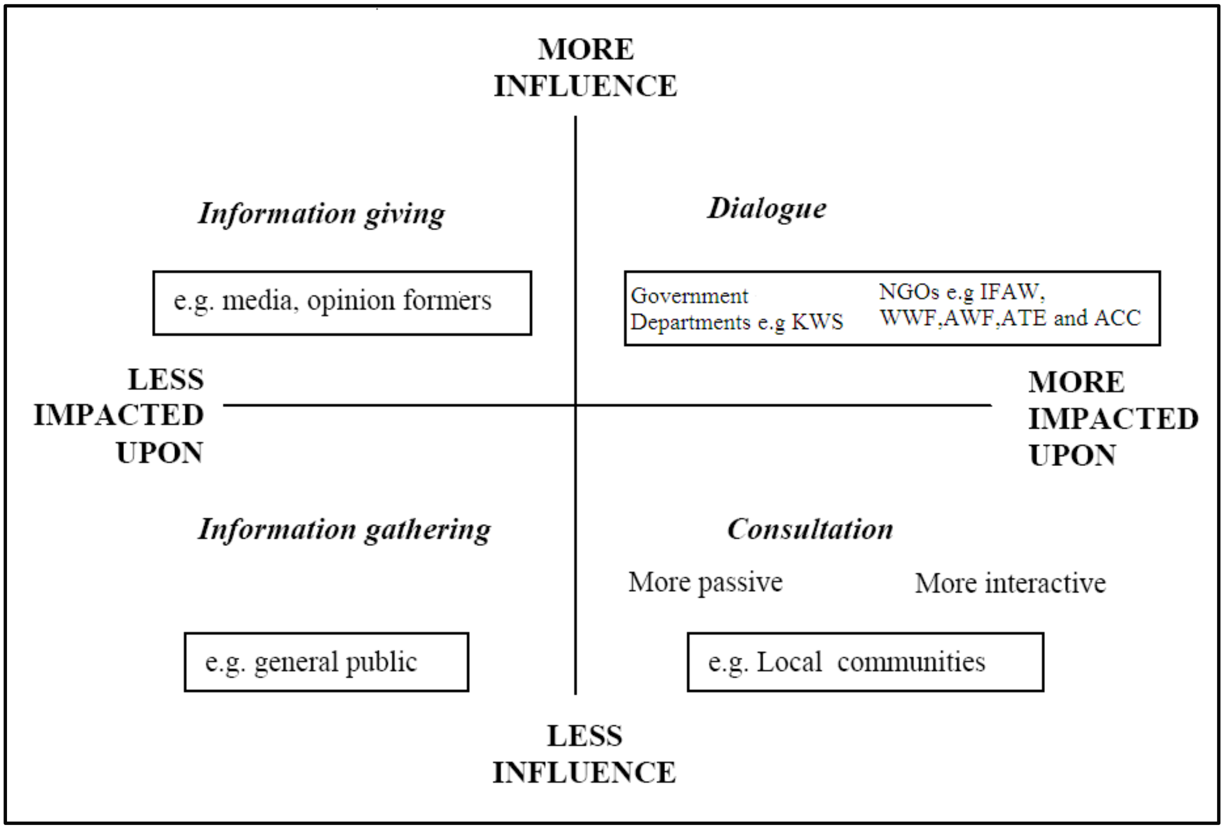



Figure 3.4 Stakeholder's grid

The stakeholders included Non-Governmental Organizations working in the area like (International Fund for Animal Welfare (IFAW), AWF, and Big Life), representatives from Kenya Wildlife Services (KWS), Area chiefs, and Chairmen of the conservancies. They included:

1. Kimare Mapeya – Chairman Olopolos conservancy
2. Kasaine Punuka – chairman Aloka conservancy
3. Timothy Saigilu -community elder
4. Lekeni Tuluapei – chairman Kilitome conservancy
5. Daudi Kaaniki – Secretary Kilitome conservancy
6. Alais Kisonkoi – chairman Oltiyani conservancy
7. Elijah Meikoki- chairman Naelepu conservancy
8. Joseph Parmuat- Representative Big life
9. Samuel Kaaka –Community representative
10. Musei Longorot –community elder
11. Francis Nkadayo – Long-serving research assistant in the area

12. John Gisa – coordinator Aloka conservancy.
13. Bernard Tulito – Chief
14. Peter M Kimani- Representative KWS
15. Daniel Kosygei – senior warden KWS
16. Cornelius Muoka - Community warden
17. Joseph Dadacha – community warden
18. Samuel Karangi – representative IFAW
19. Arnest Lenkoina - Field assistant elephant collaring project.

The tenacity of the field survey was to understand the perspectives of the local inhabitants towards the large herbivores and their distribution and the contribution of climate change towards these attitudes among people living within the Amboseli ecosystem. ArcGIS data collector tool was used to carry out the field surveys. This is a mobile data collection app that is part of ESRI Geospatial cloud collectors. The App enables the researcher to capture accurate data and return with it to the office with the least effort. Fieldworkers use mobile device web maps to capture and edit data. The ArcGIS data collector operates even when it is disconnected from the internet and smoothly integrates into ArcGIS. The areas visited during the process of data collection are indicated in Figure 3.1.

### *3.4.2 Sample Size and Sampling Technique*

Sampling is the process of choosing a part of the population to represent the whole (Naderifar *et al.*, 2017). The Amboseli Ecosystem, also categorized as Kajiado South sub-county, has an estimated population density of 137,496 people based on the 2009 national census. A sample size calculator in the Creative Research Systems survey software (Creative Research Systems, 2016) was used to arrive at the sample size representative of the population. The software uses the confidence interval, confidence level and population size to determine the sample size. The confidence interval is the margin of error, while the confidence level shows the probability that the value of a parameter falls within the confidence interval. For this study, the confidence interval was 9.85, and a confidence level of 95%. This gave a sample size of about ninety-nine for the estimated 137,496 people in the study area.

In this study, the snowball sampling technique was used (Goodman, 1961). This technique falls within the category of non-probability sampling. A researcher starts with a small population of known individuals and extends the sample by asking those initial participants to consider anyone to be included in the study. The process takes a short time and allows the researcher to talk easier with the identified persons, as they are acquainted with the primary sample, and thus the first sample is connected to the researcher. It also helped to reduce cost since subjects were used to locate the target population.

#### *3.4.3 Survey*

The surveys were done early mornings and in the evenings because community members were busy taking care of their farms and animals during the day. In most cases, the enumerators used the Maasai and Kiswahili language to communicate and respond to the survey questions. A questionnaire was designed from the set of objectives and administered to 99 respondents to collect data from the population within the group ranches (Kimana, Imbirikani, Olgulului Olorashi, and Kuku). The questionnaire was divided into four sections. Part one was for background information; part two evaluated climate change as understood and experienced by the general public; part three was for understanding ecosystem services as perceived by communities; and the final section focused on community knowledge on biodiversity and ecosystem services.

Pilot research was done before the primary survey, in which the survey was translated into the native language, and no incentives were given to participants. For ethical considerations, we clarified to the participants the intentions of the study, participation in the survey was voluntary, consent of the participants obtained, and anonymity was assured. For validation purposes, research questions were explored with key informants (representatives from local NGOs, Chairmen of conservancies, Kajiado administration, and key community members). They were then discussed collectively before the actual study until a questionnaire that could meet the needs and the gaps was designed (see the questionnaire in Appendix A).

#### *3.4.4 Key Informant Interviews*

"Key informant interviews are in-depth interviews of people selected for their first-hand knowledge about a topic of interest (Tremblay, 2009)." Key Informant Interviews were conducted between June 2016 and July 2017, depending on the availability of the targeted informants. Those interviewed included: Patrick Omondi (Director of research KWS), Nathan Gichohi (AWF), Lucy Njino (DRSRS), Victor Mose (ACC), Prof Moses Okello Makonjio (School for Field Studies Kimana), Dr Thadeus Obare (KWS), Dr Kenani Simeon (DRSRS), and David Kipaito Kitasho community representative on the Kajiado county environmental committee (the interview schedule is in Appendix B ). The aim was to assist in designing the research and understanding and ascertaining the history of large herbivores and land use. The key informants were crucial in understanding the prevailing global climate change-related policies and any past and future planning on adaptation and mitigation. The interviews also served to clarify the survey respondents' perspectives toward herbivores.

### *3.4.5 Participatory Mapping of Herbivore Corridors*

The participants were organized into groups to first engage in a brainstorming session to identify significant routes used by the elephants and other herbivores in the ecosystem. They were divided into four groups based on the four group ranches in the Amboseli ecosystem. Each group was guided on picking maps that correspond to their group ranch and creating a mosaic showing only actual routes used by the animals. One leading group was constituted from the original four groups by picking two representatives from each. The selection criteria were based on edge matching between groups to ensure routes flow from one ranch to another. After merging maps from different group ranches, the groups engaged in a discussion to make information flow from one ranch to another. Each group had to document what appeared in their maps. The marked topographic maps were scanned. Digitization of routes was done on screen using the ArcGIS tool and assigned codes.

## 3.5 Methods of Analyses

This section describes the data collection instruments and statistical procedures utilized to analyze data for the study to satisfy all of the stated objectives.

### *3.5.1 Data Quality Control*

Data quality control was carried out to correct discrepancies and anomalies created along the chain of collecting, processing, transferring, storing, and transmitting the climate data. Assessment of the data commenced by isolating anomalous deviations and suspicious zeros in the space of missing data. Homogeneity tests were conducted on long-term data sets to ensure non-climatic factors do not cause that variation in the climate data, thus creating a bias in the results (Aguilar *et al.*, 2003). The climate data in this study were tested for homogeneity using the single mass curve test.

#### *3.5.1.1 Estimation of Missing Rainfall Data*

The rainfall data were scrutinized by thoroughly checking to establish if they had any data gaps. Any missing data were filled in by using the arithmetic mean. In this method, simultaneous rainfall records of close-by stations are used. A simple arithmetic average of the precipitation of the selected stations was used to derive the approximate missing monthly and annual values. This method should be used only when the average yearly rainfall at each of the chosen stations is within 10% of that station for which records are missing (De Silva *et al.*, 2007). In this study, very few data points were missing.

The arithmetic mean is calculated as illustrated in equation (1)

$$\text{Arithmetic mean} = \frac{a_1 + a_2 + a_{3....} + a_n}{n} = \sum_{i=1}^{n} \frac{a_i}{n} \qquad \textit{Equation (1)}$$

Where $n$ is the number of observations and $a_i$ is the value of the $i^{th}$ observation.

#### *3.5.1.2 Data Consistency*

To check for data homogeneity, the collected precipitation data was plotted against time. Single mass curves provide immediate information regarding data consistency, and a single mass curve with a straight line demonstrates data uniformity. The ratio of the two successive lines obtained is employed if the data is not uniform. The ratio of the slopes after and before the break is multiplied by the rainfall records before the break.

### *3.5.2 Validation of Gridded Rainfall Data against Observed Station Data*

The suitability of using the gridded rainfall data in place of observed data was done using correlation coefficient statistics. The correlation coefficient measured the level of association between the gridded data and the observed data. The r-squared coefficient of determination is "a statistical calculation that measures the degree of interrelation and dependence between two variables in a regression model. In other words, it determines how much a variable's behaviour can explain the behaviour of another variable". The correlation coefficient (r) is calculated as illustrated in equation (2)

$$r^2 = \frac{Cov(x,y)}{\sigma_x \sigma_y} \qquad \textit{Equation } (2)$$

where:

Cov($x$,$y$) = covariance of variables $x$ and $y$

$\sigma x$ = standard deviation of $x$

$\sigma y$ = standard deviation of $y$

A correlation coefficient of zero represents no association between the observed data used for validation while positive and negative one (1) shows a strong positive and association, respectively. The CHIRPs data from the same period as the observed data was compared. The F-value, r-squared, and p-value were calculated for the selected relationship or model.

### *3.5.3 Standardized Precipitation Index (SPI) as a Drought Indicator*

The Standardized Precipitation Index (SPI) examined trends in the study area's drought stress condition. SPI expresses the real rain as a standardized departure for rainfall probability distribution function, and hence the index is negative for drought and positive for wet conditions. SPI allows comparisons across space and time. The SPI indicator, which was developed by Mckee *et al*. (1993), and described in detail by (Edwards and McKee, 1997), measures precipitation anomalies at a given location, based on a comparison of observed total precipitation amounts for an accumulation period of interest (e.g., 1, 3, 12, 48 months), with the long-term historical rainfall record for that period. The historical record is fitted to a probability distribution (the "gamma" distribution), then transformed into a normal distribution. The mean SPI value for that location and period is zero. Table 3.2 gives the classification of the precipitation conditions, and this classification was used in interpreting the variability of both annual and seasonal changes in the Amboseli Ecosystem. Positive SPI specifies above-median precipitation, and negative values indicate below-median precipitation – adapted from European Drought Observatory (EDO). The index tends to become more negative or positive, while the dry or wet conditions become more severe. To capture various short- and long-term droughts, the SPI is assessed over multiple time frames ranging from one month to 24 months

Table 3.2: Summary of the cumulative probabilities for various SPI values and possible interpretation of wet (or dry) conditions using the resulting SPI values

| **Anomaly** | **Range of SPI values** | **Precipitation Regime** | **Cumulative Probability** | **Probability of Event (%)** |
|---|---|---|---|---|
| Positive | 2.0 <SPI <=Max | Extremely wet | 0.977 – 1.000 | 2.3 |
| | 1.5 <SPI <= 2.0 | Very wet | 0.933 – 0.977 | 4.4 |
| | 1.0 <SPI <=1.5 | Moderately wet | 0.841 – 0.933 | 9.2 |
| None | -1.0 <SPI <=1.0 | Normal precipitation | 0.159 – 0.841 | 68.2 |
| Negative | -1.5 <SPI <=-1.0 | Moderately dry | 0.067 – 0.159 | 9.2 |
| | -2.0 <SPI <=-1.5 | Very dry | 0.023 – 0.067 | 4.4 |
| | MIN <=SPI <=-2.0 | Extremely dry | 0.000 – 0.023 | 2.3 |

### *3.5.4 Determination of Trends*

The magnitude of the trend and its statistical significance are included in the trend analysis of a time series. Understandably, different researchers have used various methods for detecting trends (Kundzewicz and Robson, 2004). Generally, non-parametric approaches are used to determine the magnitude of a trend in a time series.The methods include the Mann-Kendall and parametric tests such as the regression analysis. The parametric tests assume that the data is normally distributed. A positive slope indicates an upward tendency, while a negative slope indicates a downward trend.

#### *3.5.4.1 Mann-Kendall Test*

A non-parametric Mann–Kendall (MK) test is used to determine the presence of a statistically significant trend in climatic variables such as temperature and precipitation. (MK) (Bera, 2017;

Singh *et al.*, 2008). In this test, data is presented in time-series order and then ranked. In Equation (3), S represents the Mann-Kendall test, $X_i$ and $X_j$ are the time series observations in chronological order and *n* is the length of the time series.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sig}\left(X_j - X_i\right),$$

$$\text{sgn}\left(X_j - X_i\right) = \begin{cases} +1 & \text{if } \left(X_j - X_i\right) > 0 \\ 0 & \text{if } \left(X_j - X_i\right) = 0 \\ -1 & \text{if } \left(X_j - X_i\right) < 0, \end{cases} \qquad \textit{Equation } (3)$$

Mann-Kendall's rank statistics are used for trend analysis. After all, it takes only a few underlying assumptions about the structure of the data. In Mann Kendall's analysis, positive values indicate a rise in the constituent with time, whereas negative values indicate a decline. The significant level of the Mann Kendall values was tested, and where $p \leq 0.05$, then the time series was statistically significant. This was verified at a confidence level of 95%. Significant trends form one in all the critical foundations of global climate change detection. Further details on these methods can be obtained from Kendall (Kendall, 1938; 1975).

### *3.5.4.2 Parametric Test Regression Analysis*

The regression models utilized were linear, polynomial, logarithmic, exponential, and power regression. An example of a polynomial regression model is described and given in equation 4.

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \cdots + \beta_n x^n + \varepsilon \qquad \textit{Equation } (4)$$

Where the dependent variable is represented by y, and the betas are the coefficients for different nth powers of the independent variable x starting from 0 to n.

Trends for RCP 2.6 were analyzed using quadratic models because of the predicted drop in radiative forcing by the end of the century as a result of mitigation measures leading to a curve and not an exponential line. The relationships were tested for all these regression models. The best model was selected based on the lower corrected Akaike Information Criterion (AICc). The lower the AIC, the better the model since they indicate a trade-off between the nonexistence of fit and the number of parameters in the model (Burnham and Anderson, 2002). The F-value, r-squared, and p-value were calculated for the selected relationship or model.

### *3.5.5 Relationship between Species Range and Temperatures*

The herbivores distribution maps were generated by combining the herbivore surveys conducted in Kajiado from 1977 to 2014. A total of 16 surveys were used to create a range of maps. Each of the maps was classified into three classes low, medium, and high. The ESRI Geographic Information Software, ArcGIS Spatial analyst tool, was used to plot the distribution of species within the ecosystem. Range maps for the herbivore species were created by superimposing individual species range maps on temperature maps. The ranges-temperature maps were created using grid-to-grid maps overlaying of species occurrences and temperature. The relationship of large wild herbivore species with temperature was established based on Ogutu *et al*. (2016). To relate the population of each of the 15 herbivore species with maximum temperatures, a generalized linear mixed model with a negative binomial error distribution and a log link function was used (Ogutu *et al*., 2016).

Linear and quadratic models for each species had its covariate chosen individually using the corrected Akaike Information Criterion (AICc). The model-fitting method automatically calculates the dispersion (scale) parameter of the negative binomial model. It allowed for potential dispersal and serial autocorrelation in population size (Ogutu *et al*., 2016). The SAS GLIMMIX procedure was used to fit the models, and graphs showed a relationship between each of the 15 species against temperature. There was a threshold temperature adapted for each species, where there will be a potential impact on the species above that temperature. Temperature thresholds for each of the 15 species were used to analyze which wildlife range areas would be lost. The results of the 15 species are summarized in bar graphs for the nine climate scenarios. All the spatial analyses are carried out in ArcGIS, areal calculations in Microsoft Access and figures generated in excel.

### *3.5.6 Calculating Elephant Population size for the Amboseli Ecosystem*

The elephant population size, variation, and standard error for the Amboseli habitat were calculated using Jolly's method 2 for aerial transects of unequal length (Jolly 1969; Norton

Griffiths 1978). Amboseli was masked from the Kajiado census, and Jolly was rerun for the masked area for the 16 counts. The total population size $\hat{Y}$ was estimated as:

$\hat{Y} = Z\hat{R}$

With variance $Var(\hat{Y}) = \frac{N(N-n)}{n}\left(s_y^2 - 2\hat{R}s_{zy} + \hat{R}^2 s_z^2\right)$ *Equation* (5)

And standard deviation $SE(\hat{Y}) = \sqrt{\left(Var(\hat{Y})\right)}$

"$Z$ is the area of the census zone (e.g., county) and $\hat{R} = \frac{\sum y}{\sum z}$ is the sample population density calculated as the total number of all animals counted in each sampling unit $y$ divided by the area of each sampling unit $z$ summed over all the units included in the survey sample. $N$ is the population of all the sampling units in the census zone, whereas $n$ is the number of sampling units included in the survey sample. $s_y^2$ is the sample variance of the number of animals counted in all the sampled units while $s_z^2$ is the variance of the area of all the sampling units included in the survey sample. $s_{zy}$ is the covariance between the number of animals counted and each sampling unit."

### *3.5.7 Relationship between Elephant Population and Rainfall*

The annual elephant population was related to annual, dry, and wet season rainfall components based on moving averages ranging from one to 15 years. The rainfall components were defined as annual (January-December), long-rains (March-April-May), long dry season (June-July-August-September), and short-rains (October-November-December), and short dry season (January-February). The moving averages of rainfall were calculated from Year 1 (t1) to Year 15 (t15) by creating a series of percentages of different subsets (see Moehlman *et al.*, 2020; Ogutu *et al.*, 2017; Olaka *et al*., 2019). Every year, the moving average was calculated to demonstrate the influence of the present and the previous years of rainfall on resources and, eventually, elephant population dynamics. This sample of rainfall data was compared to elephant censuses, and a relationship was observed between rainfall and the elephant population. Further, linear, polynomial, exponential, and power regressions were tested, and the best model was chosen based on the Akaike Information Criterion (AICc). The best model was used in projecting the elephant population for the three RCP scenarios for the anticipated period 2006 to 2100.

### *3.5.8 Statistical Analysis of Survey*

IBM SPSS Version 24 was used to analyze the survey data. Descriptive statistics were employed to explain the summary of demographic traits. In this study, the central tendency methods were used to describe the response pattern to each variable on its own. The data were grouped into different classes for the biographic characteristics and displayed using pie charts and bar graphs. Percentage distributions were also used to describe and explore the data.

# CHAPTER 4 : HISTORICAL CLIMATE TRENDS AND THEIR RELATIONSHIP WITH HERBIVORE POPULATION AND DISTRIBUTION IN AMBOSELI ECOSYSTEM

## 4.0 Introduction

This chapter presents the results of this thesis's first and second objectives: to analyze changes in historical climate trends and establish their relationship with large herbivore populations and distribution Amboseli ecosystem. The first step was to run data quality control checks to confirm that the data was accurate, and the CHIRPS data had to be validated in the second stage. The final step involved analyzing historical rainfall and temperature patterns in the Amboseli ecosystem using CHIRPS data. Further research was conducted to determine the relationship between historical climate trends and herbivore population dynamics and distribution in the Amboseli ecosystem.

## 4.1 Data Quality.

Homogeneity tests were performed on the four-station rainfall datasets used in this work: Mashuru Dispensary, Amboseli Baboon Camp, and Isara Range Station. Results show that the observed rainfall data is homogeneous (see Figure 4.1). The normality test indicated that all the four stations' data were normally distributed (see Figure 4.2). Shapiro-Wilk p-value and Anderson-Darling p-values were > 0.001 (see Supplementary Tables Appendix C1-4).

### *4.1.1 Validation of the CHIRPS Data*

There are few meteorological stations in most African countries, notably in the drylands (Boko *et al*., 2007; Ouma *et al*., 2018; WMO, 2012). According to the World Bank (2017), Africa has the fewest stations that meet the World Meteorological Organization (WMO) observation requirements (https://www.worldbank.org/en/region/afr/brief/hydromet-in-africa), with only a quarter of the required density and less than 300 weather stations. Most meteorological stations in the Amboseli habitat are currently inactive. As a result, the number of stations providing updated rainfall data is extremely limited, and many of them have closed down, and many stations have missing data.

As a result, it's critical to find alternate sources of rainfall data. According to Li and Shao (2010), Blended satellite-rainfall data could fill in the gaps when the number of meteorological stations is insufficient to cover the area adequately. As an alternative, the CHIRPS data collection was employed in this investigation. However, it was critical to determine how sensitive the CHIRPS was to rainfall station data.

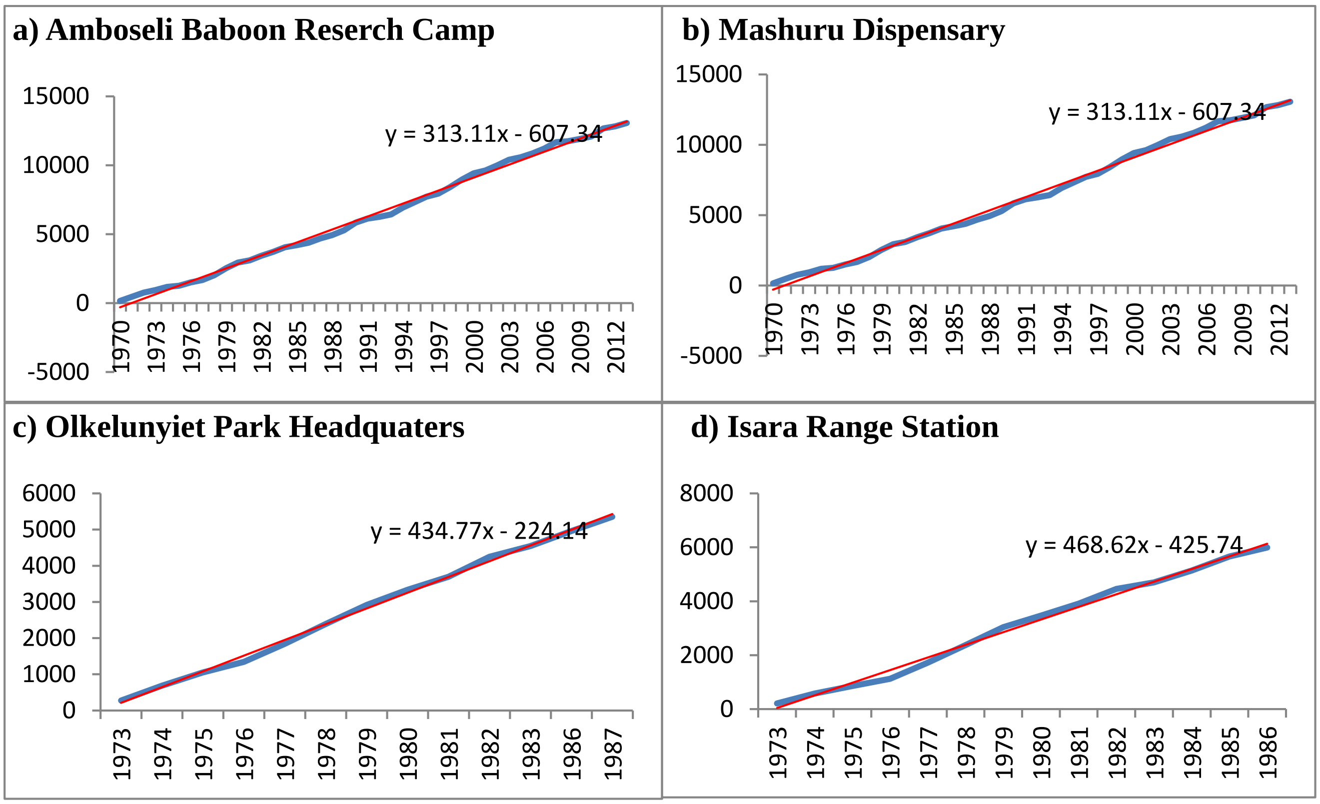



Figure 4.1: Single Mass curve plots for observed rainfall data

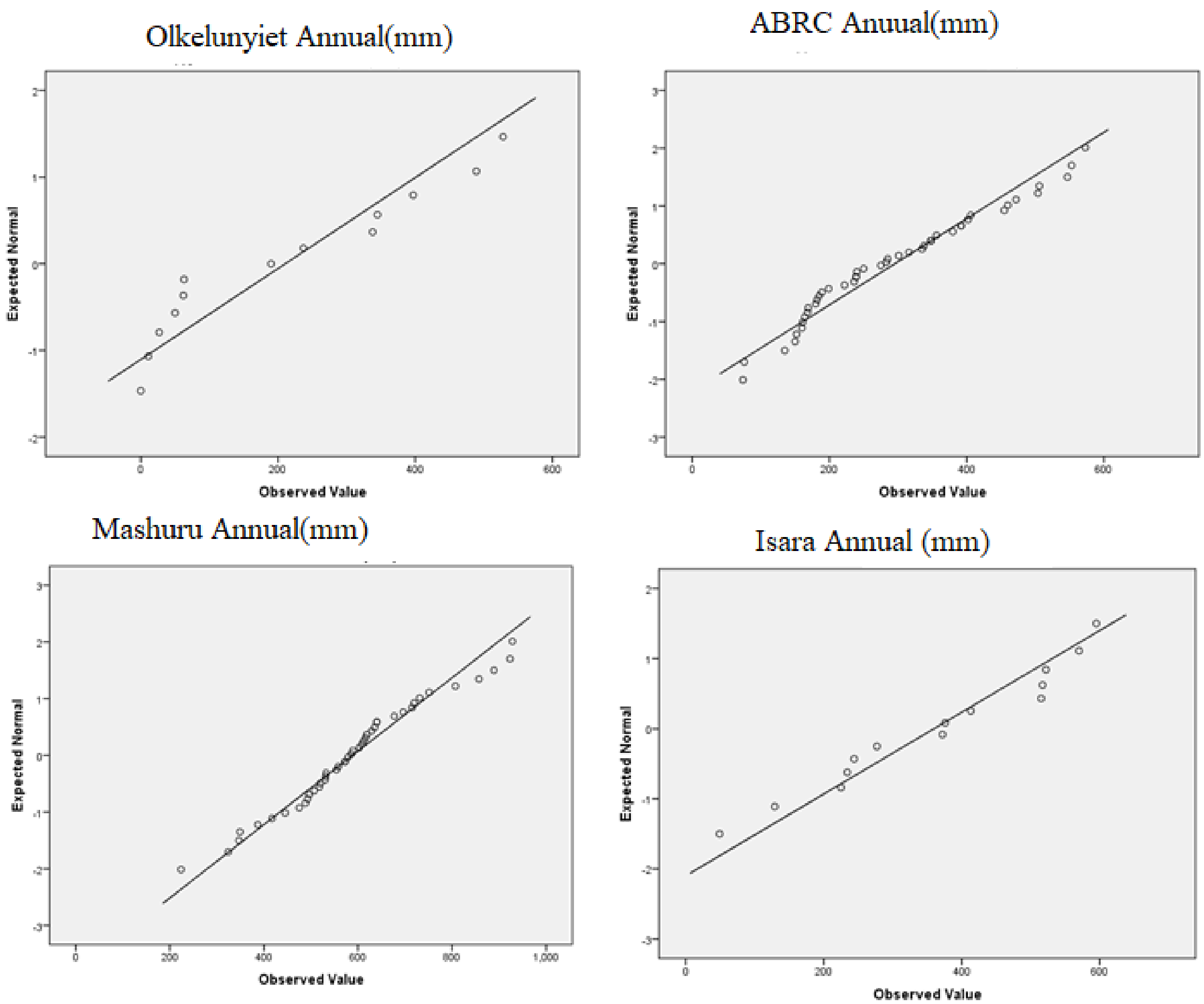



Figure 4.2 Normal distribution plots for annual rainfall for the four rainfall stations

The findings revealed that the annual rainfall of all four sites had a relationship with the CHIRPS data (Table 4.1). Annual rain and CHIRPS had the strongest correlations in Mashuru Dispensary ($r^2$=0.972, p = 0.0000), Amboseli Baboon Camp ($r^2$ = 0.903 p = 0.0000) and Isara Range Station ($r^2$= 0.961, p = 0.0000) and moderate associations were observed with Olkelunyiet Park headquarters ($r^2$ = 0.756, p = 0.0000). The OND ($r^2$ varied between 0.447 and 0.700 for the four stations) was more strongly associated with CHIRPS than the MAM months ($r^2$ varied between 0.471 and 0.592; refer to Table 4.1). The Mashuru station's observed rainfall had the strongest association with CHIRPS both for OND and MAM seasons in terms of seasonality. These results showed that satellite-based CHIRPS data set adequately represented the station observed data, and therefore CHIRPS data was used in the rest of the analysis. Evidence comes from other studies such as Doan *et al*. (2014), Mukhopadhyay *et al*. (2019), Setiawan *et al*. (2017) and Dinku *et al.* (2018). Following the approval of CHIRPS satellite precipitation gauges over eastern Africa, Dinku *et al*., 2018 exhibited considerable advantages over others such as the African Rainfall Climatology version 2 (ARC2) and the Tropical Applications of Meteorology employing Satellite data (TAMSAT). This makes CHIRPS data even more useful in locations where rainfall data is scarce, such as the Amboseli environment.

Table 4.1: Correlation statistics describing the relationship between the observed rainfall and modelled rainfall

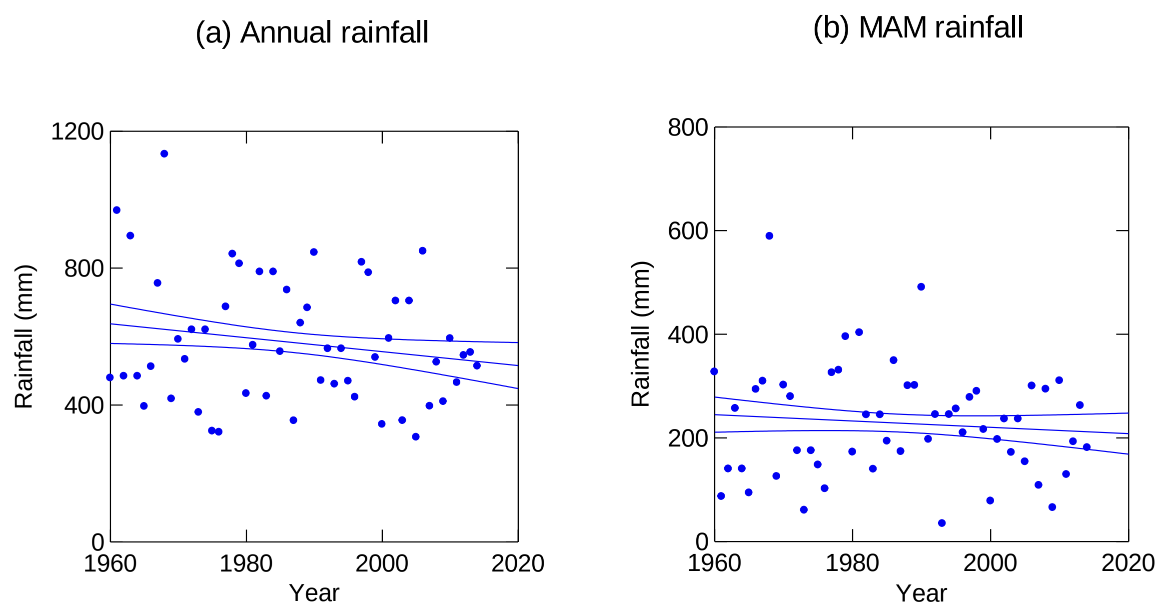
| **Station name** | **Data Length (Years)** | **Period** | **F ratio** | **R-squared value** | **P-value** |
|---|---|---|---|---|---|
| Mashuru Dispensary | 33 | Annual | 343.54 | 0.972 | 0.0000 |
| | | MAM | 27.579 | 0.471 | 0.0000 |
| | | OND | 72.465 | 0.7 | 0.0000 |
| Amboseli Baboon Camp | 33 | Annual | 92.622 | 0.903 | 0.0000 |
| | | MAM | 26.26 | 0.459 | 0.0000 |
| | | OND | 34.561 | 0.527 | 0.0000 |
| Isara Range Station | 14 | Annual | 248.012 | 0.961 | 0.0000 |
| | | MAM | 17.386 | 0.592 | 0.0010 |
| | | OND | 14.857 | 0.553 | 0.0020 |
| Olkelunyiet Park headquarters | 11 | Annual | 31.062 | 0.756 | 0.0000 |
| | | MAM | 8.451 | 0.484 | 0.0170 |
| | | OND | 7.267 | 0.447 | 0.0250 |

### 4.2 Historical Rainfall Trends

Table 4.2 and Figure 4.3 (a-d) depict a historical trend in the yearly and seasonal precipitation of the Amboseli ecosystem based on the CHIRPS data (See monthly regression trends in appendix D Table D-1). Between 1960 and 2014, annual and seasonal rainfall (long rains of MAM and short rains of OND) decreased marginally but not significantly (p > 0.001). The JJAS rainfall, on the other hand, revealed a significant modest decrease (r2 = 0.080, p = 0.0307). The drop in JJAS season rainfall and mild declines in long and short rainfall can be linked to the total annual rainfall decline in the Amboseli ecosystem between 1960 and 2014. The Mann-Kendell test also confirms no significant trends in precipitation (Table 4.3), despite a minor drop in precipitation over time.

Table 4.2: Regression trends in the analysis of historical rainfall Amboseli Ecosystem 1960-2014

| Season | Equation | R-squared | F-Ratio | P-value |
|---|---|---|---|---|
| Annual | Y = 4626.69892 - 2.03534x | 0.032 | 1.728 | 0.1943 |
| MAM | Y = 1440.94291 - 0.61023x | 0.008 | 0.446 | 0.5070 |
| JJAS | Y = 704.13476 - 0.34537x | 0.080 | 4.577 | 0.0370 |
| OND | Y = 1814.34409 - 0.78111x | 0.009 | 0.474 | 0.4943 |



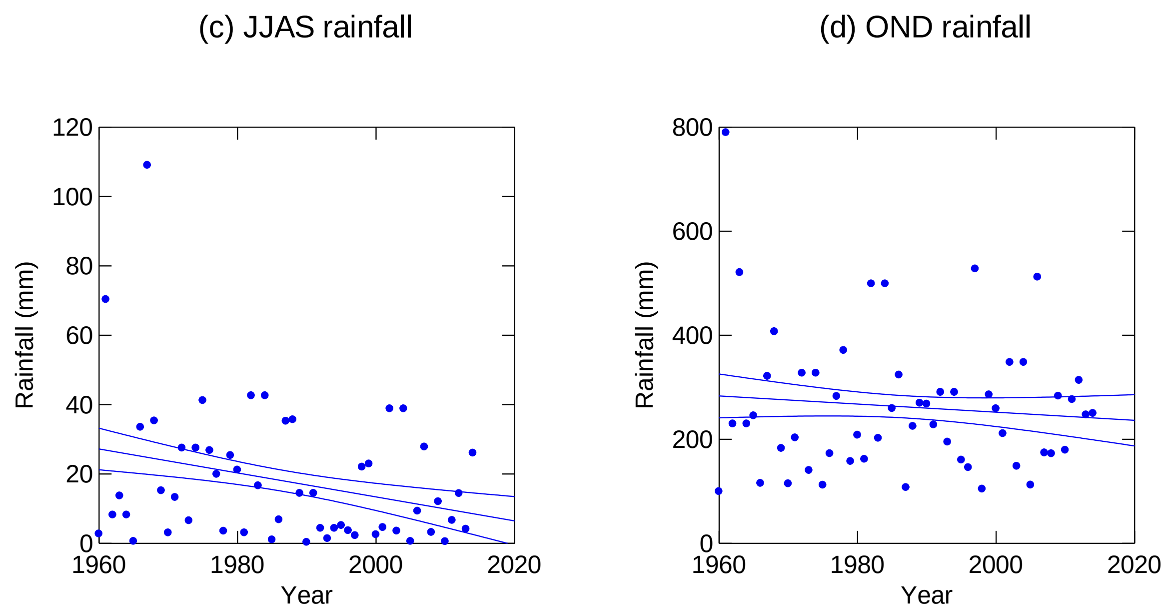



Figure 4.3: Historical rainfall trends in the Amboseli Ecosystem from 1960 to 2014, with 95 per cent confidence levels. The totals for the year and season are represented by the data points.

Table 4.3: Man Kendall's test for historical trends in rainfall

| Period | S-Value | Slope Tau | P-value | Significance |
|---|---|---|---|---|
| Annual | 68 | 0.0327 | 0.70443 | No significant trend |
| MAM | 18 | 0.0087 | 0.92332 | No significant Monotonic trend |
| JJAS | -123 | 0.0592 | 0.48971 | No significant Monotonic trend |
| OND | 164 | 0.0790 | 0.35606 | No significant Monotonic trend |

These findings are in line with those of Altmann *et al.* (2002), which showed a non-significant decrease in both annual and seasonal rainfall in the Amboseli ecosystem (see also plots in Figure 4.3 and those of Ogutu *et al*., (2016) on analysis of the Kajiado county.

In savannah ecosystems, rainfall influences vegetation and surface water supply and quality for herbivores in savannah habitats (Bartzke *et al*., 2018). Rain is one of the principal climatic factors controlling herbivore population dynamics across Africa (Ogutu, and Owen-Smith, 2003; Owen-smith *et al*., 2005). Overseeing wildlife resources and populaces requires comprehending the nature, extent, and distribution of present and future climates effects (Wilsey *et al.*, 2013). These results provide more insight into the climate trends of Amboseli, which could be helpful in ecosystem methods for adaptation and mitigation. Although the decline in rainfall is not statistically significant, the slight decrease in precipitation for all seasons can significantly impact the herbivores and the people who depend on these resources, especially grazing for their livelihoods. This reduction could affect the distribution and accessibility of food and surface water for herbivore species (Berry *et al.*, 2013).

### *4.2.1 Standardized Precipitation Index Amboseli Ecosystem*

The analysis of this study area indicates a mean annual rainfall of 582 mm and a standard deviation of 182 mm. The yearly rainfall fluctuated from 306 mm to 1133 mm, with 22 out of the 54 years receiving rainfall above the mean value while 32 received rainfall below the annual mean. Annual, dry, and wet season precipitation components differed markedly in the Amboseli Ecosystem during the period 1960-2014. The annual SPI analysis indicates 1965, 1973, 2008, 2009 were drought periods of moderate impacts based on (Mckee *et al*., 1993) classification. The worst drought situation experienced in the study area was in 1980, 1987, 2005 (very dry), and 2000 (extremely dry). In terms of extent and intensity, the period 2008 to 2009 was the worst. High rainfall occurred in 1961, 1968, and 1997 (extremely wet – El Nino), 1963 and 1977 (very wet) and 1967, 1978, and 2012 (moderately wet). There were also wetter periods that were long, like 1977 to 1978. The chances of the annual rainfall being normal are 70%, moderately wet 7%, very wet 6% and extremely wet 7%, moderately dry 7%, very dry 6%, and extremely dry 2% (refer to Figure 4.4 and Table 4.4).

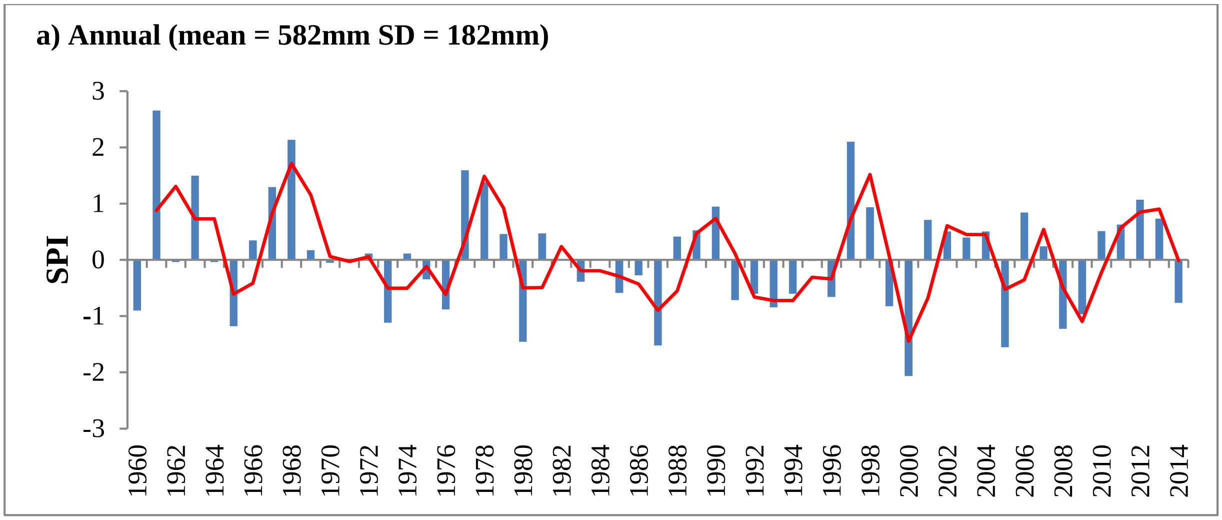



Figure 4.4: Standardized Precipitation Index for annual rainfall for the Amboseli ecosystem

The MAM season's average rainfall is 228 mm, with a standard deviation of 107 mm. This season's rainfall ranged from 35 to 589 millimetres. The wettest years in this season were 1968 and 1990 (extremely wet) as well as 1979 and 1981 (very wet). The MAM period records the probability of receiving average rainfall at 74%, extremely wet at 3%, moderately dry conditions at 7.4%, and very dry conditions at 6%. The relatively dry years were 1961, 1976, 2000, and 2007 while 1973, 1993, and 2009 were extremely dry (Figure 4.5 and Table 4.4). This agrees with the overall negative precipitation pattern observed during the long downpour season shown in Figure 4.1b, even though this trend is statistically insignificant. Several studies on the March-May long rains in the GHA region have also demonstrated a decrease in MAM (Indeje *et al.*, 2000; Omondi *et al.*, 2014). Since 2000 the rain in the Amboseli ecosystem in MAM has been persistently below average.

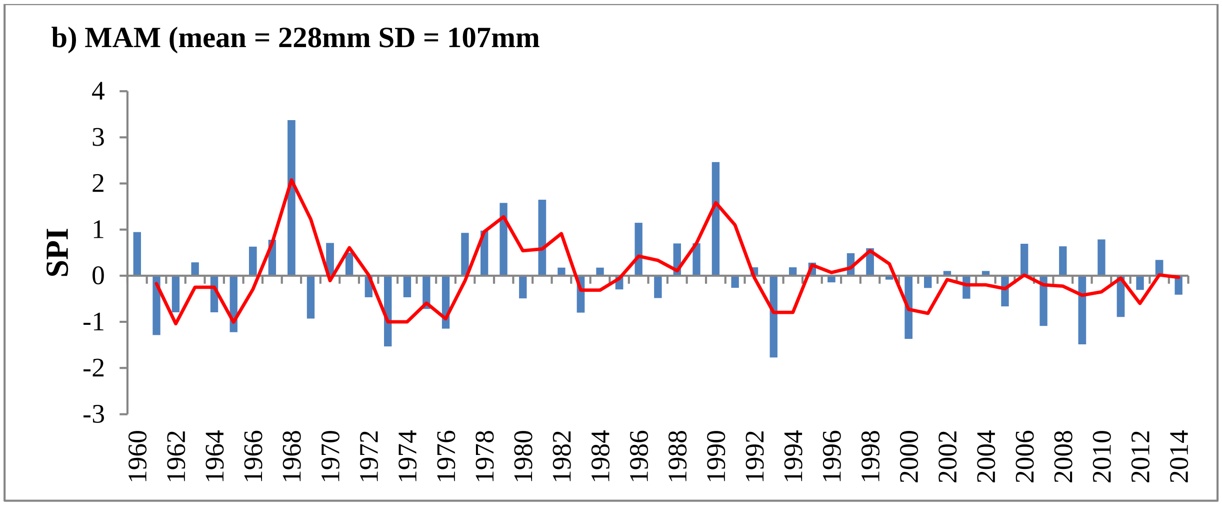



Figure 4.5: Standardized Precipitation Index for MAM rainfall for the Amboseli ecosystem

The OND season indicates a rainfall mean of 336 mm and a standard deviation of 182 mm in this study. The OND rainfall varied from 135 mm to 810 mm. 24 out of the 54 years received rainfall above the mean value, while 30 received rainfall below the mean. In this season, a lot of rain occurred in the years 1968 (moderately wet), 1982, 1984, and 2006 1982, 1984, 2006 and (very wet), and 1961, 1963, and 1997 (extremely wet). Most of the other years received average rainfall. The Probability of the season receiving normal rain is 76%, moderately wet 2%, very wet 6%, and extremely wet 6%, and moderately dry is 11% (Figure 4.6 and Table 4.4).

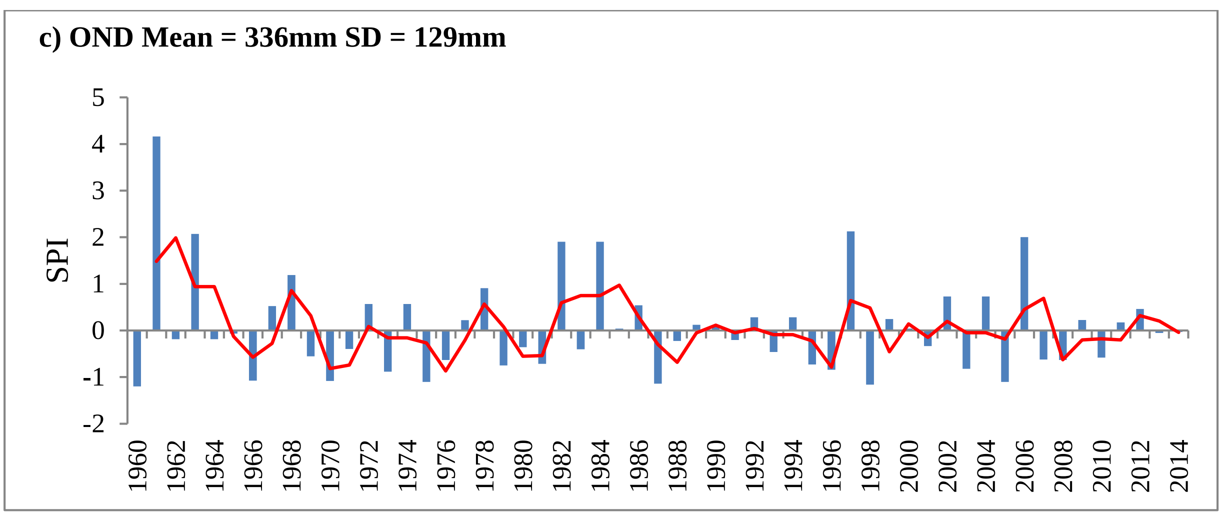



Figure 4.6: Standardized Precipitation Index for OND rainfall for Amboseli

The mean rainfall for the JJAS season was 18 mm and had a standard deviation of 19 mm. The rainfall varied between 0.3 mm and 109 mm over the period 1960 to 2014. The probability of the season receiving near normal rains was 89%, although the amounts were depressed. The chances were at 9% for moderately wet conditions and 3% for extremely wet conditions. The years that recorded moderately wet rainfall were: 1975, 1982, 1984, 1987, 1988, 2002, 2004, while 1961and 1967 were extremely wet (Figure 4.7 and Table 4.4). The JJAS has registered depressed rains for 15 years, since 1990.

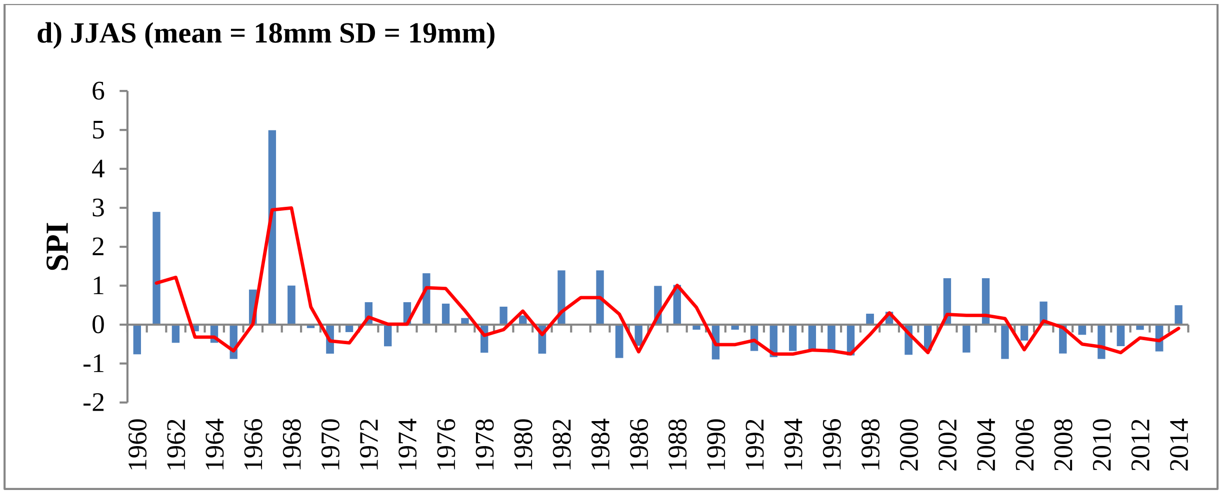



Figure 4.7: Standardized Precipitation Index for JJAS rainfall for Amboseli

In conclusion, the analysis of historical rainfall trends in Amboseli shows an overall increase in depressed rainfall typically related to drought. During the MAM and JJAS seasons, there was an overall decrease in rainfall. and a general increasing trend during the OND season. However, these observed trends were not statistically significant.

Table 4.4: Summary of occurrence of wet and dry periods in the Amboseli Ecosystem between 1960 and 2014

| Range of SPI values | Precipitation Regime | Annual | MAM | JJAS | OND |
|---|---|---|---|---|---|
| **2.0 <SPI <= Max** | **Extremely wet** | 1961, 1968, 1997 | 1968, 1990 | 1961,1967 | 1961, 1963, 1997, |
| **1.5 <SPI <= 2.0** | **Very wet** | 1963, 1977 | 1979, 1981 | | 1982, 1984, 2006 |
| **1.0 <SPI <= 1.5** | **Moderately wet** | 1967, 1978, 2012 | 1986 | 1975, 1982, 1984, 2002, 2004 | 1968 |
| **-1.0 <SPI <=1.0** | **Normal precipitation** | 1962,1964, 1966, 1969, 1970,1971, 1972, 1974,1975, 1976, 1979,1981,1982, 1983, 1984, 1985, 1986, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1998, 1999, 2001, 2002, 2003, 2004, 2006, 2007, 2010, 2011, 2013.2014. | 1960, 1963, 1964, 1966, 1967, 1970, 1971, 1972, 1974, 1975, 1977, 1978, 1980, 1982, 1983, 1984, 1985, 1987, 1988, 1989, 1991,1992, 1994, 1995, 1996, 1997, 1998, 1999, 2001, 2002, 2003, 2004, 2005, 2006, 2008, 2010, 2011, 2012, 2013, 2014. | 1960, 1962,1963,1964, 1965, 1966, 1968, 1969, 1970, 1971, 1972,1973, 1974, 1976, 1977, 1978, 1979, 1980, 1981, 1983, 1985, 1986, 1987, 1988, 1989, 1990,1991,1992, 1993,1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2003,2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014 | 1962,1964, 1965,1967,1969,1971, 1972,1973,1974,1976, 1977,1978,1979,1980, 1981,1983,1985,1986, 1988,1989,1990,1991, 1992,1993, 1994,1995,1996,1999 ,2000,2001,2002,2003, 2004,2007,2008,2009, 2010,2011,2012,2013, 2014 |
| **-1.5 <SPI <= -1.0** | **Moderately dry** | 1965, 1973, 2008, 2009 | 1961, 1976, 2000, 2007 | | 1960, 1966, 1970, 1975, 1987, 2005 |
| **-2.0 <SPI <= -1.5** | **Very dry** | 1980, 1987, 2005, | 1973, 1993, 2009 | | |
| **MIN <=SPI<=-2.0** | **Extremely dry** | 2000 | | | |

### 4.3 Temperature Trends in the Amboseli Ecosystem between 1960 and 2014

This section presents results from analyzing historical temperature trends in the Amboseli ecosystem during the study period. The trends in average maximum and minimum temperatures for annual, MAM, JJAS, and OND in the Amboseli ecosystem show statistically significant increases (Table 4.5, 4.6, and Figures 4.7and 4.7).

Table 4.5: Regression trends of maximum and minimum temperature in the Amboseli ecosystem 1960-2014

| | **Season** | **Equation** | **r-squared** | **F-Ratio** | **P-value** |
|---|---|---|---|---|---|
| Maximum | Annual | -1.02686 + 0.01485x | 0.295 | 26.044 | 0.0000 |
| | MAM | 3.38536 + 0.01297x | 0.125 | 8.907 | 0.0041 |
| | JJAS | 0.58611 + 0.01317x | 0.229 | 18.458 | 0.0001 |
| | OND | -4.24069 + 0.01669x | 0.226 | 18.192 | 0.0001 |
| Minimum | Annual | -29.57478 + 0.02319x | 0.519 | 56.289 | 0.0000 |
| | MAM | -21.49333 + 0.01971x | 0.323 | 24.893 | 0.0000 |
| | JJAS | -35.90128 + 0.02547x | 0.476 | 47.276 | 0.0000 |
| | OND | -32.73641 + 0.02518x | 0.337 | 26.523 | 0.0000 |

Table 4.6: Mann– Kendall's test for historical trends in maximum and minimum temperatures

| | Period | S-Value | Slope/Tau | P value | Significance |
|---|---|---|---|---|---|
| Maximum | Annual | 748 | 0.371 | 0.000015 | Significant positive trend |
| | MAM | 511 | 0.254 | 0.00313 | Significant positive trend |
| | JJAS | 694 | 0.344 | 0.0000595 | Significant positive trend |
| | OND | 602 | 0.299 | 0.0005 | Significant positive trend |
| Minimum | Annual | 772 | 0.383 | 0.0000079 | Significant positive trend |
| | MAM | 488 | 0.242 | 0.00478 | Significant positive trend |
| | JJAS | 748 | 0.371 | 0.000015 | Significant positive trend |
| | OND | 570 | 0.283 | 0.00098 | Significant positive trend |

Table 4.7 shows that the maximum annual temperature increased from 28.08°C in 1960 to 28.87°C in 2014, while the MAM increased from 28.81°C to 29.49. The JJAS increased from 26.40°C to 27.10°C, and OND increased from 28.47°C to 29.36°C. The statistical significance of the trends is shown in Table 4.6. The average minimum annual temperature increased significantly from 15.88°C in 1960 to 17.11°C in 2014, the MAM increased from 17.14 °C to 18.18°C, JJAS increased from 14.02°C to 15.37 °C, and OND increased from 16.62°C to 17.95°C (Table 4.7).

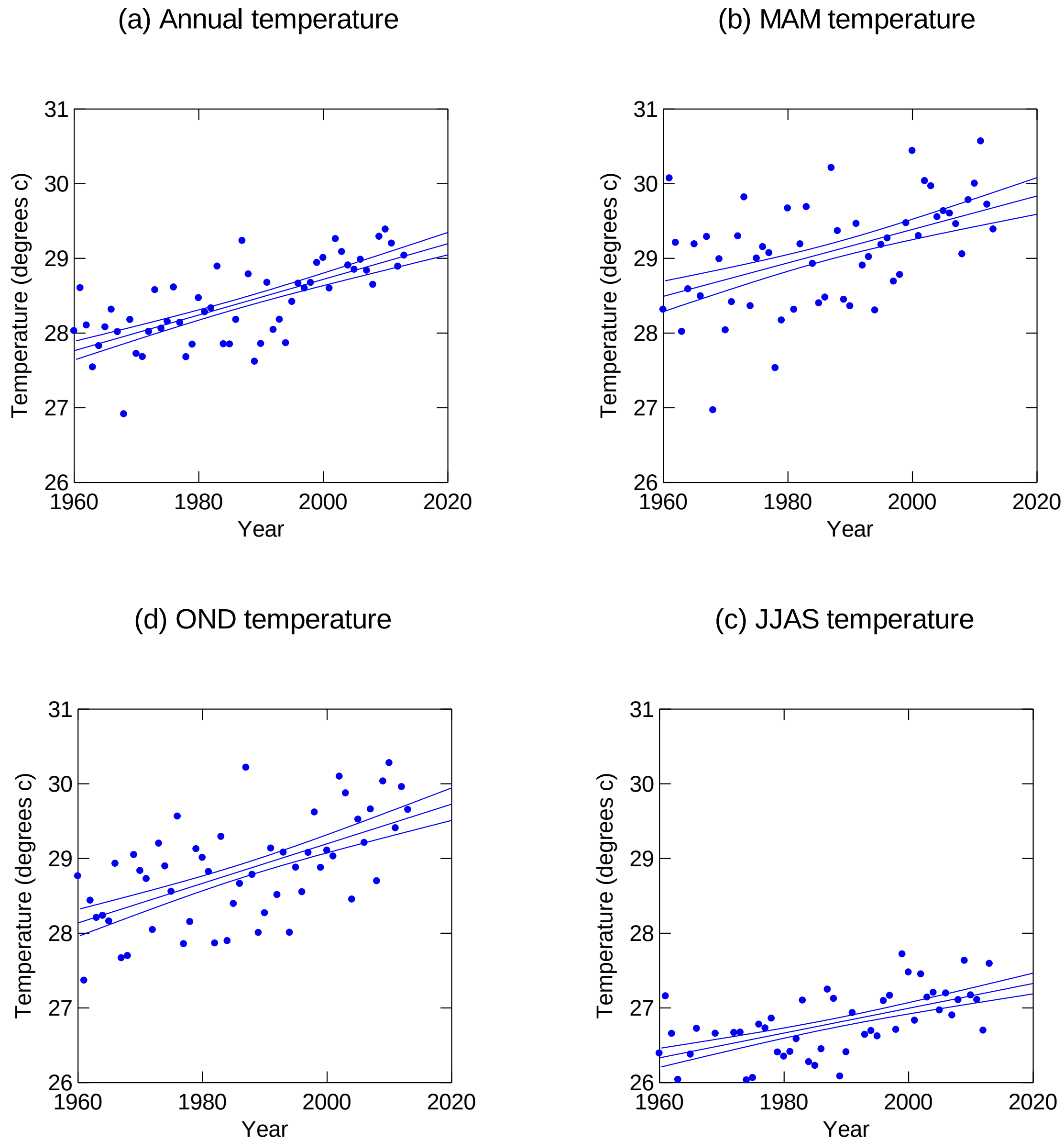



Figure 4.8: Historical maximum temperature trends, including the 95% confidence levels for the Amboseli Ecosystem. The data points represent the annual and seasonal averages.

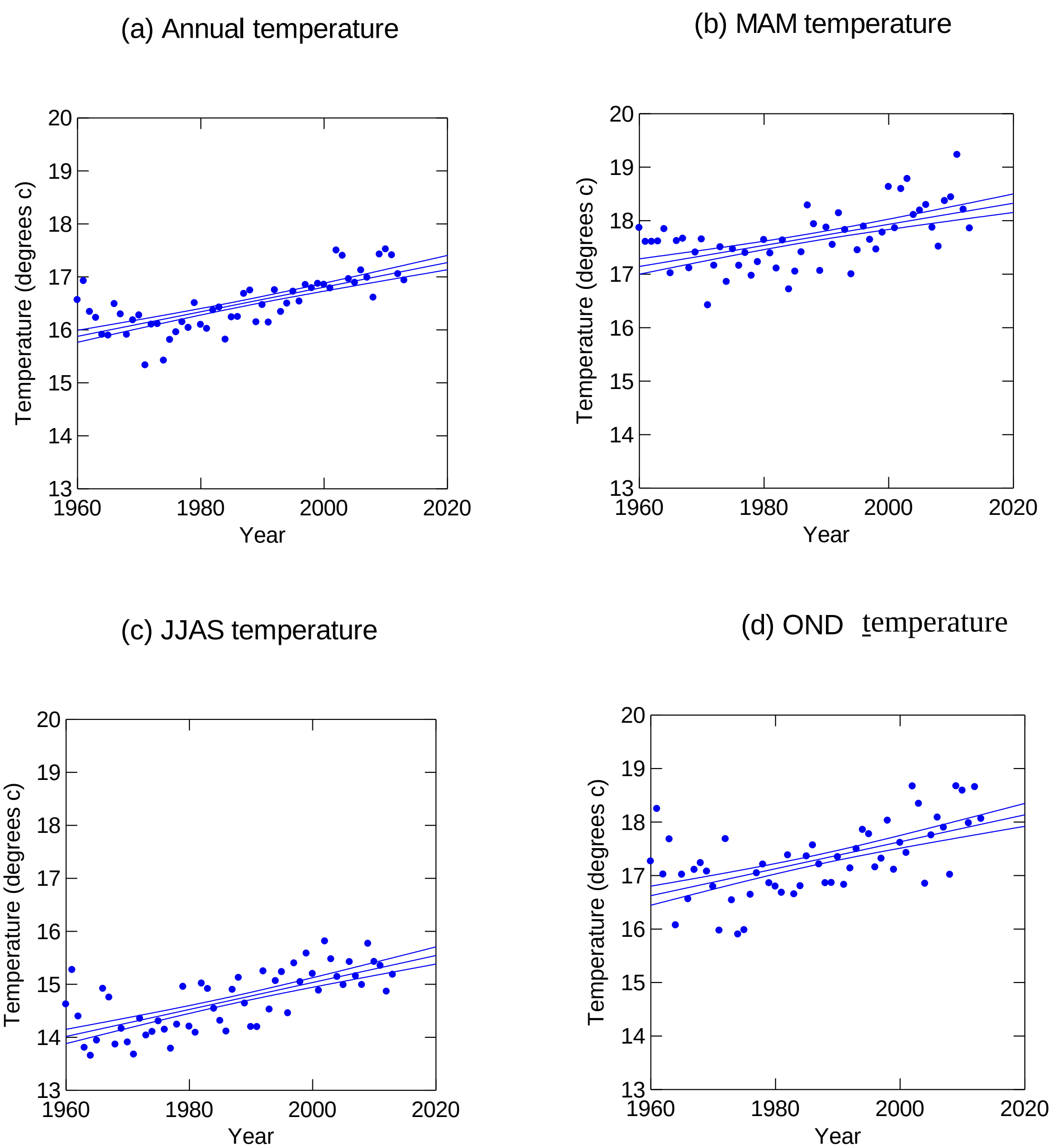



Figure 4.9: Historical minimum temperature trends, including the 95% confidence levels for the Amboseli Ecosystem. The data points represent the annual and seasonal averages.

Table 4.7 summarizes seasonal and annual changes in the Amboseli ecosystem's maximum and minimum temperatures between 1960 and 2014 (See detailed tables in Appendix D Tables D2-3). The temperature increases were higher in the minimum compared to the maximum. The total increase in the average annual minimum temperatures between 1960 and 2014 was 1.23°C, while the average maximum temperatures increased by 0.79°C. Similarly, it is evident that observed the minimum seasonal temperatures for the periods' MAM (1.04°C), JJAS (1.35°C), and OND (1.33°C) were much higher compared to the maximum seasonal temperatures. The highest increases in temperatures were observed in months of OND (0.88°C) and the slightest increases in MAM (0.69°C). The highest increase in minimum temperatures temperature was observed in the months of JJAS (1.35°C) and the slightest increase in MAM (1.04°C).

Table 4.7: Summary of maximum and minimum temperature changes for the Amboseli ecosystem.

| | Season | Year | Degree (°C) | Change (°C) |
|---|---|---|---|---|
| Maximum | Annual | 1960 | 28.08 | 0.79 |
| | | 2014 | 28.87 | |
| | MAM | 1960 | 28.81 | 0.69 |
| | | 2014 | 29.49 | |
| | JJAS | 1960 | 26.40 | 0.70 |
| | | 2014 | 27.10 | |
| | OND | 1960 | 28.47 | 0.88 |
| | | 2014 | 29.36 | |
| Minimum | Annual | 1960 | 15.88 | 1.23 |
| | | 2014 | 17.11 | |
| | MAM | 1960 | 17.14 | 1.04 |
| | | 2014 | 18.18 | |
| | JJAS | 1960 | 14.02 | 1.35 |
| | | 2014 | 15.37 | |
| | OND | 1960 | 16.62 | 1.33 |
| | | 2014 | 17.95 | |

Generally, the entire ecosystem exhibited a positive trend in temperature change. The observation concurs with a study by Altmann *et al.* (2002), which indicated increases in maximum and minimum temperatures in Amboseli. The daily maximum temperatures increased by 0.275°C, while the daily minimum temperatures increased by 0.071°C. Recent studies by Ogutu *et al*. (2016) focusing on 21 arid and semi-arid (ASALs) counties of Kenya, including Kajiado, indicated the warming of these counties. All 21 counties showed increases in both maximum and minimum temperatures. Between 1960 and 2014, the average maximum temperature increased by 0.7 to 1.9 degrees Celsius every year, ranging from 24.3 to 33.2 degrees Celsius (Ogutu *et al*., 2016).

These results showing non-significant declines in rainfall and significant increases in temperature in the Amboseli ecosystem will impact the wildlife population in different ways based on whether they are water-dependent or not water-dependent, migratory or non-migratory, browsers or grazers, small, medium, or large herbivores (Bhola *et al*., 2012). Warming of the atmosphere can lead to heat stress for animals, and the Thermal-humidity index going beyond 28°C can lead to the deaths of the animals (Dash *et al*., 2016). Most herbivores' (water-dependent) densities declined to approach zero at maximum temperatures of about 30°C, whereas, for non-water dependent animals, it is about 34°C (Ogutu *et al*., 2016).

The following section explores the relationship between large herbivore densities and historical climate variables such as rainfall and temperature in the Amboseli ecosystem.

## 4.4 Distribution of Large Herbivores and their Range

The range occupation in the ecosystem demonstrates the importance of environmental conditions in determining herbivore species distribution patterns. The following section is a description of the distribution of the 15 species.

### *4.4.1 Migratory and dispersal species*

The distribution patterns of migratory species were comparable, and they were found in most ecosystem regions. Migratory species such as Burchell's zebra and wildebeest can be seen in considerable numbers in the ecosystem's north (Athi Kapuitei), south (Nguruman highlands and plains), and west (Nguruman mountains and plains) (Figures 4.10 (a-b). The Athi Kaputei region is home to large populations of Thomson's gazelle (Figure 4.10 (c)), but their distribution pattern is similar to that of wildebeest and zebra.

The African Elephants (*Loxodonta africana*), which are ecosystem engineers who shift habitats by picking preferred resources in the landscape, are another essential species in the Amboseli ecosystem that traverses long distances in search of water and grass (Pringle, 2008; Ripple *et al*., 2015). In the ecology, elephants can be found in Amboseli National Park and the Nguruman escarpment (Figure 4.10 (e)). Eland is also abundant throughout the county, with a small population residing in the Amboseli environment (Figure 4.10(d)).

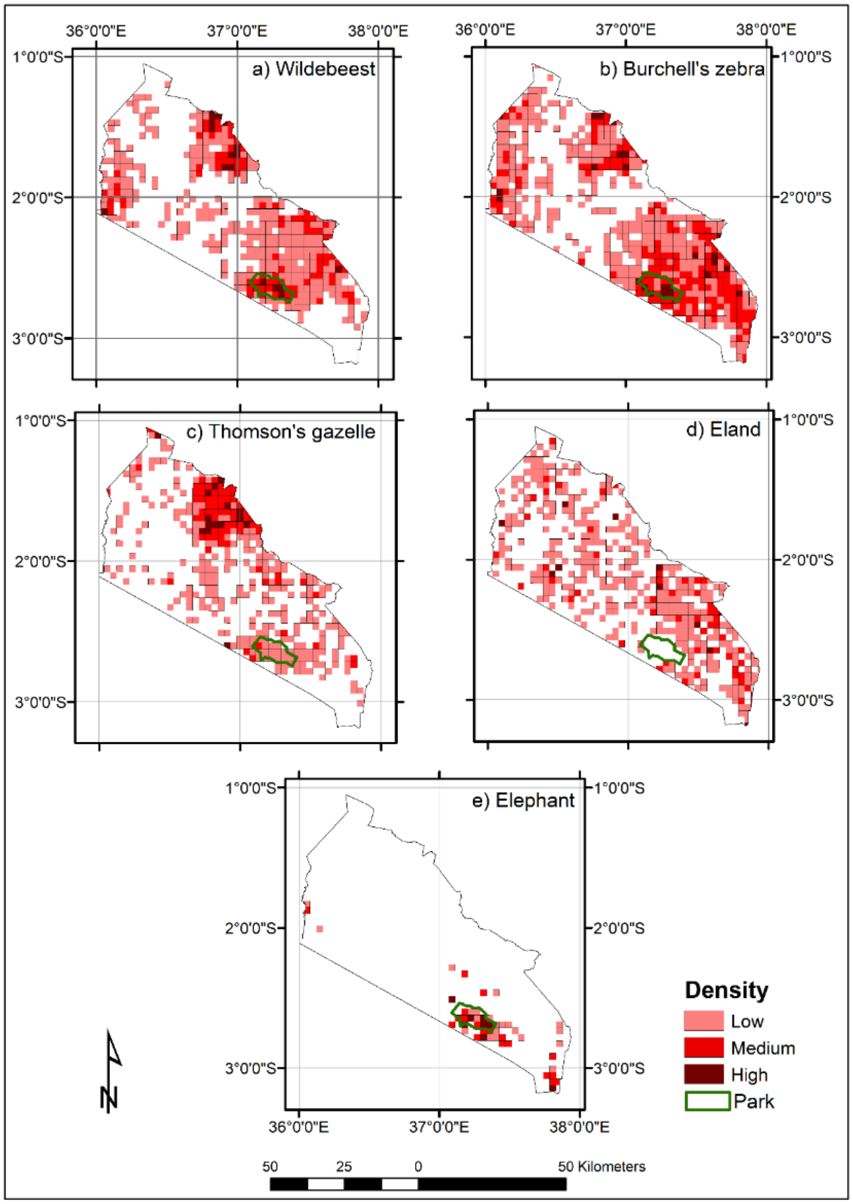



Figure 4.10: Species range for the four migratory large herbivores and one dispersal (elephant) species in Kajiado County

### *4.4.2 Resident species – grazers, browsers, and mixed feeders*

The central plains and the Amboseli ecosystem are home to gerenuk and Lesser kudu, and the range of the two species is almost similar in extent. The other browsing species include the giraffe, widely distributed in Kajiado but resides in high densities in Amboseli National Park, the central sections of the county, and western parts (Figures 4.11 (a-c)).

Grant's gazelle, impala, and oryx are among the resident mixed feeding species. In terms of distribution, Grant's gazelle may be found all over the county, with the highest concentrations in Amboseli National Park and Athi Kaputiei. Grant's gazelle can be found in moderate numbers in central and western Kajiado counties. The Impala is located across the county but is particularly abundant in the Amboseli environment and western regions. On the other hand, the oryx is restricted to dry portions of the county, including the Amboseli environment and the west half of Kajiado (Figures 4.11 and 4.12 (d-f)).

Buffalo, hartebeest, warthog, and waterbuck were the four resident grazing species, and their distribution differed from that of migratory species (Figures 4.12) (a-d)). Buffalo and warthogs, which had a similar distribution pattern, also had a constrained range. Their range is limited to Amboseli Park and the western sections of the park in the Nguruman woods, close to water sources (wetlands and forest). The two of them had a small population as well. The hartebeest (or kongoni) and waterbuck have a somewhat even distribution across the county. Large concentrations of hartebeest were found in Athi Kaputiei, Chyulu Conservation Game Area, and near Ngong Hills, but also scarce in Kajiado's southern plains. They were also sparingly dispersed near the park and the county's central part. Waterbuck were predominantly found in the Amboseli environment in the county's central region, with a large population throughout the foothills of the Nguruman escarpment.

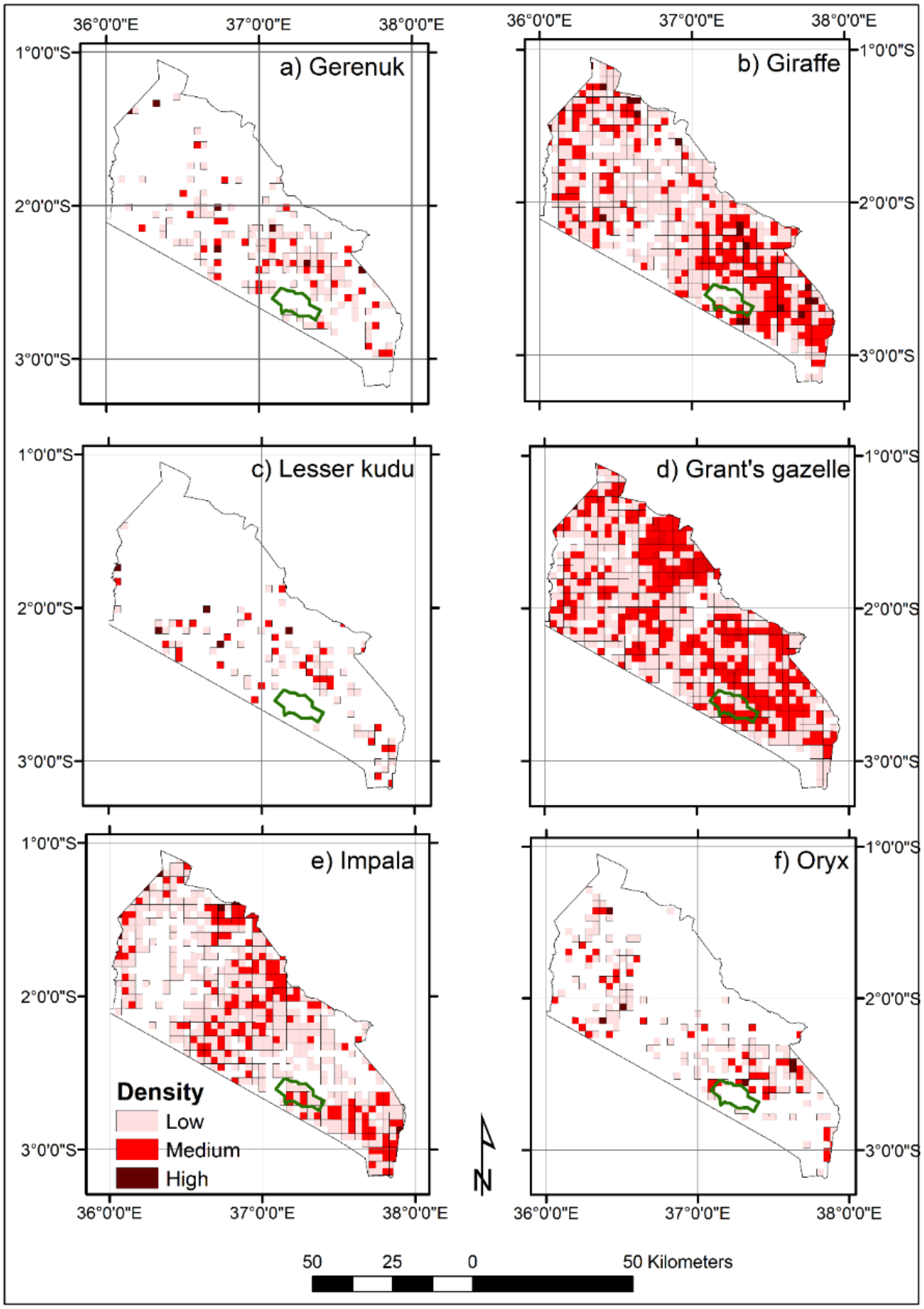



Figure 4.11: Distribution of resident large herbivore browsers and mixed feeders species in Kajiado County

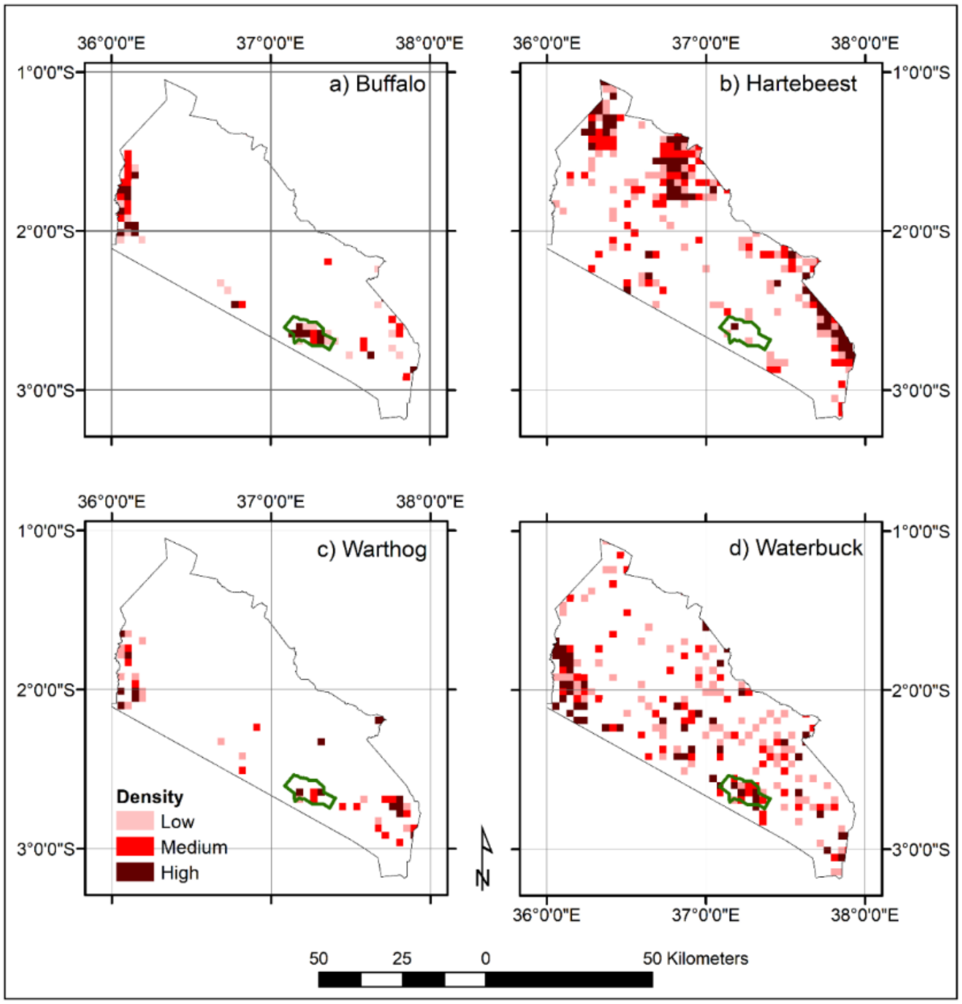



Figure 4.12: Distribution of resident large herbivore grazer's species in Kajiado County

**4.6: Relationships between the Population Density of each of the 15 Wildlife Species and the Annual Average Maximum Temperature**

One potential strategy for identifying biologically significant heatwaves is to use threshold temperatures ($T_{thresh}$) above which animals of interest experience physiological costs. (Cunningham *et al.*, 2013). This study assumed that the animals have a maximum temperature beyond which it becomes difficult to survive. The results show that individual relationships between the species and maximum temperature were similar for Thomson's gazelle, impala, Grant's gazelle, hartebeest, wildebeest, Burchell's zebra, and giraffe (see Figure 4.13 (a, b, e), 4.14 (a, b, d, h). Their population densities were declining exponentially as the temperature increased. The threshold temperature for these species was 30°C, beyond which it was tending towards zero.

The temperature threshold for wildebeest is 28°C (Figure 4.14 (b)). and warthog is 32°C (Figure 4.13 (c)). On the contrary, the relationship between the waterbuck and temperature was not as strong. An increase in temperatures favoured species like the elephants (Figure 4.14 (i)), Lesser kudu (Figure 4.13 (f)), and oryx (Figure4.14 (e)), whose density increased with an increase in temperature but reduced when the temperatures got too high. Their densities decrease as follows: oryx, after 31°C, Lesser kudu around 33°C and elephant around 28°C. The most resilient species is the gerenuk, which can survive in very high temperatures above 34°C (Figure 4.13 (d)).

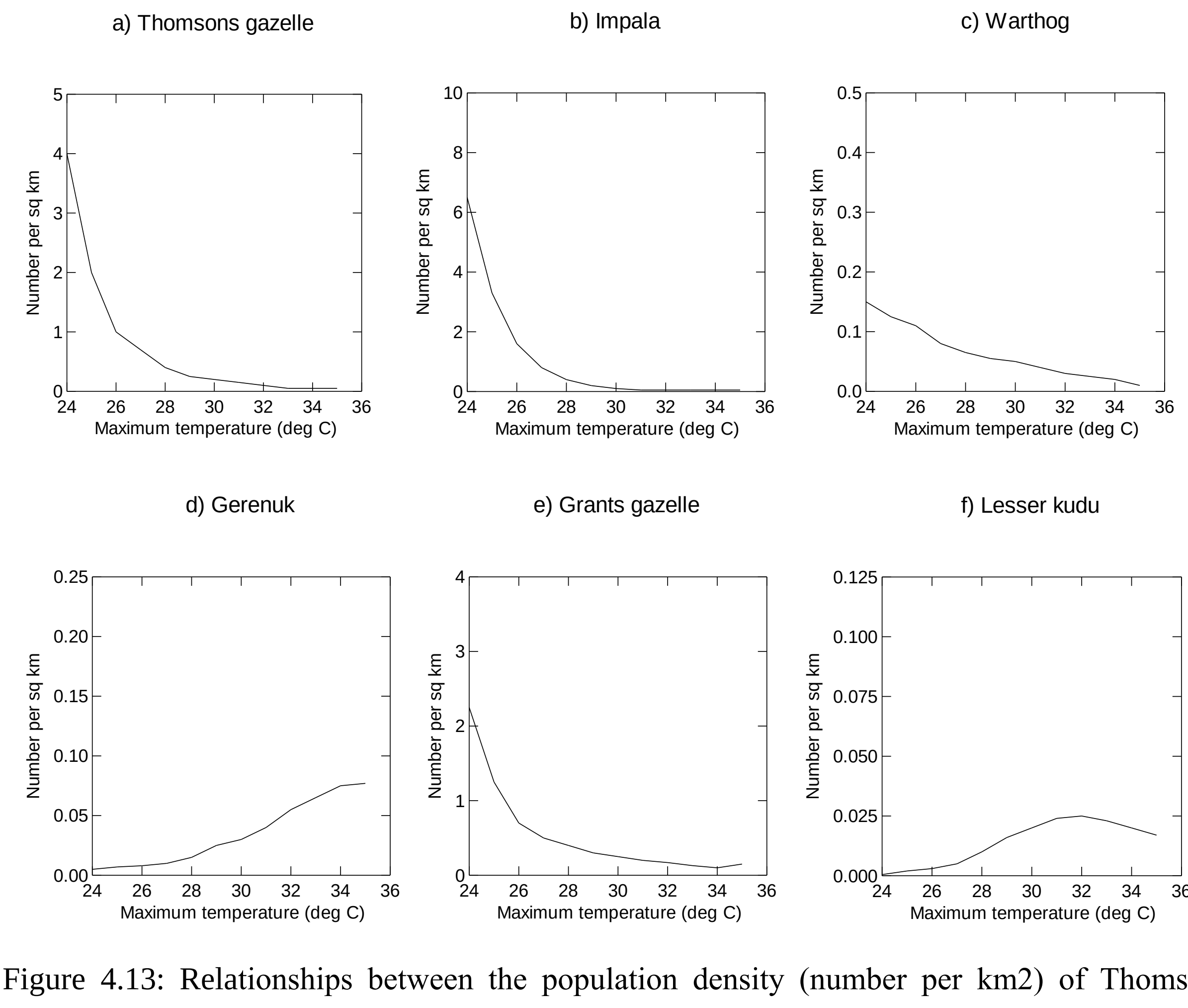



Figure 4.13: Relationships between the population density (number per km2) of Thomson's gazelle, Impala, Warthog, Gerenuk, Grant's gazelle, and Lesser kudu and annual average maximum temperature (in °C).

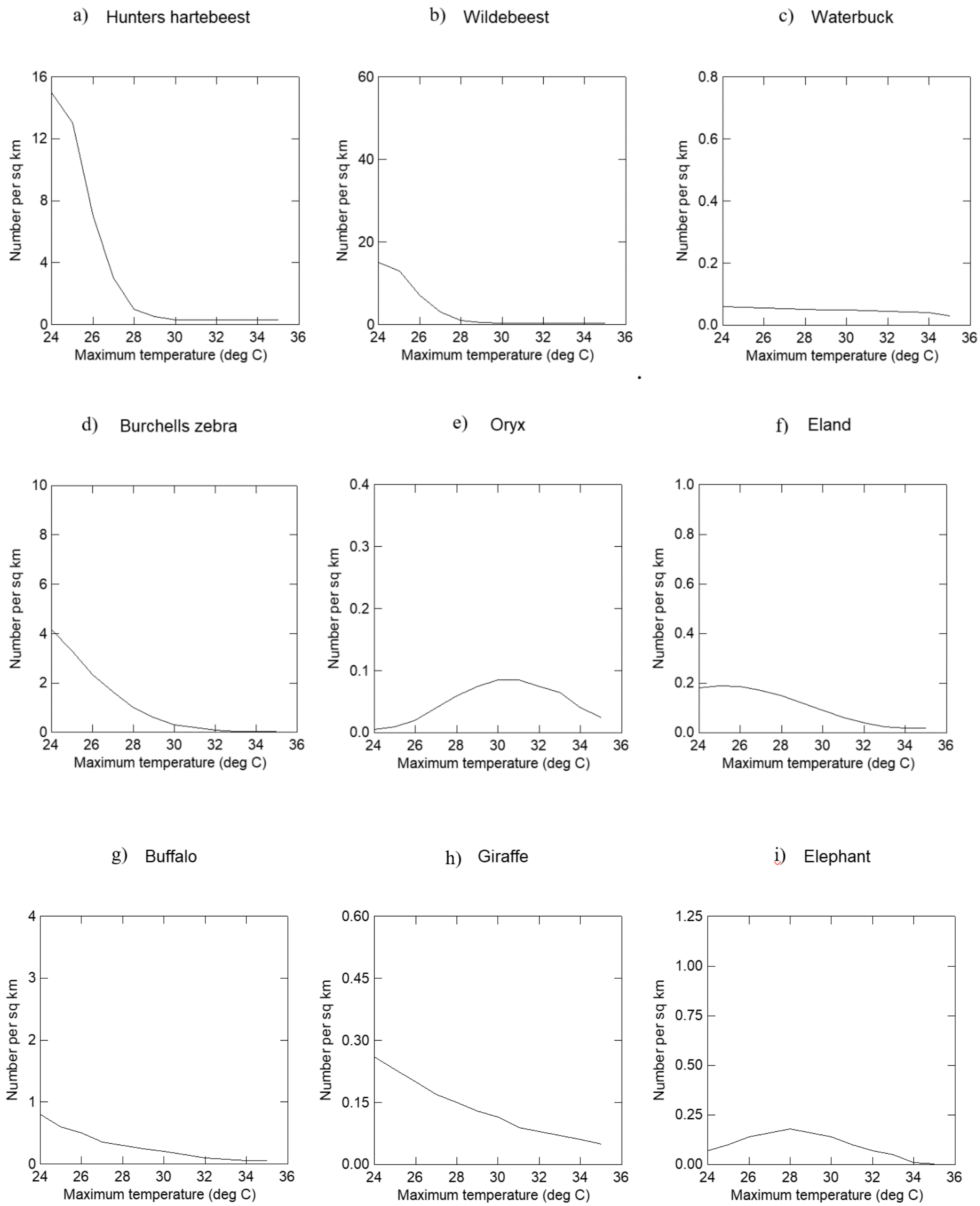



Figure 4.14: Relationships between the population density (number per km2) of hartebeest, wildebeest, waterbuck, Burchell’s zebra, Oryx, Eland, and Buffalo, Giraffe and Elephant and the annual average maximum temperature (in °C).

The results show that changes in temperatures resulting from climate change are a big concern in the entire county of Kajiado. Although the distribution density of wildlife species in high potential and heavily human-populated areas of Kajiado county has been affected tremendously by human activities in the past years, climate change is likely to exacerbate the situation leading to a decline in many herbivores (Okello *et al*., 2016). While the Amboseli National Park is the ecological lifeline of herbivorous wildlife species, the distribution pattern exhibited in this study shows large populations are located outside the protected area.

### 4.7 Elephant Population Trend of Amboseli Ecosystem

The elephant is one of the key wildlife species in the Amboseli ecosystem that can transform the savannah landscape (Okello *et al*., 2016). Elephants are more distressed by water stress rather than heat stress (Dunkin *et al*., 2013). When there is a decline in rainfall, elephants are forced to migrate for long distances in search of water, exposing them to the risk of poaching. "Foley *et al*., 2008 documented the decline of elephant populations during a severe drought in Tanzania in 1993, which coincided with an upsurge in elephant poaching (Prins *et al*., 1994; Prins and van der Jeugd, 1993)." Between 1977 and 2014, the number of elephants in the Amboseli habitat increased dramatically, according to this study ($Y = 24.329x + 47553$, $r^2 = 0.44$, $F = 10.02$ and $P = 0.007$). Figure 4.14 shows the increasing trends of the elephant population in the Amboseli ecosystem for the period 1977-2014, from around 480 in 1977 to 1400 animals in 2014. The percentage increase is approximately 300% or a growth rate of 2.4% per year.

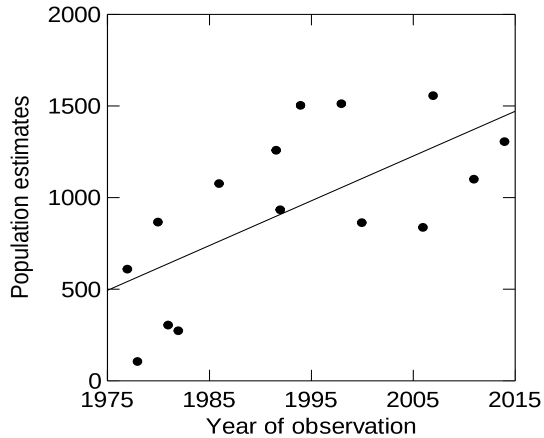



Figure 4.15: Elephant population trend in the Amboseli ecosystem from 1977-2014, showing an increasing population.

## 4.8 Distribution of Elephants in the Amboseli Ecosystem 1977-2014

The spatial distribution of elephants from 1977 to 2014 is depicted in Figure 4.16. The findings suggest two distinct elephant distribution patterns in the Amboseli habitat: elephants may be limited to the park or wander out into dispersal areas at times. During the 1970s and late 1980s, most of the elephants were contained within the park's boundaries. The reason for the enclosure was due to widespread poaching in the 1970s and early 1980s. According to the IUCN report, elephant dispersal beyond the park increased significantly after 1991, but not in 1998, when poaching operations nearly tripled. The Asian market for ivory products was blamed for this. As a result, the elephants were kept in the park. Between the years 2000 and 2014, they began to disperse once more. An increase in anti-poaching patrols enabled the free movement of the elephants. Many elephants were seen in the park and nearby group ranches of Lengesim, Imbirikani, Kuku, Olgulului, and Kimana, indicating a significant expansion in their range.

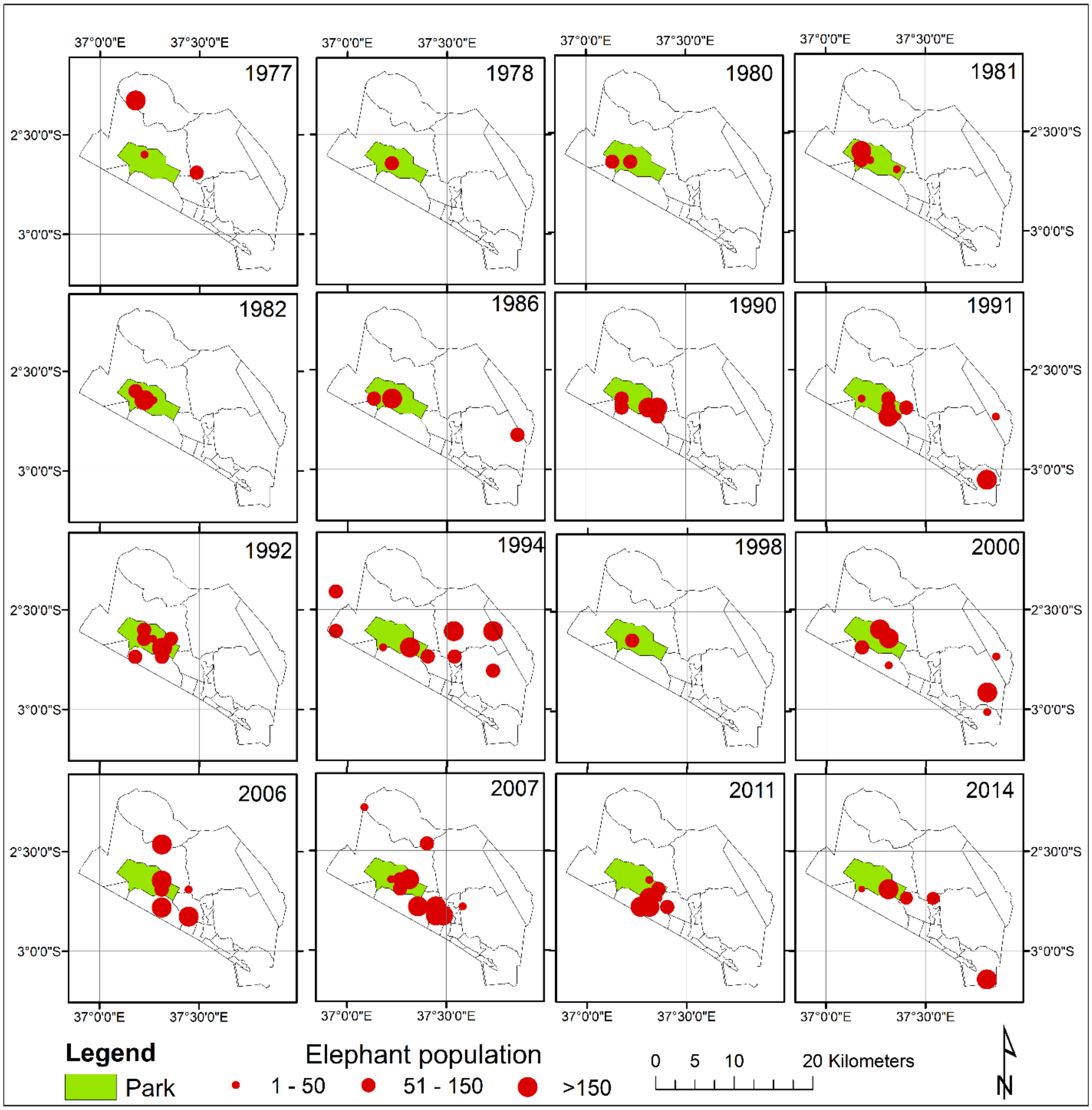



Figure 4.16: Spatial distribution of elephants in the Amboseli Ecosystem 1977-2014

Birkett *et al*. (2012), examining elephant movement patterns in conjunction with rainfall patterns, indicated that all herds under observation in Kruger National Park modified their behaviour at two independent thresholds. The thresholds were when the dry season ended, before the first rains arrived, and towards the end of the rainy season when the average daily rainfall was at its greatest. Such conditioning may play a very important role in the movement behaviour of the current elephant population in the Amboseli ecosystem, as indicated in the distribution patterns of elephants in the Amboseli ecosystem between 1977 and 2014. The distribution was mainly governed by rainfall seasons and security. The elephants were primarily found in the park in the 1970s, 1980s, and early 1990s, and in later years, the elephants moved more frequently outside the park due to increased protection (Groom and Western, 2013; Okello *et al*., 2014). Thus, there should be every effort to safeguard the park's landscape so that elephants and other migratory species can use them, as is customary.

In communities that have lived close to elephants for millennia, myths and tales explain the relationship between elephants and rainfall. For instance, the Samburu people of northern Kenya harbour the belief that when an elephant is seen after months of no rain, it is an indicator that the rains are coming soon. (Christo *et al*., 2009). Elephants change their migratory patterns in response to seasonal rainfall changes (dry to wet) and rainy incidents. The reactions are triggered by rainfall occurring at some distant location, perhaps as much as 300 km from the site of the elephants (Garstange *et al*., 2014). Therefore, understanding the relationship between elephants and rainfall is essential for understanding elephants' behaviour and future conservation.

### 4.9 Relationship between Elephant Population and Climate (temperature and rainfall)

A correlation between elephant population and temperature was developed based on yearly, MAM, OND, and JJAS seasons at various time lags. Results show significant quadratic relationships for annual (4 models), MAM (5 models), and JJAS (5 models), and OND (5 models), in which the elephant population increases and later declines as maximum temperature increases. There was only one linear model for OND that was statistically significant ($OND_0$). The results from the annual are shown in Table 4.8, and for MAM, JJAS, and OND are given in Appendix E (Table E-1, E-2, and E-3).

Table 4.8: Relationship between elephant population and annual maximum temperature in the Amboseli Ecosystem

| *Effect* | **Equation** | **F Ratio** | **R-Squared** | **P-Value** |
|---|---|---|---|---|
| *Annual₀* | Y= 378.61x - 9860.90 | 1.910 | 0.137 | 0.182 |
| *Annual₁* | Y= 319.54x - 8183.51 | 1.067 | 0.082 | 0.322 |
| *Annual₂* | Y= 235.37x - 5776.68 | 0.578 | 0.046 | 0.462 |
| *Annual₃* | Y= 457.81x - 12094.69 | 1.941 | 0.139 | 0.189 |
| *Annual₄* | Y= 507.75x - 13522.44 | 2.225 | 0.156 | 0.162 |
| *Annual₅* | Y= 463.48x - 12265.43 | 1.620 | 0.119 | 0.227 |
| *Annual₆* | Y= 512.07x - 13637.20 | 1.756 | 0.128 | 0.210 |
| *Annual₇* | $Y = -3198667 + 223422x - 3900x^2$ | 4.602 | 0.4555 | 0.0353 |
| *Annual₈* | $Y = -2746427 + 191818x - 3348x^2$ | 3.661 | 0.3996 | 0.06046 |
| *Annual₉* | Y= 544.64x - 14541.02 | 2.166 | 0.153 | 0.167 |
| *Annual₁₀* | $Y = -1775112 + 124019x - 2164x^2$ | 3.181 | 0.3665 | 0.08124 |
| *Annual₁₁* | $Y = -2271601 + 158776x - 2773x^2$ | 6.301 | 0.5339 | 0.01501 |
| *Annual₁₂* | $Y = -1846387 + 129020x - 2252x^2$ | 4.378 | 0.4432 | 0.03993 |
| *Annual₁₃* | $Y = -1993515 + 139473x - 22438x^2$ | 4,756 | 0.4637 | 0.03248 |
| *Annual₁₄* | $Y = -2285556 + 160080x - 2801x^2$ | 6.557 | 0.5438 | 0.01334 |
| *Annual₁₅* | $Y = -2446535 + 171446x - 3002x^2$ | 7.498 | 0.5769 | 0.00882 |

*Numeric suffixes in rainfall component (x) names indicate the time over which the moving averages of the selected annual components of the rainfall are calculated. Thus, $Annual_8$ means the 8-year moving average for Annual.

Annual MAM, OND, and JJAS rainfall (Table 4.9) at various time lags were used to link the elephant population and rainfall. The MAM, OND, and JJAS reveal that the elephant population and rainfall have a weak and insignificant relationship. However, the OND rains strongly correlated with the elephant population (Table 4.9 and Figure 4.17). The correlation was strongest at the rainfall moving average of 13 years lag (Table 4.9; $r^2 = 0.459$, $F_{1,13} = 11.01$, $P = 0.006$) in the OND models.

Table.4.9: Statistics describing relationships between the population of elephants and preceding rainfall over 8–15 years in the Amboseli Ecosystem.

| ***Effect*** | **Constant** | **Slope** | **F-ratio** | **r-squared** | **P-value** |
|---|---|---|---|---|---|
| $OND_0$ | 1489.152 | -1.955 | 3.825 | 0.227 | 0.723 |
| $OND_1$ | 794.302 | 0.537 | 0.046 | 0.004 | 0.833 |
| $OND_2$ | 431.306 | 1.953 | 0.517 | 0.038 | 0.485 |
| $OND_3$ | -294.167 | 4.775 | 1.228 | 0.086 | 0.288 |
| $OND_4$ | 907.678 | 0.119 | 0.001 | 0.000 | 0.974 |
| $OND_5$ | 67.403 | 3.442 | 0.606 | 0.045 | 0.450 |
| $OND_6$ | -250.048 | 4.752 | 0.764 | 0.055 | 0.398 |
| $OND_7$ | -682.433 | 6.556 | 1.368 | 0.095 | 0.263 |
| $OND_8$ | -1428.83 | 9.4658 | 3.93 | 0.232 | 0.069 |
| $OND_{10}$ | -1874.4 | 10.977 | 4.5 | 0.257 | 0.054 |
| $OND_{12}$ | -2757.43 | 14.744 | 8.33 | 0.390 | 0.012 |
| $OND_{13}$ | -4016.43 | 19.911 | 11.01 | 0.459 | 0.006 |
| $OND_{14}$ | -4476.79 | 21.325 | 9.61 | 0.425 | 0.008 |
| $OND_{15}$ | -3509.13 | 17.558 | 3.86 | 0.229 | 0.071 |

*Numeric suffixes in rainfall component (x) names indicate the window of time over which the moving averages of the selected for October-November-December (OND) season components of the rainfall calculated. Thus, $OND_8$ means the 8-year moving average for OND.

The findings show a robust positive relationship between the elephant population and the OND season with a 13-year lag. Other studies in the savannah ecosystem, such as those conducted in the Tsavo (Tyrell and Coe, 1974), Mara (Serneels and Lambin, 2001; Ogutu *et al*., 2015), Lake Nakuru (Ogutu *et al*., 2017), Amboseli (Western, 1973), Serengeti (Sinclair *et al*.,1985), and Addo National Park in South Africa (Gough and Kerley, 2006) have discovered that ungulate population varies with rainfall and is influenced by annuals, seasons (wet or dry), or a combination of seasons and time lags. (Ogutu *et al*., 2017). However, time lags were shorter than ten years. The elephant is one of the key wildlife species that have lived for a long era in the savannah. Elephants have a 60-year lifespan and do not reproduce until they are ten years old (Shiao *et al*., 1980). Elephants begin reproducing at the age of about 13 years. (De Silva *et al*., 2013). Longer-lived animals react to environmental changes more slowly (Margaret, 1986).

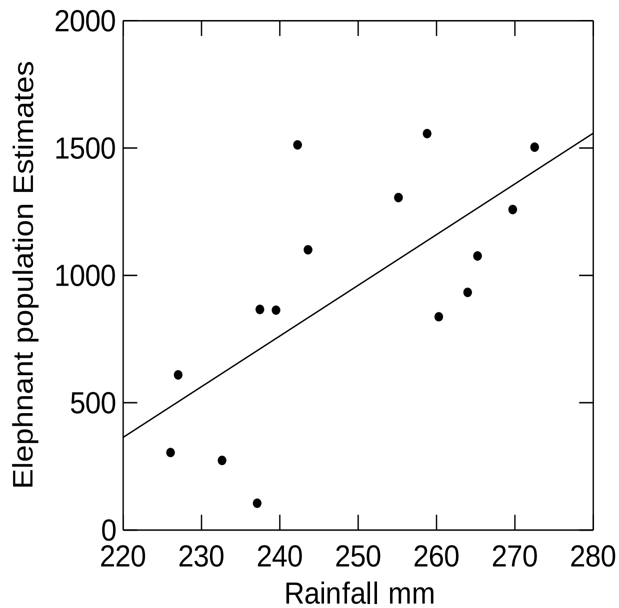



Figure 4.17: The relationships between the elephant and the best supported cumulative moving averages (OND13)

Because of the variability of precipitation and the time lag between responses, populations never reach a stable age distribution (a population with equal birth rates and death rates) (Davis, 1986). In East Africa, years correlate with when elephants reproduce successfully (Davis, 1986). Because of the significant amounts of rain received (Chapter 3, Figure 3.2), the OND season is critical in the Amboseli ecology, impacting the survival and reproduction of elephants in the area.

Changes in seasonal rainfall have long been known as influencing elephant migration in savanna ecosystems (Cushman *et al*., 2005; Woolley *et al.*, 2009; Young *et al*., 2009). Seasonal rainfall fluctuations (dry to wet) and seasonal wet episodes cause elephants to modify their movement patterns. The reactions are caused by rainfall at some distant location, probably as much as 300kmfrom the elephant's site (Garstange *et al*., 2014). Birkett *et al*. (2012) studied elephant movement patterns in connection with rainfall patterns. They found that all herds under observation changed their behaviour at two distinct thresholds at the start of the rainy season, before the first rains, and at the end of the rainy season, when the mean daily rainfall is highest.

Breeding rates and genetic patterns in these populations' relationships are affected by seasonal variations in the severity or duration of wet vs drought periods. African elephants (Loxodonta Africana) reproduce throughout the year, according to Poole (1989) and Rubenstein (1992). On the other hand, the dominant males mate during the wet season, while the inferior males breed during the dry season. According to previous studies, elephants have a high rate of juvenile elephant mortality during dry periods (Foley *et al*., 2006; Moss *et al*., 2011; Moss, 2001). During drought seasons, male calves have a shorter life expectancy and smaller bodies (Lee *et al*., 2013). Moreover, drought also affects adult elephants, leading to increased mortality (Foley *et al*., 2008; Owen-Smith, 2006; Corfield, 1973).

# CHAPTER 5 : IMPACTS OF PROJECTED RAINFALL AND TEMPERATURE TRENDS ON HERBIVORES IN AMBOSELI ECOSYSTEM

## 5.0 Introduction

This chapter focuses on RCP scenarios (2.6, 4.5, and 8.5) and the future impacts of climate change on the large herbivores in the Amboseli ecosystem. "The predicted rainfall shifts and maximum and minimum temperatures based on the RCP2.6, RCP4.5, and RCP8.5 scenarios have been evaluated for four potential time slices: 2030s (2016–2045), 2050s (2036–2065), and 2070s (2055–2085) to provide details on the anticipated severity of the climate response in each period." The period from1970 to –2006 is the reference for the current climate.

## 5.1 Projected Rainfall in the Amboseli Ecosystem Based on the Three Climate Scenarios

Figures 5.1 to 5.3 depict annual and seasonal rainfall forecasts in the Amboseli based on the three RCPS. The projected rises in the yearly rainfall factor suggest very little change relative to estimated changes in the components of seasonal rainfall in each of the three scenarios. In all three conditions, the short rains (October–December or OND period) are expected to increase over most parts of the region. By contrast, the long rains (March –April - May or MAM period) and the June–September dry (June – July – August – September or JJAS) season is projected to decrease. Annual, MAM, JJAS, and OND seasonal rainfall for all RCPs are summarized in Tables 5.1, 5.2, and 5.3. For all four seasons, RCP 2.6 predicts a decrease in precipitation.

Annual precipitation for RCP 4.5 is predicted to increase slightly, owing mostly to rises in the rain for the OND season (Table 5.2 and Figure 5.2 (a-d)). However, the increases are not statistically significant ($p > 0.05$). Rainfall for MAM and JJAS is expected to decrease marginally relative to RCP 2.6; the decrease is not statistically significant ($p > 0.05$). RCP 8.5 projects a significant increase in OND rainfall $P = 0.0002$; (see Table 5.3). JJAS is expected to see a considerable decrease in rainfall ($P = 0.0126$; Table 5.3) and will become much drier.

Table 5.1: Rainfall trends for Amboseli Ecosystem for RCP 2.6 between 2006 - 2100

| Annual/ Season | Trendline equation | F-Ratio | P-Value |
|---|---|---|---|
| Annual | Y = 763.587 – 0.0640x | 0.015 | 0.9014 |
| MAM | Y = 346.714 – 0.0615x | 0.043 | 0.8354 |
| JJAS | Y = 94.4536 – 0.0295x | 0.131 | 0.7183 |
| OND | Y = 485.237 – 0.0799x | 0.045 | 0.8333 |

Table 5.2: Seasonal rainfall trend for Amboseli Ecosystem for RCP 4.5 between 2006 - 2100

| Annual/ Season | Trendline equation | F- Ratio | P-Value |
|---|---|---|---|
| Annual | Y = 287.983 + 0.1968x | 0.099 | 0.7536 |
| MAM | Y = 465.295 – 0.0996x | 0.068 | 0.7946 |
| JJAS | Y = 81.2521 – 0.0236x | 0.108 | 0.7428 |
| OND | Y = -25.1041 + 0.2879x | 0.614 | 0.4352 |

Table 5.3: Seasonal rainfall trend for Amboseli Ecosystem for RCP 8.5 between 2006 - 2100

| Annual/ Season | Trendline equation | F- Ratio | P-Value |
|---|---|---|---|
| Annual | Y = -400.653 + 2.3022x | 15.266 | 0.0002 |
| MAM | Y = -344.632 + 0.2937x | 0.795 | 0.3748 |
| JJAS | Y = 390.734 – 0.1767x | 6.459 | 0.0126 |
| OND | Y = -3017.99 + 1.6509x | 17.251 | 0.0001 |

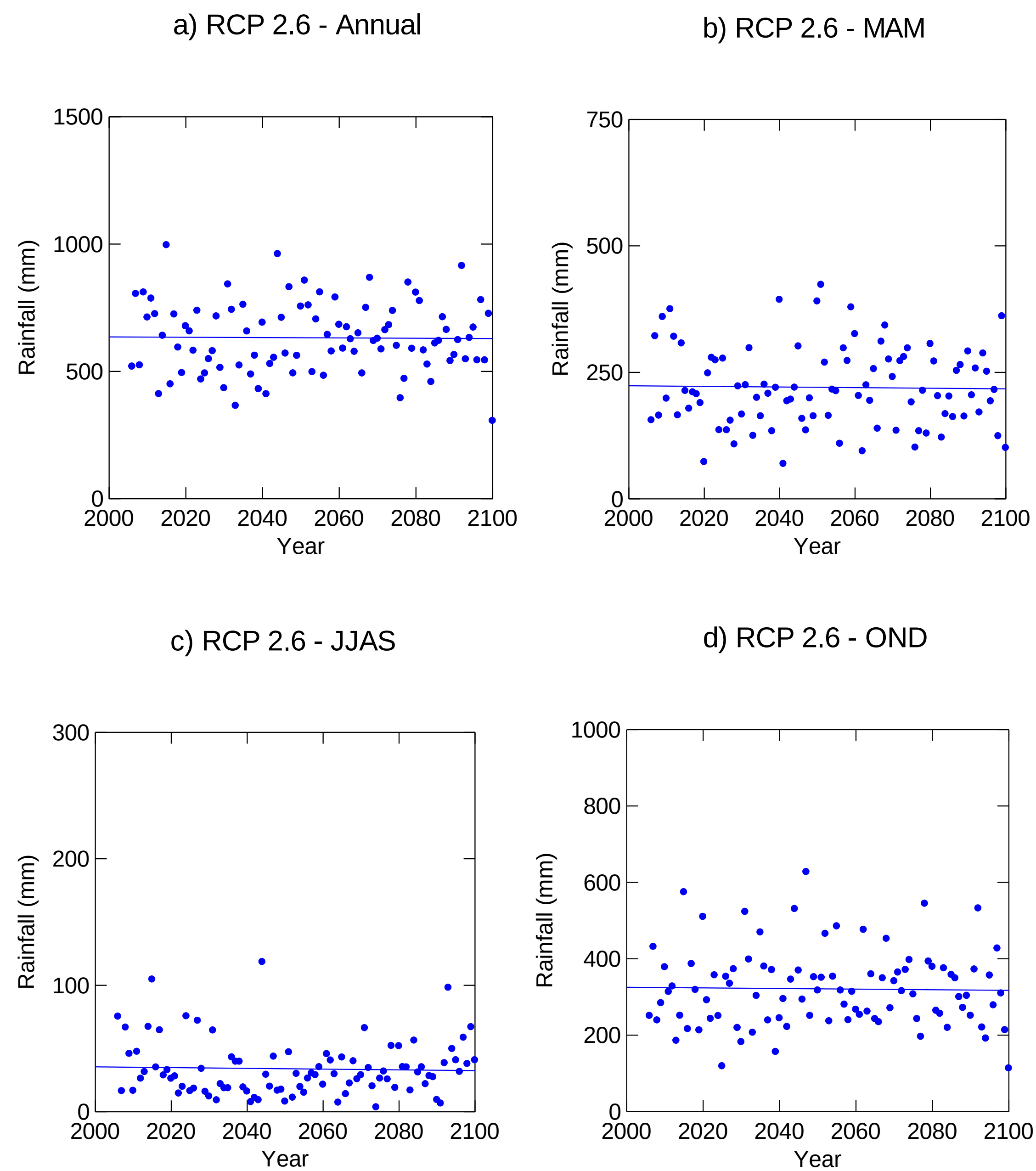



Figure 5.1: Projected rainfall trends for the Amboseli Ecosystem for RCP 2.6 from 2006-2100. The data points represent annual and seasonal rainfall totals.

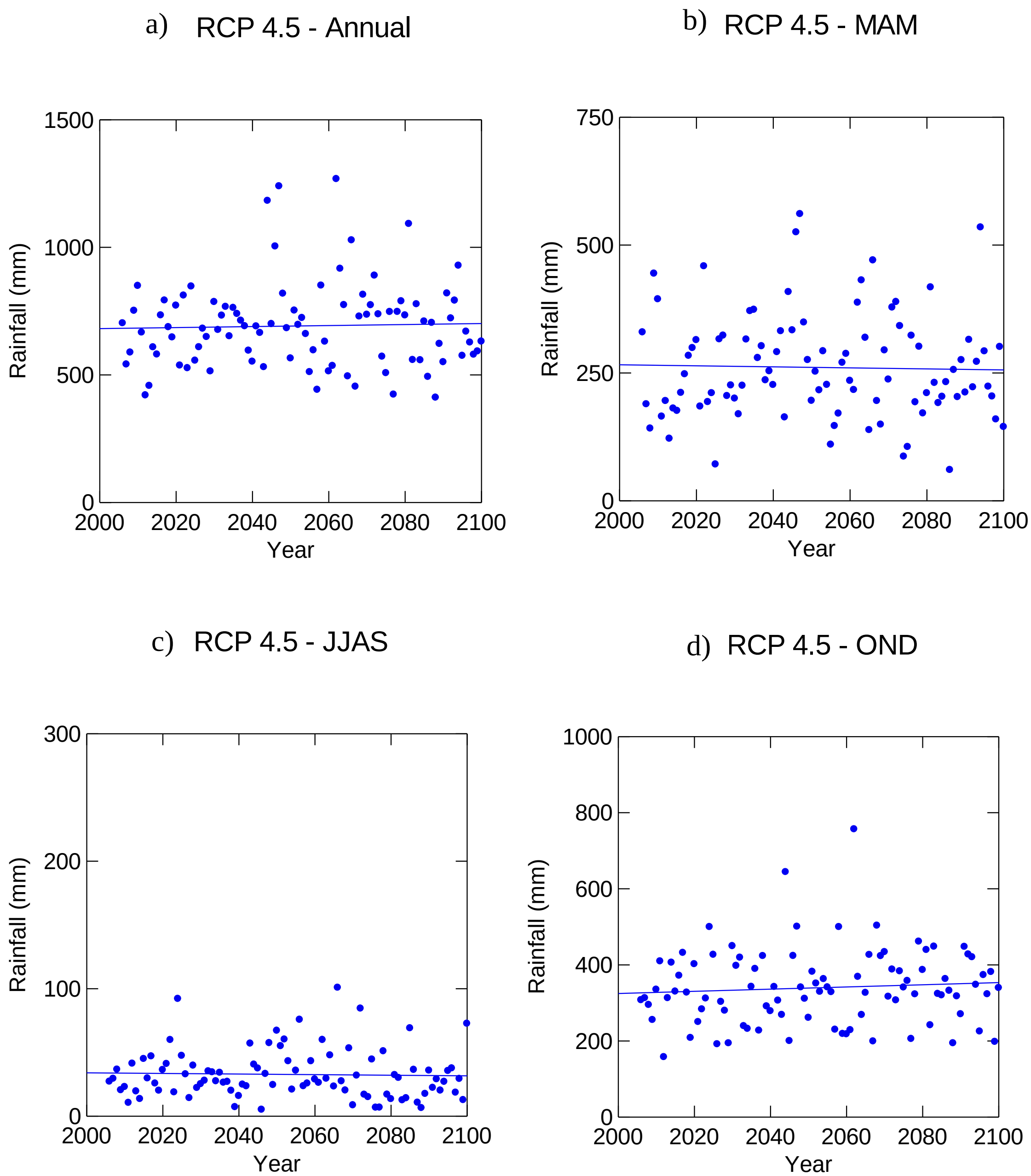



Figure 5.2: Projected rainfall trends for Amboseli Ecosystem for RCP 2.6 for the period 2006-2100. The data points represent annual and seasonal rainfall totals.

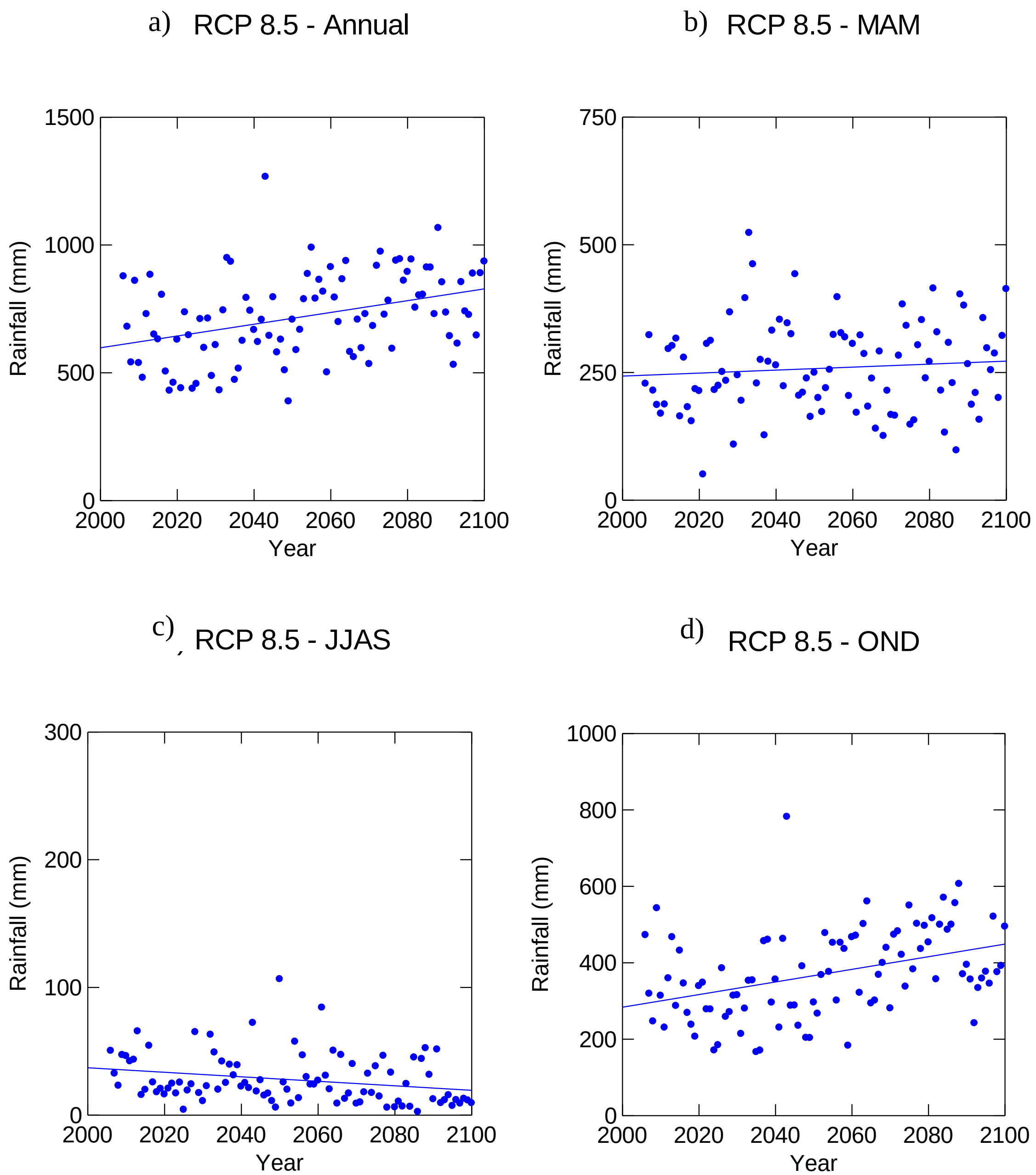



Figure 5.3: Projected rainfall trends for Amboseli Ecosystem for RCP 2.6, 4.5, and 8.5 for 2006-2100. The data points represent annual and seasonal rainfall totals.

Figures 5.4, 5.5, and 5.6 depict the expected spatial patterns of annual and seasonal rainfall components over the Amboseli ecosystem. Compared to the reference period (1970–2006), the time windows are the 2030s, 2050s, and 2070s. Compared to the expected changes in the seasonal rainfall components, the predicted increases in the annual rainfall variable show comparatively minimal change under any of the three scenarios and timeframes. The significant decline in rains for the MAM season is driving the decrease in annual rainfall in the 2030s under RCP 2.6. The drop was widespread, ranging from 5 to 50 per cent, with the majority of the reduction occurring in the ecosystem's southwestern, northern, and central regions. In the central and southern parts, the drop was 5 to 10% under RCP 4.5 and 8.5. In all three scenarios, short rains (October–December or OND period) are likely to increase by 5– 25% in most parts of the study region by 2030; however, some areas in the southwestern parts are expected to be drier. This area of Mount Kilimanjaro is predicted to have decreasing rainfall in all scenarios because it is on the leeward side of the mountain. The model strongly suggests that rainfall would decrease in the 2030s. The long rains MAM period, on the other hand, is expected to decrease in the northern half of the region while increasing in the southeastern part.

Most portions of the area are predicted to see rainfall decreases  (5–50 per cent) during the dry JJAS season by 2030. (See Figure 5.4)The annual pattern in the 2050s shows increases in rainfall spatially, with RCP 2.6 having the most negligible increases and RCP 8.5 having the most. Seasonal contributions drive the differences in geographic patterns. For RCP 2.6, the JJAS season rainfall loss is expected to be between 20 and 50 per cent. Precipitation is likely to decrease in central and south-western locations during the MAM season. Seasonal variations drive the annual changes. The MAM season had the highest rise in rainfall of the three scenarios in the RCP 4.5 2050s. The MAM season had significantly more rain than the OND season. However, the JJAS season still projects a continued decline in rainfall (See Figure 5.5).

In the 2070s, all RCPs show an increase in annual rainfall, with RCP 8.5 showing substantial increases in the northern and central regions, ranging from 25 to 50 per cent. Except for JJAS, the expected annual rainfall tends to increase in the locations of the north. Because both MAM and JJAS are expected to have decreased rainfall, RCP 2.6 will have the smallest rise. In the already dry season, the southwestern area saw considerable 5 to 10% reductions over the four seasons.

RCP 4.5 and 8.5 have a similar pattern, although RCP 8.5 is expected to increase by 25–50 per cent for OND. The southwestern and Nguruman Escarpments (western) are indicated by the JJAS season for RCP 8.5.

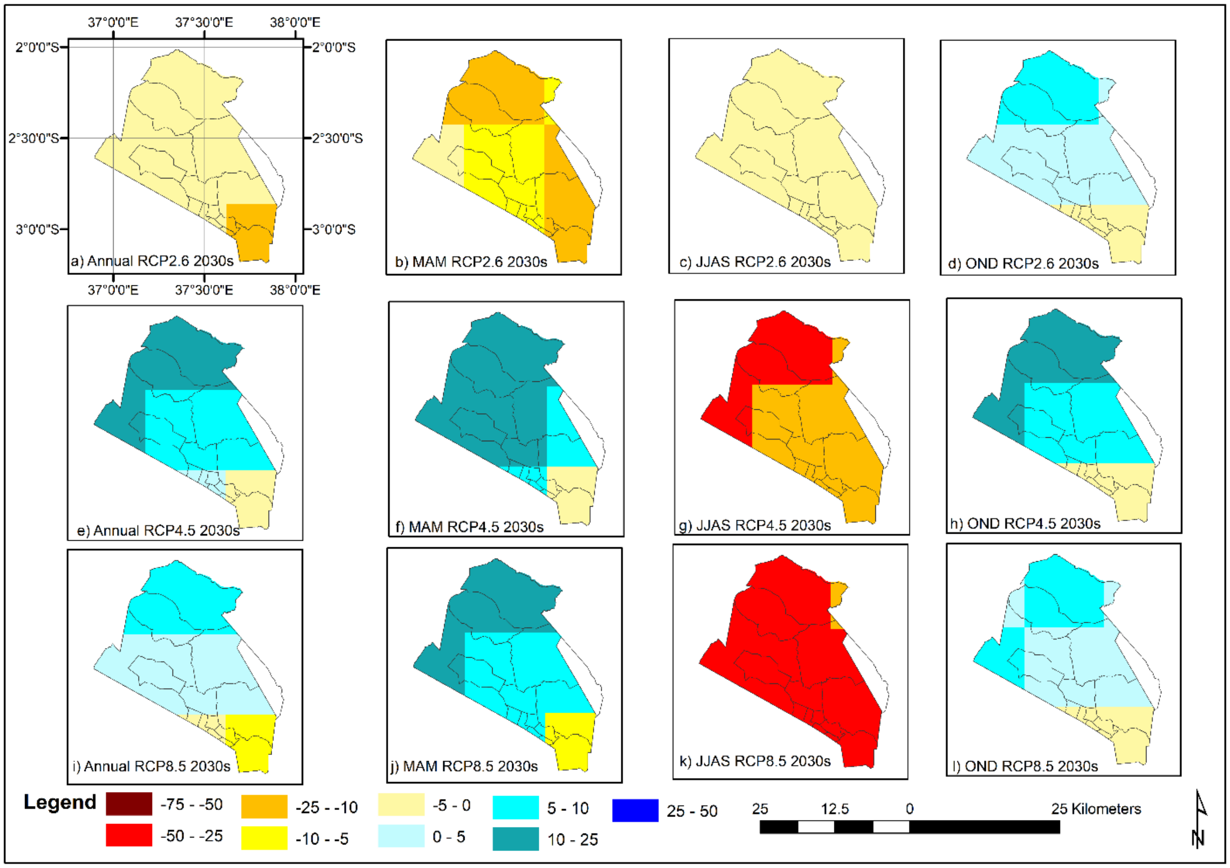



Figure 5.4: Projected annual and seasonal rainfall (in percentage) for the Amboseli Ecosystem for the period 2030s

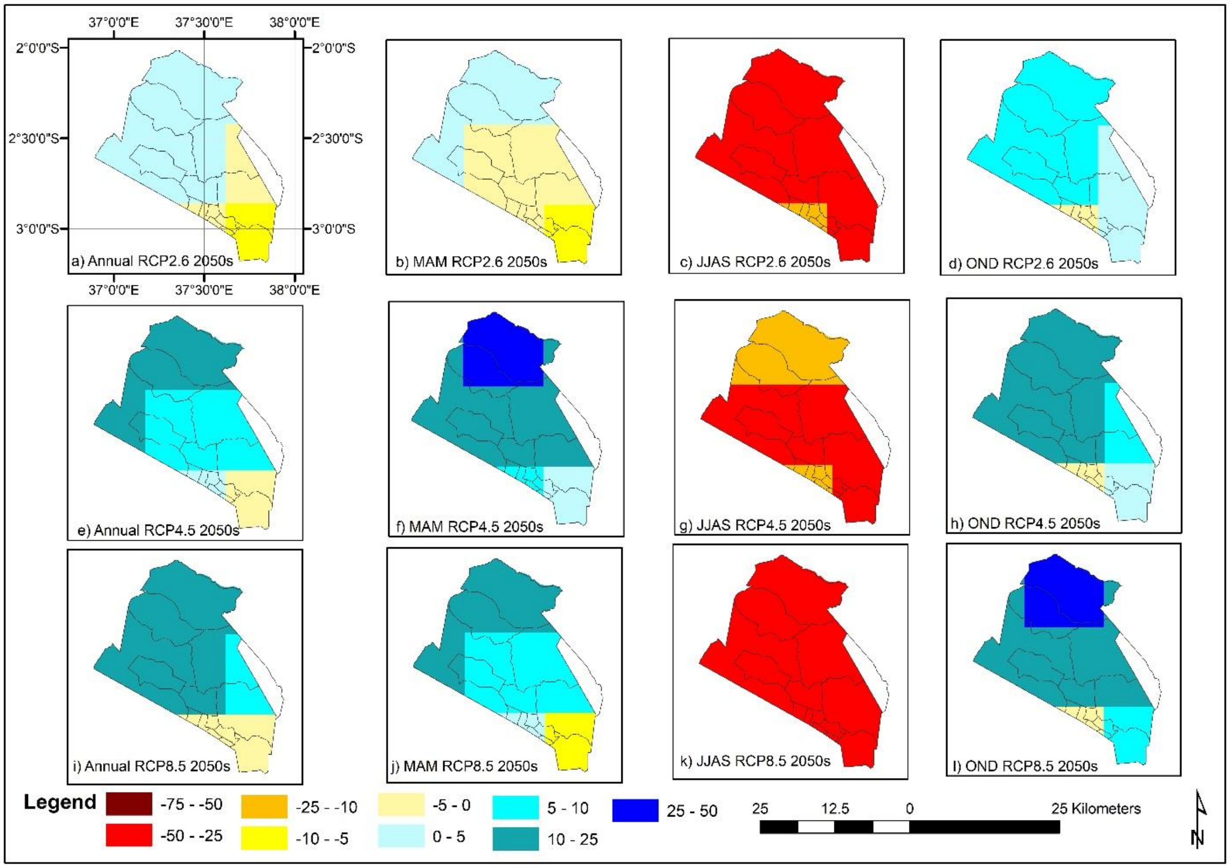



Figure 5.5: Projected annual and seasonal rainfall (in percentage) for the Amboseli Ecosystem for the 2050s.

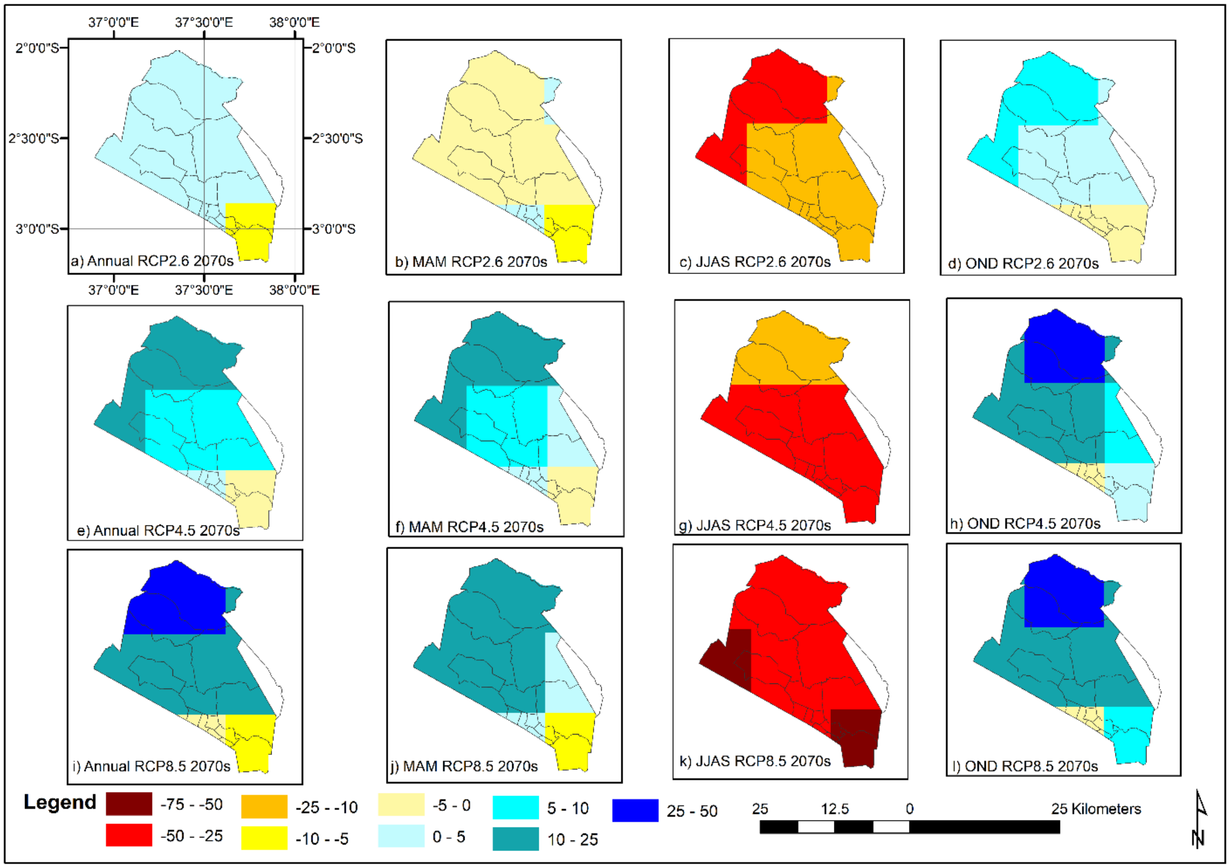



Figure 5.6: Projected annual and seasonal rainfall (in percentage) for the Amboseli Ecosystem for the period 2070s

**5.2: Projected Minimum Temperatures for RCP 2.6, 4.5, and 8.5 for the Amboseli Ecosystem**

The expected changes in minimum temperatures over time for the three scenarios are depicted in Figures 5.7-5.9 and Tables 5.4-5.7. Table 5.7 summarizes the complete projected minimum temperature changes based on the three RCPs. But a detailed table is provided in appendix F (Table F-2.). The findings show that the minimum is likely to increase more rapidly than the potential maximum temperatures. Annual minimum temperatures are anticipated to be 0.1 to 0.5°C higher by 2030 under RCP 2.6 and RCP 4.5 scenarios but 1.0 to 1.3°C higher under the 8.5 scenarios across most parts of the Amboseli region. Minimum temperatures during the long rains (MAM), dry season (JJAS), and short rains (OND) are predicted to rise by 0.5 to 1.5°C warmer than the base period by 2030 for the three scenarios, with the most dramatic warming expected during the dry season months (JJAS) under the RCP8.5.

Under all RCP scenarios, minimum temperatures will be between 0.7 and 2.5°C higher by 2050. In the dry season (JJAS (07 to 2.7°C) and during the long rains (MAM (0.6 to 2.4°C), the greatest potential seasonal warming would possibly occur. In the OND season, the warming will be 0.8 to 2.3°C lower.

During 2070-2100, under the RCP8.5 scenarios, the expected rise in annual minimum temperatures is likely to be 3.6 to 5.3°C higher than the base period. For RCP 4.5, this will be between 1.4 and 2.0°C. On the contrary, under the RCP 2.6 scenario, the projected annual minimum temperatures will likely be 0.1 to 0.7°C higher than the anticipated changes by 2050under. "This is due to the reduction in radiative forcing expected towards the end of the century due to RCP 2.6 mitigation measures." The seasonal changes for the MAM, JJAS and OND will be 0.1 to 0.8°C higher under RCP 2.6 and 1.2 to 2.0°C higher under RCP 4.5. In comparison, the predicted seasonal warming under the RCP8.5 scenarios will likely result in temperatures 3.3 to 5.0°C higher than the reference period, with much greater warming occurring during the dry season JJAS (3.9 to 5.7°C).

Table 5.4: Minimum Temperature trend for Amboseli for RCP 2.6

| Annual /Season | Equation | R-Squared | F-Ratio | P-Value |
|---|---|---|---|---|
| Annual | $Y = -1256.85080 + 1.237090x - 0.000301x^2$ | 0.206 | 11.963 | 0.0000 |
| MAM | $Y = -1038.80122 + 1.024560x - 0.000249x^2$ | 0.130 | 6.901 | 0.0016 |
| JJAS | $Y = -1231.58667 + 1.210657x - 0.000294x^2$ | 0.121 | 6.316 | 0.0026 |
| OND | $Y = -1225.22324 + 1.206537x – 0.000293x^2$ | 0.170 | 9.938 | 0.0002 |

Table 5.5: Minimum temperature trend for the Amboseli Ecosystem for RCP 4.5

| Annual/ Season | Equation | R-Squared | F- Ratio | P-Value |
|---|---|---|---|---|
| Annual | Y = -26.96316 + 0.02105x | 0.698 | 214.557 | 0.0000 |
| MAM | Y = -27.32936 + 0.02150x | 0.622 | 152.990 | 0.0000 |
| JJAS | Y = -28.90549 + 0.02148x | 0.543 | 110.282 | 0.0000 |
| OND | Y = -22.98012 + 0.01936x | 0.566 | 121.270 | 0.0000 |

Table 5.6: Minimum temperature trend for the Amboseli Ecosystem for RCP 8.5

| Annual/ Season | Equation | R-squared | F- Ratio | P-Value |
|---|---|---|---|---|
| Annual | Y = -97.53562 + 0.05595x | 0.920 | 1074.175 | 0.0000 |
| MAM | Y = -91.96018 + 0.05349x | 0.875 | 651.761 | 0.0000 |
| JJAS | Y = -108.16650 + 0.06065x | 0.895 | 794.244 | 0.0000 |
| OND | Y = -87.38234 + 0.05120x | 0.893 | 775.972 | 0.0000 |

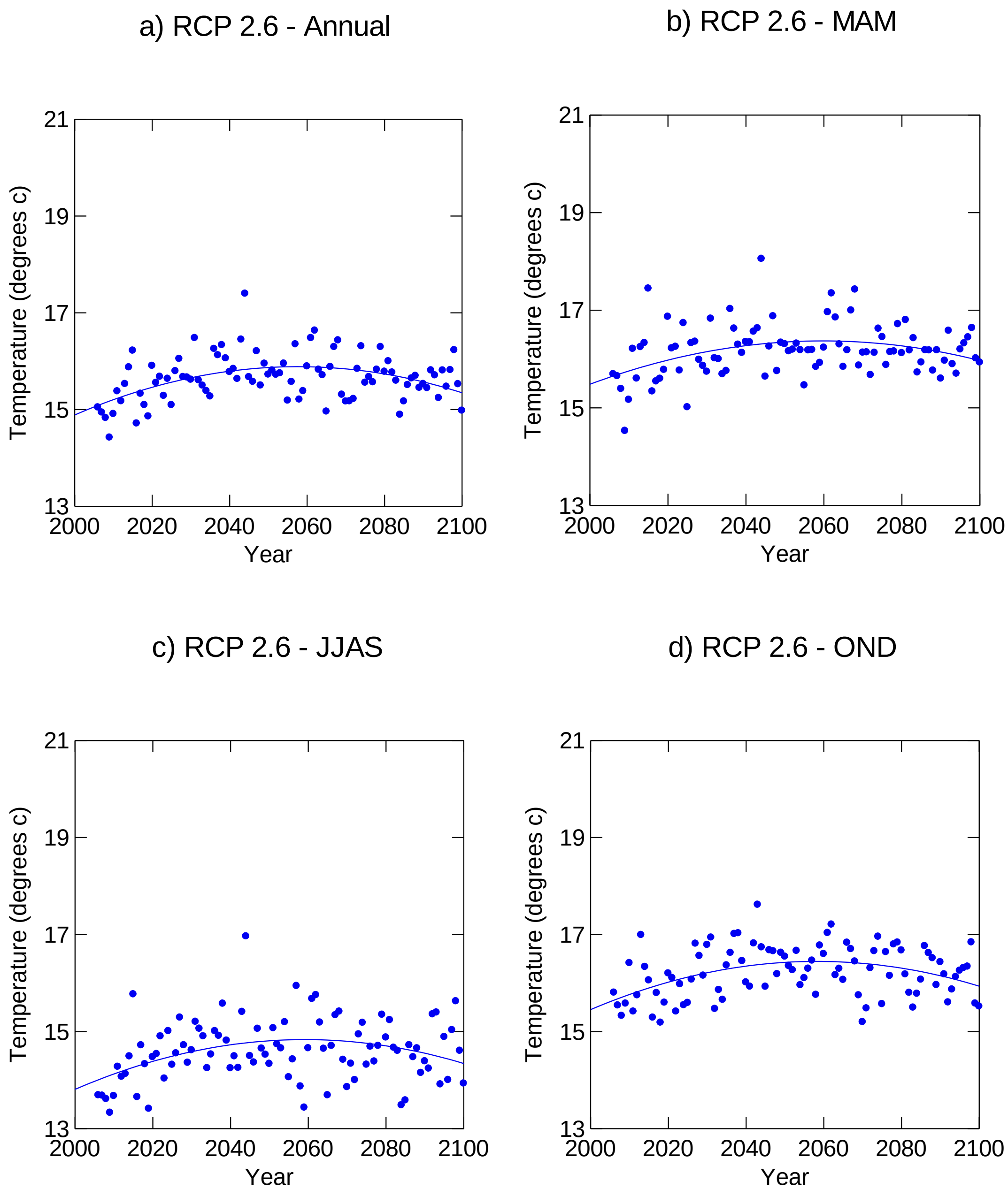



Figure 5.7: Projected trends in minimum temperature changes in Amboseli 2006-2001 for RCP 2.6

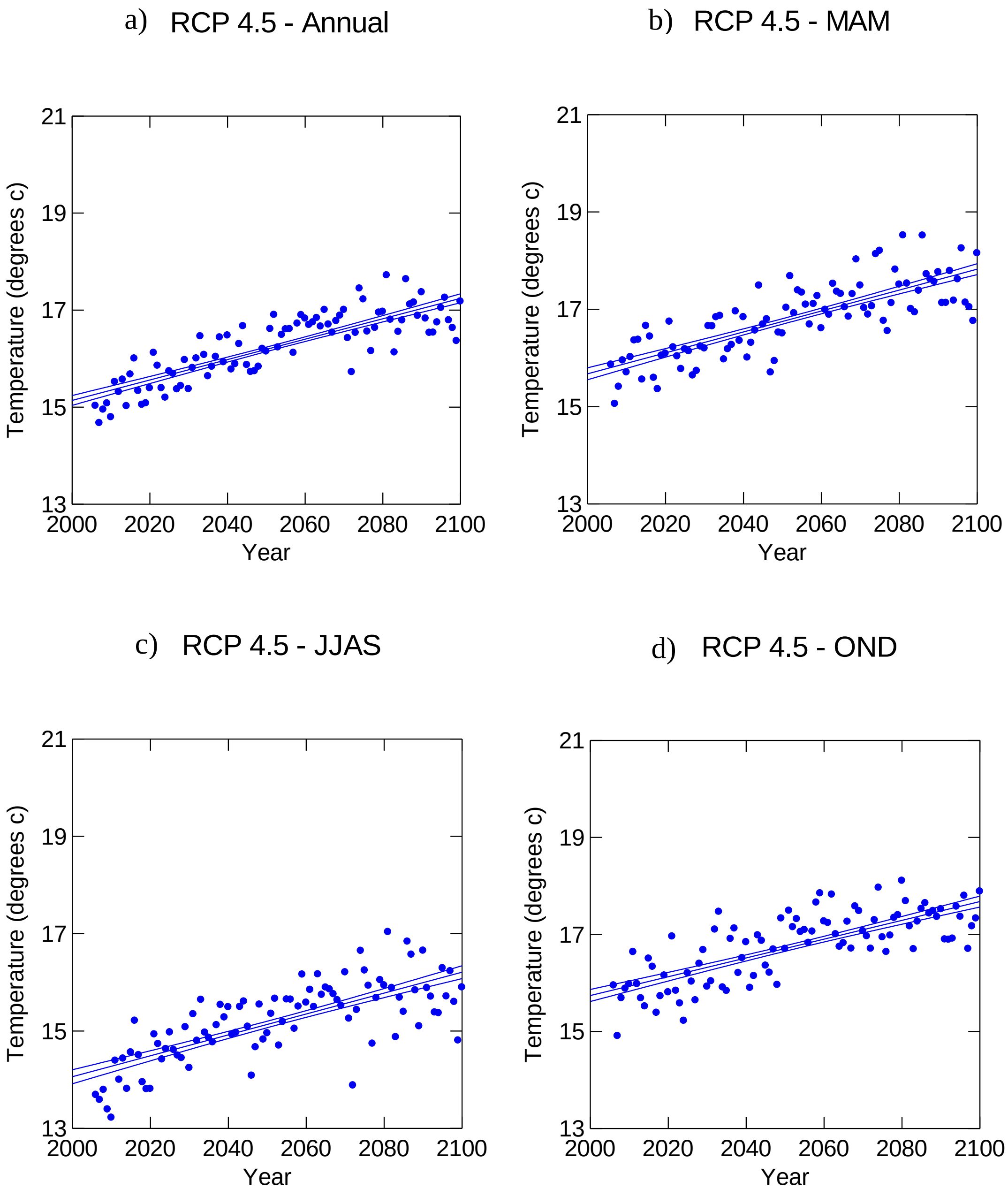



Figure 5.8: Projected trends in minimum temperature changes in Amboseli 2006-2001 for RCPs 4.5 and 8.5

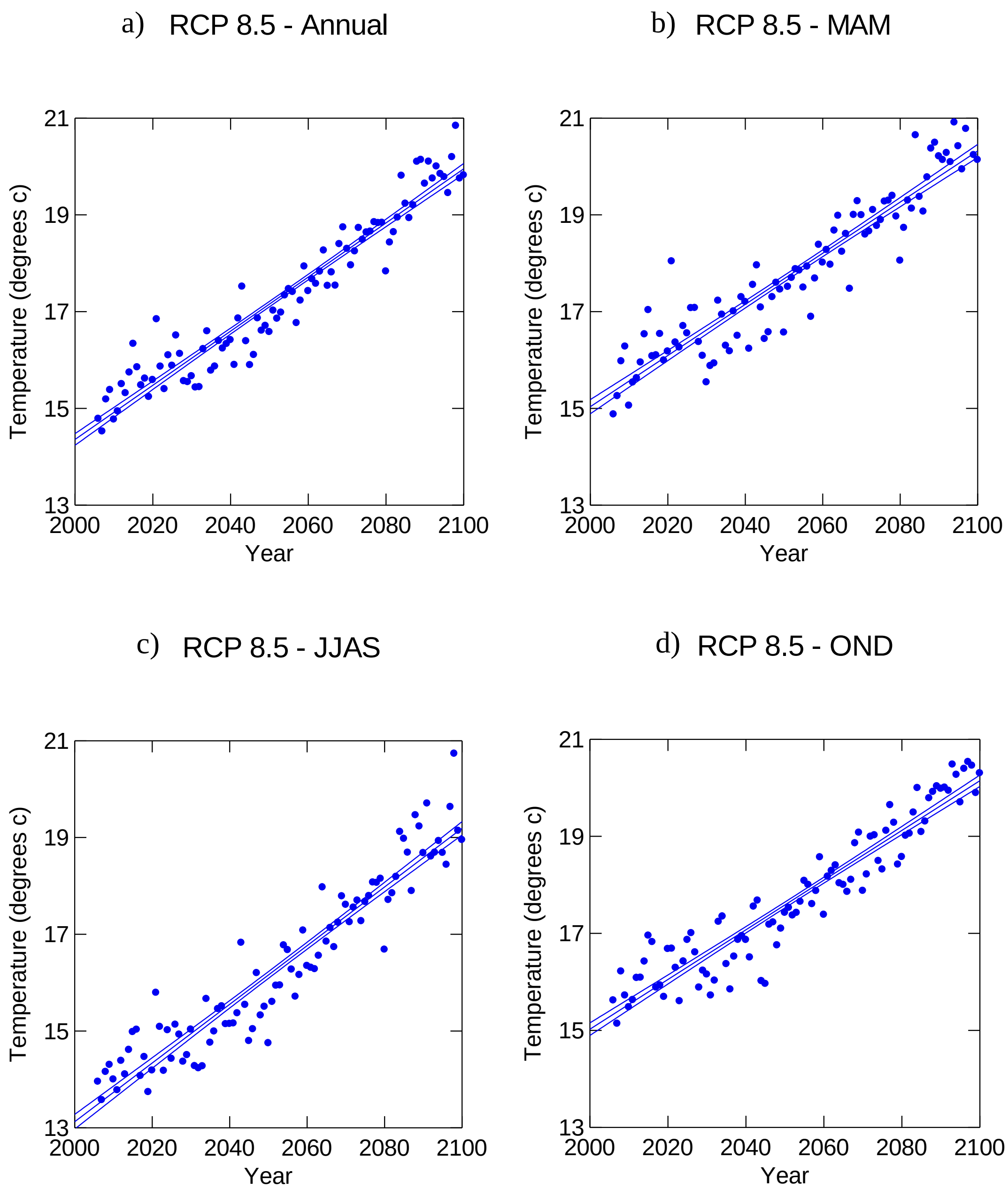



Figure 5.9**:** Projected trends in minimum temperature changes in Amboseli 2006-2001 for RCPs8.5

Table 5.7: Summary of projected minimum temperature changes in the Amboseli ecosystem in 2030, 2050, 2070, and 2100 based on RCP 2.6, 4.5 and 8.5

| | Season | Base (1970-2006) | 2030 | 2050 | 2070 | 2100 |
|---|---|---|---|---|---|---|
| **RCP 2.6** | Annual | 13.52 | 0.53 | 0.71 | 0.65 | 0.11 |
| | MAM | 14.48 | 0.47 | 0.64 | 0.62 | 0.20 |
| | JJAS | 13.52 | 0.53 | 0.71 | 0.65 | 0.11 |
| | OND | 13.92 | 0.58 | 0.81 | 0.79 | 0.33 |
| | | | | | | |
| **RCP 4.5** | Annual | 15.26 | 0.51 | 0.93 | 1.35 | 1.98 |
| | MAM | 15.80 | 0.52 | 0.95 | 1.38 | 2.02 |
| | JJAS | 14.18 | 0.52 | 0.95 | 1.37 | 2.02 |
| | OND | 15.86 | 0.46 | 0.85 | 1.24 | 1.82 |
| | | | | | | |
| **RCP 8.5** | Annual | 14.70 | 1.34 | 2.46 | 3.58 | 5.26 |
| | MAM | 15.34 | 1.28 | 2.35 | 3.42 | 5.03 |
| | JJAS | 13.50 | 1.45 | 2.67 | 3.88 | 5.70 |
| | OND | 15.32 | 1.23 | 2.26 | 3.28 | 4.82 |

## 5.3: Projected Maximum Temperatures for RCP 2.6, 4.5, and 8.5 for the Amboseli Ecosystem

Figure 5.11-5.13 and Tables 5.8-5.11 show the estimated variations in the average temperature variable in the 2030s, 2050s, and 2070s relative to the reference period (1970–2006) for the three scenarios (RCP2.6, RCP4.5, and RCP8.5). A detailed table is available in appendix F (Table F-3). The annual and seasonal components of the temperature changes estimated for the three scenarios reveal quite considerable variations.

The trends in maximum average temperatures for RCP 2.6 for the annual, MAM, JJAS, and OND showed an increase until around 2050 and after that a decline as it got to 2100 (refer to Figure 5.10 (a-d) and Table 5.8). This is owing to the RCP 2.6 scenario's predicted reduction in radiative forcing by the end of the century as a result of mitigating actions. The trends for RCP 4.5 and 8.5

showed a statistically significant increase up to 2100. RCP 8.5 had a steeper rise than RCP 4.5 (see Figures 5.11(a.d), 5.12(a-d), and Table 5.9 and 5.10).

Table 5.8: Maximum temperature trend for the Amboseli Ecosystem for RCP 2.6 between 2006 - 2100

| Annual/ Season | Equation | R-Squared | F-Ratio | P-Value |
|---|---|---|---|---|
| Annual | $Y = -1480.32030 + 1.465596x - 0.000356x^2$ | 0.267 | 16.729 | 0.0000 |
| MAM | $Y = -1302.72508 + 1.292243x - 0.000314x^2$ | 0.078 | 3.867 | 0.0244 |
| JJAS | $Y = -1842.56537 + 1.816131x - 0.000441x^2$ | 0.241 | 14.609 | 0.0000 |
| OND | $Y = -1063.47064 + 1.058156x - 0.000257x^2$ | 0.075 | 3.734 | 0.0276 |

Table 5.9: Maximum temperature trend for the Amboseli Ecosystem for RCP 4.5 between 2006 - 2100

| Annual/ season | Equation | R-Squared | F- Ratio | P-Value |
|---|---|---|---|---|
| Annual | Y = -10.25669 + 0.01829x | 0.541 | 109.795 | 0.0000 |
| MAM | Y = -14.764 06+ 0.02057x | 0.279 | 36.023 | 0.0000 |
| JJAS | Y = -15.14669 + 0.02030x | 0.497 | 91.979 | 0.0000 |
| OND | Y = -2.20172 + 0.01389x | 0.220 | 26.171 | 0.0000 |

Table 5.10: Maximum temperature trend for the Amboseli Ecosystem for RCP 8.5 between 2006 – 2100

| Annual/ season | Equation | R-Squared | F- Ratio | P-Value |
|---|---|---|---|---|
| Annual | Y = -66.55904 + 0.04617x | 0.869 | 617.725 | 0.0000 |
| MAM | Y = -65.79247 + 0.04590x | 0.658 | 179.126 | 0.0000 |
| JJAS | Y = -88.00049 + 0.05636x | 0.835 | 469.961 | 0.0000 |
| OND | Y = -48.93941 + 0.03696x | 0.702 | 218.787 | 0.0000 |

Table 5.11: Summary of projected maximum temperature changes in the Amboseli ecosystem in 2030, 2050, 2070, and 2100 based on RCP 2.6, 4.5 and 8.5

| | **Season** | **Base (1970-2006)** | **2030** | **2050** | **2070** | **2100** |
|---|---|---|---|---|---|---|
| **RCP 2.6** | Annual | 27.11 | 0.69 | 0.95 | 0.93 | 0.36 |
| | MAM | 25.97 | 0.60 | 0.82 | 0.79 | 0.28 |
| | JJAS | 25.99 | 0.87 | 1.21 | 1.19 | 0.51 |
| | OND | 25.01 | 0.50 | 0.70 | 0.68 | 0.28 |
| | | | | | | |
| **RCP 4.5** | Annual | 26.43 | 0.57 | 0.94 | 1.30 | 1.85 |
| | MAM | 26.50 | 0.49 | 0.90 | 1.32 | 1.93 |
| | JJAS | 25.58 | 0.48 | 0.89 | 1.29 | 1.90 |
| | OND | 25.66 | 0.33 | 0.61 | 0.89 | 1.31 |
| | | | | | | |
| **RCP 8.5** | Annual | 26.06 | 1.11 | 2.03 | 2.95 | 4.34 |
| | MAM | 26.28 | 1.10 | 2.02 | 2.94 | 4.32 |
| | JJAS | 25.06 | 1.35 | 2.48 | 3.60 | 5.30 |
| | OND | 25.20 | 0.89 | 1.63 | 2.37 | 3.48 |

The average mean temperatures will rise by 0.5 to 1.1 degrees Celsius in all three models than the base cycle by 2030. By 2030 for the three scenarios, In most parts of the region, maximum temperatures during the long rains (MAM), dry season (JJAS), and short rains (OND) will likely increase by 0.3 to 1.4°C for the three scenarios. During the dry season, the expected extent of heating (JJAS) is greater, moderate during the MAM, and low within the OND season.

In 2050, the mean annual maximum temperatures for most parts of the Amboseli ecosystem will be 0.7 to 1.0°C higher under the RCP2.6, 0.6 to 0.9°C higher under the RCP4.5 and 1.0 to 2.0°C higher under the RCP8.5. The greatest seasonal warming will probably occur in the dry season JJAS (0.9 to 2.5°C) and during the long rains season MAM (0.8 to 2.0°C). During the OND season, warming will be 0.6 to 1.6°C lower.

“In the far future (2070 and 2100), projected annual maximum temperatures will likely be 0.4 to 0.9°C higher under the RCP 2.6 scenario, which is notably smaller than the changes anticipated by 2050. This is due to the reduction in radiative forcing expected toward the end of the century due to mitigation measures under the RCP 2.6 scenario.” RCP 4.5 scenario will be 1.3 to 1.9°C warmer. By contrast, under the RCP8.5 scenarios, annual warming will likely be 3.0 to 4.0°C higher than the reference period, with substantially larger warming projected during the dry JJAS season (3.6 to 5.3°C). During this time, MAM and OND seasons will be 2.4 to 4.3°C higher.

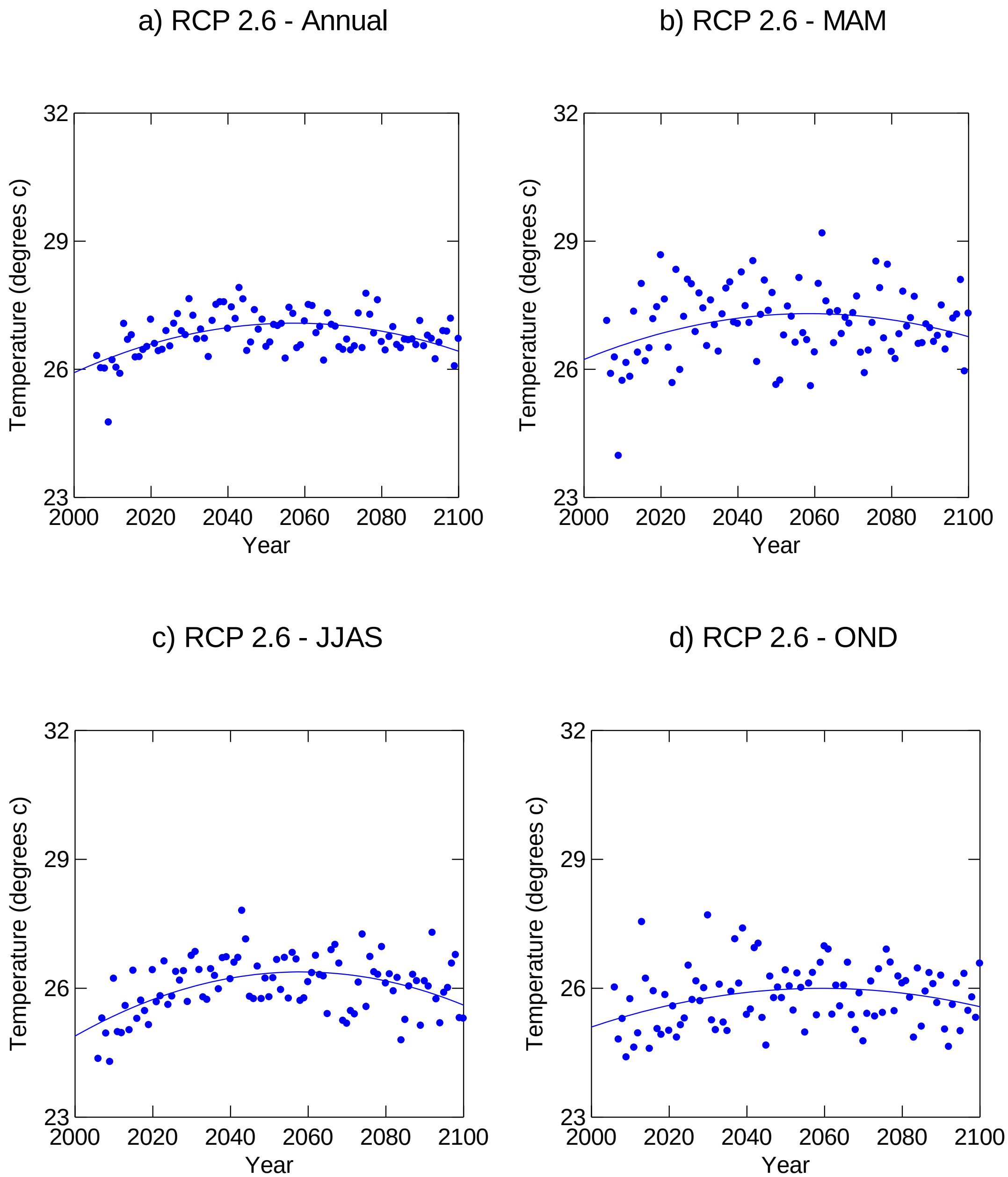



Figure 5.10: The projected maximum temperature for Amboseli Ecosystem for RCP 2.6 for the period 2006-2100

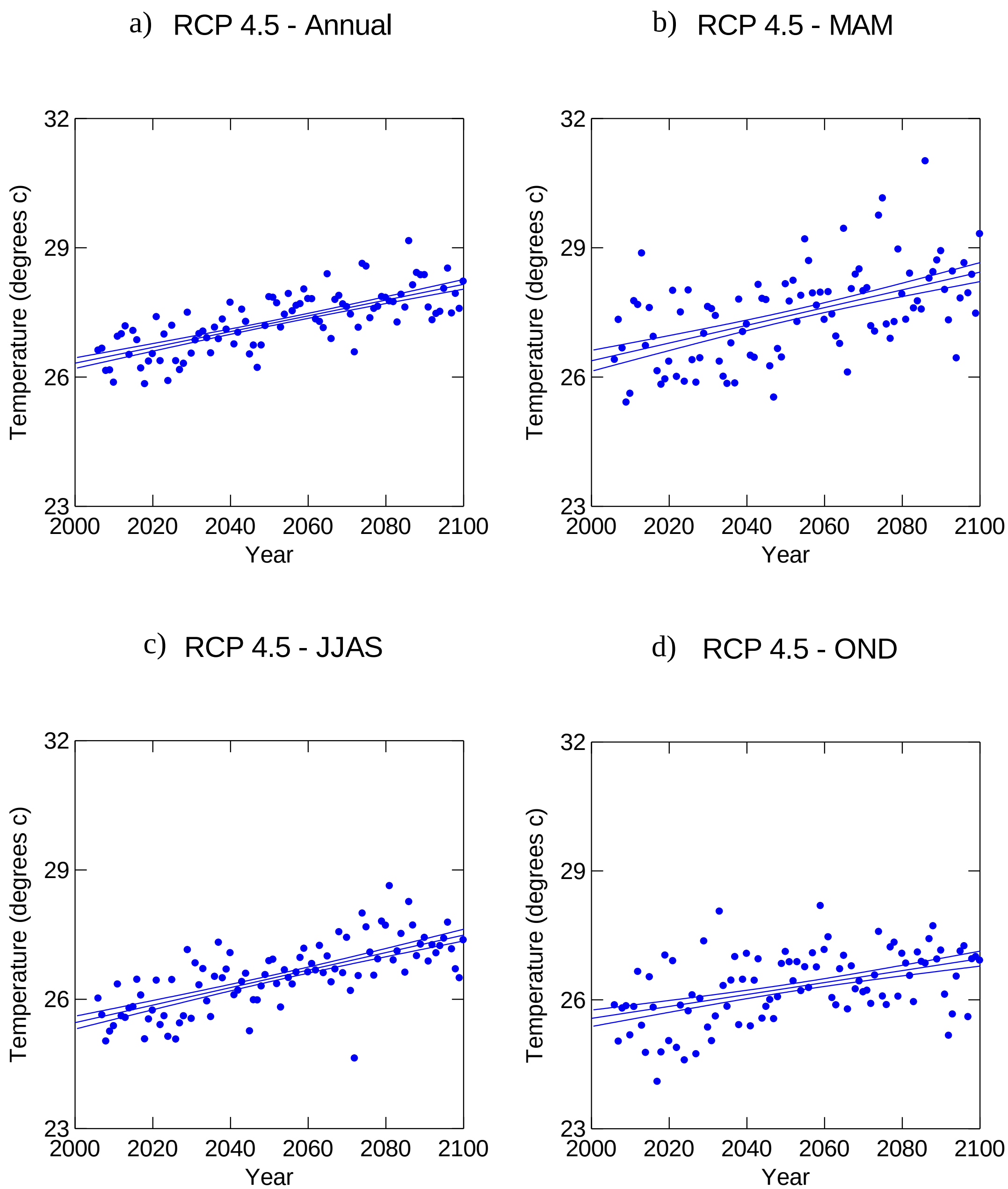



Figure 5.11: The projected maximum temperature for Amboseli Ecosystem for RCP 4.5 for the period 2006-2100

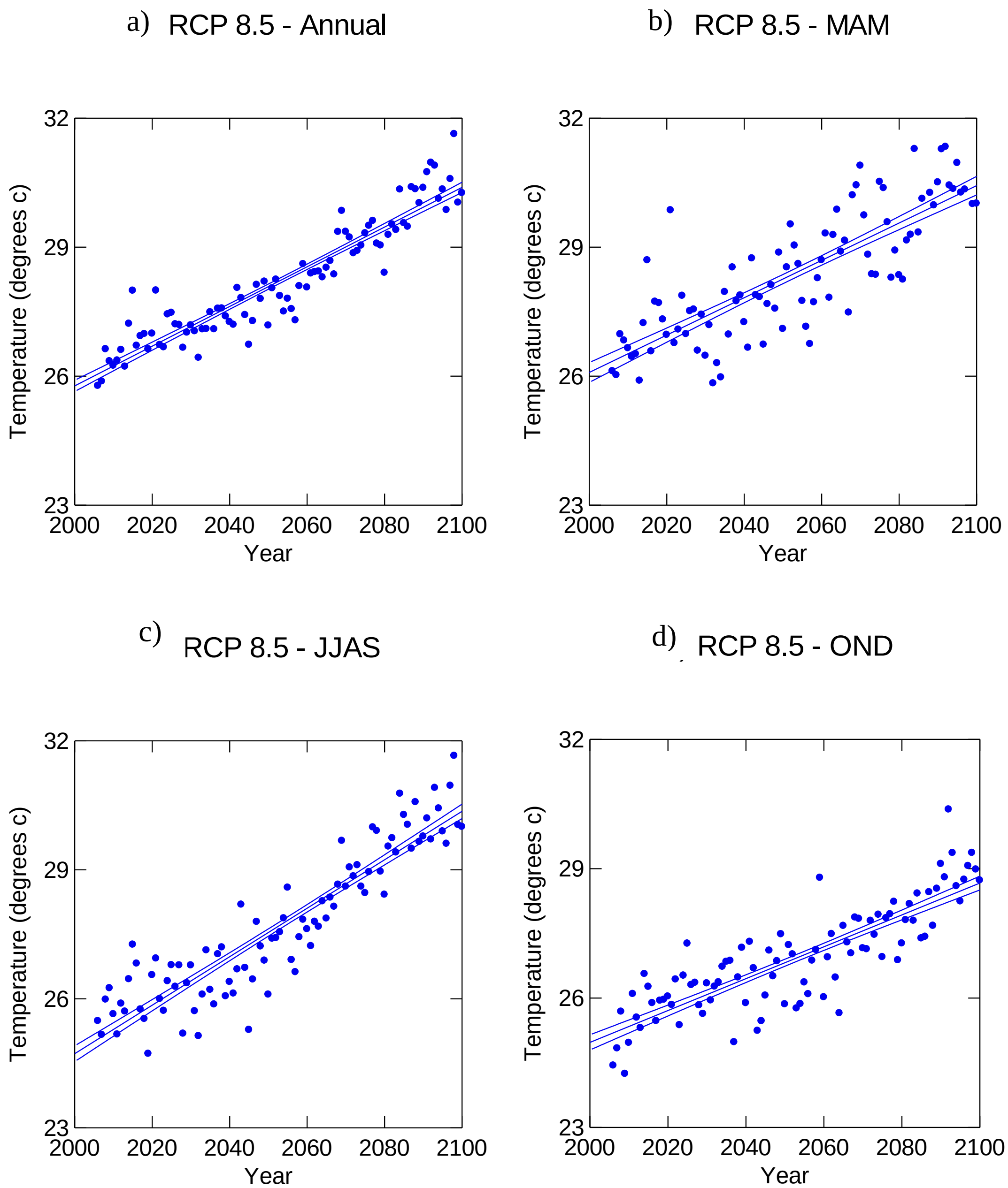



Figure 5.12**:** The projected maximum temperature for Amboseli Ecosystem for RCP 2.6, 4.5, and 8.5 for the period 2006-2100

Several reports have projected climate change in rainfall and temperature projections, but the focus has been mainly at the continental level or regional level and not at the country or landscape level (Hulme1 *et al.*, 2001; Niang *et al.*, 2014; Worldbank, 2013). Compared to other parts of the world, Africa will experience a higher temperature rise, which might reach 2°C by the mid-twentieth century and 4°C by the end of the century (Niang *et al*., (2014). However, the future remains unknown. Forecasts for potential precipitation are uncertain, but they appear to be increasing in eastern Africa and decreasing in the southern part of the continent (Niang *et al*., (2014). However, according to Funk (2010), specific locations in east Africa would increase rainfall while others may experience a decrease.

The findings of this study predict a decrease in the long rainy season (MAM) and an increase in the short rainy season (OND), and a rise in both maximum and lowest temperatures under all three RCPS. These expected changes will significantly influence livestock and wildlife numbers, species composition, and distribution. These outcomes are supported by studies done by Endris, 2016; Luhunga *et al.*, 2018; Olaka *et al.*, 2019). The effects of climate change in the Amboseli have previously been investigated by Ogutu *et al*. (2016), who looked at the relationship between different herbivores and temperature, human density, and rainfall in the region. Many water-dependent species saw their populations plummet at around 30°C, which is similar to the findings of this study. The water-independent species had a more significant temperature threshold. For example, Grevy's zebra, gerenuk, lesser kudu, and oryx reach their highest numbers when the temperature rises above 30°C. Their temperature thresholds in this investigation ranged from 28 to 34°C.

Temperature projections, according to studies like this thesis, point to a hotter environment. The annual and seasonal temperatures continue to rise in the RCP 4.5 and RCP 8.5 scenarios, with maximum temperatures ranging from 1.85°C to 4.34°C and lowest temperatures ranging from 1.98°C to 5.26°C., and we would expect far more substantial impacts on ecosystems and biodiversity. The temperature rise exceeds the 1.5°C global warming over pre-industrial levels. The following section examines the predicted climate change's effects on herbivores. Because the species' range sizes under examination stretch outside the Amboseli environment, the study area has been expanded to include Kajiado County. With the fifteen species chosen, the temperature is the most crucial climate factor to consider. In section 5.6, a more detailed analysis of the expected elephant population depending on rainfall is presented. 5.4 Projected temperature hotspots with herbivore distribution.

## 5.4 Projected Temperature Hotspots with Herbivore Distribution

The anticipated changes in temperatures for the three scenarios "RCP 2.6, 4.5, and 8.5 were based on three future time slices, the 2030s (2016-2045), 2050s (2036-2065), and 2070s (2055- 2085). The objective was to make information available for each period on the expected severity of the climate response. The period 1971-2000 is taken into account as a reference for the current climate."

Figure 5.13 shows the nine projected scenarios of climate used in this analysis related to the distribution of large wild herbivores. Spatial research of temperature changes for the three RCPs in Kajiado indicates significant differences in maximum temperature for the 2030s, 2050s, and 2070s. From the spatial maps of temperature projections, it is clear that western sections, which include the Nguruman and Magadi areas and the Amboseli ecosystem, are the hotspots for temperature changes (refer to Figure 5.13). The temperatures in these areas range between 30˚C and 37˚C. The increase in temperatures will affect several herbivores like the buffalo, warthog, giraffe, elephant, waterbuck, wildebeest, grant's gazelle, and Burchell's zebra. Moderate temperature increases are expected in the Athi Kaputei plains and the central plains for the RCP 2.6 (the 2030s, 2050s, and 2070s), as shown in Figures 5.13 (a-c) and RCP 4.5 (2030s and 2050s) in Figure 5.13 (e) and Figure 5.13 (f), and RCP 8.5 (2030s)- in Figure 5.13 (g).

Significant temperature increases will be experienced under RCP 4.5 in the 2070s and RCP 8.5 in the 2050s and 2070s. As temperatures rise, evaporation from the soil increases, making dry periods drier than they would be under milder conditions. Spatial analysis of rainfall in section 5.1 projects a decline in rainfall in JJAS, especially in the Nguruman escarpments. In semi-arid environments, rain which is a proxy for primary production dramatically influences the quantity and quality of forage. (Deshmukh, 1984; Mduma *et al*., 1999). Droughts can persist due to a "positive feedback" mechanism, in which arid soils and less plant cover decrease rainfall in an already dry environment like the Amboseli habitat. "Droughts have been reported to have devastating effects on large herbivore populations directly through starvation and indirectly by weakening animals, amplifying their vulnerability to predation, diseases and parasites (Ogutu *et al.*, 2008)". Therefore, the herbivores are likely to migrate to areas of low temperatures, and the shift could affect the ecosystem balance, especially the community's livelihoods. Other species, such as carnivores who feed on some herbivores as prey, will be impacted. Furthermore, incidences of human conflict with the herbivores are likely to increase significantly in the central Amboseli, which is witnessing an increase in human population and change in land use.

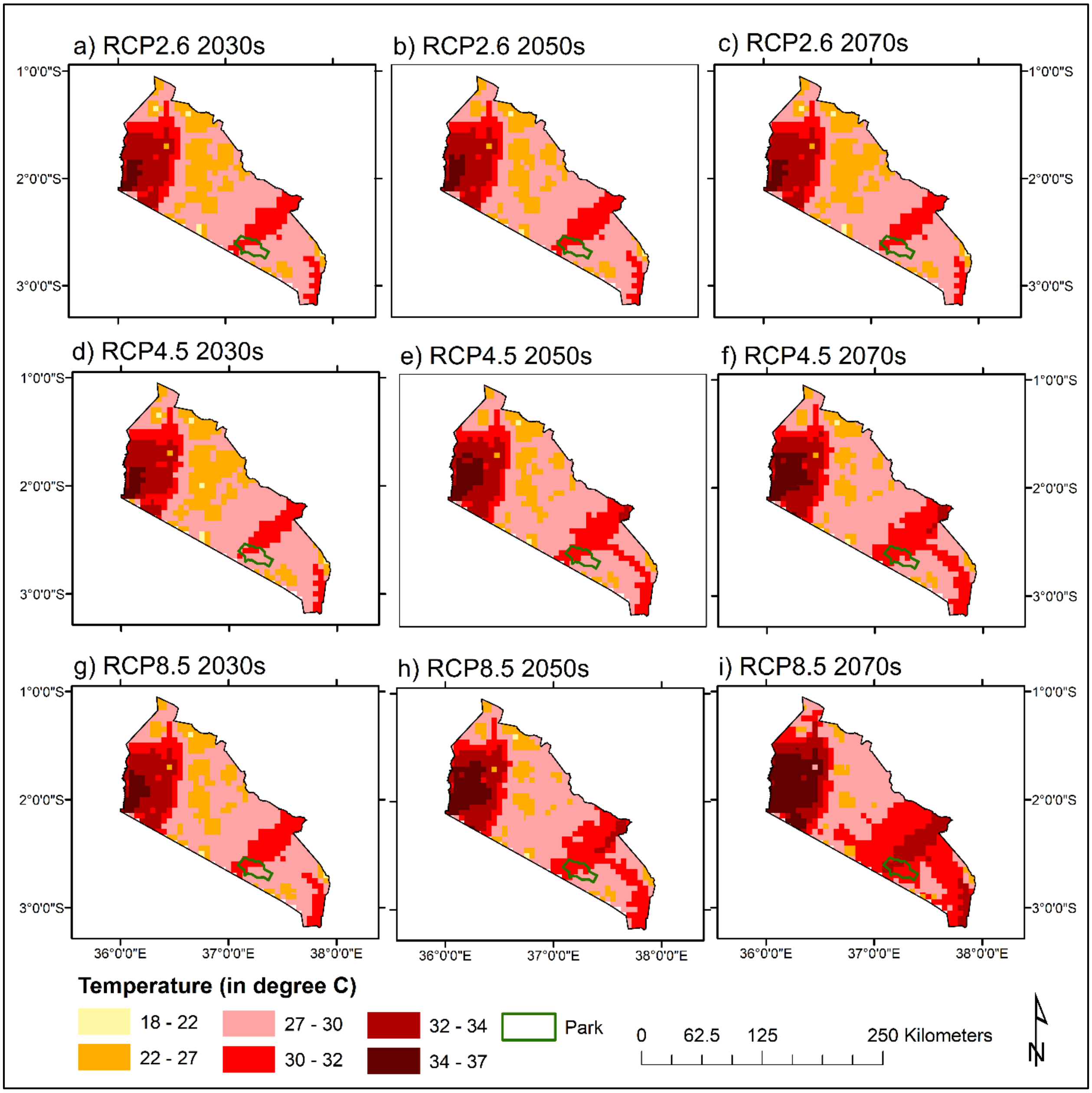



Figure 5.13: Spatial projections of maximum temperatures changes in Kajiado county based on RCPs 2.6, 4.5, and 8.5 scenarios for the period 2030s, 2050s, and 2070s

### 5.5 Projected Changes in Species Range Size Based on Temperature Changes

Temperature changes were analyzed for the three RCPs for the periods 2030s, 2050s, and 2070s. The temperature threshold for each of the fifteen species was used to determine the percentage of range areas likely to reduce. Under RCP2.6, it is projected that some species are prone to lose over 50% of their range sizes in the given periods. The trend shows 3 out of the fifteen species by 2030s, five out fifteen by 2050s, and three out fifteen by 2070s (Figure 5.14(a-c)). The expectation under RCP 4.5 is that by the 2030s, three species would lose more than 50% of their range, and the number would increase to five species in the year 2050 and 2070 (Figure 5.15(a-c)).

In the extreme scenario of RCP 8.5, five species are expected to lose more than 50% of their currently occupied range by 2030, 7 species by 2050, and 10 species by 2070 (Figure 5.16 (a-c). Amongst these species, the extremely affected in range loss include the buffalo, Thomson's gazelle, waterbuck, and wildebeest, which are majorly water-dependent. The four species are anticipated to lose between 48% - 96% of their range based on RCP 2.6; 46% - 97% based on RCP 4.5 and 51% - 98% based on RCP 8.5. Conversely, the elephant, gerenuk, hartebeest, lesser kudu, and oryx are anticipated to retain most of their range in all the RCPs scenarios. Their range lose is minimal at 4% - 27% (RCP 2.6); 4% - 23% (RCP 4.5) and 2% - 31% (RCP 8.5) respectively.

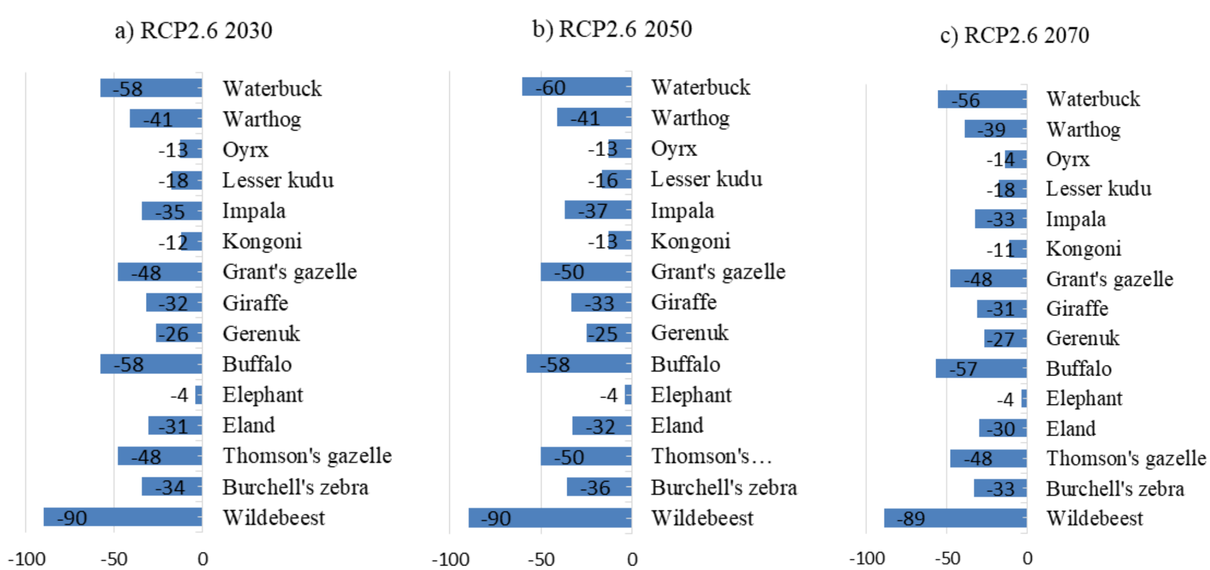



Figure 5.14: Projected loss of species range (in percentage) due to temperature changes under RCP 2.6

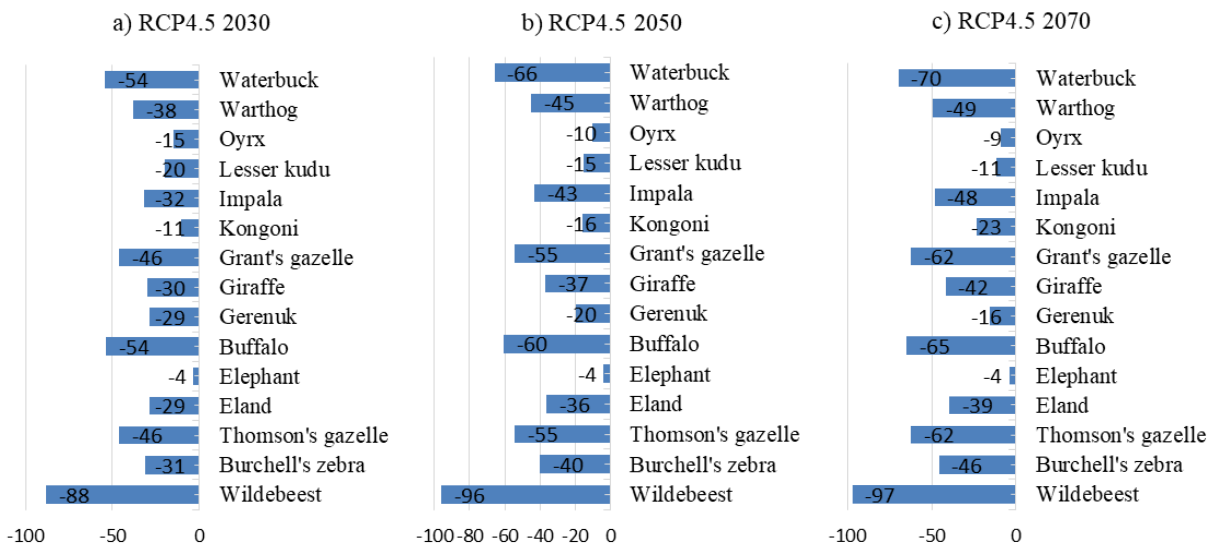



Figure 5.15: Projected loss of species range (in percentage) due to temperature changes under RCP 4.5

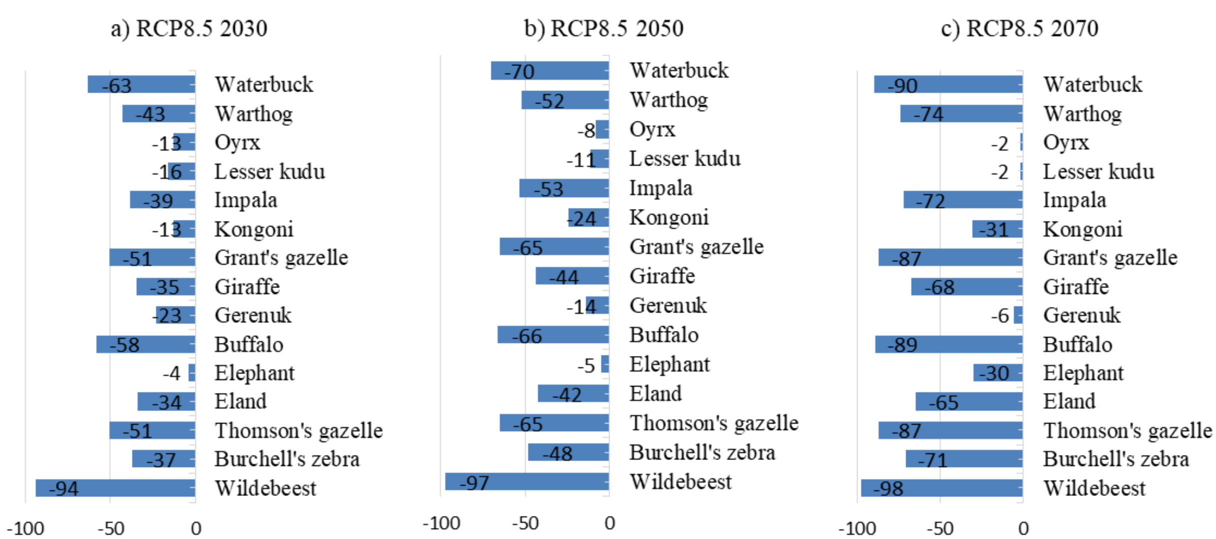



Figure 5.16: Projected loss of species range (in percentage) due to temperature changes under RCP 8.5

Between 2006 and 2100, maximum temperatures in Kajiado county are anticipated to increase by 1.7°C under RCP 4.5 and 4.4°C under RCP 8.5 scenarios. Other studies have also noted an increase in temperatures for Kajiado, which shows that there is regional warming in the county (Ogutu *et al*., 2016).

Global warming can hasten the species' physiological and biological processes with rising impacts on population dynamics and species interactions (Fordham, 2015). The magnitude of range loss contrasted among species but was severe for Thomson's gazelle, the grants gazelle buffalo, waterbuck, and wildebeest. This group of animals have big body sizes and are water-dependent. Previous studies show a positive correlation between body sizes of mammals with extinction risk (Cardillo *et al*., 2005; Davidson *et al*., 2009; Hilbers *et al*., 2016).

The impacts on migratory species were high, and the effects on wildebeest as expected would be too severe. As its range is likely to reduce by 98 per cent, the wildebeest is among the five most endangered species. This species migrates seasonally and has a temperature threshold of about 28˚C. Higher temperatures will pose a further challenge to its movement cycle. Generally, human activities like constructing houses, fragmentation of land through fencing, especially in the central plains and Athi-Kaputei plains (Said *et al*., 2016), and poaching activities have affected wildebeests (Ogutu *et al*., 2013). The numbers plummeted by more than 90%, from over 30,000 animals in 1978 to below 2000 animals in 2011. This decline was triggered by urbanization, fencing, settlements, mining, and other developments (Cardillo *et al*., 2005; Said *et al*., 2016). With climate change as an additional risk, the frequency of extreme occurrences and shocks, including droughts and floods, is rising. (Field *et al*., 2014). With climate change, land fragmentation will connect so that intensifying fragmentation will hamper the wildebeests' agility and movement if corridors are severed, thereby threatening their survival.

"In contrast, the elephant, gerenuk, hartebeest, lesser kudu, and oryx have projected to lose the minimal size of their range in all the RCPs scenarios as the increase in temperature is within the species ranges." Other studies have shown that elephant numbers have also gradually increased from 2000 to 2011 in Kajiado east (Moss *et al*., 2011; Ogutu *et al*., 2014; Western *et al*., 2009). In Kajiado, other drivers like settlements, agribusiness, land subdivisions, and developments may adversely affect the elephants. This study established that agricultural activities block key corridors like the one from the park through Kimana conservancy. This agrees with Ojwang' *et al.*, 2017, which confirmed that many elephant corridors had been partially blocked in the ecosystem.

### 5.6 Projected Elephant Population in Amboseli Ecosystem for Rcp 2.6, 4.5 and 8.5

The three climate scenarios chosen for this study varied in their rainfall predictions between 2006 and 2100. RCP 2.6 projections show a general decrease in precipitation due to projected rain decreases in all three seasons (MAM, JJAS, and OND). RCP 4.5 estimates an average marginal rise in annual rainfall, powered by intensified rains in OND.

Table 5.12: Projected Regression relationships between elephant population and OND rainfall

| RCP | Equation | r-squared | F-ratio | P-value |
|---|---|---|---|---|
| 2.6 | Y= -9879.24292x + 5.9647x | 0.05050 | 4.25472 | 0.04239 |
| 4.5 | Y= -11450.55357 + 6.92656x | 0.26253 | 28.47826 | 0.00000 |
| 8.5 | Y= - 92497.40369 + 46.53845 | 0.81652 | 356.01651 | 0.00000 |

Table 5.13 summarizes the anticipated elephant populace in the study area for the RCPs. The RCP 2.6 has the most reduced average mean population of 2457 (SD 340) elephants, and RCP 8.5 has the most significant average population of 3349 (SD 1226). The equations used are presented in table 5.12.

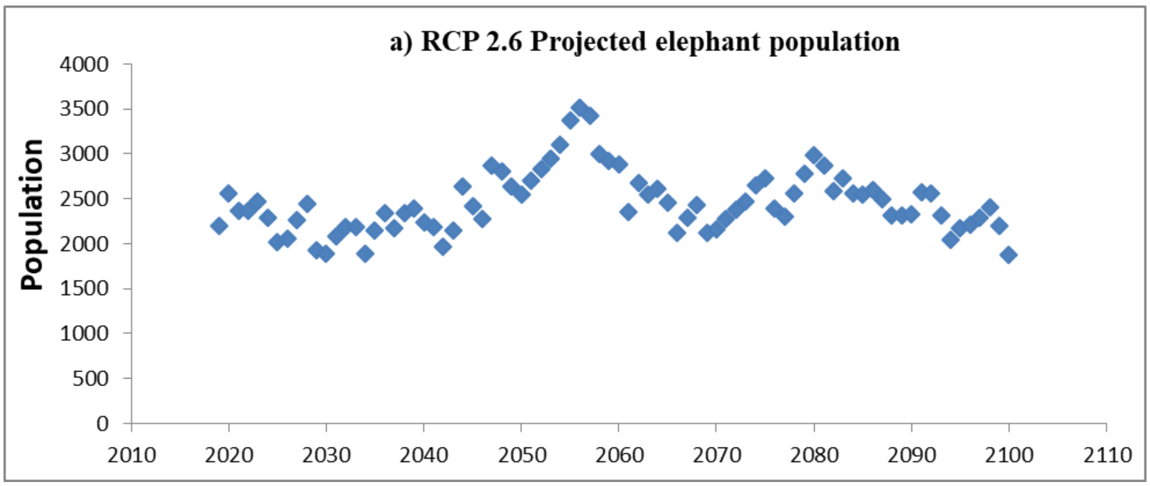
Table 5.13: Summary of the projected elephant population in the Amboseli ecosystem for three RCPs between the years 2019 to 2100

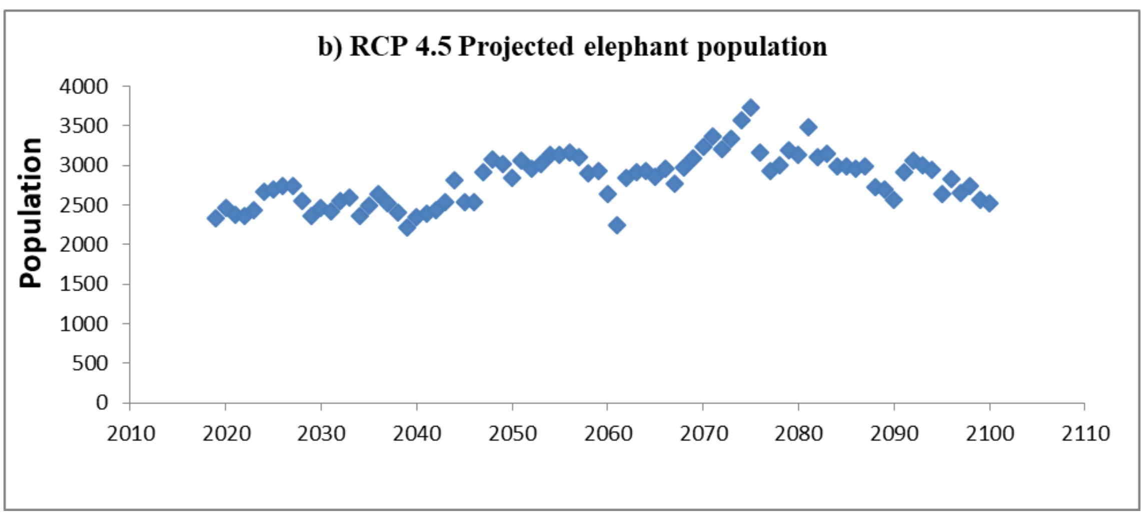
| RCP | Mean | N | Maximum elephant population | | Minimum elephant population | |
|---|---|---|---|---|---|---|
| | | | Year | Number | Year | Number |
| 2.6 | 2457 (SD 340) | 82 | 2056 | 3510 | 2100 | 1870 |
| 4.5 | 2815 (SD 322) | 82 | 2075 | 3725 | 2039 | 2216 |
| 8.5 | 3349 (SD 1226) | 82 | 2088 | 5820 | 2036 | 1272 |

The elephant population in the Amboseli Ecosystem is expected to grow, according to the three RCPs (Figure 5.17a). According to the RCP 2.6 scenario, there would be 2200 elephants in

Amboseli between 2019 and 2040 and by  2056, the population will have grown to 3510 animals, then decrease to around 2160 animals in 2070. Another phase of elephant increase will follow, with an estimated total of 2980 elephants by 2080, albeit a drop will follow this to approximately 1870 elephants by 2100. (Figure 5.17a).

The RCP 4.5 trajectory indicates three stages: between 2019 and 2050, when the predicted elephant population is expected to expand from 2300 to 3020 elephants. (Figure 5.17b). The animal population normalized at 2930 elephants between 2051 and 2069 in the 2nd phase. After that, the year 2075 will post the most considerable increment of 3725 elephants. In the third step, the population is expected to decline by the year 2100 to1870 elephants. (refer Figure 5,17b).



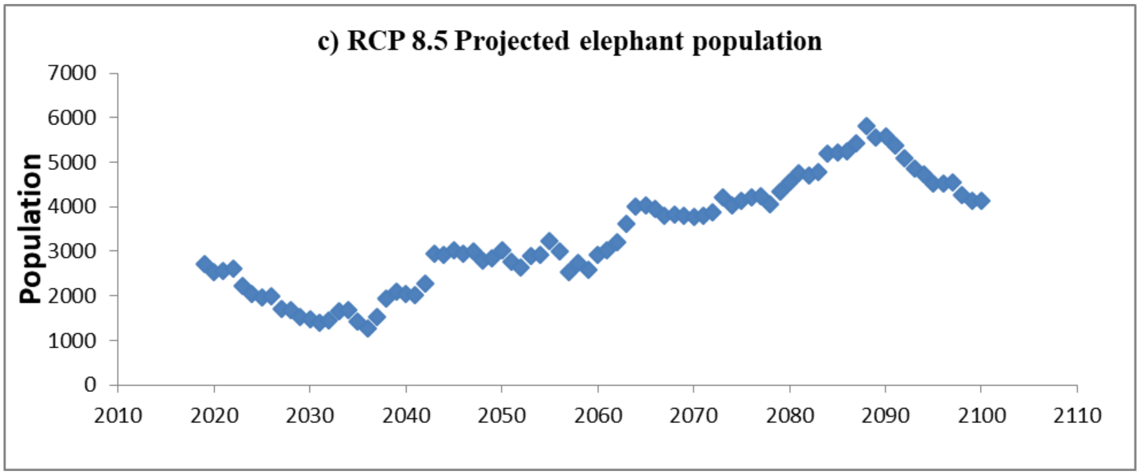



Figure 5.17: Projected Elephant Population for RCPs: 2.5, 4.5, and 8.5 based on OND rainfall.

As seen in the rainfall study, under RCP 8.5, both the annual and OND would dramatically increase; the elephant population reflects this rainfall trend. Under RCP 4.5, the elephant population has seven distinct patterns or broken sticks (Figure 5.17c). The projections for the elephant population under RCP 8.5 for the years 2019 to 2036 indicates a decline from a population of 2715 in 2019 to 1270 animals in 2036. In the subsequent phase, there will be an increase in 2950 animals in the year 2043. Between 2043 and 2060, elephant populations plummeted to around 2870 animals before rebounding to 4000 in 2064. The average elephant population will drop to 3890 elephants between 2064 and 2078 but will climb to 5820 elephants in 2088. Elephants are anticipated to reduce to a number of around 4130 by 2100 after this period. (Figure 5.17c).

On the other hand, elephants have the highest survival rates during the wettest months, according to studies. A research survey by Mumby *et al*. (2013) on Asian elephants showed more elephant survival during wet seasons for all ages. The same happens with the African elephants, whose mortality rate in the wet season decreases dramatically (Lee *et al*., 2013; Moss *et al*., 2011). Hence, increased rainfall within the OND season would positively affect the Amboseli ecosystem's elephant population.

Since the RCP 2.6 and RCP 4.5 precipitation patterns were identical to the elephant population estimate, their patterns are comparable. The highest population projected under RCP 2.6 is 3510 elephants by the year 2056. On the other hand, RCP 4.5 projects a peak of 3725 elephants by the year 2075. “By 2036, the population of elephants under RCP 8.5 is projected to decline from 2715 elephants to 1270 elephants, growing to a maximum of 5820 elephants by 2088.

After this time, by the year 2100, there will be a reduction to around 4130 animals”. Between 2045 and 2060, the average population is expected to be about 2966 elephants, followed by a constant population of 4039 between 2065 and 2080. Ndiritu (2013) used mathematical models to show that the elephant population in Amboseli National Park (ANP) is projected to rise exponentially between 2008 and 2032. The ARIMA model predicts that the population will grow from 1451 elephants in 2008 to 2514 elephants in 2032, which is similar to the results of this study under RCP 2.6 and RCP 4.5.

Based on all three RCPs (2.6, 4.5, and 8.5) in the Amboseli environment, our study predicts an increase in the elephant population, promoting tourism. However, the population's survival in the limited park space will be a major challenge because Amboseli Park alone cannot support the numbers. Therefore, many elephants would have to move outside of the park to the dispersal areas. The likelihood of increased human-elephant conflicts will be high in the coming years as the human population is projected to steadily increase in rangelands (Pricope *et al*., 2013). Studies have documented an increase in the population of Kajiado from 149,005 in 1979 to 687,312 512 people in 2009 (CBS, 1981; KNBS, 2010; Said *et al.,* 2019).

Although elephants are resilient to global climate change since they are long-range (Okello *et al.*, 2014), other factors such as poaching, habitat loss and fragmentation will play a critical role in any future dynamics of their population (IUCN, 2013; Said *et al*., 2016). Besides, the invasion of elephant habitats that obstruct migration routes (Ojwang’ *et al* ., 2017; Wayumba and Mwenda, 2006) will continue to be intensified by climate change impacts that make the region hotter and drier, impacting the supply of critical natural resources for elephants and people alike ( Okello *et al.*, 2014). These threats to elephants are predicted to intensify in the future. As a result, they will jeopardize Amboseli's efforts in reducing elephant mortality and increasing long-term populations, as national parks and reserves are already struggling to maintain significant numbers of elephants.Additionally, resources to expand existing parks and reserves are declining (Western *et* *al*., 2009). Massive elephant populations will require special conservation measures to ensure their long-term viability in a fragmented and patchy ecology.

It would be critical to invest in successfully protecting wildlife and ecosystems on private or community-owned pastoral properties. (Georgiadis *et al.*, 2011). Pastoralism is gradually being replaced by agro-pastoralism and agribusiness in the Amboseli ecosystem. (Okello *et al*., 2014). In the Amboseli environment, 61% of the land has been commercialized, 28% is still under community ranch ownership, and 11% is protected (Amboseli National Park and Chuylu National Park) (Said *et al.*, 2019). Furthermore, government, private, and community conservation programs are critical to addressing the expected increase in elephant populations. Such strategies are more likely to protect the ecosystem, landscape, and wildlife populations in the region.

The anticipated elephant population based on the three RCPs shows a slight increase for RCP 2.6 and RCP 4.5 and a massive boost for RCP 8.5. As elephants disperse to the community and private property, the expected expansion could be managed by involving local groups. Their survival is dependant on the goodwill of the locals. As a result, every action to preserve the ecosystem should include a human socio-economic component rather than solely on the elephant's well-being. Locals have been compelled to move to horticulture farming and leasing to commercial farmers due to the lack of direct benefits from wildlife-based tourism. (Nyamasyo and Kihima, 2014). As the human population grows within the environment, so does the demand for food, which leads to an increase in land subdivision (Mwenda, 2001). As a result of these demands, legal rights have shifted from community to individual ownership, resulting in the partition of natural resources between pastoralism, conservation, and agriculture. Increased confrontations with the local community are likely if the RCP 8.5 elephant population emerges (doubling this number). As a result, further actions will be required, such as relocating elephants to different sites.

# CHAPTER 6 : COMMUNITY PERCEPTIONS ON IMPACTS OF CLIMATE CHANGE ON HERBIVORES AND LIVELIHOODS OF AMBOSELI

## 6.0 Introduction

The fifth specific objective was to investigate how the community's livelihoods are affected by climate change impacts on herbivores of the Amboseli ecosystem. This section gives results from the survey undertaken in the study area. Ninety-nine questionnaires were distributed, and the analysis of the results was presented.

## 6.1 Demographics of Respondents

Figure 6.1(a-b) presents the percentage distribution of interviewed women and men and their educational levels. Fifty-four per cent of those interviewed were women, while forty-six per cent were men. The percentage of women is higher because they could be found at home when most men grazed livestock away from home. Education levels are low in Amboseli.

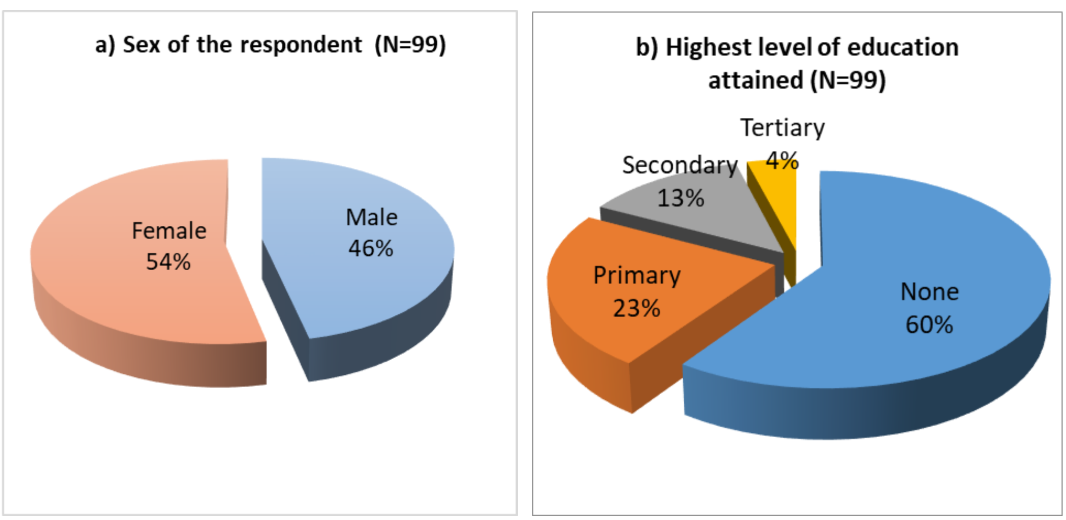



Figure 6.1: Percent distribution of the sex and level of education of respondents

Overall, sixty per cent of respondents have not attained education at any level. Twenty-three per cent attended primary school; thirteen per cent had secondary education, and only four per cent tertiary education. Other studies have also shown that the Amboseli ecosystem exhibit high levels of illiteracy (Ondicho, 2017).

The highest percentages (31%) of those interviewed were between 31-40 years, and most of them were found in the market and the grazing fields. The age group of 41-50 years presented the least number in the survey. The age groups of 21-30, 51-60, and above 60 showed a percentage between 18-20% in the study (Figure 8.2).

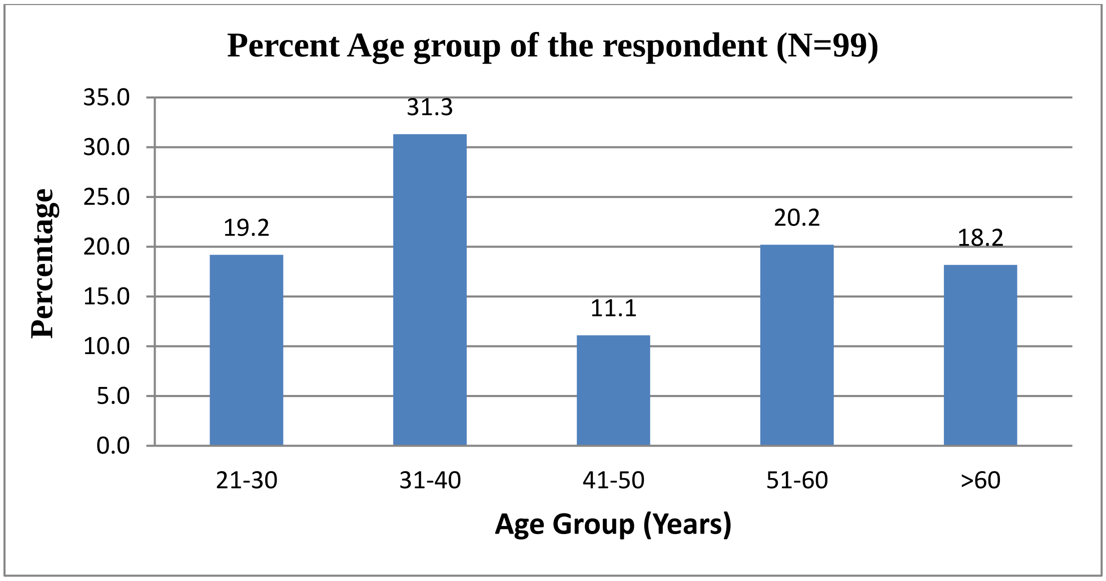



Figure 6.2: Age group of respondents in percentage.

## 6.2 Impacts of Climate on Herbivores

### *6.2.1 Rainfall Characteristics*

Figure 8.3 shows the communities view on rainfall variability, with 63% of the respondents interviewed in the survey strongly agreeing to an increase in drought incidences in Amboseli. 37% agreed with this fact while the undecided, disagree and strongly disagree recorded zero per cent. This implies that the local community members are witnessing the changes in the climate patterns. The finding supports the results of the rainfall anomalies reported in chapter 4 that show the recurrence of depressed rainfall. Ondicho (2017) study also confirmed that Amboseli experiences hostile climatic conditions characterized by recurrent droughts. The results have negative impacts on the ecosystem because unpredictable droughts affect both livestock and wildlife considerably.

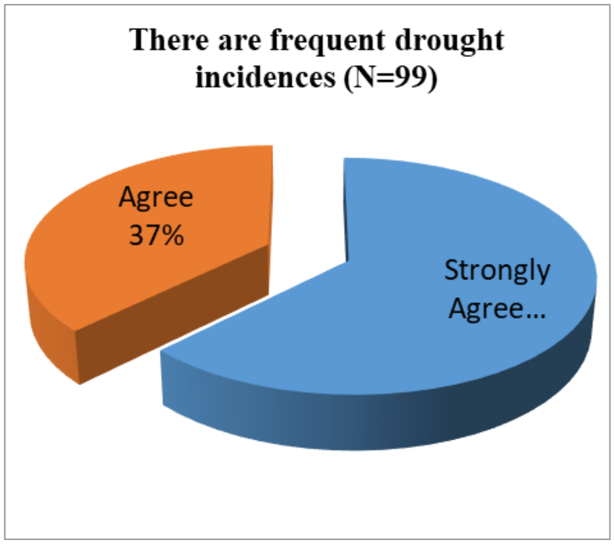



Figure 6.3: Reporting of drought incidences in the Amboseli Ecosystem

### *6.2.2 Observed Temperature Characteristics*

The question presented to the respondents was to ascertain if the temperatures had become warmer in the recent past. 41% strongly agreed, 59% simply agreed, while the undecided, disagree, and strongly disagree categories registered zero per cent each. The results are presented in figure Figure 6.4. The findings support the increasing positive trend in temperature shown in Chapter 4. It also helps confirm the reports on the definite increase in temperature described by IPCC (2014) about the expected high rise in temperature in the African continent compared to the rest of the globe. Altmann *et al.* (2002) also recorded a dramatic increase in temperatures in Amboseli from the year 1976 to 2000.

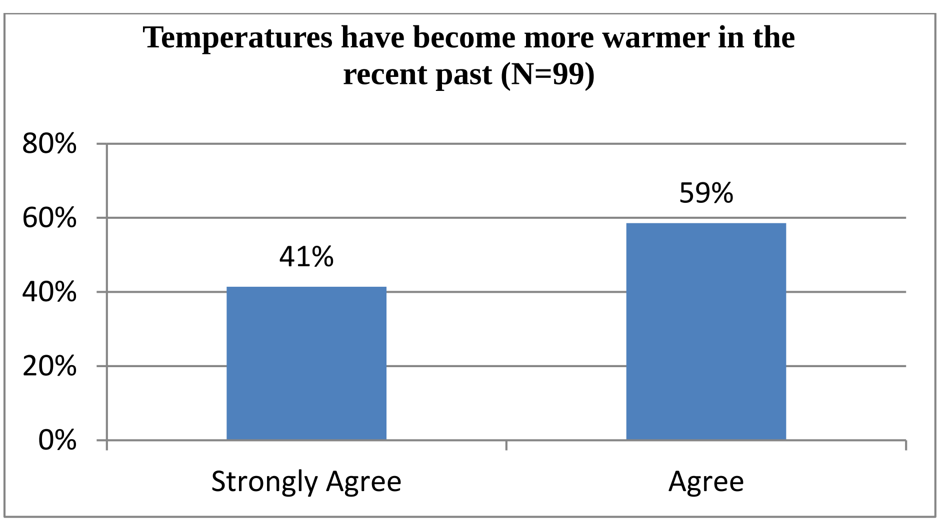


Figure 6.4: Observations on temperatures of the Amboseli Ecosystem

## 6.3 Impacts of Climate Variability on Livelihoods

The community has observed the impact of climate variability discussed in chapter 4, and the locals are facing water stress impacts. From Figure 6.6, it can be seen that 53% of respondents agreed strongly while 47% just decided that there was a decline in stream and river flows. There were no undecided respondents, disagreed or strongly disagreed. The decrease in river and stream flows was attributed to rainfall unreliability and increased water abstraction for irrigation. The "Amboseli swamps and river systems are the lifeline of both herbivores and livestock in the ecosystem. The major wetlands systems outside the park include Kimana-Kikarankot and Nolturesh river systems. Other equally essential springs and swamps, e.g., Namelok, are centres of horticulture production and critical dry season drinking points for both herbivores and livestock."

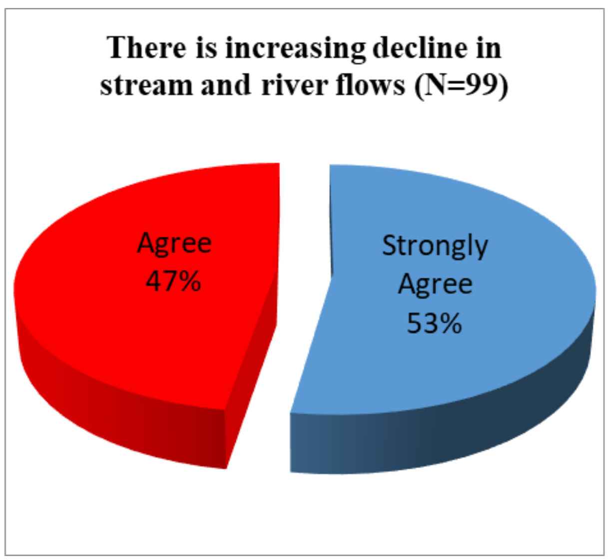



Figure 6.5: Respondents views on river and stream flows

However, climate change and human encroachment appear to be posing a threat to these wetlands. Because they are fenced off to promote irrigated farming, and some are no longer accessible to wildlife. Water is abstracted from the springs that supply the Kimana River and pumped into irrigation canals or piped away, limiting water flow downstream. (Stakeholders Amboseli Ecosystem, 2009). The transition from wildlife conservation and pastoralism to irrigated agriculture (Nyamasyo and Kihima, 2014) has taken on a more commercial form than subsistence agriculture leading to the expansion of agricultural land through the clearance of wetlands, woods, grasslands, and parks. Consequently, wetlands and other wildlife areas act as grazing areas for livestock, and herbivores are now declining (Nyamasyo and Kihima, 2014).

### 6.4 Herbivore Distribution in the Dispersal Areas

A group ranch was categorized as either being busy or not by the presence of herbivores in its setting. The question posed was how active the different group ranches were. The company of herbivores in the dispersal areas confirmed its status given by the respondents living in these areas. (Table 6.1). Kimana had 54% stating the ranch was very busy, 35% said it was generally busy, and 11% did not know its status. In Kimana, it is evident that the large herbivores are keeping off due to increased agricultural activity in privately owned farms and fenced for crop farming. The findings clearly showed that herbivores no longer move in big herds in the various group ranches. In the Kuku ranch, 36 people were interviewed, 6% noted that the farm was bustling, 22% said it was busy, 44% thought it was moderately busy, 17% thought it was a little busy, and 11% did not know. This is because the herbivores use the ranch as they move to Tsavo or Chyulu hills.

Furthermore, there is no subdivision of land on the ranch. In the Mbirikani group ranch, 80% stated that the ranch was moderately busy, and 20% did not know. In Olgulului/ Ololorashi ranch, out of the 11 people interviewed, only18% did not know how active the ranch was.

Table 6.1 Presence of herbivores in the dispersal areas

| How busy | Kimana<br>n=37 | Kuku<br>n=36 | Mbirikani<br>n=15 | Olgulului/ Ololorashi<br>n=11 |
|---|---|---|---|---|
| Very busy | 54% | 6% | 0% | 0% |
| Busy | 35% | 22% | 0% | 0% |
| Moderately busy | 0% | 44% | 80% | 82% |
| A little busy | 0% | 17% | 0% | 0% |
| Don't Know | 11% | 11% | 20% | 18% |

In the past, migratory herbivores like the elephants would move in large herds led by a matriarch. This movement is obstructed by land fragmentation, encroachment on the corridors, and infrastructure developments that have made it difficult for herbivores to disperse effectively in the ecosystem. Land adjacent to wetlands that used to be herbivorous dispersal areas has become individual property. The areas that have been transformed into agriculture and human settlements are no longer available to herbivores. As a result, many herbivores are concentrated in areas without (or with little) farms and human settlements. Herbivores have entirely avoided urban areas and built-up areas such as schools, dispensaries, and marketplaces.

### 6.5 Herbivore Corridors

The interference of herbivore corridors by human activities affects their movements and exacerbates conflicts with humans. It was, therefore, essential to establish if the passages used by the herbivore were known to the locals. The respondents were asked whether they knew the location of some of the corridors in the study area. Knowledge of herbivore corridors was established by 81% of the respondents agreeing that the animal corridors in the ecosystem are known. However, a small percentage (19%) of the respondents (mainly people who are not Maasai) were not able to locate the corridors (Figure 6.6).

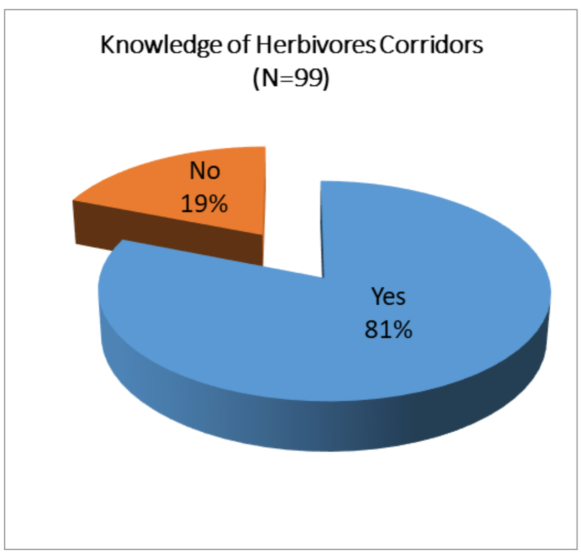



Figure 6.6: Knowledge of wildlife corridors

The respondents were asked to name the corridors used by wildlife that are known to them. The answer to the question was sort from both men and women and also different age groups. It emerged that generally, the community members are well informed of the wildlife movements in the ecosystem. They were able to tell the corridors from the park to various destinations and back to the park. The respondents named and mapped some of the routes they knew, as depicted in Figure 6.7 as follows:

- Amboseli National Park -Kimana-kuku-Chyulu hills
- Amboseli National Park -Imbirikani Chyulu hills
- Amboseli – Kimana- Intonet –Chyulu Hills.
- Amboseli – Serengeti National park in Tanzania.

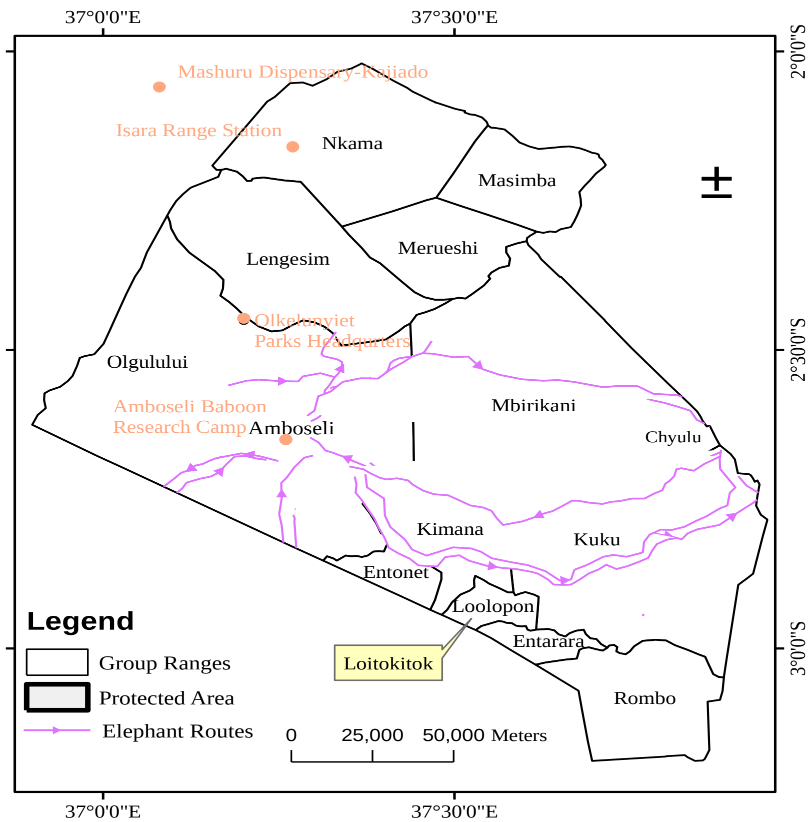



Figure 6.7: Community-mapped wildlife corridors in Amboseli

The competence of the community to join in mapping the herbivore corridors demonstrates that these corridors are static over time. Elders of 60 years and above confirmed that the corridors they knew when they were Moran's are today's same. These corridors are similar to those mapped by Wayumba and Mwenda (2006). The corridor through Kimana is one of the most used corridors and is very important to the survival of wildlife in the ecosystem. "This area is utilized heavily by elephants and other herbivores. Wildlife disperses out of Amboseli via Kimana Group Ranch (25,120 hectares) to Kimana Sanctuary to Chyulu West National Park in the wet season. This corridor provides strategic connectivity, which is vital to the viability of Amboseli's elephants and other herbivores."

However, there is an increase in human activities in Kimana that is compromising the habitats of herbivores in general. The situation has been exacerbated by the subdivision of the land leading to a private land tenure system. As a result, there has been an influx of other communities into the area. Landowners are selling their property to non-locals who are fencing their private plots and blocking the known herbivore corridors forcing species like the elephants to go round the fenced land to trace their corridors. In the process, they get agitated and destroy the water pipes for irrigation and even destroy the fences and uproot the crops. This was observed in the field where elephants had raided a tomato farm and destroyed the water pipes. In another location, the elephants had destroyed a perimeter fence within the Kimana conservancy corridor. African elephants are known to use the same migration route year by year as they locate food and water. Instances of elephants consuming or causing damage to property and crops have been reported in many countries in Sub-Saharan Africa (Hoare, 1999; Mackenzie and Ahabyona, 2012; Naughton *et al.*, 1999; Osborn and Parker, 2003). Therefore, land subdivisions, human settlement, and land-use changes will impede animals' migration, especially the weak ones searching for suitable habitats.  In addition, climate change will significantly add more burdens on large herbivores in the Kenyan savanna as they struggle with other stressors to survive.

### 6.6: Threats to Herbivore Distribution in Dispersal Areas

The study further evaluated the respondents' knowledge about changes in the group ranches as dispersal areas for the elephants. The respondents were asked to identify the various threats to elephant corridors in the area. Numerous factors were identified as threats to the distribution of wildlife in the dispersal areas. The dangers evaluated and the percentages of respondents who agree are shown in Figure 6.8: Changes in the hydrological regime (e.g., rains arriving later than expected or rains failing) have increased droughts and animal fatalities (79 per cent), Cultivation is encroaching on wildlife corridors, putting animals' lives at jeopardy due to conflicts (56 per cent), Overexploitation of forests, which leads to desertification (51%), land subdivision (41%), overstocking and overgrazing (35%), and development (35%). These threats are similar to those identified by Ripple *et al*. (2015), threatening large herbivores in the wild.

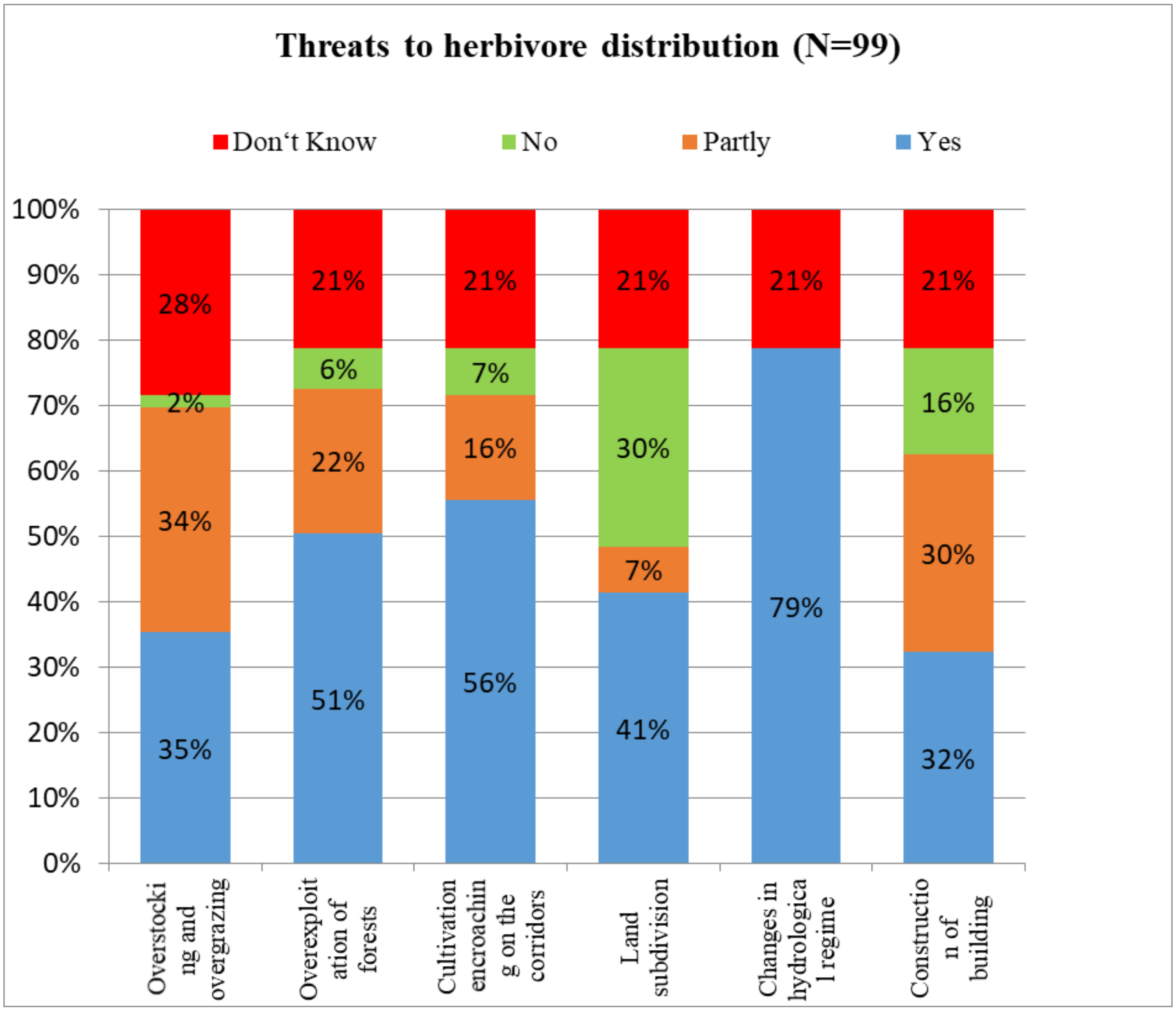



Figure 6.8: Threats to wildlife in the Amboseli ecosystem

These threats are related to the improvement of livelihoods and focus on the ability of people to make money from agriculture and feed themselves, be able to settle and own land. Changes in rainfall patterns and intensity are driving wildlife to move to locations that have rainfall and water. The changes also drive the local community to switch to irrigated agriculture to feed their families because drought has threatened their livestock dependency. Hard economic times in Kenya are threatening the existence of conservancies to secure wildlife corridors because the proceeds the landowners are given per year cannot sustain them. Crop raiding from large herbivores like the giant elephants as they move across the landscape attracts resentment and bitterness from the locals as they incur a double loss. Different researchers have also developed similar perceptions (Msoffe *et al.*, 2011; Okello and Kioko, 2010; Western and Nightingale, 2004; Western and Maitumo, 2004). Their findings showed decreasing tendencies in habitat diversity, woodlands, and grass quantity; converting large tracts of land into settlements, croplands, and trading centres; and reducing dry and wet season grazing areas. In particular, agricultural activities have increased (Okello *et al.*, 2011), constricting grazing land (Western and Nightingale, 2004).

## 6.7 Views from Key Informants

The key informants pointed out that the wildlife population had generally decreased except for elephants, which had increased. The success in the elephant scenario is a result of joint efforts from organizations like the Amboseli Elephant Trust (AET), African Conservation Centre (ACC), and African Wildlife Foundation (AWF). In Amboseli, the elephants are fitted with a collar that tracks their movements and can be located remotely by the rangers, minimizing poaching. AWF and BIG life have also partnered with the community to secure the animal corridors. They pay those who have given their land for wildlife conservation and even organize education scholarships for their children as an incentive for safeguarding wildlife. There are different perspectives in evaluating key stressors to elephants in the ecosystem. Past studies have looked at land fragmentation, settlements, infrastructural developments, agriculture, and increasing population. However, studies focusing on the relationship between historical climate and future projections and the distribution of herbivores have not been done.

## 6.8 Way Forward for the Community and Herbivore Conservation

A stakeholder's workshop was held to discuss the results of scientific research. The aim was to get views of how best the community and the wildlife can live harmoniously in a changing climate. The discussion involved representatives from various Non-Governmental Organizations working in the area like (International Fund for Animal Welfare (IFAW), AWF, and Big Life), representatives from Kenya Wildlife Services (KWS), Area chiefs, and Chairmen of the conservancies (see the list in chapter three section 3.4.1). It emerged that wildlife movements and

distribution in the ecosystem had become very unpredictable, unlike in the past, when they could tell where the animals were during the various seasons. Further discussions noted that conservancies were experiencing difficulties sustaining large herbivores like the elephants. Most members were pulling out and opting to lease or even sell their land to horticulture farmers.
The reasons given for the choice were the high cost of living, which could not be met by the meagre proceeds they were receiving from the conservancies. The greatest challenge that emerged was the fact that the land buyers have not lived with wildlife, and therefore, they do not have the interest of the animals at heart. The critical corridor linking the park through Kimana to Chyulu hills was the most affected. From field observations, it was also clear that the corridor was being blocked since most of the land was fenced and under cultivation. As rainfall continues to decrease, more and more people are shifting to irrigation agriculture for food production. This is reducing the range size of most of the herbivore species. Moreover, high temperatures drive humans and herbivores to shift to other suitable habitats away from the hotspots. As the range size decreases, the pressure on the limited resources increases, leading to more human herbivore conflicts, especially with the elephants.

It is essential to look at ways of dealing with elephant numbers sustainably. However, the people were not in support of methods like culling, which they termed as barbaric. Most of them were in favour of conservancies. However, they proposed improvements like increasing the payment to those in conservancies that have accepted maintaining the corridors used by the herbivores. This goal could be best achieved through ecotourism investments and innovations. Besides, landowners let herbivores wander without land (Ogutu, 2002). According to USAID (2016), community and private conservancies in Kenya represent a great opportunity. “In the last three decades, Kenya saw remarkable growth in the number and types of conservancies implementing various conservation strategies, such as law enforcement, ecotourism, species protection, land, and water management.”

Further, Kenya Wildlife Conservancies Association (KWCA) documents that private conservation is a nascent movement. More than 6.3 million hectares of land have been conserved, providing important connectivity for biodiversity across entire ecoregions and between parks and community lands. Improved security, living standards, social cohesion, education, and health are the tangible benefits of community conservancies (KWCA, 2019).

They propose that the KWS collaborate with landowners transforming their land to agriculture to form conservancies managed by the locals. One of the suggestions by the locals that stood out was allowing the conservation of wildlife to benefit people through land lease programs where space is paid for. The land lease program should be voluntary and provide landowners with financial and technical support on maintaining or enhancing grasslands on their property for wildlife. “This program allows the restoration of multiple types of grasslands, including shrubland, pasture, and range. This program aims to prevent the conversion of native grasslands to other land uses such as development and agriculture.” Besides, easements may be provided, like allowing temporary practices such as grazing. The strategy will provide multiple benefits to the environment, raise the economic standards of the local people, and improve their livelihoods. Without any compensation or benefit, yielding land or space to be used by the herbivores in the dispersal areas will not be an option for the people. Stakeholders need to consider how the locals can be paid for leasing their land to create space for herbivore dispersal. Without such initiatives, there is the likelihood of agricultural expansion, increased human encroachment, and more retaliatory killings (Sitati *et al.*, 2005).

# CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Conclusions

The social-ecological systems concept was used in this study, which researchers argue is beneficial for guaranteeing natural resource sustainability and ecosystem services and a healthy environment for human existence and well-being. Ecological resilience is related to ecosystem diversity, ecological function stability, and keystone species survival. However, the adaptability of social-ecological systems is influenced by social factors such as people's ability to forecast changes and plan for the future (i.e., adaptive capacity), which is controlled by human reason, legal structures, and the degree of exposure to and impacts of global change on people's lives. Ecological and societal resilience is thus dynamically intertwined due to changing natural resource management practices and the biophysical systems' subsequent responses.

As a fundamental concern in the ecosystem, this study intended to address local-level challenges linked to herbivore conservation and community livelihoods. The lack of firsthand information on the future range size and distribution of herbivores in the environment makes adequate conservation plans for the species challenging to implement. Thus, it aimed to bridge the gap between the challenges faced by conservationists and local communities in dealing with herbivore conservation issues on the one side. On the other, there are climate change scientists. This was accomplished by modelling climate trends and temporal and regional trends in animal numbers and dispersion patterns. Both quantitative and qualitative analyses were employed in the study.

This research found that there has been a long-term increase in the occurrence of low rainfall, which is commonly connected with drought. There was an overall decline in rainfall during the MAM and JJAS seasons but increased during the OND season. Furthermore, the historical minimum and maximum temperatures have been rising. It was also established that historical climate trends are linked to historical herbivore populations and dispersion. Reduced rainfall and rising temperatures result in decreasing water availability and the loss of savanna vegetation, particularly grasses hastening the death of some herbivore species in Amboseli.

According to this study, annual maximum temperatures rose by 0.79°C from 28.08°C in 1960 to 28.8°C in 2014, while minimum temperatures increased by 1.23°C from 15.88°C in 1960 to

17.11°C in 2014. These increases altered the population density of herbivores in the Amboseli environment. Eight of the fifteen species (Thomson's gazelle, impala, Grant's gazelle, hartebeest, wildebeest, Burchell's zebra, and giraffe) saw their population density fall as temperatures rose exponentially. The temperature threshold for this species was 30°C, after which they began to degrade and eventually died.

The wildebeest had the lowest temperature threshold of 28°C, making it the most vulnerable of the species. The relationship between temperature and warthog and waterbuck, on the other hand, was not as robust. The temperature rises supported wildlife such as elephants, Lesser kudu, and oryx, whose density grew with rising temperatures but dropped when temperatures rose too high. The gerenuk appeared to be the most tolerant species, enduring temperatures as high as 34°C. There is a risk of animals dying when the thermal-humidity index hits 28°C. Most herbivores, especially water-dependent ones, perish at maximum temperatures of 30°C, whereas those not water-dependent die at 34°C. The distribution patterns showed that most herbivores avoided hotspot areas (like the Magadi and central Kajiado), which recorded high temperatures and low rainfall. Still, they tended to congregate in relatively low temperatures and close to water sources, such as the Nguruman woods and Amboseli National Park.

Similarly, projected climate trends from 2006 to 2021 show important influences on herbivore distributions and population dynamics. Herbivore distribution is mainly affected by a reduction in range sizes and a decrease in their populations. The findings based on RCPs projections demonstrate that high temperatures caused herbivore range sizes to shrink, with the majority of them losing more than half of their range sizes and the elephant range shrinking only slightly. Annual and seasonal temperatures increased consistently in the RCP 8.5 and RCP 4.5 scenarios, ranging from 1.85°C to 4.34°C for maximum temperatures and 1.98°C to 5.26°C for minimum temperatures. In addition, projected rainfall assessments revealed a reduction in annual rainfall and a modest rise in OND seasonal rainfall. For the first time, our study proved that the OND rainfall was critical to elephant survival. With a 13-year lag, there was a positive link between the growth in elephant population and the increase in OND rainfall. Elephants, unlike other herbivores, are temperature resistant, which means they are unaffected by rising temperatures in the research region. The elephant is one of the key wildlife species with a long lifespan. This study projects a rise in elephant population supported by all the three RCPs within the Amboseli ecosystem.

The rise could boost tourism activities within the area, although other factors such as poaching, habitat loss and other human disturbance will play a critical role in future dynamics. It is important to note that tourists are attracted by the variety of species in the habitat and not just one species. As such, the conservation of other herbivore species is vital in boosting tourism in the area. The point of concern is that reduced rainfall and rising temperatures will, as expected, result in reduced water availability and the loss of savanna vegetation, particularly grasses. The consequences on animals and livestock in the Amboseli environment would be enormous. With the rising temperatures, the animals may be forced to flee the heat, pushing them to shift to an unsafe habitat where their survival rate may drop to the point where the population is no longer viable. The animals may face extinction if suitable habitat is not available due to human disturbance and land fragmentation. Because of fragmentation, herbivores cannot alter their distribution as easily as they could in the past in response to climate-related concerns.

From the community perceptions survey and participatory mapping of the migratory corridors of the herbivores, it emerged that the ecosystem was experiencing a rise in temperatures, incidences of drought were more frequent, and the corridors of the animals were being blocked. The situation affects how the herbivores adapt to climate changes. In the past, the animals would migrate in response to climate change to follow optimal environmental conditions for survival, but now it is impossible to achieve. Although temperature changes relative to species thresholds may be a future driver of population decline and range shifts, the interaction of temperature and rainfall on forage production and human land-use decisions and land-use change will all be essential components of shifting species ranges.

To adapt to the changes in the environment, the animals must disperse because the protected areas alone will not be sufficient to sustain the animal population. As a result, most herbivores will have to forage and browse outside of the park, potentially increasing human conflicts. Consequently, the government of Kenya must develop strategies that will ensure the survival of the animals. The findings emphasize the necessity of combining regional and species-level analyses and the need to consider both physiological and physiographic components when assessing the consequences of global warming on large herbivores in the East African savanna. It is projected that a decline in population densities and range sizes among large herbivores in the twenty-first century will be worse than in the best-case scenario. Like other studies (Bellard *et al.*, 2012, 2014; Ceballos *et al.*, 2017; Sintayehu*, 2018;* Thuiller *et al*., 2018), this study has shown that climate change is affecting herbivores, particularly in the Kenyan Savanna fact conservation managers cannot ignore.

## 7.2 Recommendations

### 7.2.1 Recommendations to Kenya wildlife Service

The Kenya Wildlife Service should encourage conservancies led by local communities working closely with private entrepreneurs through land leases or other payment for environmental services (PES) schemes. The economic returns resulting from ecotourism and related activities should be distributed equitably to the local community to enhance their livelihoods. This might change their attitudes towards conservation, leading to lower levels of conflict. Furthermore, within the greater Amboseli ecosystem, herbivores disperse to the community and private lands, and their survival depends on the goodwill of the local people. This means that any conservation action should have a socio-economic dimension of the community and not concentrate on herbivores' welfare. They will have a positive attitude towards herbivores since it is a cash cow to them.

The Kenyan government and other stakeholders must shift from rigid nature-based conservation goals to a nature–human conservation approach to prevent species losses and associated vital ecosystem services and provide a good quality of life that does not affect the environment. This can be achieved by coordinating adaptation to climate change efforts and policy formulation across many sectors while avoiding competing objectives. Finally, Kenya Wildlife Service may require new legal tools or rules to incorporate expected climate change impacts into wildlife and conservation management plans.

### 7.2.2 Recommendations to the Local Community

Blocking herbivore corridors due to land-use change in a changing climate will lead to increased human herbivore conflicts. The local community must own designed or proposed programs that maintain sustainable practices and encourage developing a healthy habitat for wildlife. Alternative sources of income generation like beekeeping, agroforestry, fodder, and pasture growth should be encouraged.

### 7.2.3 Recommendations for Further Work

Several subjects were uncovered throughout the research for this thesis that would benefit from further exploration. While the research in this thesis addressed some of them, others remain. There are few observational studies of changes in temperature and precipitation spatial characteristics that may have occurred in recent decades. Future research might explore trends in the spatial association of precipitation and temperature in Amboseli over the last few decades. The extent to which the proportion of seasonal and annual rainfall influences herbivore distribution could also be explored. It could reflect how accurate the spatial attributes assessed using the method utilized here are.

The studies conducted for this thesis have identified several additional areas for further research. These include further investigating the relationship between rainfall and the distribution and population dynamics of the other 14 herbivore species and the small herbivores excluded from this study. High-resolution rainfall data could be used to establish if increased spatial resolution climate models improve the representation of the spatial data. The findings would aid in confirming any changes in spatial correlation that might occur as a result. Furthermore, it would be important to investigate if the OND rainfall impacts the other herbivores positively, as was the case with the elephant.

Additional data from other ecosystems in the country or other parts of the world might be used to evaluate the degrees of uncertainty associated with the estimating methodologies. More research is needed to see how much these uncertainty limitations vary for different regions, seasons, and climatic regimes, particularly when estimates are based on a small number of in-situ stations.The animal aerial surveys data was also limiting because it is point data based on estimates. This can be improved by using collared data of the species and integrating GIS and remote sensing techniques to improve the spatial-temporal analysis.

The effects of a change in range size on the temporal variability experienced at places inside a grid-box in a projected future climate were studied in this study. This demonstrates the need to take variations in herbivore range size into account and spatial studies where rainfall and temperature point variability are essential when multi-site downscaling models are utilized. Similar approaches may be taken, especially when the resulting predictions are used for environmental impact studies such as flood assessment. The hydrological repercussions of climate change (e.g. flood frequency) may be significantly influenced by anticipated, estimated, or hypothetical changes in spatial and temporal variability.

This study attempted to bridge the gap between climate science and conservation. However, ecosystem management issues are under-represented in broader policy, and rigorous strategies and initiatives at the international, national, and local levels are frequently ineffective. Future research must focus on bridging the gaps that exist between the relevant sectors. They must adapt to changing circumstances by increasing knowledge, public awareness, and responsibility, thereby changing the situation. Through the ministry of education, the government should make funds available to support ongoing research and carry out modelling studies targeting students and researchers to provide more evidence and models for incorporating climate change and instituting public awareness and education on the impact of climate change and its contribution to animal migration.

# REFERENCES


Abraham, M. A. A. (2006). *Sustainability Science and Engineering_ Defining Principles* (volume1 ed.). Elsevier.

Adler, P. B., Leiker, J., & Levine, J. M. (2009). Direct and indirect effects of climate change on a prairie plant community. In *PLoS ONE* (Vol. 4, Issue 9). https://doi.org/10.1371/journal.pone.0006887

Aduma, M. M., Ouma, G., Said, M. Y., Wayumba, G. O., Omondi, P. A., & Njino, L. W. (2018). Potential impacts of temperature projections on selected large herbivores in savanna ecosystem of Kenya. *American Journal of Climate Change*, *07*(01), 5–26. https://doi.org/10.4236/ajcc.2018.71003

Agrawal, A. (2001). Common property institutions and sustainable governance of resources. In *World Development* (Vol. 29, Issue 10, pp. 1649–1672). https://doi.org/10.1016/S0305-750X(01)00063-8

Aguilar , E., Auer , I., Brunet , M., Peterson , T. C., & Wieringa, J. (2003). Guidelines on climate metadata and homogenization. *World Meteorological Organization*.

Albrecht, G., Freeman, S. & Higginbotham, N. (1998). Complexity and Human Health: The Case for a Transdisciplinary Paradigm. *Culture, Medicine and Psychiatry*, *22*(1), 55–92. https://doi.org/https://doi.org/10.1023/A:100532882

Allen, C.R., G.S. Cumming, A.S. Garmestani, P.D. Taylor, and B. H. W. 2011. (2011). Managing for resilience. *Wildlife Biology*, *17*(4), 337–349.

Altmann, J., Alberts, S. C., Altmann, S. A., & Roy, S. B. (2002). Dramatic change in local climate patterns in the Amboseli basin, Kenya. *African Journal of Ecology*, *40*, 248–251.

Andere, D. K. (1981). Wildebeest Connochaetes taurinus (Burchell) and its food supply in Amboseli Basin. In *African Journal of Ecology* (Vol. 19, Issue 3, pp. 239–250). https://doi.org/10.1111/j.1365-2028.1981.tb01062.x

Anderies, J. M., Janssen, M. A., & Ostrom, E. (2004). A Framework to Analyze the Robustness of Social-ecological Systems from an Institutional Perspective. In *Ecology and Society* (Vol. 9, Issue 1). https://doi.org/10.5751/es-00610-090118

Andrew S. Pullin. (2002). *Conservation Biology*. Cambridge University Press. https://doi.org/10.7208/chicago/9780226500829.003.0008

Armstrong, E., Hopcroft, P. O., & Valdes, P. (2019). Reassessing the Value of Regional Climate

Modeling Using Paleoclimate Simulations Geophysical. *GEOPHYSICAL RESEARCH LETTERS*, *46*, 12464–12475. https://doi.org/10.1029/2019GL085127

Baker, D. J., Hartley, A. J., Burgess, N. D., Butchart, S. H. M., Carr, J. A., Smith, R. J., Belle, E., & Willis, S. G. (2015). Assessing climate change impacts for vertebrate fauna across the West African protected area network using regionally appropriate climate projections. *Diversity and Distributions*, *21*(9), 991–1003. https://doi.org/10.1111/ddi.12337

Bale, J. S., Hodkinson, I. D., & Jones, T. H. (2002). Herbivory in global climate change research : Direct effects of rising temperature Herbivory in global climate change research : direct effects of rising temperature on insect herbivores. *Global Change Biology*, *8*, 1–16. https://doi.org/10.1046/j.1365-2486.2002.00451.x

Balsiger, P. W. (2004). Supradisciplinary research practices: History, objectives and rationale. In *Futures* (Vol. 36, Issue 4, pp. 407–421). https://doi.org/10.1016/j.futures.2003.10.002

Barrios, E., Valencia, V., Jonsson, M., Brauman, A., Hairiah, K., Mortimer, P. E., & Okubo, S. (2018). Contribution of trees to the conservation of biodiversity and ecosystem services in agricultural landscapes. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *14*(1), 1–16. https://doi.org/10.1080/21513732.2017.1399167

Barsugli, J., Vogel, J., Kaatz, L., Smith, J., Waage, M., & Anderson, C. (2012). Two Faces of Uncertainty: Climate Science and Water Utility Planning Methods. In *Journal of Water Resources Planning and Management* (Vol. 138, Issue 5, pp. 389–395). https://doi.org/10.1061/(ASCE)WR.1943-5452.0000188

Bartzke, G. S., Ogutu, J. O., Mukhopadhyay, S., Mtui, D., Dublin, H. T., & Piepho, H. (2018). Rainfall trends and variation in the Maasai Mara ecosystem and their implications for animal population and biodiversity dynamics. *PLoS ONE*, *13*(9).

Beier, P., & Noss, R. F. (1998). Do Habitat Corridors Provide Connectivity? *Conservation Biology*, *12*(6), 1241–1252. https://doi.org/10.1111/j.1523-1739.1998.98036.x

Bellard, C., Bertelsmeier, C., Leadley, P., & Thuiller, W. (2014). Impacts of climate change on the future of biodiversity. *Ocological Letters*, *15*(4), 365–377. https://doi.org/10.1111/j.1461-0248.2011.01736.x.Impacts

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters*, *15*(4), 365–377. https://doi.org/10.1111/j.1461-0248.2011.01736.x

Bera, S. (2017). Trend Analysis of Rainfall in Ganga Basin, India during 1901-2000. *American Journal of Climate Change*, *06*(01), 116–131. https://doi.org/10.4236/ajcc.2017.61007

Berry, P., Ogawa-Onishi, Y., & McVey, A. (2013). The Vulnerability of Threatened Species: Adaptive Capability and Adaptation Opportunity. *Biology*, *2*(3), 872–893. https://doi.org/10.3390/biology2030872

Bhola, N., Ogutu, J. O., Said, M. Y., Piepho, H. P., & Olff, H. (2012). The distribution of large herbivore hotspots in relation to environmental and anthropogenic correlates in the Mara region of Kenya. *Journal of Animal Ecology*, *81*(6), 1268–1287. https://doi.org/10.1111/j.1365-2656.2012.02000.x

Biju Kumar, A., & Ravinesh, R. (2017). Climate change and biodiversity. *Bioresources and Bioprocess in Biotechnology*, *1*, 99–124. https://doi.org/10.1007/978-981-10-3573-9_5

Birkett, P. J., Vanak, A. T., Muggeo, V. M. R., Ferreira, S. M., & Slotow, R. (2012). Animal perception of seasonal thresholds: Changes in elephant movement in relation to rainfall patterns. In *PLoS ONE* (Vol. 7, Issue 6). https://doi.org/10.1371/journal.pone.0038363

Blair, A., & Meredith, T. (2018). Community perception of the real impacts of human-wildlife conflict in Laikipia, Kenya- capturing the relative significance of high-frequency,low-severity events. *Oryx*, *52*(3), 497–507. https://doi.org/10.1017/S0030605316001216

Bohrer, G., Beck, P. S., Ngene, S. M., Skidmore, A. K., & Douglas-Hamilton, I. (2014). Elephant movement closely tracks precipitation-driven vegetation dynamics in a Kenyan forest-savanna landscape. *Movement Ecology*, *2*(1), 2. https://doi.org/10.1186/2051-3933-2-2

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R., & Yanda, P. (2007). *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. https://doi.org/10.2134/jeq2008.0015br

Boone, R. B., Burnsilver, S. B., Thornton, P. K., Worden, J. S., Galvin, K. A., Boone, R. B., Burnsilver, S. B., Thornton, P. K., Worden, J. S., & Galvin, K. A. (2005). Quantifying Declines in Livestock Due to Land Subdivision Quantifying Declines in Livestock Due to Land Subdivision. *Society for Range Managem*, *58*(5), 523–532. https://doi.org/http://dx.doi.org/10.2111/1551-5028(2005)58[523:QDILDT]2.0.CO;2

Borger, L , Dalziel, B. D., & and Fryxell, J. M. (2008). Are there general mechanisms of animal home range behaviour ? A review and prospects for future. *Ecology Letters*, *11*, 637–650.

https://doi.org/10.1111/j.1461-0248.2008.01182.x

Boudjemadi, K., Lecomte, J., & Clobert, J. (1999). Influence of connectivity on demograohy and dispersal in two contrasting habitats: an experimental approach. *Journal of Animal Ecology*, *68*, 1207–1224.

Bozinovic, F., Calosi, P., and Spicer, J. I. (2011). Physiological Correlates of Geographic Range in Animals _ Annual Review of Ecology, Evolution, and Systematics. *Annual Review of Ecology, Evolution and Systematics*, *42*(155–172). https://doi.org/https://doi.org/10.1146/annurev-ecolsys-102710-145055

Bulte, E., Lipper, L., Stringer, R., Zilberman, D. (2008). Payments for ecosystem services and poverty reduction: concepts, issues, and empirical perspectives. *Environment and Development Economics*, *13*(3), 245–254. https://doi.org/https://doi.org/10.1017/S1355770X08004348

Bulte, E. H., Boone, R. B., Stringer, R., & Thorton, P. K. (2006). Wildlife conservation in Amboseli, Kenya: paying for nonuse values. In *Report* (Issue December). papers://df763eb3-d427-4085-8a21-10fb2c44520b/Paper/p9484

Burkart, S., Gugerli, F., Senn, J., & Kuehn, R. (2015). Evaluating the functionality of expert-assessed wildlife corridors with genetic data from roe deer Evaluating the functionality of expert-assessed wildlife corridors with genetic data from roe deer. *Basic and Applied Ecology*, *17*(1), 52–60. https://doi.org/10.1016/j.baae.2015.09.001

Burkepile, D. E., Burns, C. E., Tambling, C. J., Amendola, E., Buis, G. M., Govender, N., Nelson, V., Thompson, D. I., Zinn, A. D., & Smith, M. D. (2013). Habitat selection by large herbivores in a southern African savanna: The relative roles of bottom-up and top-down forces. *Ecosphere*, *4*(11), 1–19. https://doi.org/10.1890/ES13-00078.1

Burt, W. H. (1943). Territoriality and Home Range Concepts as Applied to Mammals. In *Journal of Mammalogy* (Vol. 24, Issue 3, p. 346). https://doi.org/10.2307/1374834

Cahill, A. E., Aiello-Lammens, M. E., Fisher-Reid, M. C., Hua, X., Karanewsky, C. J., Yeong Ryu, H., Sbeglia, G. C., Spagnolo, F., Waldron, J. B., Warsi, O., & Wiens, J. J. (2012). How does climate change cause extinction? *Proceedings of the Royal Society B: Biological Sciences*, *280*(1750), 20121890–20121890. https://doi.org/10.1098/rspb.2012.1890

Cai, W., Cowan, T., & Sullivan, A. (2009). Recent unprecedented skewness towards positive Indian Ocean Dipole occurrences and its impact on Australian rainfall. In *Geophysical*

*Research Letters* (Vol. 36, Issue 11). https://doi.org/10.1029/2009GL037604

Campbell, D. J. (1999). Response to drought among farmers and herders in Southern Kajiado District, Kenya: A comparison of 1972-1976 and 1994-1995. In *Human Ecology* (Vol. 27, Issue 3, pp. 377–416). https://doi.org/10.1023/A:1018789623581

Campbell, D. J., & Lusch, D. P. (2003). *Root causes of land use change in the Loitokitok Area, Kajiado District, Kenya. LUCID Working Paper, no. 19.*

Campbell, D. J., Lusch, D. P., Smucker, T. A., & Wangui, E. E. (2005). Multiple methods in the study of driving forces of land use and land cover change: A case study of SE Kajiado District, Kenya. *Human Ecology*, *33*(6), 763–794. https://doi.org/10.1007/s10745-005-8210-y

Cardillo, M., Mace, G. M., Jones, K. E., Bielby, J., Bininda-emonds, O. R. P., Sechrest, W., Orme, C. D. L., & Purvis, A. (2005). Multiple Causes of High Extinction Risk in Large Mammal Species. *Science*, *1067*(August), 1239–1241. https://doi.org/10.1126/science.1116030

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., ... Mitchell, R. B. (2003). Knowledge systems for sustainable development. In *Proceedings of the National Academy of Sciences of the USA (PNAS)* (Vol. 100, Issue 14, pp. 8086–8091). https://doi.org/10.1073/pnas.1231332100

CBS. (1981). *Kenya population Census 1979. Volume 1. Central Bureau of Statistics (CBS), Ministry of Economic Planning and Development*.

Ceballos, G., Ehrlich, P. R., & Dirzo, R. (2017). Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *Proceedings of the National Academy of Sciences*, 201704949. https://doi.org/10.1073/pnas.1704949114

Chamaillé-Jammes, S., Fritz, H., & Holdo, R. M. (2007). Spatial relationship between elephant and sodium concentration of water disappears as density increases in Hwange National Park, Zimbabwe. In *Journal of Tropical Ecology* (Vol. 23, Issue 6, pp. 725–728). https://doi.org/10.1017/S0266467407004531

Chamaillé-Jammes, S., Mtare, G., Makuwe, E., & Fritz, H. (2013). African Elephants Adjust Speed in Response to Surface-Water Constraint on Foraging during the Dry-Season. *PLoS ONE*, *8*(3). https://doi.org/10.1371/journal.pone.0059164

CHG (Producer) (13/12/2019). (2019). *Climate Hazards Center -CHIRTS*. University of California, Santa Barbara.

Chirima, J.G, Owen-Smith, N., Abd Elbasit M., Nyamugama, A. (2018). Expansions and contractions of occupied range by large mammalian herbivores in Kruger Park, South Africa: a response to rainfall variability. *Biodiversity International Journal*, *2*(6). https://doi.org/10.15406/bij.2018.02.00111

Christo, Cyril and Wilkinson, M. (2009). *WALKING THUNDER. In the Footsteps of the African* (First Edit). Merrell, 2009.

Coe, M.J., Cumming, D.H. & Phillipson, J. (1976). Biomass and production of large African herbivores in relation to rainfall and primary production. *Oecologia*, *22*, 341–354. https://doi.org/https://doi.org/10.1007/BF00345312

Coe, M. J. D., Cumming, D. H., Phillipson, J., Cummings, D. H., & Phillipson, J. (1976). Biomass and production of large herbivores in relation to rainfall and primary production. *Oecologia*, *22*(4), 341–354. https://doi.org/10.1007/BF00345312

Coe, R., & Stern, R. D. (2011). Assessing and Addressing Climate-Induced Risk in Sub-Saharan Rainfed Agriculture: Lessons Learned. *Experimental Agriculture*, *47*(Special Issue 02), 395–410. https://doi.org/10.1017/S001447971100010X

Collins, M., An, S. Il, Cai, W., Ganachaud, A., Guilyardi, E., Jin, F. F., Jochum, M., Lengaigne, M., Power, S., Timmermann, A., Vecchi, G., & Wittenberg, A. (2010). The impact of global warming on the tropical Pacific Ocean and El Nĩo. *Nature Geoscience*, *3*(6), 391–397. https://doi.org/10.1038/ngeo868

Consequences, C., Osima, S., Indasi, V. S., Nikulin, G., Lennard, C., Dosio, A., Kjellstr, E., & Chen, Y. (2018). The effects of 1 . 5 and 2 degrees of global warming on Africa in the CORDEX ensemble OPEN ACCESS The effects of 1 . 5 and 2 degrees of global warming on Africa in the CORDEX ensemble. *Environmental Research Letters*, *13*.

Corfield, T. F. (1973). Elephant mortality in Tsavo National Park, Kenya. *African Journal of Ecology*, *11*(3–4), 339–368. https://doi.org/10.1111/j.1365-2028.1973.tb00098.x

Craigie, I. D., Baillie, J. E. M., Balmford, A., Carbone, C., Collen, B., Green, R. E., & Hutton, J. M. (2010). Large mammal population declines in Africa ' s protected areas. *Biological Conservation*, *143*(9), 2221–2228. https://doi.org/10.1016/j.biocon.2010.06.007

Cumming, G. S., Allen, C. R., Ban, N. C., & Biggs, H. C. (2015). Understanding protected area resilience : a multi- scale , social-ecological approach. *Nebraska Cooperative Fish and Wildlife Research Unit*.

Cumming, G. S., Allen, C. R., & Survey, U. S. G. (2017). Protected areas as social-ecological systems : perspectives from resilience and social-ecological systems theory. *Ecological Society of America*, *27*(6), 1709–1717.

Cunningham, S. J., Kruger, A. C., Nxumalo, M. P., & Hockey, P. A. R. (2013). Identifying Biologically Meaningful Hot-Weather Events Using Threshold Temperatures That Affect Life-History. *PLoS ONE*, *8*(12), 1–11. https://doi.org/10.1371/journal.pone.0082492

Cushman, S.A., Chase, M., & Griffin, C. (2005). Elephants in space and time. *Oikos*, *109*(2), 331–341. https://doi.org/10.1111/j.0030-1299.2005.13538.x

Dash, S., Chakravarty, A. K., Singh, A., Upadhyay, A., Singh, M., & Yousuf, S. (2016). Effect of heat stress on reproductive performances of dairy cattle and buffaloes: A review. *Veterinary World*, *9*(3), 235–244. https://doi.org/10.14202/vetworld.2016.235-244

David N. Koons, Pat Terletzky, Peter B. Adler, Michael L. Wolfe, Dustin Ranglack, Frank P. Howe, Kent Hersey, Wade Paskett, J. T. du T. (2012). Climate and density-dependent drivers of recruitment in plains bison. *Journal of Mammalogy, 93*(2), 475–481. https://doi.org/10.1644/11-MAMM-A-281.1

Davidson, A. D., Hamilton, M. J., Boyer, A. G., Brown, J. H., & Ceballos, G. (2009). Multiple ecological pathways to extinction in mammals. *Proc Natl Acad Sci U S A*, *106*(26), 1–4. https://doi.org/10.1073/pnas.0901956106

Dawson, T. P., Jackson, S. T., House, J. I., Prentice, I. C., & Mace, G. M. (2011). Beyond predictions: biodiversity conservation in a changing climate. *Science (New York, N.Y.)*, *332*(6025), 53–58. https://doi.org/10.1126/science.1200303

De Leeuw J., Prins, H.H.T, Njuguna, E.C., Said, M., De By, R. (1998). *Interpretation of the Department of Resource Surveys and Remote Sensing (DRSRS) animal counts (1977–1997) in the rangeland Districts of Kenya. Ministry of Planning and National Development, Nairobi, Kenya*.

De Silva, R. P., Dayawansa, N. D. K., & Ratnasiri, M. D. (2007). A Comparison of Methods Used in Estimating Missing Rainfall Data. *University of Peradeniya*, *May*, 101–108.

De Silva, S., Elizabeth Webber, C., Weerathunga, U. S., Pushpakumara, T. V., Weerakoon, D. K., & Wittemyer, G. (2013). Demographic variables for wild Asian elephants using longitudinal observations. *PLoS ONE, 8*(12). https://doi.org/10.1371/journal.pone.0082788

Demment, M. W., Soest, P. J. Van, Naturalist, T. A., & May, N. (1985). A Nutritional Explanation for Body-Size Patterns of Ruminant and Nonruminant Herbivores. *The American Naturalist*, *125*(5), 641–672.

Deshmukh, I. (1984). A common relationship between precipitation and grassland peak biomass for East and southern Africa - DESHMUKH - 1984 - African Journal of Ecology - Wiley Online Library. *African Journal of Ecology*, *22*(3), 181–186. https://doi.org/10.1111/j.1365-2028.1984.tb00693.x

Diffenbaugh, N. S., & Field, C. B. (2013). Changes in Ecologically Critical Terrestrial Climate Conditions. *Science*, *341*(6145), 486–492. https://doi.org/10.1126/science.1237123

Dinku T, Funk C,Peterson P, et al. (2018). Validation of the CHIRPS satel-lite rainfall estimates over eastern Africa. *Quartely Journal of the Royal Meteorological Society*, *144*(711). https://doi.org/https://doi.org/10.1002/qj.3244

Doan, C. D., Liu, J., Liong, S.-Y., Kim, D. E., Sanders, R., & Fewtrell, T. (2014). *Combining Satellite And Gauge Precipitation Data With Co-Kriging Method For Jakarta Region*.

Dore, M. H. I. (2005). Climate change and changes in global precipitation patterns: What do we know? *Environment International*, *31*(8), 1167–1181. https://doi.org/10.1016/j.envint.2005.03.004

Douglas-Hamilton, I., Krink, T., & Vollrath, F. (2005). Movements and corridors of African elephants in relation to protected areas. In *Naturwissenschaften* (Vol. 92, Issue 4, pp. 158–163). https://doi.org/10.1007/s00114-004-0606-9

Dublin, H. T., Sinclair, A. R., and McGlade, J. (1990). Elephants and Fire as Causes of Multiple Stable States in the Serengeti-Mara Woodlands. *The Journal of Animal Ecology*, *59*(3), 1147–1164. https://doi.org/10.2307/5037

Dublin, H.T. & Ogutu, J. O. (2015). Population regulation of African buffalo in the Mara – Serengeti ecosystem. *Wildlife Research, 42*, 382–393.

Dublin, H. T., & Ogutu, J. O. (2015). Population regulation of African buffalo in the Mara-Serengeti ecosystem. *Wildlife Research, 42*(5), 382–393. https://doi.org/10.1071/WR14205

Dunkin, R. C., Wilson, D., Way, N., Johnson, K., & Williams, T. M. (2013). Climate influences thermal balance and water use in African and Asian elephants: Physiology can predict drivers of elephant distribution. *Journal of Experimental Biology*, *216*(15), 2939–2952. https://doi.org/10.1242/jeb.080218

East, R. (1984). Rainfall, soil nutrient status and biomass of large African savanna mammals. *African Journal of Ecology*, *22*(4), 245–270. https://doi.org/https://doi.org/10.1111/j.1365-

2028.1984.tb00700.x

Edwards, D.C. and McKee, T. B. (1997). Characteristics of 20th Century Drought in the United States at Multiple Times Scales. *Atmospheric Science, Paper, 634*, 1–30.

Ehrlich, P. R., & Pringle, R. M. (2009). Where does biodiversity go from here? A grim business-as-usual forecast and a hopeful portfolio of partial solutions. In *In the Light of Evolution* (Vol. 2, pp. 329–346). https://doi.org/10.17226/12501

Ellis, J., & Galvin, K. A. (1994). Climate Patterns and Land-Use Practices in the Dry Zones of Africa. In *BioScience* (Vol. 44, Issue 5). https://doi.org/10.2307/1312384

Endris, H., Lennard, C., Hewitson, B., Dosio, A., Nikulin, G., Panitz, H. (2015). Teleconnection responses in multi-GCM driven CORDEX RCMs over Eastern Africa. *Springer*. https://doi.org/10.1007/s00382-015-2734-7

Endris, H. S. (2016). *Projected changes in rainfall and temperature over Greater Horn of Africa ( GHA ) in different scenarios In Support of : Planning for Resilience in East Africa through Policy , Adaptation , Research , and Economic Development ( PREPARED ) Project March 20* (Issue March).

Endris, H. S., Omondi, P., Jain, S., Lennard, C., Hewitson, B., Chang'a, L., Awange, J. L., Dosio, A., Ketiem, P., Nikulin, G., Panitz, H. J., B??chner, M., Stordal, F., & Tazalika, L. (2013). Assessment of the performance of CORDEX regional climate models in simulating East African rainfall. *Journal of Climate*, *26*(21), 8453–8475. https://doi.org/10.1175/JCLI-D-12-00708.1

Endris, H. S., Omondi, P., Prediction, I. C., Centre, A., Jain, S., & Lennard, C. (2013). Assessment of the Performance of CORDEX Regional Climate Models in Simulating East African Rainfall Assessment of the Performance of CORDEX Regional Climate Models in Simulating East African Rainfall. *Journal of Climate*, *21*(26), 8453–8475. https://doi.org/10.1175/JCLI-D-12-00708.1

Esikuri, E. E. (1998). *Spatio-Temporal Effects of Land Use Changes in A Savanna Wildlife Area of Kenya. Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Doctor of Philos* (Issue June).

Estes, R. D., Atwood, J. L., & Estes, A. B. (2006). Downward trends in Ngorongoro Crater ungulate populations 1986-2005: Conservation concerns and the need for ecological research.

In *Biological Conservation* (Vol. 131, Issue 1, pp. 106–120). https://doi.org/10.1016/j.biocon.2006.02.009

Fedorov, A. V., & Philander, S. G. (2000). Is El Nino changing? *Science*, *288*(5473), 1997–2002. https://doi.org/10.1126/science.288.5473.1997

Field, C.B., V.R. Barros, K.J. Mach, M.D. Mastrandrea, M. van Aalst,W.N. Adger, D.J. Arent, J. Barnett, R. Betts, T.E. Bilir, J. Birkmann, J. Carmin, D.D. Chadee, A.J. Challinor, M. Chatterjee, W. Cramer, D.J. Davidson, Y. O. E., J.-P. Gattuso, Y. Hijioka, O. Hoegh-Guldberg, H.Q. Huang, G.E. Insarov, R.N. Jones, R.S. Kovats, P. R.-L., J.N. Larsen, I.J. Losada, J.A. Marengo, R.F. McLean, L.O. Mearns, R. Mechler, J.F. Morton, I. Niang, T. Oki, J. M. O., M. Opondo, E.S. Poloczanska, H.-O. Pörtner, M.H. Redsteer, A. Reisinger, A. Revi, D.N. Schmidt, M. R. S., W. Solecki, D.A. Stone, J.M.R. Stone, K.M. Strzepek, A.G. Suarez, P. Tschakert, R. Valentini, S. Vicuña, A. V., & K.E. Vincent, R.Warren, L.L.White, T.J.Wilbanks, P.P.Wong, and G. W. Y. (2014). Technical summary. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. https://doi.org/10.1016/j.renene.2009.11.012

Foley, C., Pettorelli, N., & Foley, L. (2008). Severe drought and calf survival in elephants. *Population Ecology*, *August*, 541–544. https://doi.org/10.1098/rsbl.2008.0370

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive Governance of Social-Ecological Systems. *Annual Review of Environment and Resources*, *15*(30), 441–473. https://doi.org/10.1146/annurev.energy.30.050504.144511

Fordham, D. A. (2015). Mesocosms Reveal Ecological Surprises from Climate Change. *PLoS Biology*, *13*(12), 1–7. https://doi.org/10.1371/journal.pbio.1002323

Funk, C., Eilerts, G., Davenport, F., & Michaelsen, J. (2010). *A Climate Trend Analysis of Kenya — August 2010*. *1975*(August), 4 pp. http://www.fews.net/docs/Publications/FEWS Kenya Climate Trend Analysis.pdf

Funk, C., Dettinger, M. D., Michaelsen, J. C., Verdin, J. P., Brown, M. E., Barlow, M., & Hoell, A. (2008). Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(32), 11081–11086. https://doi.org/10.1073/pnas.0708196105

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., & Michaelsen, J. (2015). The climate hazards infrared precipitation with stations - A new environmental record for monitoring extremes. *Scientific Data*, *2*, 1–21. https://doi.org/10.1038/sdata.2015.66

Fynn, R. W. S., Augustine, D. J., Peel, M. J. S., & de Garine-Wichatitsky, M. (2016). REVIEW: Strategic management of livestock to improve biodiversity conservation in African savannahs: A conceptual basis for wildlife-livestock coexistence. *Journal of Applied Ecology*, *53*(2), 388–397. https://doi.org/10.1111/1365-2664.12591

Galaty, J.G. and Munei, K. O. (1998). *Maasai Land, Law, and Dispossession. Cultural Survival*. Quartely. https://www.culturalsurvival.org/publications/ cultural-survival-quarterly/maasai-land-law-and-dispossession

Galaty, J. G. (2013). The collapsing platform for pastoralism: Land sales and land loss in kajiado county, kenya. In *Nomadic Peoples* (Vol. 17, Issue 2, pp. 20–39). https://doi.org/10.3167/np.2013.170204

Gandiwa, E. (2016). Rainfall variability and its impact on large mammal populations in a complex of semi-arid African savanna protected areas. *Tropical Ecology*, *57*(2), 163–180.

Gara, T. W. (2014). *Effect of Water Availability, Landscape Fragmentation and Forage Abundance onThe Movement And Habitat Utilization of Elephants*.

Garstange, M., Davis, R. E., Leggett, K., Frauenfeld, O. W., Greco, S., Zipser, E., & Peterson, M. (2014). Response of African Elephants (Loxodonta africana) to Seasonal Changes in Rainfall. In *Plos One* (Vol. 9, Issue 10, p. e108736). https://doi.org/10.1371/journal.pone.0108736

Gaston, K.J., and Curnutt, J.L. (1998). The Dynamics of Abundance-Range Size Relationships. *Oikos*, *81*(1), 38–44. https://doi.org/10.2307/3546465

Georgiadis, N. J., Olwero, N., Ojwang, G., & Aike, G. (2011). Reassessing Aerial Sample Surveys for Wildlife Monitoring , Conservation , and Management. In *Research gate*. https://doi.org/10.5479/si.00810282.632.31

Giannini, A., Biasutti, M., Held, I. M., & Sobel, A. H. (2008). A global perspective on African climate. *Climatic Change*, *90*(4), 359–383. https://doi.org/10.1007/s10584-008-9396-y

Gillingham, S., & Lee, P. (1999). The impact of wildliferelated\nbenefits on the conservation attitudes of\nlocal people around the Selous Game Reserve, Tanzania. In *Environmental Conservation* (Vol. 26, Issue 3, pp. 218–228). https://www.cambridge.org/core/services/aopcambridge-core/content/view/DA99AE4F27AFB1DDB77C780FCA596876/S0376892999000302a.pdf/div-class-title-the-impact-of-wildlife-related-benefits-on-the-conservation-attitudes-of-local-people-around-the-selous-game-re

GISTEMP Team. (2017). *GISS Surface Temperature Analysis (GISTEMP)*. NASA Goddard Institute for Space Studies.

GoK. (2009). *Republic of Kenya - National Disaster Management Plan*.

Goodman, L. . (1961). Snowball Sampling. *Annals of Mathematical Statistics*, *31*(1), 148–170. https://doi.org/10.1214/aoms/1177705148

Gough, K. F., & Kerley, G. I. H. (2006). Demography and population dynamics in the elephants Loxodonta africana of Addo Elephant National Park, South Africa: is there evidence of density dependent regulation? *Oryx*, *40*(04), 434. https://doi.org/10.1017/S0030605306001189

Graham, I. S. . P. and A. D. (1989). Elephant decline: downward trends in African elephant distribution and numbers (part ii). *International Journal of Environmental Studies*, *35*(1–2), 13–26. https://doi.org/https://doi.org/10.1080/00207238908710546

Groom, R. J., & Western, D. (2013). Impact of land subdivision and sedentarization on wildlife in kenya's southern rangelands. *Rangeland Ecology and Management*, *66*(1), 1–9. https://doi.org/10.2111/REM-D-11-00021.1

Hansen, J., Nazarenko, L., Ruedy, R., Sato, M., Willis, J., Genio, A. Del, Koch, D., Lacis, A., Lo, K., Menon, S., Novakov, T., Perlwitz, J., Russell, G., Schmidt, G. A., & Tausnev, N. (2005). Earth's Energy Imbalance: Confirmation and Implications. *Science*, *308*, 1431–1435. https://doi.org/10.1126/science.1110252

Hastenrath, S., Polzin, D., & Mutai, C. (2007). Diagnosing the 2005 drought in equatorial East Africa. *Journal of Climate*, *20*(18), 4628–4637. https://doi.org/10.1175/JCLI4238.1

Hayhoe, K., Edmonds, J., Kopp, R. E., LeGrande, A. N., Sanderson, B. M., Wehner, M. F., & Wuebbles, .J. (2017). Climate Models, Scenarios, and Projections. *Climate Science Special Report: Fourth National Climate Assessment*, *I*, 133–160. https://doi.org/10.7930/J0WH2N54.U.S.

Hilbers JP, Schipper AM, Hendriks AJ, Verones F, Pereira HM, H. M. (2016). An allometric approach to quantify the extinction vulnerability of birds and mammals. *Pub Med*, *97*(3), 615-

26.

Hillmann JC. and Hillman AKK. (1977). Mortality of wildlife in Nairobi National Park, during the drought of 1973–1974. *African Journal of Ecology*, *15*(1), 1–18.

Hoare, R. E. (1999). Determinants of human-elephant conflict in a land-use mosaic. *Journal of Applied Ecology*, *36*(5), 689–700. https://doi.org/10.1046/j.1365-2664.1999.00437.x

Hoegh-Guldberg, O., D. Jacob, M. Taylor, M. Bindi, S. Brown, I. Camilloni, A. Diedhiou, R. Djalante, K.L. Ebi, F. E., & J.Guiot, Y. Hijioka, S. Mehrotra, A. Payne, S.I. Seneviratne, A. Thomas, R. Warren, and G. Z. (2018). Impacts of 1.5ºC Global Warming on Natural and Human Systems. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of . *Special Report, Intergovernmental Panel on Climate Change*, *ISBN 978-92-9169-151-7*, 175–311.

Holdo, R. M., Holt, R. D., & Fryxell, J. M. (2009). Opposing Rainfall and Plant Nutritional Gradients Best Explain the Wildebeest Migration in the Serengeti. *American Naturalist*, *173*(4), 431–445. https://doi.org/10.1086/597229

Hopcraft, J. G. C., Morales, J. M., Beyer, H. L., Borner, M., Mwangomo, E., Sinclair, A. R. E., Olff, H., & Haydon, D. T. (2014). Competition, predation, and migration: Individual choice patterns of Serengeti migrants captured by hierarchical models. *Ecological Monographs*, *84*(3), 355–372. https://doi.org/10.1890/13-1446.1

Howe, M., Okello, M. M., & Davis, J. M. (2013). Interspecific Variation in the Distribution of Ungulates Relative to Human Infrastructure Surrounding Amboseli National Park. *African Zoology*, *48*(1), 159–166. https://doi.org/10.3377/004.048.0107

Huey, R. B., Kearney, M. R., Krockenberger, A., Holtum, J. A. M., Jess, M., & Williams, S. E. (2012). Predicting organismal vulnerability to climate warming: roles of behaviour, physiology and adaptation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1596), 1665–1679. https://doi.org/10.1098/rstb.2012.0005

Illius, A. W., & Gordon, I. J. (1992). Modelling the nutritional ecology of ungulate herbivores: evolution of body size and competitive interactions. In *Oecologia* (Vol. 89, Issue 3, pp. 428–434). https://doi.org/10.1007/BF00317422

Indeje, M., Semazzi, F. H. M., & Ogallo, L. J. (2000). ENSO signals in East African rainfall seasons. *International Journal of Climatology*, *20*(1), 19–46.

https://doi.org/10.1002/(SICI)1097-0088(200001)20:1<19::AID-JOC449>3.0.CO;2-0

Infield, M., & Namara, A. (2001). Community attitudes and behaviour towards conservation : an assessment of a community conservation programme around Lake Mburo National Park , Uganda. *Oryx Banner*, *35*(1), 48–60. http://www.infieldconservation.com/uploads/2/7/6/0/27607009/community_attitudes_to_lmnp_paper_oryx_2001.pdf

IPBES. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. Settele, E. S. Brondízio E.S., H. T. Ngo, M. Guèze, J. Aga. In *Debating Nature's Value* (Issue 6 May). https://doi.org/10.1007/978-3-319-99244-0_2

IPCC. (2007). Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Ave. In *New York Cambridge University Press*. https://doi.org/10.1038/446727a

IPCC. (2014). Summary for Policymakers. In *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. https://doi.org/10.1017/CBO9781107415324

IPCC. (2019). *Climate Change and Land:An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.*

IUCN. (2013). *2013 IUCN Annual Report*.

Jachmann, H., & Croes, T. (1991). Effects of browsing by elephants on the Combretum/Terminalia woodland at the Nazinga Game Ranch, Burkina Faso, West Africa. In *Biological Conservation* (Vol. 57, Issue 1, pp. 13–24). https://doi.org/10.1016/0006-3207(91)90105-I

Jachowski, D. S. (2012). Moss, C. J., H. Croze, and P. C. Lee (eds.). 2011. The Amboseli Elephants: A Long-term Perspective on a Long-lived Mammal. University of Chicago Press, Chicago, Illinois, 383 pp. ISBN-13 978-0-226-54223-2 and ISBN-10 0-226-54223-8, price (hardbound), $65. *Journal of Mammalogy*, *93*(1), 294–295. https://doi.org/10.1644/11-mamm-r-329.1

Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O. B., Bouwer, L. M., Braun, A., Colette, A., Déqué, M., Georgievski, G., Georgopoulou, E., Gobiet, A., Menut, L., Nikulin, G., Haensler, A., Hempelmann, N., Jones, C., Keuler, K., Kovats, S., … Yiou, P. (2014). EURO-CORDEX: New high-resolution climate change projections for European impact research. *Regional Environmental Change*, *14*(2), 563–578. https://doi.org/10.1007/s10113-013-0499-2

Jain, S. K., & Kumar, V. (2012). Trend analysis of rainfall and temperature data for India. *Current Science*, *102*(1), 37–49.

Jonathan, K. H., & Suvarna Raju, P. (2017). Analysis of rainfall pattern and temperature variations in three regions of sultanate of Oman. *International Journal of Civil Engineering and Technology*, *8*(2), 173–181.

Kaelo, D. (2007). *Human-elephant conflict in pastoral areas north of Massai Mara National Reserve, Kenya*. Moi University, Eldoret, Kenya.

Kagwa, S. (2011). *Spatial Distribution of Human Elephant Conflict (HEC) and Characterization of Crop-Raiding Elephants in Kasigau Region, Kenya* [Western Kentucky University]. http://digitalcommons.wku.edu/theses/1083/

Kandalam, G. and Samireddypalle, A. (2015). *Impact of Climate Change on Forage Availability for Livestock. Climate Change Impact on Livestock: Adaptation and Mitigation* (pp. 92–117). https://doi.org/10.1007/978-81-322-2265-1_7

Kearney, M., Shine, R., & Porter, W. P. (2009). The potential for behavioral thermoregulation to buffer “cold-blooded” animals against climate warming. *Proceedings of the National Academy of Sciences*, *106*(10), 3835–3840. https://doi.org/10.1073/pnas.0808913106

Kendall, M. (1938). A New Measure of Rank Correlation. *Biometrika*, *30*(1–2), 81–93. https://doi.org/org/10.1093/biomet/30.1-2.81

Kendall, M. G. (1975). *Rank Correlation Methods.* (4th Editio). Griffin, Charles.

Kimani, K., & Pickard, J. (1998). Recent Trends and Implications of Group Ranch Sub-Division and Fragmentation in Kajiado District, Kenya. *The Geographical Journal*, *164*(2), 202.

Kioko, J., okello, M., Muruthi, P. (2006). Elephant dynamics Amboseli Tsavo.pdf. *Pachyderm*, *40*.

Kioko, J., & Okello, M. M. (2010). Land use cover and environmental changes in a semi- arid rangeland, Southern Kenya. *Journal of Geography and Regional Planning*, *3*(11), 322–326. http://www.academicjournals.org/JGRP

Kisembe, J. (2019). Evaluation of rainfall simulations over Uganda in CORDEX regional climate models. *Theoretical and Applied Climatology*, *137*, 1117–1134.

Klein, J. T. (2008). Evaluation of Interdisciplinary and Transdisciplinary Research: A Literature Review. In *American Journal of Preventive Medicine* (Vol. 35, Issues 2, Supplement, pp. S116–S123). https://doi.org/10.1016/j.amepre.2008.05.010

Knaepen, H., Torres, C., & Rampa, F. (2015). *Making agriculture in Africa climate-smart From continental policies to local practices*. *80*, 1–20.

KNBS. (2010). The 2009 Kenya population and housing census. "Counting our people for the implementation of vision 2030". Volume II. Kenya National Bureau of Statistics, Ministry of State for Planning, National Development and Vision 2030. In *Kenya National Bureau of Statistics: Vol. IC*. http://www.knbs.or.ke/index.php?option=com_phocadownload&view=category&download=584:volume-1c-population-distribution-by-age-sex-and-administrative-units&id=109:population-and-housing-census-2009&Itemid=599

Knutti, R., & Sedláˇ, J. (2014). Robustness and uncertainties in the new CMIP5 climate model projections. *Nature Climate Change*, *3*(4), 1–6. https://doi.org/10.1038/nclimate1716

Kundzewicz, Z. W., Robson, A. J., & Robson, A. J. (2004). Change detection in hydrological records — a review of the methodology. *Hydrological Sciences Journal*, *6667*. https://doi.org/10.1623/hysj.49.1.7.53993

KWCA. (2019). *Strategic Plan 2019 -2023. Kenya Wildlife Conservancies Association*.

Lawrence, R. J., & Després, C. (2004). Futures of Transdisciplinarity. *Futures*, *36*(4), 397–405. https://doi.org/10.1016/j.futures.2003.10.005

Lee, P., & Graham, M. D. (2006). African elephants Loxodonta africana and human-elephant interactions: implications for conservation. In *International Zoo Yearbook* (Vol. 40, Issue 1, pp. 9–19). https://doi.org/10.1111/j.1748-1090.2006.00009.x

Lee, P. C., Bussière, L. F., Webber, C. E., Poole, J. H., & Moss, C. J. (2013). Enduring consequences of early experiences: 40 year effects on survival and success among African elephants (Loxodonta africana). *Biology Letters*, *9*(2), 20130011. https://doi.org/10.1098/rsbl.2013.0011

Leggett, K. E. A. (2006). Home range and seasonal movement of elephants in the Kunene Region, northwestern Namibia. *African Zoology*, *41*(1), 17–36. https://doi.org/10.1080/15627020.2006.11407332

Lennard, C. J., Nikulin, G., Dosio, A., & Moufouma-Okia, W. (2018). On the need for regional climate information over Africa under varying levels of global warming. *Environmental Research Letters*, *13*(6). https://doi.org/10.1088/1748-9326/aab2b4

Lilian Shiao-Yen Wu and Daniel B. Botkin. (1980). Of Elephants and Men: A Discrete, Stochastic Model for Long-Lived Species with Complex Life Histories. *The American Naturalist*, *116*(6), 831–849.

Luhunga, P., Botai, J., & Kahimba, F. (2016). Evaluation of the performance of CORDEX regional climate models in simulating present climate conditions of Tanzania Evaluation of the performance of CORDEX regional climate models in simulating present climate conditions of Tanzania. *Journal of Southern Hemisphere Earth Systems Science*, *66*(March), 32–54. https://doi.org/10.22499/3.6601.005

Luhunga, P. M., Kijazi, A. L., Chang'a, L., Kondowe, A., Ng'ongolo, H., & Mtongori, H. (2018). Climate change projections for Tanzania Based on high-resolution regional climate models from the Coordinated Regional Climate Downscaling Experiment (CORDEX)-Africa. *Frontiers in Environmental Science*, *6*(OCT), 1–20. https://doi.org/10.3389/fenvs.2018.00122

Lyon, B., & Dewitt, D. G. (2012). A recent and abrupt decline in the East African long rains. *Geophysical Research Letters*, *39*(2), 1–5. https://doi.org/10.1029/2011GL050337

Mackenzie, C. A., & Ahabyona, P. (2012). Elephants in the garden: Financial and social costs of crop raiding. In *Ecological Economics* (Vol. 75, pp. 72–82). https://doi.org/10.1016/j.ecolecon.2011.12.018

Madliger, C. L., Cooke, S. J., Crespi, E. J., Funk, J. L., Hultine, K. R., Hunt, K. E., Rohr, J. R., Sinclair, B. J., Suski, C. D., Willis, C. K. R., & Love, O. P. (2016). Success stories and emerging themes in conservation physiology. *Conservation Physiology*, *4*(1), 1–17. https://doi.org/10.1093/conphys/cov057

Margaret, B. D. (1986). *climatic Instability, Time Lag,and community Disequilibrium* (J (Ed.)). community ecology.

Mazaris, A. D., Papanikolaou, A. D., Barbet-Massin, M., Kallimanis, A. S., Jiguet, F., Schmeller, D. S., & Pantis, J. D. (2013). Evaluating the Connectivity of a Protected Areas' Network under the Prism of Global Change: The Efficiency of the European Natura 2000 Network for Four Birds of Prey. *PLoS ONE*, *8*(3). https://doi.org/10.1371/journal.pone.0059640

Mckee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. *Applied Climatology*, *January*, 179–184. https://doi.org/citeulike-article-id:10490403

McPhaden, M. J., Zebiak, S. E., & Glantz, M. H. (2006). ENSO as an integrating concept in earth science. In *Science* (Vol. 314, Issue 5806, pp. 1740–1745). https://doi.org/10.1126/science.1132588

Mduma SAR, Sinclair ARE, H. R. (1999). Food regulates the Serengeti wildebeest_ a 40-year record. *Journal of Animal Ecology*, *68*, 1101–1122. https://doi.org/https://doi.org/10.1046/j.1365-2656.1999.00352.x

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S. C. B. (2007). *Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. A.*

Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M. L. T., Lamarque, J., Matsumoto, K., Montzka, S. A., Raper, S. C. B., Riahi, K., Thomson, A., Velders, G. J. M., & van Vuuren, D. P. P. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic Change*, *109*(1), 213–241. https://doi.org/10.1007/s10584-011-0156-z

Meinzen-Dick, R., Raju, K. V., & Gulati, A. (2002). What affects organization and collective action for managing resources? Evidence from canal irrigation systems in India. In *World Development* (Vol. 30, Issue 4, pp. 649–666). https://doi.org/10.1016/S0305-750X(01)00130-9

Metzger, K. L., Sinclair, A. R. E., Hilborn, R., Hopcraft, J. G. C., & Mduma, S. A. R. (2010). Evaluating the protection of wildlife in parks: The case of African buffalo in Serengeti. *Biodiversity and Conservation*, *19*(12), 3431–3444. https://doi.org/10.1007/s10531-010-9904-z

Midgley, G. F., Hannah, L., Millar, D., Rutherford, M. C., & Powrie, L. W. (2002). Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. *Global Ecology and Biogeography*, 445–451.

Ministry of Tourism and Wildlife. (2018). *National Wildlife Strategy 2030. Full report.* (Issue

June). https://kwcakenya.com/download/national-wildlife-strategy-2030/

Moehlman, P. D., Ogutu, J. O., Piepho, H. P., Runyoro, V. A., Coughenour, M. B., & Boone, R. B. (2020). Long-term historical and projected herbivore population dynamics in Ngorongoro crater, Tanzania. In *PLoS ONE* (Vol. 15, Issue 3). https://doi.org/10.1371/journal.pone.0212530

Moiko, S., Bedelian, C., Yahya, M., Robina, S., & Joanes, A. (2019). Land use transformation in Kajiado county, Kenya: Implications of a changing climate. *Policy Brief*.

Morgan, E., O' Riordan, R. M., & Culloty, S. C. (2013). Climate change impacts on potential recruitment in an ecosystem engineer. *Ecology and Evolution*, *3*(3), 581–594. https://doi.org/10.1002/ece3.419

Morrison, J. C., Sechrest, W., Dinerstein, E., Wilcove, D. S., & Lamoreux, J. F. (2007). Persistence of Large Mammal Faunas as Indicators of Global Human Impacts. *Journal of Mammalogy*, *88*(6), 1363–1380. https://doi.org/10.1644/06-mamm-a-124r2.1

Mose, V. N., Nguyen-Huu, T., Western, D., Auger, P., & Charles, N. (2013). Modelling the dynamics of migrations for large herbivore populations in the Amboseli National Park, Kenya. In *Ecological Modelling* (Vol. 254, pp. 43–49). https://doi.org/10.1016/j.ecolmodel.2013.01.016

Moses, M. O., John, W. K., Stephen, J. N., & James, I. (2016). Prevalence of human elephant conflicts in Amboseli ecosystem, Kenya: Current opinions of local community. *International Journal of Biodiversity and Conservation*, *8*(3), 60–71. https://doi.org/10.5897/IJBC2015.0865

Moss, C.J., Croze, H., and Lee, P.C. (2011). The Amboseli elephants: a long-term perspective on a long-lived mammal. In *Oxford University Press* (Vol. 93, Issue 1). https://doi.org/10.7208/chicago/9780226542263.001.0001

Moss C.J. (2001). The demography of an African elephant (Loxodonta africana) population in Amboseli, Kenya. *Journal of Zoology*, *255*, 145–156.

Moss, R. H., Edmonds, J. a, Hibbard, K. a, Manning, M. R., Rose, S. K., van Vuuren, D. P., Carter, T. R., Emori, S., Kainuma, M., Kram, T., Meehl, G. a, Mitchell, J. F. B., Nakicenovic, N., Riahi, K., Smith, S. J., Stouffer, R. J., Thomson, A. M., Weyant, J. P., & Wilbanks, T. J. (2010). The next generation of scenarios for climate change research and assessment. *Nature*, *463*(7282), 747–756. https://doi.org/10.1038/nature08823

Msoffe, F. U., Ogutu, J. O., Said, M. Y., & Shem, C. (2019). Wildebeest migration in East Africa: Status, threats and conservation measures. In *bioRxiv* (Issue February). https://doi.org/10.1101/546747

Msoffe, F. U., Said, M. Y., Ogutu, J. O., Kifugo, S. C., De, J., Gardingen, P. Van, & Reid, R. S. (2011). *Spatial correlates of land-use changes in the Maasai- Steppe of Tanzania : Implications for conservation and environmental planning*. *3*(July), 280–290.

Mukhopadhyay, S., Ogutu, J. O., Bartzke, G., Dublin, H. T., & Piepho, H. P. (2019). Modelling Spatio-Temporal Variation in Sparse Rainfall Data Using a Hierarchical Bayesian Regression Model. In *Journal of Agricultural, Biological, and Environmental Statistics* (Vol. 24, Issue 2, pp. 369–393). https://doi.org/10.1007/s13253-019-00357-3

Mumby, H. S., Courtiol, A., Mar, K. U., & Lummaa, V. (2013). Birth seasonality and calf mortality in a large population of Asian elephants. *Ecology and Evolution*, 3794–3803. https://doi.org/10.1002/ece3.746

Mwangi, E., Meinzen-dick, R., & Ostrom, E. (2006). CAPRi Working Paper # 46 Subdividing the Commons : The Politics of Property Rights Transformation in Kenya ' s Maasailand This research was supported by the American Association of University Women , the Compton Foundation , the Institute for the Study of. *Food Policy*.

Mwenda, J. (2001). Spatial information in land tenure reform with special reference to Kenya. *International Conference on Spatial Information for …*, *October*, 1–11. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:SPATIAL+INFORMATION+IN+LAND+TENURE+REFORM+WITH+SPECIAL+REFERENCE+TO+KENYA#0

Mworia, J. K., Kinyamario, J. I., & Githaiga, J. M. (2008). Influence of cultivation, settlements and water sources on wildlife distribution and habitat selection in south-east Kajiado, Kenya. In *Environmental Conservation* (Vol. 35, Issue 2, pp. 117–124). https://doi.org/10.1017/S0376892908004670

Naderifar, M., Goli, H., & Ghaljaie, F. (2017). Snowball Sampling : A Purposeful Method of Sampling in Qualitative Research Snowball Sampling : A Purposeful Method of Sampling in Qualitative. *Strides Development Medical Education*, *14*(3). https://doi.org/10.5812/sdme.67670

Nathan, R., Getz, W. M., Revilla, E., Holyoak, M., Kadmon, R., Saltz, D., & Smouse, P. E. (2008). Movement ecology special feature: a movement ecology paradigm for unifying organismal movement research. *Proc Natl Acad Sci USA, 105*. https://doi.org/10.1073/pnas.0800375105

Naughton, L., Rose, R., & Treves, A. (1999). *The social dimensions of human-elephant conflict in Africa: A literature review and case studies from Uganda and Cameroon. A Report to the African Elephant Specialist , Human-Elephant Task Conflict Task Force, of IUCN, Glands, Switzerland* (Issue December). http://african-elephant.org/hec/pdfs/hecugcarev.pdf

Ndiritu, M. J. (2013). *Mathematical and statistical population models: elephants population modeling*. 171. http://erepository.uonbi.ac.ke:8080/xmlui/handle/11295/52890%5Cnhttp://erepository.uonbi.ac.ke/bitstream/handle/11295/52890/Mathematical and Statistical Population Models%3A Elephants Population Modeling ?sequence=3

Newbold, T. (2018). Future effects of climate and land-use change on terrestrial vertebrate community diversity under different scenarios. *Proceedings of the Royal Society B: Biological Sciences, 285*(1881). https://doi.org/10.1098/rspb.2018.0792

Newmark, W. D. (1996). Insularization of Tanzanian Parks and the Local Extinction of Large Mammals. In *Conservation Biology* (Vol. 10, Issue 6, pp. 1549–1556). https://doi.org/10.1046/j.1523-1739.1996.10061549.x

Ngene, S. M., Skidmore, A. K., Van Gils, H., Douglas-Hamilton, I., & Omondi, P. (2009). Elephant distribution around a volcanic shield dominated by a mosaic of forest and savanna (Marsabit, Kenya). In *African Journal of Ecology* (Vol. 47, Issue 2, pp. 234–245). https://doi.org/10.1111/j.1365-2028.2008.01018.x

Ngigi, M. W., Mueller, U., & Birner, R. (2016). *Gender differences in climate change perceptions and adaptation strategies_ an intra-household analysis from rural Kenya*. Discussion Papers 232900, Univesity of BonnCenter for Development Research (ZEF).

Niang, I., Ruppel, O. C., Abdrabo, M. A., Essel, A., Lennard, C., Padgham, J., & Urquhart, P. (2015). Africa. *Climate Change 2014: Impacts, Adaptation and Vulnerability: Part B: Regional Aspects: Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 1199–1266. https://doi.org/10.1017/CBO9781107415386.002

Nikulin, G., Jones, C., Giorgi, F., Asrar, G., Büchner, M., Cerezo-Mota, R., Christensen, O. B., Déqué, M., Fernandez, J., Hänsler, A., van Meijgaard, E., Samuelsson, P., Sylla, M. B., & Sushama, L. (2012). Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations. *Journal of Climate*, *25*(18), 6057–6078. https://doi.org/10.1175/JCLI-D-11-00375.1

Norton-Griffiths .M. (1978). *Revised second edition Handbook* (J.J.R Grimsdell (Ed.); Revised se).

Ntiati, P. (2002). Group Ranches Subdivision Study in Loitokitok Division of Kajiado District, Kenya. *CGSpace*, 31. LUCID-WP7.pdf

Nullis, C. (2018). IPCC issues Special Report on Global Warming of 1.5 °C. *World Meteorological Organization*, *67*(2). https://public.wmo.int/en/resources/bulletin/ipcc-issues-special-report-global-warming-of-15-°c

Nyamasyo, S. K., & Kihima, B. (2014a). Changing Land Use Patterns and Their Impacts on Wild Ungulates in Kimana Wetland Ecosystem, Kenya. *International Journal of Biodiversity*, *2014*, 1–10. https://doi.org/10.1155/2014/486727

Nyamasyo, S. K., & Kihima, O. B. (2014b). Changing Land Use Patterns and Their Impacts on Wild Ungulates in Kimana Wetland Ecosystem, Kenya. *International Journal of Biodiversity*, *2014*, 1–10. https://doi.org/10.1155/2014/486727

Ogutu, J. O., Piepho, H.P., Said, M. Y., & Kifugo, S. C. (2014). Herbivore Dynamics and Range Contraction in Kajiado County Kenya: Climate and Land Use Changes, Population Pressures, Governance, Policy and Human-wildlife Conflicts. *The Open Ecology Journal*, *7*(1), 9–31. https://doi.org/10.2174/1874213001407010009

Ogutu, J.O., and Owen-Smith, N. (2003). ENSO, rainfall and temperature influences on extreme population declines among African savannah ungulates. *Ecology Letters*, *6*, 412–419.

Ogutu, J.O., and Owen-Smith, N. (2005). Oscillations in large mammal populations: are they related to predation or rainfall? *African Journal of Ecology*, *43*(4), 332–339. https://doi.org/https://doi.org/10.1111/j.1365-2028.2005.00587.x

Ogutu, J.O., Kuloba, B., Piepho, H.P., Kanga, E. (2017). Wildlife Population Dynamics in Human-Dominated Landscapes under Community- Based Conservation : The Example of Nakuru Wildlife Conservancy , Kenya. *Plos One*, *12*(641918), 1–30. https://doi.org/10.1371/journal.pone.0169730

Ogutu, J.O., Owen-Smith, N., Piepho, H.P, Dublin, H.T. (2015). How Rainfall Variation Influences Reproductive Patterns of African Savanna Ungulates in an Equatorial Region Where Photoperiod Variation Is Absent. *PLoS ONE*, *10*(8), 1–13.

https://doi.org/10.1371/journal.pone.0133744

Ogutu, J.O., Owen-Smith, N., Piepho, H.P., Kuloba, B. and Edebe, J. (2012). Dynamics of ungulates in relation to climatic and land use changes in an insularized African savanna ecosystem. *Biodiversity and Conservation*, *21*(4), 1033–1053. https://doi.org/10.1007/s10531-012-0239-9

Ogutu, J.O., Piepho, H.P., Dublin, H.T., Bhola, N., Reid, R. S. (2010). Rainfall extremes explain interannual shifts in timing and synchrony of calving in topi and warthog. In *Population Ecology* (Vol. 52, Issue 1, pp. 89–102). https://doi.org/10.1007/s10144-009-0163-3

Ogutu, J.O. & Owen-Smith, N. (2003). ENSO, rainfall and temperature influences on extreme population declines among African savanna ungulates. In *Ecology Letters* (Vol. 6, Issue 5, pp. 412–419). https://doi.org/10.1046/j.1461-0248.2003.00447.x

Ogutu, J. ., Piepho, H., & Dublin, H. . (2014). Responses of phenology , synchrony and fecundity of breeding by African ungulates to interannual variation in rainfall. *Wildlife Research*. https://doi.org/http://dx.doi.org/10.1071/WR13117

Ogutu, J. O., Owen-Smith, N., Piepho, H. P., Said, M. Y., Kifugo, S. C., Reid, R. S., Gichohi, H., Kahumbu, P., & Andanje, S. (2013). Changing wildlife populations in Nairobi national park and adjoining Athi-Kaputiei plains_ Collapse of the migratory Wildebeest. *Open Conservation Biology Journal*, *7*, 11–26. https://doi.org/https://dx.doi.org/10.2174/1874839201307010011

Ogutu, J. O., Piepho, H. P., Dublin, H. T., Bhola, N., & Reid, R. S. (2008). Rainfall influences on ungulate population abundance in the Mara-Serengeti ecosystem. In *Journal of Animal Ecology* (Vol. 77, Issue 4, pp. 814–829). https://doi.org/10.1111/j.1365-2656.2008.01392.x

Ogutu, J. O., Piepho, H., & Said, M. Y. (2011). Continuing wildlife population declines and range contraction in the Mara region of Kenya during 1977–2009. *Zoology*, 1–11. https://doi.org/10.1111/j.1469-7998.2011.00818.x

Ogutu J.O, Piepho H.P, Said M.Y, Ojwang G.O, Njino L.W, Kifugo S.C, et al. (2016). Extreme wildlife declines and concurrent increase in livestock numbers in Kenya: What are the causes? *PLoS ONE*, *11*(9), 1–46. https://doi.org/10.1371/journal.pone.0163249

Ogutu, Z. A. (2002). The impact of ecotourism on livelihood and natural resource management in eselenkei, amboseli ecosystem, Kenya. *Land Degradation and Development*, *13*(3), 251–256. https://doi.org/10.1002/ldr.502

Ojwang', G. O., Wargute, P. W., Said, M. Y., Worden, J. S., Davidson, Z., Muruthi, P., Kanga, E., Ihwagi, F., & Okita-Ouma, B. (2017). Wildlife Migratory Corridors and Dispersal Areas: Kenya Rangelands and Coastal Terrestrial Ecosystems. In *Tourist Management Perspectives*. http://www.kws.go.ke/content/launch-report-wildlife-corridors-and-dispersal-areas

Okello, M. , Njumbi, S. , Kiringe, J. and Isiiche, J. (2014). Prevalence and Severity of Current Human-Elephant Conflicts in Amboseli Ecosystem , Kenya : Insights from the Field and Key Informants. *Natural Resources*, 462–477. https://doi.org/org/10.4236/nr.2014.59043

Okello,M.M; Manka,S.G & D'Amour, D. E. (2008). The relative importance of large mammal species for tourism in Amboseli The relative importance of large mammal species for tourism in Amboseli National Park , Kenya. *Journal of Tourism Management*, 751–760. https://doi.org/10.1016/j.tourman.2007.08.003

Okello,M.M & D'Amour, D. E. (2008). Agricultural expansion within Kimana electric fences and implications for natural resource conservation around Amboseli National Park, Kenya. *Journal of Arid Environments*, *72*(12), 2179–2192. https://doi.org/10.1016/j.jaridenv.2008.07.008

Okello, M. M. (2005). Land Use Changes and Human – Wildlife Conflicts in the Amboseli Area, Kenya. *Human Dimensions of Wildlife*, *10*(1), 19–28. https://doi.org/10.1080/10871200590904851

Okello, M. M., Buthmann, E., Mapinu, B., & Kahi, H. C. (2011). Community opinions on wildlife, resource use and livelihood competition in Kimana Group Ranch near Amboseli, Kenya. *Open Conservation Biology Journal*, *5*, 1–12. https://doi.org/10.2174/1874839201105010001

Okello, M. M., & D'Amour, D. E. (2008). Agricultural expansion within Kimana electric fences and implications for natural resource conservation around Amboseli National Park, Kenya. In *Journal of Arid Environments* (Vol. 72, Issue 12, pp. 2179–2192). https://doi.org/10.1016/j.jaridenv.2008.07.008

Okello, M. M., Kenana, L., Maliti, H., Kiringe, J. W., Kanga, E., Warinwa, F., Bakari, S., Ndambuki, S., Massawe, E., Sitati, N., Kimutai, D., Mwita, M., Gichohi, N., Muteti, D., Ngoru, B., & Mwangi, P. (2016). Population density of elephants and other key large herbivores in the Amboseli ecosystem of Kenya in relation to droughts. *Journal of Arid Environments*, *135*, 64–74. https://doi.org/10.1016/j.jaridenv.2016.08.012

Okello, M. M., & Kioko, J. (2010). Contraction of Wildlife Dispersal Area in Olgulului – Ololorashi Group Ranch Around Amboseli National Park, Kenya. *The Open Conservation Biology Journal*, *4*(1), 34–45. https://doi.org/10.2174/1874839201004010034

Okello, M. M., & Kiringe, J.W. (2004). Threats to biodiversity and their implications in protected and adjacent dispersal areas of Kenya. *Journal of Sustainable Tourism*, *12*(1), 55–69. https://doi.org/10.1080/09669580408667224

Okello, M. M., Kiringe, J. W., & Warinwa, F. (2014). Human-Carnivore Conflicts in Private Conservancy Lands of Elerai and Oltiyiani in Amboseli Area , Kenya. *Natural Resources*, *5*, 375–391.

Okello, M. M., Wishitemi, B. E., & Mwinzi, A. M. (2001). Relative importance of conservation areas in Kenya based on diverse tourist attractions. *Journal of Tourism Studies*, *12*(1), 39–49. http://www.cabdirect.org/abstracts/20023013150.html?freeview=true

Okello M.M, Seno S.K, Nthiga, R. . (2009). Reconciling people's livelihoods and environmental conservation in the rural landscapes in Kenya: Opportunities and challenges in the Amboseli landscapes. *Natural Resources Forum*, *33*(2), 123–133. https://doi.org/10.1111/j.1477-8947.2009.01216.x

Olaka, L. A., Ogutu, J. O., Said, M. Y., & Oludhe, C. (2019). Projected climatic and hydrologic changes to Lake Victoria Basin Rivers under three RCP emission scenarios for 2015-2100 and impacts on the water sector. *Water (Switzerland)*, *11*(7). https://doi.org/10.3390/w11071449

Olga L.K., Gandiwa E., Kativu S, Nhamo, G. (2018). *Impacts of Climate Change and Climate Variability on Wildlife Resources in Southern Africa: Experience from Selected Protected Areas in Zimbabwe*. Intech Open. https://doi.org/10.5772/intechopen.70470

Omondi, P. A., Awange, J. L., Forootan, E., Ogallo, L. A., Barakiza, R., G., Fesseha, G.B., I., Kululetera, V., Kilembe, C., Mbati, M. M., Kilavi, M., King'uyu, S. M., Omeny, P. A., Njogu, A., Badr, E. M., Musa, T. A., Muchiri, P., Bamanya, D., & Komutunga, E. (2014). Changes in temperature and precipitation extremes over the Greater Horn of Africa region from 1961 to 2010. *International Journal of Climatology*, *34*(4), 1262–1277. https://doi.org/10.1002/joc.3763

Ondicho, T. . (2017). The contribution of tourism to poverty reduction: A case study of communities living adjacent to Amboseli. *The International Journal of Development*

*Dialogue*, *2*(1), 34–53.

Opere, A., Omwoyo, A., Mueni, P., & Arango, M. (2019). Impact of climate change on water resources in Eastern Africa. *Hydrology and Water Resources Management in Arid, Semi-Arid, and Tropical Regions*, 199–227. https://doi.org/10.4018/978-1-7998-0163-4.ch010

Osborn, F. V., & Parker, G. E. (2003). Towards an integrated approach for reducing the conflict between elephants and people: A review of current research. *Oryx*, *37*(1), 80–84. https://doi.org/10.1017/S0030605303000152

Ostrom, E. (1990). *Governing the Commons :The Evolution of Institutions for Collective Action.* Cambridge University Press. https://doi.org/https://doi.org/10.1017/CBO9780511807763

Ostrom, E. (1999). Coping With Tragedies of the Commons. In *Annual Review of Political Science* (Vol. 2, Issue 1, pp. 493–535). https://doi.org/10.1146/annurev.polisci.2.1.493

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15181–15187. https://doi.org/10.1073/pnas.0702288104

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science*, *325*(5939). https://doi.org/10.1126/science.1172133

Oswald, S. A., Huntley, B., Collingham, Y. C., Russell, D. J. F., Anderson, B. J., Arnold, J. M., Furness, R. W., & Hamer, K. C. (2011). Physiological effects of climate on distributions of endothermic species. In *Journal of Biogeography* (Vol. 38, Issue 3, pp. 430–438). https://doi.org/10.1111/j.1365-2699.2010.02435.x

Ottichilo, W. K. and Sinange, R. K. (1985). *Differences in the visual and photographic measurements in the estimation of strip widths for aerial censuses of animal populations. DRSRS, Ministry of Planning and National Development, Nairobi*.

Ottichilo, W. K., De Leeuw, J., & Prins, H. H. T. (2001). Population trends of resident wildebeest [Connochaetes taurinus hecki (Neumann)] and factors influencing them in the Masai Mara ecosystem, Kenya. *Biological Conservation, 97*(3), 271–282. https://doi.org/10.1016/S0006-3207(00)00090-2

Ouma, J. O., Olang, L. O., Ouma, G. O., Oludhe, C., Ogallo, L., & Artan, G. (2018). Magnitudes of Climate Variability and Changes over the Arid and Semi-Arid Lands of Kenya between 1961 and 2013 Period. *American Journal of Climate Change*, *07*(01), 27–39. https://doi.org/10.4236/ajcc.2018.71004

Owen-smith, N. (1990). Demography of a Large Herbivore, the Greater Kudu Tragelaphus strepsiceros, in Relation to Rainfall on JSTOR. *Journal of Animal Ecology*, *59*(3), 893–913.

Owen-Smith, N. (2006). Demographic determination of the shape of density dependence for three African ungulate populations. *Ecological Monographs*, *76*(1), 93–109. https://doi.org/10.1890/05-0765

Owen-Smith, N., Mason, D. R., & Ogutu, J. O. (2005). Correlates of survival rates for 10 African ungulate populations: Density, rainfall and predation. In *Journal of Animal Ecology* (Vol. 74, Issue 4, pp. 774–788). https://doi.org/10.1111/j.1365-2656.2005.00974.x

Owen-Smith, R. N. (1988). Megaherbivores: The Influence of Very Large Body Size on Ecology. In *The Journal of Animal Ecology* (Vol. 59, Issue 1, p. 381). https://doi.org/10.2307/5184

Owiti Z., Ogallo, L. A., & Mutemi J. (2008). Linkages between the Indian Ocean Dipole and east African seasonal rainfall anomalies. *Journal of the Kenya Meteorological Society*, *2*(2), 2–17. www.kenyamet.org

Pareek, N. (2017). Climate Change Impact on Soils: Adaptation and Mitigation. *MOJ Ecology & Environmental Sciences*, *2*(3), 136–139. https://doi.org/10.15406/mojes.2017.02.00026

Parmesan, C ; Ryrholm, N ; Stefanescu, C ; Hill, J K ; Thomas, C D ; Descimon, H ; Huntley, B ; Kaila, L ; Kullberg, J ; Tammaru, T ; Tennent, W J ; Thomas, J A ; Warren, M. . (1999). Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature*, *399*(6736), 579–583.

Parmesan, C. (2006). Ecological and Evolutionary Responses to Recent Climate Change -. *Annual Reviews*, *37*.

Parmesan, C., Burrows, M. T., Duarte, C. M., Poloczanska, E. S., Richardson, A. J., Schoeman, D. S., & Singer, M. C. (2013). Beyond climate change attribution in conservation and ecological research. *Ecology Letters*, *16*(SUPPL.1), 58–71. https://doi.org/10.1111/ele.12098

Parry, J.-E., Echeverria, D., Dekens, J., & Maitima, J. (2012). *Climate Risks, Vulnerability and Governance in Kenya: A review*. 83. http://www.preventionweb.net/files/globalplatform/entry_bg_paper~keynaclimaterisksvulnerabilityandgovernanceinkenyaareviewiisdundpjan13.pdf

Peden, D. G., Stelfox, J. G., Mutira, J. K., and Mwanje, J. (1979). *Factors affecting the precision and accuracy of national-wide aerial censuses of animal populations. Technical Report Number 8. Kenya Rangeland Ecological Monitoring Unit (KREMU). Ministry of Tourism* *and Wildlife, Nairobi.*

Pennycuick, L. (1975). Movements of the migratory wildebeest population in the Serengeti area between 1960 and 1973. In *African Journal of Ecology* (Vol. 13, Issue 1, pp. 65–87). https://doi.org/10.1111/j.1365-2028.1975.tb00124.x

Pereira, H. M., Leadley, P. W., Proença, V., Alkemade, R., Scharlemann, J. P. W., Fernandez-Manjarrés, J. F., Araújo, M. B., Balvanera, P., Biggs, R., Cheung, W. W. L., Chini, L., Cooper, H. D., Gilman, E. L., Guénette, S., Hurtt, G. C., Huntington, H. P., Mace, G. M., Oberdorff, T., Revenga, C., … Walpole, M. (2010). Scenarios for global biodiversity in the 21st century. *Science*, *330*(6010), 1496–1501. https://doi.org/10.1126/science.1196624

Pimm, S. L., Jenkins, C. N., Abell, R., Brooks, T. M., Gittleman, J. L., Joppa, L. N., Raven, P. H., Roberts, C. M., & Sexton, J. O. (2014). The biodiversity of species and their rates of extinction, distribution, and protection. In *Science* (Vol. 344, Issue 6187). https://doi.org/10.1126/science.1246752

Pittiglio, C., Skidmore, A. K., Gils, H. A. M. J. Van, & Prins, H. H. T. (2012). International Journal of Applied Earth Observation and Geoinformation Identifying transit corridors for elephant using a long time-series. *International Journal of Applied Earth Observations and Geoinformation*, *14*(1), 61–72. https://doi.org/10.1016/j.jag.2011.08.006

Poole, J. H. (1989). Mate guarding , reproductive success and female choice in African elepliants. *Animal Behaviour*, *37*(1982), 842–849.

Poteete, A. R., Janssen, M. A., & Ostrom, E. (2010). *Working Together*. Princeton University Press. https://doi.org/10.1515/9781400835157

Preston, G. R., & Seigfried, W. R. (1995). The protection of biological diversity in South Africa: profiles and perceptions of professional practitioners in nature conservation agencies and natural history museums. *South African Journal of Wildlife Research*, *25*(2), 49–56.

Pricope, N. G., Husak, G., Lopez-Carr, D., Funk, C., & Michaelsen, J. (2013). The climate-population nexus in the East African Horn: Emerging degradation trends in rangeland and pastoral livelihood zones. *Global Environmental Change*, *23*(6), 1525–1541. https://doi.org/10.1016/j.gloenvcha.2013.10.002

Pringle, R. M. (2008). Elephants as agents of habitat creation for small vertebrates at the patch scale. *Ecology*, *89*(1), 26–33. https://doi.org/https://doi. org/10.1890/07-0776.1

Prins, H. H. T., Der Jeugd, H. P. V., & Beekman, J. H. (1994). Elephant decline in Lake Manyara

National Park, Tanzania. *African Journal of Ecology*, *32*(3), 185–191. https://doi.org/https://doi.org/10.1111/j.1365-2028.1994.tb00570.x

Prins, H. H. T., & van der Jeugd, H. P. (1993). Herbivore Population Crashes and Woodland Structure in East Africa. In *The Journal of Ecology* (Vol. 81, Issue 2, p. 305). https://doi.org/10.2307/2261500

Prudhomme, C., Giuntoli, I., Robinson, E. L., Clark, D. B., Arnell, N. W., Dankers, R., Fekete, B. M., Franssen, W., Gerten, D., Gosling, S. N., Hagemann, S., Hannah, D. M., Kim, H., Masaki, Y., Satoh, Y., Stacke, T., Wada, Y., & Wisser, D. (2014). Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(9), 3262–3267. https://doi.org/10.1073/pnas.1222473110

Ramadier, T. (2004). Transdisciplinarity and its challenges: the case of urban studies. *Futures*, *36*, 423–439. https://doi.org/DOI 10.1016/j.futures.2003.10.009

Raymond, F., Ullmann, A., Tramblay, Y., Drobinski, P., & Camberlin, P. (2019). Evolution of Mediterranean extreme dry spells during the wet season under climate change. In *Regional Environmental Change* (Vol. 19, Issue 8, pp. 2339–2351). https://doi.org/10.1007/s10113-019-01526-3

Reid, R.S. , Gachimbi, L.N., Worden, J., Wangui, E.E, Mathai, S., Mugatha, S.M, Campbell, D.J., Maitima, J.M, Butt, B., Gichohoi, H., Ogol, E. (2004). *Linkages between changes in land use, biodiversity and land degradation in the Loitokitok area of Kenya. LUCID Working Paper 49, International. Livestock Research. Institute and United Nations Environment Programme/Division of Global Environment Facility* .

Ripple, W. J., Newsome, T. M., Wolf, C., Dirzo, R., Everatt, K. T., Galetti, M., Hayward, M. W., Kerley, G. I. H., Levi, T., Lindsey, P. A., Macdonald, D. W., Malhi, Y., Painter, L. E., Sandom, C. J., Terborgh, J., & Van Valkenburgh, B. (2015). Collapse of the world's largest herbivores. *Science Advances*, *1*(4), e1400103–e1400103. https://doi.org/10.1126/sciadv.1400103

Rogelj, J., Meinshausen, M., & Knutti, R. (2012). Global warming under old and new scenarios using IPCC climate sensitivity range estimates. *Nature Climate Change*, *2*(4), 248–253. https://doi.org/10.1038/nclimate1385

Rohling, E. J., Sluijs, A. , Dijkstra, H. A. , Köhler, P., van de Wal, R. S. W., von der Heydt, A. S., Beerling, D. J., Berger, A., Bij. Rohling, A. Sluijs, H, M. Crucifix, R. DeConto, S. S. Drijfhout, A. Fedorov, G. L. Foster, A.P. K. Ganopolski, J. Hans, J. C. Z. & R. E. Z. (2012). Making sense of palaeoclimate sensitivity. *Nature*, *491*(7426), 683–691. https://doi.org/10.1038/nature11574

Rowell, D. P., Booth, B. B. B., Nicholson, S. E., & Good, P. (2015). Reconciling past and future rainfall trends over East Africa. *Journal of Climate*, *28*(24), 9768–9788. https://doi.org/10.1175/JCLI-D-15-0140.1

Rubenstein, D. I. (1992). The greenhouse effect and changes in animal behavior: Effects on social structure and life-history strategies. In R. L. P. and T. E. Lovejoy (Ed.), *Global Warming and Biological Diversity* (pp. 180–192). Yale University Press..

Rummukainen. (2010). State-of-the-art with regional climate models. In *Wiley Interdisciplinary Reviews-Climate Change* (Vol. 1, Issue 1, pp. 82–96). https://doi.org/10.1002/wcc.008

Rutten, M. (1992). *Selling wealth to buy poverty: The process of the individualization of landownership among the Maasai pastoralists of Kajiado District, Kenya, 1890-1990*. Verlag breitenbach.

Said, M. Y., Bedelian, C., Moiko, S., Muhwanga, J., Atela, J., & Abuya, R. (2019). *Projected climate change and its potential impact on cattle in Kajiado county: PRISE Research Brief*. Kenya Markets Trust.

Said, M. Y., Ogutu, J. O., Kifugo, S. C., Makui, O., Reid, R. S., & de Leeuw, J. (2016). Effects of extreme land fragmentation on wildlife and livestock population abundance and distribution. *Journal for Nature Conservation*, *34*, 151–164. https://doi.org/10.1016/j.jnc.2016.10.005

Saji, N. H., Goswami, B. N., Vinayachandran, P. N., & Yamagata, T. (1999). A dipole mode in the tropical Indian ocean. In *Nature* (Vol. 401, Issue 6751, pp. 360–363). https://doi.org/10.1038/43854

Salamin, N., Wüest, R. O., Lavergne, S., Thuiller, W., & Pearman, P. B. (2010). Assessing rapid evolution in a changing environment. *Trends in Ecology and Evolution*, *25*(12), 692–698. https://doi.org/10.1016/j.tree.2010.09.009

Sanjayan, M., Samberg, L. H., Boucher, T., & Newby, J. (2012). Intact Faunal Assemblages in the Modern Era. In *Conservation Biology* (Vol. 26, Issue 4, pp. 724–730). https://doi.org/10.1111/j.1523-1739.2012.01881.x

Sankaran M1, Hanan NP, Scholes RJ, Ratnam J, Augustine DJ, Cade BS, Gignoux J, Higgins SI, Le Roux X, Ludwig F, Ardo J, Banyikwa F, Bronn A, Bucini G, Caylor KK, Coughenour MB, Diouf A, Ekaya W, Feral CJ, February EC, Frost PG, Hiernaux P, Hrabar H, Metzg, Z. N. (2010). Foraging theory upscaled: the behavioural ecology of herbivore movement. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *365*(1550), 2267–2278. https://doi.org/10.1098/rstb.2010.0095

Schauer, J. (2015). The Elephant Problem: Science, Bureaucracy, and Kenya's National Parks, 1955 to 1975. In *African Studies Review* (Vol. 58, Issue 1, pp. 177–198). https://doi.org/10.1017/asr.2015.9

Serneels, S. and Lambin, E. F. (2001). Impact of land-use changes on the wildebeest migration in the northern part of the Serengeti-Mara ecosystem. *Biogiography*, *28*, 391–407. https://doi.org/10.1046/j.1365-2699.2001.00557.x

Setiawan A M, Koesmaryono Y, F. A. and G. D. (2017). Observed and blended gauge-satellite precipitation estimates perspective on meteorological drought intensity over South Sulawesi, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *54*(1), 12040.

Sinclair, A. R. E., Dublin, H., & Borner, M. (1985). Population regulation of Serengeti Wildebeest : a test of the food hypothesis. *Oecologia*, *65*(2), 266–267. https://doi.org/10.1007/BF00379227

Sinervo, B., Mendez-de-la-Cruz, F., Miles, D. B., Heulin, B., Bastiaans, E., Villagran-Santa Cruz, M., Lara-Resendiz, R., Martinez-Mendez, N., Calderon-Espinosa, M. L., Meza-Lazaro, R. N., Gadsden, H., Avila, L. J., Morando, M., De la Riva, I. J., Sepulveda, P. V., Rocha, C. F. D., Ibarguengoytia, N., Puntriano, C. A., Massot, M., … Sites, J. W. (2010). Erosion of Lizard Diversity by Climate Change and Altered Thermal Niches. In *Science* (Vol. 328, Issue 5980, pp. 894–899). https://doi.org/10.1126/science.1184695

Singh, P., Kumar, V., Thomas, T., & Arora, M. (2008). Changes in rainfall and relative humidity in river basins in northwest and central India. In *Hydrological Processes* (Vol. 22, Issue 16, pp. 2982–2992). https://doi.org/10.1002/hyp.6871

Sintayehu, D. W. (2018). Impact of climate change on biodiversity and associated key ecosystem services in Africa: a systematic review. *Ecosystem Health and Sustainability*, *4*(9), 225–239. https://doi.org/10.1080/20964129.2018.1530054

Sitati, N. W., Walpole, M. J., Smith, R. J., & Leader-Williams, N. (2014). Predicted spatial aspects of human – elephant conflict. *Journal of Applied Ecology*, *40*(4), 667–677.

https://doi.org/10.1046/j.1365-2664.2003.00828.x

Sitati, N. W., Walpole, M. J., & Leader-Williams, N. (2005). Factors affecting susceptibility of farms to crop raiding by African elephants: Using a predictive model to mitigate conflict. *Journal of Applied Ecology*, *42*(6), 1175–1182. https://doi.org/10.1111/j.1365-2664.2005.01091.x

Sonwa, D.J., A. Dieye, E.E. Mzouri, A. Majule, F.T. Mugabe, N. Omolo, H. Wouapi, J. Obando, and N., & Brooks. (2017). Drivers of climate risk in African agriculture. *Climate and Development*, *9*(5), 383–398.

Stakeholders Amboseli Ecosystem. (2009). Amboseli Ecosystem Management Plan, 2008-2018. In *Kenya Wildlife Service Biodiversity Planning, Assessment & Compliance Department*.

Sterling, E. J., Betley, E., Sigouin, A., Gomez, A., Toomey, A., Cullman, G., Malone, C., Pekor, A., Arengo, F., Blair, M., Filardi, C., Landrigan, K., & Luz, A. (2017). Assessing the evidence for stakeholder engagement in biodiversity conservation. *Biological Conservation*, *209*, 159–171. https://doi.org/10.1016/j.biocon.2017.02.008

Stokke, S., & Du Toit, J. T. (2002). Sexual segregation in habitat use by elephants in Chobe National Park, Botswana. *African Journal of Ecology*, *40*(4), 360–371. https://doi.org/10.1046/j.1365-2028.2002.00395.x

Stokols, D., Fuqua, J., Gress, J., Harvey, R., Phillips, K., Baezconde-Garbanati, L., Unger, J., Palmer, P., Clark, M. A., Colby, S. M., Morgan, G., & Trochim, W. (2003). Evaluating transdisciplinary science. *Nicotine and Tobacco Research*, *5*(SUPPL. 1). https://doi.org/10.1080/14622200310001625555

Strandberg, G., Bärring, L., Hansson, U., Jansson, C., & Jones, C. (2014). *CORDEX scenarios for Europe from the Rossby Centre regional climate model RCA4* (Issue 116).

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, *93*(4), 485–498. https://doi.org/10.1175/BAMS-D-11-00094.1

Thirgood, S., Mosser, A., Tham, S., Hopcraft, G. (2004). Can parks protect migratory ungulates ? The case of the Serengeti wildebeest. *Animal Conservation*, *7*(2), 113–120. https://doi.org/10.1017/S1367943004001404

Thomas, C. D., Thomas, C. D., Cameron, A., Cameron, A., Green, R. E., Green, R. E., Bakkenes, M., Bakkenes, M., Beaumont, L. J., Beaumont, L. J., Collingham, Y. C., Collingham, Y. C., Erasmus, B. F. N., Erasmus, B. F. N., De Siqueira, M. F., De Siqueira, M. F., Grainger, A., Grainger, A., Hannah, L., … Williams, S. E. (2004). Extinction risk from climate change. *Nature*, *427*(6970), 145–148. https://doi.org/10.1038/nature02121

Thuiller, W., Guéguen, M., Bison, M., Duparc, A., Garel, M., Loison, A., Renaud, J., & Poggiato, G. (2018). Combining point- - process and landscape vegetation models to predict large herbivore distributions in space and time — A case study of Rupicapra rupicapra. *Wiley Diversity and Distributions*, *24*, 352–362. https://doi.org/10.1111/ddi.12684

Turner, M. G., Gardner, R. H., and O'Neill, R. V. (2001). *Landscape ecology in theory and practice: pattern and process.* (Fourth). Springer-Verlag Berlin Heidelber.

Tyrell, J. G., & Coe, M. J. (1974). The rainfall regime of Tsavo National Park, Kenya and its Potential Phenological Significance. In *Journal of Biogeography* (Vol. 1, Issue 3, pp. 187–192). https://doi.org/10.2307/3037968

UNDP. (2018). *Republic of Kenya: Enhancing Wildlife Conservation in the Productive Southern Kenya Rangelands through a Landscape Approach* .

USAID. (2016). *Community Conservancy Policy Support and Implementation Program*.

Van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J. F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., & Rose, S. K. (2011). The representative concentration pathways: An overview. *Climatic Change*, *109*(1), 5–31. https://doi.org/10.1007/s10584-011-0148-z

Vautard, R., Gobiet, A., Sørland, S. L., & Sch, C. (2018). Bias patterns and climate change signals in GCM- RCM model chains OPEN ACCESS Bias patterns and climate change signals in GCM-RCM model chains. *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/aacc77

Vogler, D., Macey, S., & Sigouin, A. (2017). Network of Conservation Educators & Practitioners Stakeholder Analysis in Environmental and Conservation Planning. *In Conservation*, *7*, 5–16.

Wang, J., Wang, Y., Feng, J., Chen, C., Chen, J., Long, T., Li, J., Zang, R., & Li, J. (2019). Differential responses to climate and land-use changes in threatened Chinese Taxus species. *Forests*, *10*(9). https://doi.org/10.3390/f10090766

Wayumba, R., & Mwenda, J. N. (2006). *The Impact of Changing Land Tenure and Land Use on Wildlife Migration within Group Ranches in Kenya: A Case Study of the Amboseli Ecosystem*.

Wayumba, G. (2015). Aspects Of Customary Land Tenure Rights In Kenya. *International Journal of Scientific Research and Engineering Studies (IJSRES) International Journal of Scientific Research and Engineering Studies (IJSRES) Volume 2 Issue 7, July 2015 ISSN: 2349-8862*, *2*(7). www.ijsres.com

Webster, P. J., Moore, A. M., Loschnigg, J. P., & Leben, R. R. (1999). Coupled ocean-atmosphere dynamics in the Indian Ocean during 1997-98. *Nature*, *401*(6751), 356–360. https://doi.org/10.1038/43848

Western, D. and Gichohi, H. (1994). Segregation effects and the impoverishment of savanna parks: the case for an ecosystem viability analysis. *African Journal of Ecology*, *31*(4), 269–281.

Western, D. and Lindsay, W. K. (1984). Seasonal herd dynamics of a savanna elephant population. *African Journal of Ecology*, *22*, 229-244. https://doi.org/https://doi.org/10.1111/j.1365-2028.1984.tb00699.x

Western D, Mose V.N, Worden J, Maitumo, D. (2015). Predicting extreme droughts in savannah Africa: A comparison of proxy and direct measures in detecting biomass fluctuations, trends and their causes. *PLoS ONE*, *10*(8), 1–18. https://doi.org/10.1371/journal.pone.0136516

Western, D. (1973). The Structure, Dynamics and Changes of the Amboseli Ecosystem. *University of Nairobi*.

Western, D. (1975). Water availability and its influence on the structure and dynamics of a savannah large mammal community. *African Journal of Ecology*, *13*(3–4), 265–286. https://doi.org/10.1111/j.1365-2028.1975.tb00139.x

Western, D. (1982). The Environment and Ecology of Pastoralists in Arid Savannas. *Development and Change*, *13*(2), 183–211. https://doi.org/10.1111/j.1467-7660.1982.tb00117.x

Western, D. (2007). A half a century of habitat change in Amboseli National Park, Kenya. In *African Journal of Ecology* (Vol. 45, Issue 3, pp. 302–310). https://doi.org/10.1111/j.1365-2028.2006.00710.x

Western, D. (2010). The Worst Drought: Tipping or Turning Point. *Swara*, *2*, 16–20.

Western, D., & Dunne, T. (1979). Environmental aspects of settlement site decisions among pastoral Maasai. In *Human Ecology* (Vol. 7, Issue 1, pp. 75–98). https://doi.org/10.1007/BF00889353

Western, D., Groom, R., & Worden, J. (2009). The impact of subdivision and sedentarization of pastoral lands on wildlife in an African savanna ecosystem. *Biological Conservation*, *142*(11), 2538–2546. https://doi.org/10.1016/j.biocon.2009.05.025

Western, D., & Maitumo, D. (2004). Woodland loss and restoration in a savanna park_ a 20-year experiment. *African Journal of Ecology*, *42*(2). https://doi.org/10.1111/j.1365-2028.2004.00506.x

Western, D., & Nightingale, D. (2004). Environmental change and the vulnerability of pastoralists to drought: A case study of the Maasai in Amboseli, Kenya. *Africa Environment Outlook Case Studies: Human Vulnerability to Environment Change.*, 1–35. https://doi.org/OCLC: 56087439

Western, D., Russell, S., & Cuthill, I. (2009). The Status of Wildlife in Protected Areas Compared to Non-Protected Areas of Kenya. *PLoS One*, *4*(7). https://doi.org/10.1371/journal.pone.0006140

Western, D., Waithaka, J., & Kamanga, J. (2015). Finding space for wildlife beyond national parks and reducing conflict through community based conservation: the Kenya experience. *Parks*, *21*(1), 51–62. https://doi.org/10.2305/IUCN.CH.2014.PARKS-21-1DW.en

Whyte, I. J., & Joubert, S. C. J. (1988). Blue wildebeest population trends in the Kruger National Park and the effects of fencing. In *South African Journal of Wildlife Research* (Vol. 18, Issue 3, pp. 78–87). https://doi.org/10.4319/lo.2013.58.2.0489

Wijngaarden, W. Van. (1985). *Relationships between climate, soils, vegetation and large herbivores in a semi-arid savanna ecosystem (Tsavo, Kenya)*. ITC Publication.

William, D. . (2008). Isolation of African protected areas. *Frontiers in Ecology and the Environmentent*, *6*(6), 321–328.

Williams, A.P., Funk, C. A. (2011). A Westward Extension of the Tropical Pacific Warm Pool Leads to March through June Drying in Kenya and Ethiopia. *Climate Dynamics*, 1–16. https://doi.org/https://doi.org/10.3133/ofr20101199

Wilsey, C. B., Lawler, J. J., Maurer, E. P., Mckenzie, D., Townsend, P. A., Freund, J. A., Hagmann, K., Hutten, K. M., Wilsey, C. B., Lawler, J. J., Freund, J. A., Hagmann, K., Hutten, K. M., Sciences, F., Wildland, P., Sciences, F., & Street, N. (2013). Tools for Assessing Climate Impacts on Fish and Wildlife. *Journal of Fish and Wildlife*, *4*(1), 220–241. https://doi.org/10.3996/062012-JFWM-055

WMO. (2012). WMO statement on the status of the global climate in 2012. *World Meteorological Organization, 1108,* WMO-No. 1108.

http://www.wmo.int/pages/mediacentre/press_releases/documents/WMO_1108_EN_web_000.pdf

Woolley, L.-A., Millspaugh, J. J., Woods, R. J., van Rensburg, S. J., Page, B. R., & Slotow, R. (2009). Intraspecific Strategic Responses of African Elephants to Temporal Variation in Forage Quality. In *Journal of Wildlife Management* (Vol. 73, Issue 6, pp. 827–835). https://doi.org/10.2193/2008-412

Worldbank. (2013). *Turn Down Heat. The Climate Extremes, Regional Impacts, and the Case for Resilience*.

Young, K. D., Ferreira, S. M., & Van Aarde, R. J. (2009). Elephant spatial use in wet and dry savannas of southern Africa. In *Journal of Zoology* (Vol. 278, Issue 3, pp. 189–205). https://doi.org/10.1111/j.1469-7998.2009.00568.x

Young, K. D., & Van Aarde, R. J. (2010). Density as an explanatory variable of movements and calf survival in savanna elephants across southern Africa. In *Journal of Animal Ecology* (Vol. 79, Issue 3, pp. 662–673). https://doi.org/10.1111/j.1365-2656.2010.01667.x

Zheng, X. T. (2019). Indo-Pacific Climate Modes in Warming Climate: Consensus and Uncertainty Across Model Projections. *Current Climate Change Reports*, *5*(4), 308–321. https://doi.org/10.1007/s40641-019-00152-9

*APPENDICES*

*Appendix A: Questionnaire for data collection*

**General**

**Introduction and explanation of the Survey**
*The current study is a PHD research project. The overall objective is to determine impacts climate variability and its extremes on elephant distribution patterns in the Amboseli ecosystem. I am currently collecting data and I would be grateful if you could provide me with important information that both could be of very practical use and of scientific benefits.*
*The answers provided will be kept confidential and used only for scientific purposes. No unauthorized person will gain access to the information*

Interviewer: ______________________________ Date: ______________________

Area: __________________________________ Questionnaire No.____________

Name of respondent: (Optional) ______________________________

**<u>A. Interviewee information</u>**

| No | Question | Answer(s) /Codes | Skip |
|---|---|---|---|
| 1 | Sex of the respondent | Male ...............................................1<br>Female............................................2 | |
| 2 | The age group of the respondent | < 20...................................................1<br>21-30 .................................................2<br>31-40.................................................3<br>41-50.................................................4<br>51-60 .................................................5<br>>60 ....................................................6<br>Don't Know.......................................88<br>Refused to answer...........................99 | |

| No | Question | Answer(s) /Codes | Skip |
|---|---|---|---|
| 3 | Highest level of education attained. | None.....................................................1<br>Primary................................................2<br>Secondary..........................................3<br>Tertiary.................................................4<br>Don't Know........................................88<br>Refused to answer............................99 | |
| 4 | Place of residence | Place:________________________ | |
| 5 | Type of residence | Temporary..........................................1<br>Permanent...........................................2 | |
| 6 | Do you own land? | Yes......................................................1<br>No........................................................2 | If 2 Skip to Q11 |
| 7 | If yes, what is the Land ownership regime? | Private..................................................1<br>Communal............................................2<br>Lease....................................................3<br>Public/State..........................................4 | |
| 8 | What is the size of the land in acres | 0- 5.......................................................1<br>6- 10 .....................................................2<br>11- 15...................................................3<br>>15 ......................................................4<br>Don't Know........................................88<br>Refused to answer............................99 | |
| 9 | Is the land fenced? | Yes......................................................1<br>No........................................................2 | If 2 Skip to Q11 |
| 10 | If yes, what type of fence? | Natural...............................................1<br>Electric ..............................................2<br>Plain/barbed wire ..............................3<br>Chain link ...........................................4<br>Other (Specify)..................................5 | |
| 11 | How long have you lived in this area? | 0-5 years.............................................1<br>6-10 years...........................................2<br>>10 years............................................3 | |

| No | Question | Answer(s) /Codes | Skip |
|---|---|---|---|
| 12 | The number of people in the household (including respondent)? | 1-3............................................1<br>4-6............................................2<br>7-9............................................3<br>>10............................................4 | |
| 13 | Is there the presence of the following on the farm? | Agroforestry .....................................1<br>Forest ................................................2<br>Sustainable agriculture ....................3<br>Other (specify) …..............................4 | |
| 14 | What is the Land used for?<br>(Tick all that applies) | Idle.....................................................1<br>Leased................................................2<br>Crop...................................................3<br>Livestock............................................4<br>Forest.................................................5<br>Other (specify) …..............................6 | |
| 15 | Are the routes used by elephants known? | Yes.....................................................1<br>No.......................................................2 | If 2 Skip to Q17 |
| 16 | If yes, list some of the routes you know. | a) ________________________________<br>b) ________________________________<br>c) ________________________________<br>d) ________________________________ | |
| 17 | Threats to elephant migration routes in the ecosystem | | |
| | a). Overstocking and overgrazing | Yes....................................................1<br>Partly..................................................2<br>No.......................................................3<br>Don‘t Know.........................................4 | |
| | b). Overexploitation of forests | Yes....................................................1<br>Partly..................................................2<br>No.......................................................3<br>Don‘t Know.........................................4 | |
| | c). Cultivation encroaching on the corridors | Yes....................................................1<br>Partly..................................................2 | |

<table>
<tr><th>No</th><th>Question</th><th>Answer(s) /Codes</th><th>Skip</th></tr>
<tr><td></td><td></td><td>No........................................................3<br>Don‘t Know...........................................4</td><td></td></tr>
<tr><td></td><td>d). Land subdivision</td><td>Yes.....................................................1<br>Partly...................................................2<br>No........................................................3<br>Don‘t Know...........................................4</td><td></td></tr>
<tr><td></td><td>e). Changes in the hydrological regime</td><td>Yes.....................................................1<br>Partly...................................................2<br>No........................................................3<br>Don‘t Know...........................................4</td><td></td></tr>
<tr><td></td><td>f). Construction of roads</td><td>Yes.....................................................1<br>Partly...................................................2<br>No........................................................3<br>Don‘t Know...........................................4</td><td></td></tr>
<tr><td></td><td>g). Construction of buildings</td><td>Yes.....................................................1<br>Partly...................................................2<br>No........................................................3<br>Don‘t Know...........................................4</td><td></td></tr>
<tr><td></td><td>h). Other (specify) …..........................</td><td>Yes.....................................................1<br>Partly...................................................2<br>No........................................................3<br>Don‘t Know...........................................4</td><td></td></tr>
<tr><td>18</td><td>How busy are the following ranches as elephant dispersal areas</td><td><table>
<tr><th></th><th>Very busy (1)</th><th>Busy (2)</th><th>Moderately busy (3)</th><th>A little busy (4)</th><th>Not busy (5)</th></tr>
<tr><td>Olgulului/ ololorashi</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Mailua</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Imbirikani</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Kimana</td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td><td></td></tr>
</table>

| No | Question | Answer(s) /Codes | | | | | | Skip |
|---|---|---|---|---|---|---|---|---|
| | | Rombo | | | | | | |
| | | Kuku | | | | | | |
| | | Eselengei | | | | | | |

**In the next section, I would like to ask you several questions on how you perceive the ecosystem services.**

**III Ecosystem services as perceived by communities**

Please indicate the extent of your agreement or disagreement with each of the following statements?

| | Question | Answer(s) /Codes | | | | |
|---|---|---|---|---|---|---|
| | | Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree |
| 19 | There is an increasing decline in stream and river flows | 1 | 2 | 3 | 4 | 5 |
| 20 | Temperatures have become warmer in the recent past | 1 | 2 | 3 | 4 | 5 |
| 21 | Degradation of forests and other natural resources is increasing | 1 | 2 | 3 | 4 | 5 |
| 22 | There are frequent floods incidences | 1 | 2 | 3 | 4 | 5 |
| 23 | There are frequent drought incidences | 1 | 2 | 3 | 4 | 5 |

**IV Community Awareness on biodiversity and ecosystem services**

| No | Question | Answer(s) /Codes | Skip |
|---|---|---|---|
| 24 | Do you believe this is an area of special interest? | Yes.....................................................1<br>No........................................................2 | |
| 25 | If yes, which is the most important issue of conserving the area? | Agriculture....................................................................1<br>Tourism development ................................................2<br>Plant and animals Aesthetics ....................................3<br>History, heritage, and culture......................................4<br>Scientific value ..........................................................5<br>Other (Please specify)................................................6 | |

| | | | |
|---|---|---|---|
| 26 | Are you engaged in conservation activities? | Yes.....................................................1<br>Partly..................................................2<br>No.......................................................3<br>Don't Know..........................................4 | |
| 27 | If yes, what activities? | Tree planting...............................................................1<br>Soil conservation..........................................................2<br>Membership to conservation organization.................3<br>Other (Please specify)……………………………........4 | |
| 28 | How well do you feel informed about the environmental resources from the reserve? | Fully informed................................................1<br>Partly Informed...............................................2<br>Not informed...................................................3 | |
| 29 | Is the supply or continued existence of the resources secure? | Yes......................................................1<br>No........................................................2 | If 2 Skip to Q43 |
| 30 | If No, What are the threats to the resource? (Rank) | (see table below) | |

| | Past | Present | Future |
|---|---|---|---|
| Insecurity | 1 | 1 | 1 |
| Change in climate | 2 | 2 | 2 |
| Disease | 3 | 3 | 3 |
| Habitat change | 4 | 4 | 4 |
| Degradation | 5 | 5 | 5 |
| Human population pressure | 6 | 6 | 6 |

**Thank you for taking part in the Interview**

*Appendix B: Key informant interview questions*

**INDICATORS OF CLIMATE VARIABILITY AND CHANGE ON LOCAL LIVELIHOODS**

1. What does climate change mean to you?
2. What changes have you noted in this area, and do you think it is permanent or temporary?
3. How do these climatic events affect the following communities' source of livelihood and life activities in general?

| Activity/source of livelihood | Droughts | High temperatures | Reduced river flow |
|---|---|---|---|
| Crop yield | | | |
| Animals production | | | |
| Source of clean water | | | |
| Food security | | | |
| Migration | | | |
| Human-wildlife conflict | | | |
| Education | | | |
| Others specify | | | |

**VULNERABILITY ASSESSMENT**

1. Which areas are most vulnerable to human-elephant conflicts?
2. Which groups are most vulnerable?
3. Why do you think that they are vulnerable?
4. What do you think can be done to reduce vulnerability?

**ADAPTATION STRATEGIES**

1. Do you think the communities are doing something towards elephant conservation?
2. What challenges do they face in conservation in the wake of climate change?
3. What do you think can be done to overcome the challenges?
4. Which organizations are helping the community financially to preserve the elephant corridors?
5. What hinders proper conservation and protection of elephants in the Amboseli ecosystem?

*Appendix C: Data quality*

Table C- 1: Summary for Test for Normality for annual rainfall for the four stations

| Test for Normality | Amboseli Baboon RC | Olkelunyiet | Isara | Mashuru |
|---|---|---|---|---|
| Shapiro-Wilk p-value | 0.0321 (W = 0.9437) | 0.0837 (W = 0.8851) | 0.4801 (W = 0.9446) | 0.3918 (W = 0.9732) |

| | | | | |
|---|---|---|---|---|
| Shapiro-Francia p-value | 0 (W' = 0.0135) | 0 (W' = 0.0113) | 0 (W' = 0.1927) | 0 (W' = 0.0581) |
| D'Agostino-Pearson p-value | 0.1822 ($K^2$ = 3.4051) | 0.2309 ($K^2$ = 2.9313) | 0.5448 ($K^2$ = 1.2145) | 0.6564 ($K^2$ = 0.8420) |
| Jarque-Bera p-value | 0.2948 (JB = 2.4429) | 0.5252 (JB = 1.2878) | 0.6634 (JB = 0.8208) | 0.8447 (JB = 0.3375) |
| Cramer-von Mises p-value | 0.0846 (W = 0.1078) | 0.0859 (W = 0.1045) | 0.3961 (W = 0.0565) | 0.3037 (W = 0.0665) |
| Anderson-Darling p-value | 0.0639 (W = 0.6975) | 0.0691 (W = 0.6501) | 0.4178 (W = 0.3609) | 0.3417 (W = 0.4151) |
| Data Points | 44 | 13 | 14 | 44 |
| Mean | 295.3864 | 210.5385 | 359.8571 | 588.3636 |
| Range | 74 - 573 | 0 - 528 | 49 - 595 | 224 - 928 |
| Standard deviation | 132.4013 | 183.1290 | 165.1795 | 152.7855 |

**Table C- 2: Summary for Test for Normality for MAMl rainfall for the four stations**

| Test for Normality | Amboseli Baboon RC | Olkelunyiet | Isara | Mashuru |
|---|---|---|---|---|
| Shapiro-Wilk p-value | 0.0491 (W = 0.9487) | 0.0654 (W = 0.8772) | 0.3815 (W = 0.9370) | 0.2342 (W = 0.9669) |
| Shapiro-Francia p-value | 0 (W’ = 0.0064) | 0 (W’ = 0.2901) | 0 (W’ = 0.0953) | 0 (W’ = 0.0429) |
| D'Agostino-Pearson p-value | 0.4133 ($K^2$ = 1.7673) | 0.1065 ($K^2$ = 4.4799) | 0.41 ($K^2$ = 1.7831) | 0.4989 ($K^2$ = 1.3909) |
| Jarque-Bera p-value | 0.4275 (JB = 1.6998) | 0.5071 (JB = 1.3579) | 0.6105 (JB = 0.9870) | 0.5667 (JB = 1.1357) |
| Cramer-von Mises p-value | 0.4423 (W = 0.0542) | 0.1295 (W = 0.0920) | 0.4524 (W = 0.0522) | 0.8159 (W = 0.0318) |
| Anderson-Darling p-value | 0.3035 (W = 0.4370) | 0.0802 (W = 0.6256) | 0.4496 (W = 0.3476) | 0.6366 (W = 0.2774) |
| Data Points | 44 | 13 | 14 | 44 |
| Mean | 113.3227 | 105.6923 | 159.3571 | 275.2273 |
| Range | 0 - 269 | 0 - 239 | 0 - 366 | 52 - 504 |
| Standard deviation | 72.4248 | 89.9294 | 118.1407 | 114.9557 |

**Table C-3: Summary for Test for Normality for OND rainfall for the four stations**

| Test for Normality | Amboseli Baboon RC | Olkelunyiet | Isara | Mashuru |
|---|---|---|---|---|
| Shapiro-Wilk p-value | 0.0147 (W = 0.9342) | 0.0748 (W = 0.8815) | 0.2377 (W = 0.9224) | 0.0665 (W = 0.9522) |
| Shapiro-Francia p-value | 0 (W' = 0.0036) | 0 (W' = 0.0391) | 0 (W' = 0.1058) | 0 (W' = 0.0278) |
| D'Agostino-Pearson p-value | 0.1387 ($K^2$ = 3.9503) | 0.3713 ($K^2$ = 1.9817) | 0.1585 ($K^2$ = 3.6844) | 0.0516 ($K^2$ = 5.9298) |
| Jarque-Bera p-value | 0.1588 (JB = 3.6801) | 0.5328 (JB = 1.2594) | 0.4043 (JB = 1.8114) | 0.0862 (JB = 4.9014) |
| Cramer-von Mises p-value | 0.0267 (W = 0.1446) | 0.0907 (W = 0.1029) | 0.3336 (W = 0.0619) | 0.0783 (W = 0.1102) |
| Anderson-Darling p-value | 0.0253 (W = 0.8574) | 0.0795 (W = 0.6272) | 0.2909 (W = 0.4252) | 0.0760 (W = 0.6674) |
| Data Points | 44 | 13 | 14 | 44 |
| Mean | 114.2273 | 136.6923 | 135.2857 | 191.9773 |
| Range | 0 - 307 | 0 - 353 | 0 - 374 | 0 - 514 |
| Standard deviation | 75.9180 | 123.1643 | 101.6137 | 108.4843 |

**Table C-4: Summary for Test for Normality for JJAS rainfall for the four stations**

| Test for Normality | Amboseli Baboon RC | Olkelunyiet | Isara | Mashuru |
|---|---|---|---|---|
| Shapiro-Wilk p-value | 0 (W = 0.4963) | 0 (W = 0.3842) | 0.0075 (W = 0.8142) | 0 (W = 0.7884) |
| Shapiro-Francia p-value | 0 (W’ = 0.0013) | 0 (W’ = 0.08) | 0 (W’ = 0.0044) | 0 (W’ = 0.0124) |
| D'Agostino-Pearson p-value | 0 ($K^2$ = 54.0881) | 0 ($K^2$ = 33.7702) | 0.2628 ($K^2$ = 2.6728) | 0 ($K^2$ = 37.2034) |
| Jarque-Bera p-value | 0 (JB = 261.8830) | 0 (JB = 49.1187) | 0.3696 (JB = 1.9904) | 0 (JB = 104.8983) |
| Cramer-von Mises p-value | 0 (W = 1.7693) | 0 (W = 0.7569) | 0.0078 (W = 0.1810) | 0 (W = 0.4385) |
| Anderson-Darling p-value | 0 (W = 8.8951) | 0 (W = 3.7930) | 0.0045 (W = 1.1066) | 0 (W = 2.54) |
| Data Points | 44 | 13 | 14 | 44 |
| Mean | 2.2295 | 1 | 11 | 35.9545 |
| Range | 0 - 26.20 | 0 - 11 | 0 - 34 | 0 - 176 |
| Standard deviation | 5.1478 | 2.9352 | 11.9284 | 32.8509 |

*Appendix D: Historical Rainfall and Temperature trends*

Table D-1: Rainfall trend for Amboseli Ecosystem for period 1960-2014

| Month | Equation | r-squared | F-Ratio | P-Value |
|---|---|---|---|---|
| January | Y = 337.476 – 0.148x | 0.0023 | 0.120 | 0.729 |
| February | Y = 329.801- 0.151x | 0.0059 | 0.312 | 0.578 |
| March | Y = -200.929 + 0.145x | 0.0014 | 0.077 | 0.782 |
| April | Y = 853.925 – 0.381x | 0.0090 | 0.481 | 0.491 |
| May | Y = 787.946 – 0.374x | 0.0307 | 1.676 | 0.201 |
| June | Y = 244.554 – 0.121x | 0.0698 | 3.979 | 0.051 |
| July | Y = 254.688 – 0.127x | 0.0967 | 5.672 | 0.021 |
| August | Y = -6.734 + 0.006x | 0.0002 | 0.012 | 0.914 |
| September | Y = 211.626 – 0.104x | 0.0288 | 1.573 | 0.215 |
| October | Y = 538.203 – 0.254x | 0.0132 | 0.709 | 0.403 |
| November | Y = 1399.651 – 0.646x | 0.0213 | 1.156 | 0.287 |
| December | Y = -123.509 + 0.119x | 0.0012 | 0.066 | 0.798 |

Table D- 2: Minimum temperature trend for the Amboseli Ecosystem for period 1960 – 2014

| Month | Equation | r-squared | F-Ratio | P-Value |
|---|---|---|---|---|
| January | Y = 0.0216x - 25.972 | 0.139 | 8.378 | 0.0055 |
| February | Y = 0.0201x - 22.631 | 0.144 | 8.770 | 0.0046 |
| March | Y = 0.0207x - 23.274 | 0.156 | 9.604 | 0.0031 |
| April | Y = 0.0162x - 13.968 | 0.145 | 8.780 | 0.0046 |
| May | Y = 0.0222x - 27.238 | 0.327 | 25.313 | 0.0000 |
| June | Y = 0.0257x - 35.901 | 0.271 | 19.341 | 0.0001 |
| July | Y = 0.0226x - 30.736 | 0.292 | 21.479 | 0.0000 |
| August | Y = 0.0254x - 35837 | 0.365 | 29.858 | 0.0000 |
| September | Y = 0.0283x - 41.131 | 0.336 | 26.330 | 0.0000 |
| October | Y = 0.0231x - 29.320 | 0.238 | 16.229 | 0.0002 |
| November | Y = 0.0210x - 24.018 | 0.202 | 13.175 | 0.0007 |
| December | Y = 0.0314x - 44.871 | 0.292 | 21.436 | 0.0000 |

Table D-3: Maximum temperature trend for the Amboseli Ecosystem for period 1960 – 2014

| Month | Equation | r-squared | F-Ratio | P-Value |
|---|---|---|---|---|
| January | Y = 0.0233x - 16.824 | 0.144 | 8.737 | 0.0047 |
| February | Y = 0.0298x - 28.448 | 0.246 | 16.961 | 0.0001 |
| March | Y = 0.0273x - 23.618 | 0.164 | 10.227 | 0.0024 |
| April | Y = 0.0182x - 7.2493 | 0.100 | 5.760 | 0.0200 |
| May | Y = 0.0217x - 15.407 | 0.238 | 16.277 | 0.0002 |
| June | Y = 0.0147x - 2.6787 | 0.114 | 6.661 | 0.0127 |
| July | Y = 0.0246x - 23.203 | 0.284 | 20.599 | 0.0000 |
| August | Y = 0.0201x - 13.691 | 0.204 | 13.360 | 0.0006 |
| September | Y = 0.0272x - 25.851 | 0.320 | 24.468 | 0.0000 |
| October | Y = 0.0281x - 26.143 | 0.311 | 23.416 | 0.0000 |
| November | Y = 0.0216x - 14.226 | 0.132 | 7.930 | 0.0069 |
| December | Y = 0.0298x - 31.001 | 0.235 | 15.973 | 0.0002 |

*Appendix E: Relationships between the population and temperature*

Table E 1: Statistics describing relationships between the population of elephant and preceding MAM temperature over 15 years in the Amboseli Ecosystem

| ***Effect*** | **Equation** | **r-squared** | **F Ratio** | **P-Value** |
|---|---|---|---|---|
| $MAM_0$ | Y= 158.25x -3697.37 | 0.080 | 1.038 | 0.3283 |
| $MAM_1$ | Y= 168.27x -3984.55 | 0.042 | 0.525 | 0.4828 |
| $MAM_2$ | Y= 200.12x - 4929.78 | 0.044 | 0.548 | 0.4735 |
| $MAM_3$ | Y= 472.64x-12807.30 | 0.182 | 2.679 | 0.1277 |
| $MAM_4$ | $Y= -1243813.9 + 84862.5x – 1446x^2$ | 0.4008 | 3.679 | 0.05978 |
| $MAM_5$ | Y= 425.34x -11455.89 | 0.127 | 1.746 | 0.2110 |
| $MAM_6$ | Y= 408.52x -10965.18 | 0.108 | 1.450 | 0.2571 |
| $MAM_7$ | $Y= -2194488 + 149490x – 2544x^2$ | 0.4455 | 4.419 | 0.03903 |
| $MAM_8$ | Y= 548.73x -15032.18 | 0.186 | 2.743 | 0.1236 |
| $MAM_9$ | Y= 510.33x -13823.59 | 0.144 | 2.022 | 0.1805 |
| $MAM_{10}$ | Y= 594.24x -16332.38 | 0.184 | 2.708 | 0.1258 |
| $MAM_{11}$ | $Y= -2130398.8 + 145301x – 2475.9x^2$ | 0.5317 | 6.246 | 0.0154 |
| $MAM_{12}$ | $Y= -1556477 + 106123x -1807x^2$ | 0.417 | 3.934 | 0.05144 |
| $MAM_{13}$ | $Y= -1974117 + 134915x – 2304x^2$ | 0.4289 | 4.13 | 0.04593 |
| $MAM_{14}$ | $Y= -2564162 + 175532x – 3002x^2$ | 0.5714 | 7.331 | 0.00947 |
| $MAM_{15}$ | $Y= -2933292 + 200903x – 3438x^2$ | 0.6366 | 9.633 | 0.00382 |

Table E-2: Statistics describing relationships between the population of elephant and preceding JJAS temperature over 15 years in the Amboseli Ecosystem

| Effect | Equation | R-Squared | F-Ratio | P-Value |
|---|---|---|---|---|
| $JJAS_0$ | Y= 124.16x -2406.48 | 0.012 | 0.149 | 0.7065 |
| $JJAS_1$ | Y= 294.40x - 6966.14 | 0.054 | 0.690 | 0.4224 |
| $JJAS_2$ | Y= 249.05x - 5740.47 | 0.038 | 0.470 | 0.5059 |
| $JJAS_3$ | Y= 477.71x -11853.25 | 0.115 | 1.556 | 0.2360 |
| $JJAS_4$ | Y= 568.44x -14290.88 | 0.136 | 2.890 | 0.1943 |
| $JJAS_5$ | Y= 541.53x -13567.20 | 0.109 | 1.475 | 0.2479 |
| $JJAS_6$ | Y= 494.38x -12288.83 | 0.094 | 1.252 | 0.2852 |
| $JJAS_7$ | $Y= -2185131 + 162560x – 3022x^2$ | 0.188 | 2.783 | 0.1212 |
| $JJAS_8$ | $Y= -2250524 + 167318x – 3108x^2$ | 0.4546 | 4.584 | 0.03564 |
| $JJAS_9$ | Y= 646.44x -16324.65 | 0.191 | 2.826 | 0.1186 |
| $JJAS_{10}$ | $Y= 1207074 + 89693x – 1664x^2$ | 0.3633 | 3.138 | 0.08349 |
| $JJAS_{11}$ | $Y= 1737853 + 129317x – 2404x^2$ | 0.5459 | 6.611 | 0.01302 |
| $JJAS_{12}$ | $Y= -1695439 + 126203x – 2347x^2$ | 0.4864 | 5.210 | 0.0256 |
| $JJAS_{13}$ | $Y= -1595928 + 118884x – 2212x^2$ | 0.4654 | 4.787 | 0.03194 |
| $JJAS_{14}$ | $Y= -1701046 + 126792x – 2361x^2$ | 0.5444 | 6.573 | 0.01324 |
| $JJAS_{15}$ | $Y= -2002339 + 149414x – 2786x^2$ | 0.5907 | 7.937 | 0.00735 |

Table E-3: Statistics describing relationships between the population of elephant and preceding OND temperature over 15 years in the Amboseli Ecosystem

| *Effect* | Equation | R-Squared | F-Ratio | P-Value |
|---|---|---|---|---|
| $OND_0$ | Y= 414.12x -11009.40 | 0.3088 | 5.360 | 0.0391 |
| $OND_1$ | Y= 294.4x -6966.1 | 0.05437 | 0.6899 | 0.4224 |
| $OND_2$ | Y= 281.75x -7221.81 | 0.071 | 0.914 | 0.3579 |
| $OND_3$ | Y= 394.26x -10460.07 | 0.087 | 1.143 | 0.3061 |
| $OND_4$ | $Y= -2782733 + 206917x - 3845x^2$ | 0.3009 | 2.368 | 0.1396 |
| $OND_5$ | Y= 430.07x -11506.20 | 0.106 | 1.423 | 0.2560 |
| $OND_6$ | Y= 470.62x -12670.05 | 0.106 | 1.429 | 0.2551 |
| $OND_7$ | $Y= -2185131 + 162560x - 3022x^2$ | 0.391 | 3.532 | 0.06535 |
| $OND_8$ | $Y= -2250524 + 167318x - 3108x^2$ | 0.4546 | 4.584 | 0.03554 |
| $OND_9$ | $Y= -1169683 + 86834x - 1610x^2$ | 0.2731 | 2.066 | 0.1731 |
| $OND_{10}$ | $Y= -1207074 + 89693x - 1664x^2$ | 0.3633 | 3.138 | 0.08349 |
| $OND_{11}$ | $Y= -1737853 + 129317x - 2404x^2$ | 0.5459 | 6.611 | 0.01302 |
| $OND_{12}$ | $Y= -1695439 + 126203x - 2347x^2$ | 0.4864 | 5.210 | 0.0256 |
| $OND_{13}$ | $Y= -1595928 + 118884x - 2212x^2$ | 0.4654 | 4.787 | 0.03194 |
| $OND_{14}$ | $Y= -1701046 + 126792x - 2361x^2$ | 0.5444 | 6.573 | 0.1324 |
| $OND_{15}$ | $Y= -2002339 + 149414x - 2786x^2$ | 0.5907 | 7.937 | 0.007352 |

*Appendix F: Temperature projections*

Table F-1: Mann Kendall test for trends

| | | S value | Slope/Tau | P value | Significance |
|---|---|---|---|---|---|
| **RCP Projections** | | | | | |
| Amboseli Rainfall RCP 2.6 | Annual | 25 | 0.0056 | 0.93849 | No significant trend |
| | MAM | -69 | -0.0155 | 0.82694 | No significant trend |
| | JJAS | 187 | 0.0419 | 0.54984 | No significant trend |
| | OND | -3 | -0.00067 | 0.99487 | No significant trend |
| | | | | | |
| Amboseli Rainfall RCP 4.5 | Annual | 67 | 0.015 | 0.83195 | No significant trend |
| | MAM | -15 | -0.00336 | 0.9641 | No significant trend |
| | JJAS | -243 | -0.0544 | 0.43654 | No significant trend |
| | OND | 269 | 0.0602 | 0.38888 | No significant trend |
| | | | | | |
| Amboseli Rainfall RCP 8.5 | Annual | 1155 | 0.259 | 0.00021 | Significant positive Trend |
| | MAM | 271 | 0.0607 | 0.38535 | No significant trend |
| | JJAS | -1019 | -0.228 | 0.00106 | Significant negative Trend |
| | OND | 1365 | 0.306 | 1.16E-05 | Significant Positive |
| | | | | | |
| Amboseli Max Temp RCP 2.6 | Annual | 389 | 0.0871 | 0.21223 | No significant trend |
| | MAM | 177 | 0.0396 | 0.57149 | No significant trend |
| | JJAS | 507 | 0.114 | 0.10377 | No significant trend |
| | OND | 553 | 0.124 | 0.07594 | No significant trend |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Amboseli Max Temp RCP 4.5 | Annual | 2391 | 0.535 | 2.22E-16 | Significant Positive |
| | MAM | 1669 | 0.374 | 1.19E-07 | Significant Positive |
| | JJAS | 2375 | 0.532 | 2.22E-16 | Significant Positive |
| | OND | 1463 | 0.328 | 2.62E-06 | Significant Positive |
| | | | | | |
| Amboseli Max Temp RCP 8.5 | Annual | 3560 | 0.797 | 2.22E-16 | Significant Positive |
| | MAM | 2755 | 0.617 | 2.22E-16 | Significant Positive |
| | JJAS | 3324 | 0.745 | 2.22E-16 | Significant Positive |
| | OND | 2939 | 0.658 | 2.22E-16 | Significant Positive |
| | | | | | |
| Amboseli Min Temp RCP 2.6 | Annual | 425 | 0.0952 | 0.17282 | No significant trend |
| | MAM | 428 | 0.0959 | 0.1698 | No significant trend |
| | JJAS | 531 | 0.119 | 0.08838 | No significant trend |
| | OND | 479 | 0.107 | 0.12434 | No significant trend |
| | | | | | |
| Amboseli Min Temp RCP 4.5 | Annual | 2862 | 0.641 | 2.22E-16 | Significant Positive |
| | MAM | 2703 | 0.605 | 2.22E-16 | Significant Positive |
| | JJAS | 2527 | 0.566 | 2.22E-16 | Significant Positive |
| | OND | 2381 | 0.533 | 2.22E-16 | Significant Positive |
| | | | | | |
| Amboseli Min Temp RCP 8.5 | Annual | 3750 | 0.84 | 2.22E-16 | Significant Positive |
| | MAM | 3529 | 0.79 | 2.22E-16 | Significant Positive |
| | JJAS | 3633 | 0.814 | 2.22E-16 | Significant Positive |

| | | | | | |
|---|---|---|---|---|---|
| | OND | 3571 | 0.8 | 2.22E-16 | Significant Positive |

TableF-2: Summary of projected minimum temperature changes in Amboseli in 2030, 2050, 2070 and 2011 based on RCP 2.6, 4.5 and 8.5

| | | Season | Base | 2030 | 2050 | 2070 | 2100 |
|---|---|---|---|---|---|---|---|
| RCP 2.6 | Minimum | Annual | 13.52 | 14.05 | 14.23 | 14.17 | 13.63 |
| | | MAM | 14.48 | 14.95 | 15.12 | 15.10 | 14.68 |
| | | JJAS | 13.52 | 14.05 | 14.23 | 14.17 | 13.63 |
| | | OND | 13.92 | 14.50 | 14.73 | 14.71 | 14.25 |
| | | | | | | | |
| RCP 4.5 | Minimum | Annual | 15.26 | 15.77 | 16.19 | 16.61 | 17.24 |
| | | MAM | 15.80 | 16.32 | 16.75 | 17.18 | 17.82 |
| | | JJAS | 14.18 | 14.70 | 15.13 | 15.56 | 16.20 |
| | | OND | 15.86 | 16.32 | 16.71 | 17.10 | 17.68 |
| | | | | | | | |
| RCP 8.5 | Minimum | Annual | 14.70 | 16.04 | 17.16 | 18.28 | 19.96 |
| | | MAM | 15.34 | 16.62 | 17.69 | 18.76 | 20.37 |
| | | JJAS | 13.50 | 14.95 | 16.17 | 17.38 | 19.20 |
| | | OND | 15.32 | 16.55 | 17.58 | 18.60 | 20.14 |

Table F-3: Summary of projected maximum temperature changes in Amboseli in 2030, 2050, 2070 and 2100 based on RCP 2.6, 4.5 and 8.5

| | | Season | Base(2006) | 2030 | 2050 | 2070 | 2100 |
|---|---|---|---|---|---|---|---|
| RCP 2.6 | Maximum | Annual | 27.11 | 27.80 | 28.06 | 28.04 | 27.47 |
| | | MAM | 25.97 | 26.57 | 26.79 | 26.76 | 26.25 |
| | | JJAS | 25.99 | 26.86 | 27.20 | 27.18 | 26.50 |
| | | OND | 25.01 | 25.51 | 25.71 | 25.69 | 25.29 |
| | | | | | | | |
| RCP 4.5 | Maximum | Annual | 26.43 | 26.87 | 27.24 | 27.60 | 28.15 |
| | | MAM | 26.50 | 26.99 | 27.40 | 27.82 | 28.43 |
| | | JJAS | 25.58 | 26.06 | 26.47 | 26.87 | 27.48 |
| | | OND | 25.66 | 25.99 | 26.27 | 26.55 | 26.97 |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RCP 8.5 | Maximum | Annual | 26.06 | 27.17 | 28.09 | 29.01 | 30.40 |
| | | MAM | 26.28 | 27.38 | 28.30 | 29.22 | 30.60 |
| | | JJAS | 25.06 | 26.41 | 27.54 | 28.66 | 30.36 |
| | | OND | 25.20 | 26.09 | 26.83 | 27.57 | 28.68 |

Publications


**1.** Aduma, M.M., Ouma, G., Said, M.Y., Wayumba, G.O., Omondi, P.A., and Njino, L.W. (2018) Potential Impacts of Temperature Projections on Selected Large Herbivores in Savanna Ecosystem of Kenya. American Journal of Climate Change, 7, 5-26. https://doi.org/10.4236/ajcc.2018.71003

2. Mildred, M. Aduma, Gilbert O. Ouma, Mohamed Y. Said, Gordon O. Wayumba, Joseph Muhwanga Spatial and Temporal Trends of Rainfall and Temperature in the Amboseli Ecosystem of Kenya. World Journal of Innovative Research. 5, https://doi. Org/10.31871/WJIR.5.5.5

3. Aduma, M.M., Said, M.Y., Ouma, G., Wayumba, G. and Njino, L.W. (2018) Projection of Future Changes in Elephant Population in Amboseli under Representative Concentration Pathways. American Journal of Climate Change, 7, 649-679. https://doi.org/10.4236/ajcc.2018.74040.