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Human-elephant interactions: exploring conflicts and drivers in enduimet wildlife management area, Tanzania

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HUMAN-ELEPHANT INTERACTIONS: EXPLORING CONFLICTS AND DRIVERS IN ENDUIMET WILDLIFE MANAGEMENT AREA, TANZANIA

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A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master's in Life Sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

A globally rapid land use/land cover change in human-transformed landscapes alters the interface of human-wildlife interactions due to shifting socio-ecological and environmental pressures. Understanding these shifts is crucial for mitigating repeated negative interactions that escalate conflict states between people and wildlife. This study aimed to understand land use/land cover change changes between1989–2019, with more recent spatio-temporal patterns of high pressure at the human-elephant interface, and potentially underlying environmental and human driven factors that affect elephant movement patterns. The study analyzed a dataset of 923 human-elephant conflict occurrences, mainly crop foraging incidents in the Enduimet between the years 2016 and 2020 and combined these data with land use/land cover change for year 2019 to understand potential drivers of conflict. Furthermore, GPS datasets of elephants collared between 2019 to 2020 used to understand elephant movement patterns in changing land use types. Landsat image study revealed that 41% of the area had been converted into farmlands and settlements within the last three decades, which creates elephant-intolerant habitats and the potential to increase pressure at the human-elephant interface. The collared elephants using Enduimet moved through all land use types and did not avoid settlements, although they moved through these at higher speeds, reflecting perception of risk. Elephants travelled slightly more slowly in farmland, likely reflecting the availability of foraging opportunities. Conclusively, communities in land use/land cover change urgently need support to increase the effective distance between their farming activities and the protected areas.

DECLARATION

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

28/07/2023

John Erasto Sanare   Date

The above declaration is confirmed by:

28/07/2023

Prof. Anna Christina Treydte   Date

28/07/2023

Dr. Akida Meya   Date

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CERTIFICATION

The undersigned certify that they have read the dissertation titled "*Human-elephant interactions; exploring conflicts and drivers in Enduimet Wildlife Management Area, Tanzania*" and recommended for partial fulfillment of the requirements for the degree of Masters in Life Sciences of the Nelson Mandela African Institution of Science and Technology.

Treydte 28/07/2023

Prof. Anna Christina Treydte Date

28/07/2023

Dr. Akida Meya Date

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DEDICATION

I dedicate this work to my beloved family whose love beyond words keeps me going.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	Percentage
AfDB	African Development Bank
ANOVA	Analysis of Variance
ATE	Amboseli Elephant Trust Project
EWMA	Enduimet Wildlife Management Area
GCA	Game Controlled Areas
GIS	Geographic Information System
GPS	Global Positioning System
HECs	Human-Elephant Conflicts
IUCN	International Union for Conservation of Nature
km	Kilometer
km^2	Kilometer Square
KWC	Kitendeni Wildlife Corridor
LULC	Land Use and Land Cover
m	Meter
NDVI	Normalized Difference Vegetation Index
NM- AIST	Nelson Mandela African Institution of Science and Technology
PAs	Protected Areas
R	Statistical Package for Social Science
RF	Rufford Foundation
RS	Remote Sensing
SHF	Shape File
TAWA	Tanzania Wildlife Management Authority
TAWIRI	Tanzania Wildlife Research Institute
WC	Wildlife Corridor

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Tanzania's protected area network covers about 32.5% of it is land surface 307 800 km^2 (Hariohay *et al.*, 2020), where the African elephant *(Loxodonta africana*) home range and movement patterns are estimated to cover about 41% of the country's land (Kioko, 2011). In the early 1950s, Tanzania's elephant population was believed to found in 90% of the entire country's land area and was estimated at 80 000 individuals (Thouless *et al.,* 2016). They have experienced more than 50% overall decline of their population size within the last 30 years from 1989 to 2019 (Gubbi, 2012; Mwakatobe *et al.,* 2014; Naughton-Treves, 2019), enough to be listed as "endangered" under IUCN red list 2020 (IUCN, 2020; Thouless *et al.*, 2016). However, since 2014, the elephant population in Tanzania slightly increased to approximately 60 000 individuals in 2019 (Gubbi, 2012; Mwakatobe *et al.*, 2014; Naughton-Treves, 2019).

The elephants mainly resides in protected areas (PAs), where intensive conservation practices are conducted (Mwakatobe *et al.,* 2014). Nevertheless, they spend considerable time outside PAs, especially during dry season in search for scanty resources such as water and forage. While outside the PA boundaries, elephants have always been facing significant conservation challenges such as poaching and increased human-elephant conflicts (HECs) (Jones *et al.,* 2012). Several studies reported that HECs are becoming more frequent, since part of the African elephant's range lies outside of PAs, overlapping with human activities is an unavoidable phenomena (Graham *et al.*, 2009; Hariohay *et al.*, 2020; Sitati *et al.*, 2003; Tiller *et al.*, 2021). In Tanzania, the human-elephant interface, at which conflicts can occur, is rapidly expanding due to population pressures and escalating demand for natural resources compounded by rapid demographic, socio-economic, Land Use/Land Cover (LULC) changes and conflicting national policies (Kioko, 2011). In addition, land conversion, because of growing human populations, has increasingly fragmented the wildlife habitat decreasing the space available to elephants and other wildlife in many areas of the country (Graham *et al.*, 2009). This has hampered the connectivity between PAs, leading to increased levels of HECs, ranging from mild forms of conflict over elephant impact on their natural environment to more severe forms where both human and elephant lives have been lost (Mukeka *et al.*, 2019).

Fragmentations and loss of wildlife habitats in the vicinity of PAs leading to blockage and/or loss of wildlife migratory corridors has mainly been due to encroachment through various anthropogenic activities including an expansion of human settlements and farming which also involves livestock grazing (Graham *et al.*, 2009). This have been reported as among the critical threats to wildlife survival in different PAs in Tanzania.

Establishing and effective management of wildlife conservation corridors to link PAs networks was recently recommended to facilitate wildlife movements and reduce HECs (Mbane *et al.*, 2019). In 2013, two wildlife migratory corridors were formerly established for conservation in Tanzania namely: Kitendeni wildlife corridor in the Enduimet Wildlife Management Area connecting Kilimanjaro with the Amboseli National Parks in Tanzania and Kenya respectively and Umemarua wildlife corridor connecting Ruaha national park and Mpanga-Kipengere game reserve (Mbane *et al.,* 2019). However, Kitendeni wildlife corridor is still under threat due to the rapid increase in the human population which is not only blocking the corridor and elephants' movements but also has resulted in an increased HECs (Jones *et al.*, 2012).

Henceforth, understanding how LULC changes and elephant movement patterns drive HECs can yield crucial insights for developing effective mitigation and biodiversity conservation strategies (Martin *et al.,* 2019; Wall *et al.,* 2021). Up to now, there is only limited understanding of elephants' spatial and temporal movement and how it has been affected by anthropogenic activities. Many HEC studies conducted in the area relied only on survey questionnaires that are prone to bias, as losses can be exaggerated, especially if encounters are traumatic. Thus, it remains imperative to know elephant movement patterns in unprotected areas for understanding of the conflict distribution patterns across time and space scales within an increasingly fragmented landscape to develop appropriate conservation actions (Thompson *et al.,* 2022).

Moreover, knowing the movement patterns of elephants in relation to human activities helps to understand spatial and temporal conflict hotspots areas (Naha *et al.,* 2019; Wilson *et al.,* 2015). Furthermore, elephant speed variation across different land use categories can be used as a novel method to detect areas with high HECs, as animal movement can reflect potential risk within a certain area (Troup *et al.,* 2020).

Elephants might exhibit higher movement speeds in settlement areas, i.e., when stressed, while they might slow down inside farmland to forage intensively on crops. Yet, few studies have been conducted on these movement patterns related to conflict hotspots areas. This study, applied Geographical Information System (GIS) and Remote Sensing (RS) techniques to quantify LULC changes and elephant movements and combined this information with interviews to explore their spatial and temporal relationship and identify the areas at higher risk of conflicts in EWMA.

1.2 Statement of the Problem

Human-elephant co-existence presents a significant conservation challenge and priority in

Tanzania, where elephant populations have drastically declined over the last 30 years (Kideghesho, 2016; Thouless *et al.,* 2016). The elephants can have both positive and negative impacts on people and livelihood, the negative impacts include killing people or causing injuries, destroying crops cultivated and other infrastructures, while the positive impacts includes revenues generation through tourism which are normally distributed in the surrounding local communities to support community development such as the construction of schools and dispensary through outreach programs (Chlebek, 2016). As human population grows habitats for wildlife including elephants shrink due to human encroachment resulting in high overlaps of natural resource use between the elephant and humans (Gaynor *et al.,* 2018; Su *et al.*, 2020).

Despite the importance of human-elephant coexistence and environmental variables that influence occurrences of HEC, an understanding of the effects of natural and anthropogenic parameters in EWMA is only limited by inadequate information of elephants' spatial and temporal movement and how it has been affected by anthropogenic activities including expansions in the EWMA. Thus, it remained imperative to understand elephant movement patterns in unprotected areas to mitigate or even prevent further conflicts within the area. Also, understanding how LULC changes drive HEC can yield crucial insights for developing effective mitigation and biodiversity conservation strategies (Ahlering *et al.,* 2012; Chen *et al.,* 2016; Lohay *et al.*, 2020).

1.3 Rationale of the Study

Enduimet Wildlife Management Area (EWMA) provides an important ecological link with PAs in Northern Tanzania and Southern Kenya (Dekker, 2018; Kikoti, 2009), It is important for elephant conservation which helps them to move across the international borderlines in the boundary regions. There are limited studies on the effects of rapid expansion of anthropogenic threats on elephant range at large spatial scales. This information is important for wildlife conservation and in mitigating HEC over resource use (Neupane *et al.*, 2017). The study will provide an understanding of anthropogenic threats in the area and their importance for the remaining elephant population in this landscape. Moreover, the study will identify spatial and temporal zones of contact between elephants and people, which is a prerequisite to understanding coexistence possibilities and identifying conflict hotspots areas. Understanding the HECs hotspots areas helps formulate strategies for managing access to resources shared by elephants and people. Additionally, information on habitat transformation and its effects on elephant distribution improves and informs the management on elephant conservation actions between people and elephants outside PAs (Karimi, 2009).

1.4 Research Objectives

1.4.1 General Objective

To assess the spatiotemporal distribution of human-elephant conflicts and their underlying drivers in the dynamics of land use /land cover change for the years 1989 to 2019 in EWMA.

1.4.2 Specific Objectives

(i) To map LULC changes between 1989 and 2019 in the EWMA.

(ii) To assess the influence of environmental and anthropogenic drivers in predicting HEC.

(iii) To analyze the spatio-temporal patterns of HEC and hotspots areas based on 2019 LULC.

(iv) To estimate elephant home ranges in relation to HEC hotspots areas and different land uses.

1.5 Research Hypothesis

It was hypothesized that:

(i) Farmlands and settlements have increased in the EWMA over the last three decades and escalated the potential for HEC.

(ii) HEC incidents are high in areas of high Normalized Difference Vegetation Index values since elephants prefer rich foraging areas.

(iii) HEC incidents would increase over the years as farmlands expanded.

(iv) Elephant movement speed is high in human-dominated areas and less in farmland.

1.6 Significance of the Study

This study provides important information for the management authorities and local community living in proximity to EWMA to understand the status and possible ways of dealing with HECs. Understanding anthropogenic and environmental factors which influence the occurrences of HECs as well as identifying and mapping the hotspots areas of the conflicts will ensure long term protection of elephants and promotion of human livelihoods for the local community living adjacent to (PAs. Furthermore, this study has provided significant information for improving wildlife management particularly elephant and protection of the KWC in EWMA. Additionally, it has provided a better understanding of how to mitigate or prevent further HECs, especially in wildlife migratory routes and dispersal areas. Moreover, the study produced a piece of detailed information on the extent and the magnitude of land use and land cover classes, in relation to the locations of documented HECs. Furthermore, this information is essential and useful for long term planning and conflict prevention within the Kitendeni wildlife corridor (KWC) in EWMA as well as other PAs in other parts of Tanzania. Finally, this study has documented spatial and temporal zones of contact between elephants and people, which is a prerequisite to understanding coexistence possibilities and identifying conflict hotspots areas, thus will help to understand anthropogenic threats facing the EWMA. Moreover, information on habitat transformation and its effects on current and potential elephant distribution will improve and inform management authorities on elephant conservation actions between people and elephants outside protected areas.

1.7 Delineation of the Study

This study used geospatial tools to quantify Land use and Land cover changes and combine this information to elephant movements datasets as well as interviews to explore their spatial and temporal relationship and identify the areas at higher risk of conflicts in the Enduimet wildlife Management Area. However, it would have been prudent to have long time monitoring data for collared elephant using the Kitendeni wildlife corridor to evaluate the use and viability of the corridor for migratory animals. The field survey involved household questionnaires to assess the human-elephant coexistence in the EWMA, However, it could have been also practical to engage other wildlife conservation stakeholders to hear their opinions through stakeholders’ engagements and participatory to gain more insights and drivers of the human-elephant conflicts in this landscapes and plan for the future sustainability of the Enduimet Wildlife management area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Expansion of Anthropogenic Activities and Elephant Conservation

Over centuries, African nations have been establishing extensive networks of protected areas (Pas) to promote conservation of ecosystems and their species (Newmark, 2008). In the last 30 years, PAs in Africa experienced expansion aimed at increasing the capacity to maintain viable populations of wildlife. However over the long term, anthropogenic activities (cultivation, intense illegal hunting, livestock grazing and infrastructures development) have been a threats to many PAs in Africa (Kioko, 2011). Whereas Tanzania is the second home of the largest population of African elephants on the continent (Sayuni *et al.,* 2015; Thouless *et al.,* 2016), Several studies reported that majority of elephant's population are found in unprotected areas despite the notable record of elephant conservation in Tanzania's PAs (Kami *et al.,* 2006; Karimi, 2009; Kikoti, 2009; Mukeka *et al.,* 2019; Thompson *et al.,* 2022). This has posed challenges to ecologists and wildlife authorities due to the increase in HECs caused by the expansion of human settlement and agriculture into new areas that are previously occupied by elephants (Thompson *et al.,* 2022). Conservationists reported that the rapid conversion of landscapes that were previously used by elephants into human-dominated areas has intensified the crop raids, a sort of HEC most problematic for agricultural societies (Kikoti, 2009; Nyirenda *et al.,* 2018). It has been reported that HEC occur more frequently at the begins and end of wet and dry seasons respectively, correlating with the time of the crop matured and at night, probably because of the avoiding risk in the daytime (Jackson *et al.,* 2008; Graham *et al.,* 200).

In EWMA as in many other areas in Tanzania, areas of heavy human use (Barnes, 1996), high population and rapid LULC changes are reducing elephant home ranges (Newmark, 2008; Shaffer *et al.,* 2019), escalated an increase in HECs due to elephant vast range and demand for foraging needs at large which has been interfered by human activities (Graham *et al.,* 2009). Different literatures reported have reported the continuous existence of HECs is due to the majority of the current prevention strategies being driven by site-specific factors that offer short term solutions only. This resulted in several problems such as crops damages, human death and injuries, livelihoods loss and negative attitude toward wildlife (Mmbaga *et al.,* 2017; Tiller *et al.,* 2021).

2.2 Wildlife Management Areas in Tanzania

Wildlife Management Areas (WMA) are an areas of communal land set aside exclusively as habitat for wildlife by member villages. The WMAs in Tanzania were established as results of rapid increasing human population; consequently, the government assumed the need for finding solutions that provide incentives for communities living adjacent to PAs for their contribution in conservation initiative. This innovative conservation initiative supports the conservation of biodiversity by empowering local communities to be in charge of the wildlife on their land, using the benefits to boost livelihoods and reduce poverty, by establishing a WMAs, communities participate in a process of land use and resource management planning, promote both long term protection of wildlife and habitat and rural economic development. They negotiate with private tourism investors to generate revenue. These sustainable sources of income are very important for the long term future of these areas, the generated income from the investors divided among participating villages to fund community projects, with some of the money set aside to fund operations such as anti-poaching and management programs. In 2003, the Government of Tanzania following evaluation of the pilot phase, WMAs were formally adopted as an approach for involving communities in wildlife management. Until 2022, twenty-two WMAs in Tanzania were established, covering approximately 13% of the Tanzania's land area, where over 31 million acres of land will be managed by local communities.

2.3 Wildlife Corridors, Migratory Routes and Dispersal Areas

Wildlife Corridors are areas of land used by wild animals in their seasonal movements from one ecosystem to another in search of basic requirements such as water, food, space and habitat (Jones *et al.*, 2012). It also, allows free movements of wildlife from one PA to another where access to critical resources and exchange of genetic material take place (Talukdar *et al.*, 2020). However, wildlife corridors have been facing threats such as rapid increase in human population. In Nairobi National Park, wildlife migrates to Kitengela dispersal areas (Talukdar *et al.*, 2020), but due to rapid human population growth and agriculture expansions the wildlife movement corridors have been blocked (Rodriguez *et al.*, 2012). In South Africa, a study by Thomas *et al.* (2012) on seasonal home ranges of elephants between Sabi Sand Reserve and Kruger National Park (KNP), proposed that protection of the elephant corridors was inevitable since elephants depend upon the resources of both areas. Furthermore, in Tanzania, Kitendeni wildlife corridor situated in EWMA connecting Kilimanjaro and Amboseli National Parks is under threat due to growing human settlements and agricultural development (Mbane *et al.*, 2019). In Tanzania, many PAs are rapidly becoming isolated, yet the long-term viability of these PAs depends on watersheds outside the PAs (Mbane *et al.*, 2019), on the ability of wildlife to disperse and return to the area on an annual basis, and on a movement of animals from other PAs (Fig. 1). The reasons for the increasing isolation of PAs in Tanzania are complex, and include the growing human population in areas adjacent to PAs and land use change towards agriculture, infrastructure and settlement in areas that were previously unpopulated (Newmark, 2008). Therefore, wildlife corridors are critical integral part of ecological functioning and long-term survival of the ecosystems (Noe, 2003).

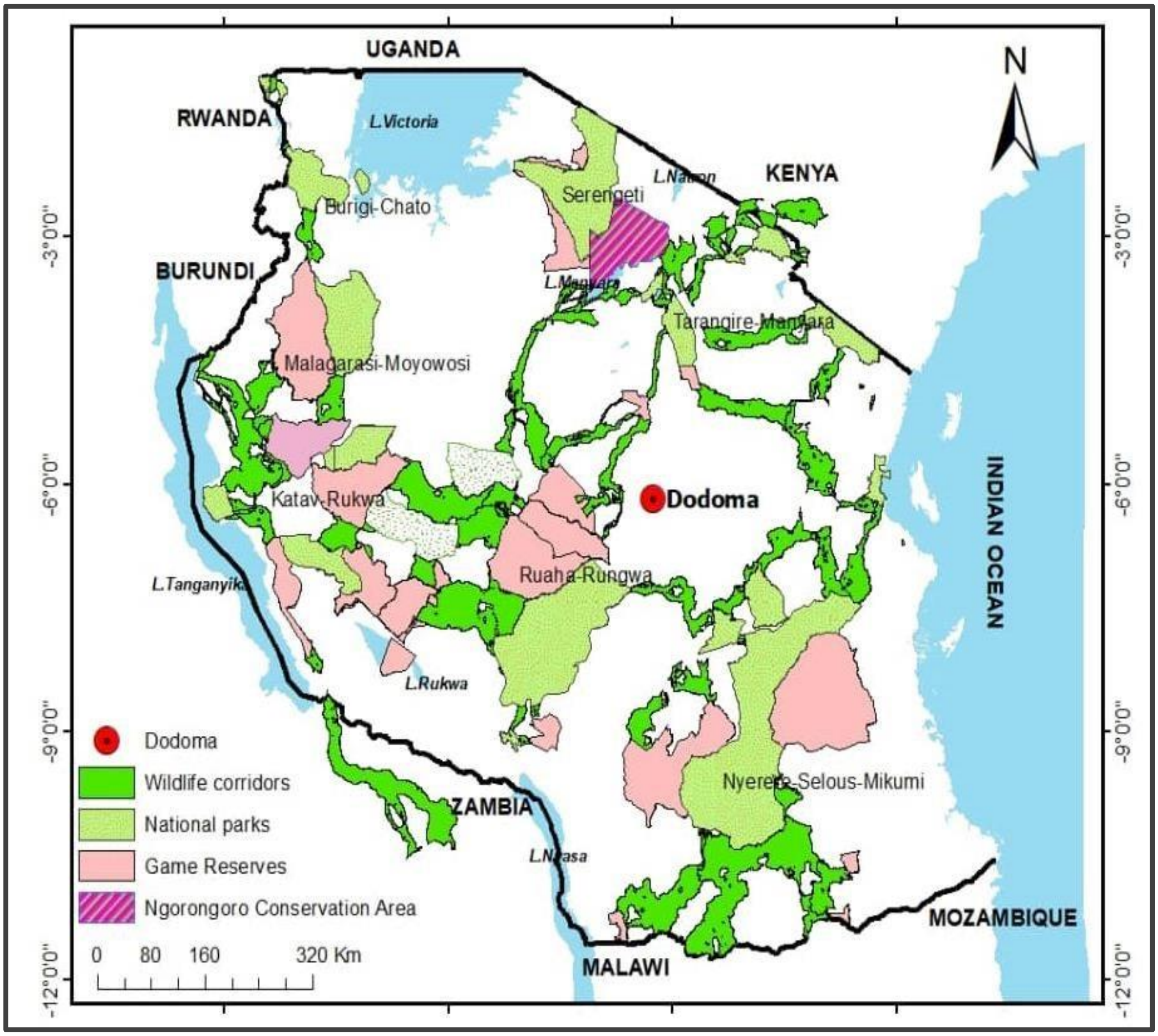

Figure 1: Map showing the location of wildlife corridors in Tanzania based on a data set by the Tanzania Wildlife Research Institute (Wildlife corridor assessment report, 2019)

2.4 Human-Elephant Conflicts

Human elephant conflict happens when elephant home ranges overlap with cultivation and settlements often compete for the same resources (Sam *et al.,* 2005). The increased levels of HECs, ranging from forms of conflict over elephant impact on their natural environment to more severe forms where both human and elephant lives have been lost (Mekonen, 2020; Nyhus, 2016). The conflicts can have socio-economic costs for instance, the extensive time for people engaging in farming and guarding their farms limits the amount of time available for other productivity activities. In addition, local community in rural areas, also feel unsafe during the day and night as pupils walk to and from schools, markets and to collect firewood. Additionally the socio-economic development of communities living adjacent to PAs are potentially affected as elephants tend to move outside the PAs and damage crops (Granados *et al.,* 2012; Gubbi, 2012). Frequent crop damage roots farmers to develop negative attitudes towards the elephants and hinder conservation initiatives (Hariohay *et al.*, 2020). The challenge of managing the co-existence between elephants and people arises because different stakeholders have different views or interests, and also because elephants are viewed as dangerous and destructive animals (Graham *et al.*, 2009). Research on human-elephant interactions can therefore improve knowledge of the costs associated with land-sharing between people and elephants and help to understand the dynamics of these interactions can help identify management strategies to protect both humans and elephants (Graham *et al.*, 2009).

2.5 Tracking Elephant Movement as a Novel Tool for Human-Elephant Conflicts Mitigations

The elephants have a long home range and can move long distances rapidly, such movement is thought to be important for accessing resources that are scarce in time and space demonstrated by the inverse relationship between rainfall and elephant home range documented among African elephants studies (Thouless *et al.*, 2016). Some studies have shown that in the arid environments of Mali and Namibia where elephants traveled large distances to meet their nutritional requirements, with recorded home ranges of 24 000 km^2 and 12 800 km^2, respectively (Blake *et al.*, 2003; Leggett, 2006). Such movement and overlaps with human practiced activities such as agriculture and settlement areas are inevitable (Fernando *et al.*, 2010). Consequently, in Tanzania over the last decade, HEC has escalated across different elephant ranges landscapes (Fernando *et al.*, 2010).

Management interventions are becoming important for conserving the elephant and mitigating HECs across different PAs in Africa. Currently, technological developments have allowed high-resolution global positioning system (GPS) tracking, allowing wildlife researchers to establish over a 24 hours' duration where collared elephants spend their time. Whereas many applications of such technology include studies of home range and habitat suitability (Chibeya *et al.*, 2021; Hemson *et al.*, 2005; Wall *et al.*, 2021), and furthermore recently, elephant social behavior (Wall *et al.*, 2021). The application of this technology has huge potential to play in understanding in human-elephant interaction, especially in the human-dominated landscapes.

2.6 Geospatial Techniques in Wildlife Conservation

In the past three decades, the human-elephant conflicts (HEC) management techniques i.e. deterrent crops, separation of humans and wildlife through buffer zones and protection of wildlife corridors, have been developed and practiced to prevent and mitigate HECs in different wildlife landscapes (Olsson, 2014). Although, these strategies are affordable and practical, impact of expansion of LULC on HEC occurrences is limited. For example, the impact of expansion of human activities which results in changes of LULC i.e., from the forest and woodlands into agriculture and settlements and escalated HECs occurrences due to edge effects is restricted (Kideghesho, 2016; Naha *et al.*, 2019; Gross, 2019). Recently, there has been improvement in conservation strategies by use of modernized geospatial techniques such as GIS and remote sensing to quantify the LULC change as well as elephant movement (López & Mulero-Pázmány, 2019). There has been an increase in the use of remote sensing and geospatial technologies to prevent wildlife crime in the last decade. Conservationists are engaging with this technology to better locate poaching incidents and combat the rapid decline of species. Remote Sensing techniques have been reported to have low cost as observation of natural phenomena is done at high spatiotemporal resolution (Christie *et al.*, 2016). For these reasons, Geographical Information System (GIS) and remote Sensing (RS) have therefore become tools for ensuring management and research in wildlife as they can raise better information that can assist in management decisions (López & Mulero-Pázmány, 2019). Also, remote sensing compared to other techniques, can cover a large area and collect a huge amount of data in a short time and reduce the time required for data collection (Barmpounakis *et al.*, 2016).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The Enduimet Wildlife Management Area (EWMA) is a wilderness area that covers 752 km^2 (Minwary, 2009), within the Longido District, in the Arusha Region (Fig. 2). The area is bordered by Kilimanjaro National park (KINAPA) to the South-east, Tanzania-Kenya political boundary to the North and Ngasurai plains open area to the West (Sayuni *et al.*, 2015) and joining the Kilimanjaro-Amboseli ecosystems and functioning as an important wet season dispersal area and feeding ground for Amboseli and Kilimanjaro wildlife. The EWMA was established in 2003 under the Tanzania wildlife policy of 1998 and comprises 9 villages (Dekker, 2018) mainly distributed along the productive slopes of Mt. Kilimanjaro. As many as 1600 elephants monitored by the Amboseli Trust for Elephants, spend 30% part, or most of the year in EWMA (Kikoti, 2009). The EWMA represents an important wet season sanctuary for elephants (*Loxodonta africana*) and other species including wildebeest (*Connochaetes taurinus*), lions (*Panthera leo*), zebras (*Equus quagga*) and African buffalos (*Syncerus caffer*) few to mention (Okello *et al.*, 2016). The average annual rainfall of EWMA ranges between 300 mm and 600 mm, daily average temperatures between 30°C to 35°C and it covers an elevation ranging between 1230 m -1600 m (Trench *et al.*, 2009). The long rainy season lasts from March to May, while the short rains season lasts from August to October (Mbane *et al.,* 2019), and cropping has become common during these months amongst the agro-pastoralists (Mbane *et al.*, 2019). Farmers practice small scale farming and plant crops that mature fast and are droughts tolerant such as maize and beans.

The vegetation in EWMA is primarily comprised of mixed *Acacia spp.* woodlands, including *Vachellia commiphora* bushland, *Vachellia tortilis* savannah and *Sporobulus africanus* short grass plains, typical of semi-arid East African savannah (Mbane *et al*., 2019). The EWMA comprises the KWC, which connects the Kilimanjaro and Amboseli national parks in Tanzania and Kenya respectively (Sayuni *et al.*, 2015) and serves as a major transboundary migratory corridor for many wildlife species, including the African elephant (Muruthi & Frohardt, 1999). This remains the only formally protected wildlife corridor that links the West Kilimanjaro ecosystem to other ecosystems, after the blockage of other corridors that link Lake Natron Game Controlled Area (GCA) and Arusha and Mkomazi national parks (Noe, 2003). The EWMA contains arable and fertile lands with high agricultural potential and a number of human settlements, in particular the villages of Tingatinga, Elerai, Lerang'wa, Kamwanga and Olmolog which has intensified recently parks (Noe, 2003; Fig. 2). The corridor is, however, under threat following the expansion of human activities in the area and the changes in land use over the years (Kija *et al.,* 2020). The human population in EWMA is about 57 103 people, having increased by 30% between 1988 and 2017 (Dekker, 2018). Although traditionally the resident Maasai are nomadic pastoralists, agriculture and tourism-related activities are becoming an important source of income (Songorwa, 2004).

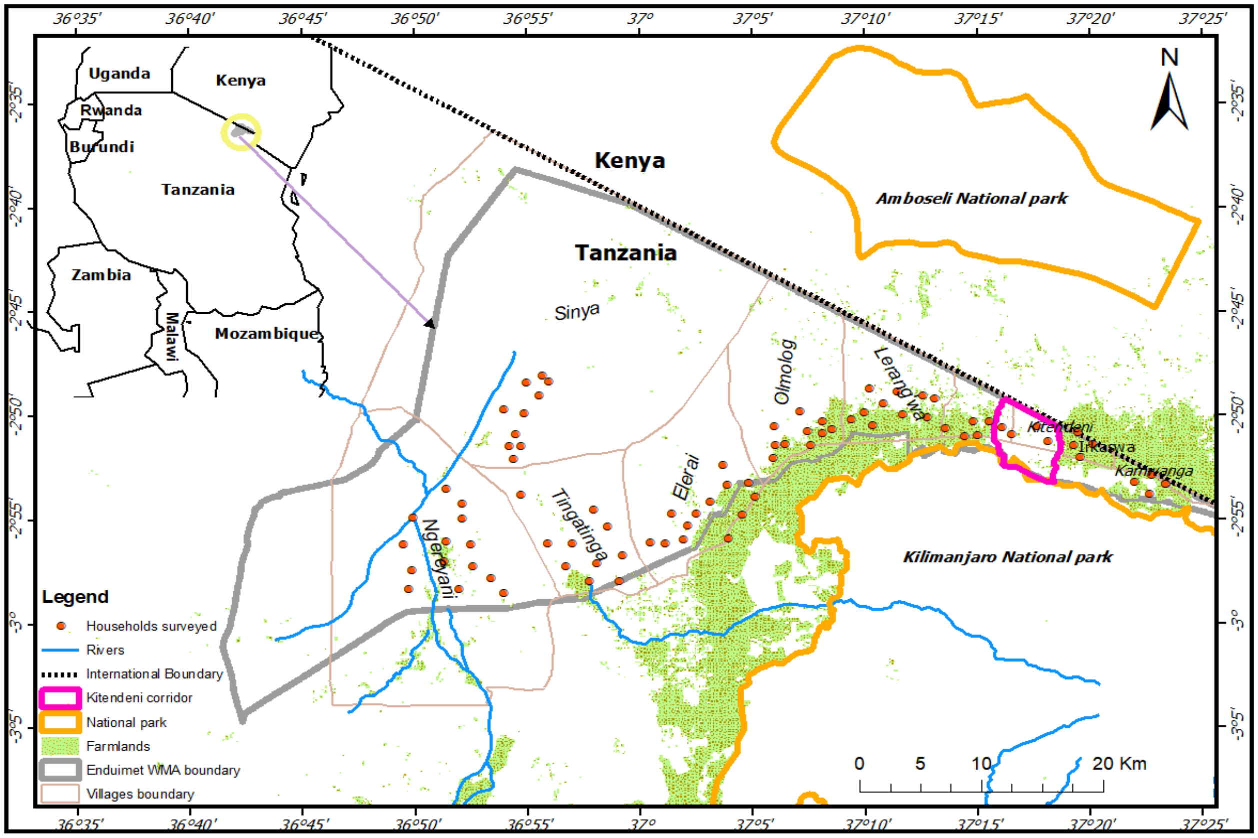

Figure 2: **Map of the study area showing the location of households surveyed across different villages, showing the Kilimanjaro and Amboseli National Parks, and the Enduimet Wildlife Management Area Tanzania, from March 2019 to June 2019**

3.2 To Capture and Map Land Use and Land Cover Changes between 1989 and 2019 in Wildlife Management Area Tanzania

3.2.1 Remote Sensing data for Land use/ cover Analysis to Assess Land Cover Dynamics in Wildlife Management Area Tanzania

(i) Image Pre-Processing

Analyzed LULC in this study employed the Landsat imagery from the United States Geological Surveys (USGS), four Landsat images (1989-2019). All the images were cloud free for wet and dry season for the years considered for analysis, all the images were less than 10% cloud free (Appendix 1). Basic image preprocessing i.e., radiometric and geometric calibration was achieved by the use of the atmospheric correction tool in ERDAS software and registered to the Universal Transverse Mercator (UTM) coordinate system datum WGS84 and UTM Zone 37S, which is a location of EMWA to correct the images atmospheric scattering such to increase the visibility of hazy image (Reis, 2008; Serra *et al.*, 2003). Distinct features on the image (e.g., roads intersections, hills, and mountains have been used to establish ground control points (GCP) for geometric calibration to match their corresponding coordinates on the ground. Thereafter, imageries were clipped to a boundary extent of the study area before classification, to enhance a quick processing and better collection of sample points. The Landsat imagery were resampled to 30 m pixel resolution to synchronize their spatial properties Landsat 8 image to easy analysis after classification.

(ii) Image Classification and Accuracy Assessment

Both supervised and unsupervised classification methods were used to classify all the images for years 1989, 1999, 2009 and 2019. Preliminary information on the spectral clusters for each images provided through unsupervised classification (Mohd *et al.*, 2009). Thereafter, a supervised image classification at maximum likelihood classifier (MLC) algorithm in ArcMap 10.6 software was used to classify images at a pixel level. Additionally, assessment of land cover training and samples validation for LULC were collected to ensure the accurateness of the classified imagery. The collected samples were assigned to land use/cover classes such as agriculture, bare lands, bushlands, forest, grasslands, settlements, woodland, wetlands and water bodies (Table 1), the training sample points were verified using high resolution Google earth imageries (Estoque *et al.*, 2015). For difficult and/or confusing classes to identify, Google earth was used to identify during the field data collection based on expert knowledge of the study area.

The agreement between the ground truthing data and the classified map (accuracy assessment) was assessed by an error matrix (Mengistu & Salami, 2007) using the test dataset (50% of the full sample). The error matrix (cross-tabulation) table for each thematic image was generated. Kappa Index of Agreement (KIA) that measures how well the classified map matches the reference data was also computed (Foody, 2002; Maxwell & Warner, 2020).

(iii) Change Detection/Post Classification Analysis

Post-classification change detection method is the most widely used technique to ascertain the type, and magnitude of land cover and use changes between two or more temporal images to detect the differences (Mengistu & Salami, 2007). In this study, a post-classification comparison between time series images was performed using QGIS version 3.6 to assess the land use changes that occurred from 1989, 1999, 2009 and 2019 in EWMA.

Table 1: Description of Land use/Land cover (LULC) classes used in analysis modified from a classification system in the EWMA from 1989, 1999, 2009 to 2019

LULC types	LULC Description
Agriculture	Land actively used to grow crops (maize and tomato) (seasonal and permanent)
Bare ground	No vegetation (exposed rock outcrops and bare soil)
Bushland	Dominated by multi-stemmed plants from a single root base and woody cover
Forest	> 50% canopy cover of woody plants of ≥ 5 m height
Grassland	< 10% cover of sparse woody plants, dominated by continuous herbaceous cover
Settlement	Urban and rural settlements (houses, roads, infrastructure)
Water	Water bodies, mostly permanent (inland water)
Wetland	Marshes or swamps; saturated land
Woodland	< 50% canopy cover of woody plants of ≥ 5 m height

Kija *et al.* (2020) and Msofe *et al.* (2019)

3.3 Predicting Human-Elephant Conflicts based on Environmental and Anthropogenic Drivers

3.3.1 Secondary Data for Human-Elephant Conflicts and Environmental Dynamics

Data on the spatial location of HEC in EWMA, in particular crop forage incidents, were collected between May 2016 and May 2020 by the Tanzania Wildlife Research Institute (TAWIRI) (www.tawiri.or.tz) and OIKOS East Africa (http://oikosea.co.tz) under the EU-funded project CONNEKT (Greater Kilimanjaro Initiatives to enhance community participation in sustainable conservation of the trans frontier ecosystem and wildlife). Each HEC incident less than 1km to the household was assumed to be a unique event, and information about the location of crop raids as well as name of the village were collected. The distances of all HEC locations to the park boundaries, nearest road networks and the nearest rivers derived from (https://www.usgs.gov) were obtained using a nearest tool in QGIS software version 3.6; elevation of the HEC locations areas were extracted from a Digital Elevation Model (DEM) (https://www.usgs.gov) having a spatial resolution of 30 m (Wang *et al.*, 2011). Normalized Difference Vegetation Index (NDVI) values computed following (Bhandari *et al.*, 2012) procedures for the years 2016 - 2019 related to occurrences of HEC and elephant home ranges were derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) (https://modis.gsfc.nasa.gov) (Table 2).

3.3.2 Statistical Analysis

A binary multiple logistic regression model was used to examine the relative influence of key underlying correlates of HEC, field observations and grey literature (Runyoro, 2019). Data associated with HEC in the EWMA were analyzed in relation to environmental (NDVI, elevation, distances from PAs, main road network, rivers and elephant home range) and anthropogenic variables (the proportion of land converted to agriculture and settlements (Table 2). Before running the binary logistic regression, variables showing multicollinearity, i.e., having a Variance Inflation Factor (VIF) greater than 3, were identified and dropped from the model (Tabachnick & Fidell, 2007).

Table 2: Major environmental variables that were used in the model to test whether they influenced human-elephant conflict occurrences were collected in the EWMA, from 2016 to 2020

Variable	Unit	Category	Range (min-max)
Dependent variable			
HEC occurrence		categorical	0 and 1
Independent variables			
Distance from river	km	continuous	0 - 24
Distance from main road	km	continuous	0 - 13
Distance from protected area	km	continuous	0 - 46
Distance from farmland	km	continuous	0 - 18
Distance from settlement	km	continuous	0 - 60
Elevation	m. a. s. l.	continuous	1125 – 5120
Year		numerical	2016-2020
NDVI	values	numerical	0 -1
Season		categorical	wet and dry
Time of day		categorical	night and day

3.4 A Spatio-Temporal Patterns of Human-Elephant Conflicts and Hotspots Areas based on 2019 Land Use and Land Cover

3.4.1 Household Questionnaire Survey for Primary Land Use and Land Cover Hotspots

A semi-structured questionnaire survey was adapted from (Punch, 2013) and used to collect data on the locations and numbers of HEC incidents in eight administrative villages (Fig. 1). A total of 96 households about 30% of population in area were interviewed (Punch, 2013). Based on the household scattered distribution patterns, the households were systematically selected and were located at least 1 km apart from each other. The selection of individual respondents was based on the knowledge of the individual about HEC incidents, be a resident in the area for more than 5 years and be willing to share the intended information. In addition, elders (>55 years) of each village were asked to recall the trend in LULC changes and the nature of HEC incidents that happened in the area over the past 5 years to complement data from classified Landsat satellite images on LULC.

3.4.2 Identifying Conflict Hotspots

The HECs hotspots areas data was collected by using focus group discussion and Key informants.

One focus group discussion composing of seven people from each village that forms EWMA was conducted. The FGD was formed with individuals who were willing to participate in the interview discussion and by making sure there is a balance between men and women. The information from FGD was taken after the agreement was reached between the participants and was regarded as single information. The Key-informant interviews (KII) were administered to villages executives' officers, district forest officer and the EWMA manager (Appendix 7). In depth, interviews were conducted to explore the conflict-prone zones where HEC is highly reported. According to Mmbaga *et al.* (2017), an area considered a HEC hotspot area, if an incident reported to occur at least three time in four consecutive years (Mmbaga *et al.,* 2017). In addition, direct observation on nearby farms whenever possible was performed to identify and observe the identified HECs hotspots area.

3.4.3 Statistical Analysis

Kruskal-Wallis' test and Mann-Whitey U-test were used to evaluate differences in HEC incidents among the years, across seasons and time of the day, respectively. Global Moran's function in ArcMap 10.6 software was used to measure HEC spatial autocorrelation. A Kernel Density Estimation (KDE) and Gedis-Ord Gi algorithms were carried out to estimate and identify high concentration and hotspot areas of HEC. Further analyses were carried out to combine the KDE surface with different LULC classes and generate the HEC hotspot areas map.

3.5 Estimate Elephant Home Ranges in Relation to Land Use and Land Cover Hotspots Areas and Elephant Movement Speed under Different Land use

3.3.3 Spatial and Temporal Distribution of Elephants

About 52 488 GPS locations of three male elephants ranging in the EWMA between July 2019 to September 2020, collected from collars fitted by the Amboseli Trust for Elephants (ATE). Collared elephants were based on known IDs from Amboseli elephant families studied since 1972 (Chiyo, Archie *et al.,* 2011). All males were of dispersal age (range 8-19, mean 13 years old) and were either still in association with their natal family or had known dispersal dates within the previous 6 months. The GPS collars (GSM IPO-95 supplied by Savannah Tracking Ltd, Kenya) recorded hourly location fixes and had been monitored for fit and wear during observations of target elephants. Permissions to deploy collars had been obtained from Kenya Wildlife Service (KWS).

3.3.4 Statistical Analysis

A Kernel Density Estimation (KDE) and Gedis-Ord Gi algorithms were carried out to identify high concentration and hotspot areas of HEC. Further analyses were carried out to combine the KDE surface with different LULC classes and generate the HEC hotspot areas map. Moreover, home range of each sampled male elephant was estimated using 100% minimum convex polygon (MCP100%) and 95% fixed-kernel density (KDE) methods (Kikoti, 2009) and overlaid with the dataset on crop raids. The KDE was implemented using Hawth's tools in ArcMap 10.5 software and overlaid with HEC locations to reveal the relationship between elephant home range and HEC hotspots areas. Furthermore, One-way ANOVA test (Welch's) was used to determine the difference of studied parameters (settlement, farmland and other areas of EWMA). All statistical analyses were performed using R version 3.4.1 (https://www.r-project.org) and at 5% level of significance ($\alpha = 0.05$) unless otherwise stated.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Land Use / Land Cover Changes

The land cover types obtained through classification and analyses of satellites imageries for EWMA are revealed that thirty years, EWMA experienced LULCC resulting from a grassland dominated ecosystem to one, in which wildlife incompatible activities i.e., agriculture and settlements have more than doubled (Table 3). Results revealed changes in land cover patterns at a certain time interval by increasing or decreasing in the area.

The shrinkage in bare land and forest in courtesy of grassland and woodland was observed between 1999 and 2019. The forest which is the focal land cover type in conservation efforts of EWMA was observed to decrease by 956 ha in the span of five years, i.e., 2009 to 2019. This change was mainly due to the rapid conversion of 1042 ha of forest and 17 711 ha of grassland to farmland within the last 10 years (Table 3).

Bushland and woodland cover did not change, while bare ground declined slightly over time from 2009 to 2019 (Table 3). Furthermore, results showed a high rate of agreement between the user's accuracy and producer's accuracy in terms of grassland, woodland, and water cover changes across all images with Kappa Indices of Agreement of 0.86, 0.87, 0.79 and 0.91 for the periods under investigation, which is similar to the standard land cover mapping accuracy (Kija *et al.*, 2020) of 85-90%. Above 0.75 Kappa is the minimum acceptable interrater agreement (McHugh, 2012). Therefore, this makes us confident in the analytical process.

Table 3: Land Use/ Land Cover classes (in ha and % coverage) between 1989 and 2019 in the Enduimet Wildlife Management Area

LULC classes	LULC coverage							
	1989		1999		2009		2019	
	ha	%	ha	%	ha	%	ha	%
Agriculture	25 999	14	28 698	15	35 017	18	50 685	27
Bare ground	3291	2	2827	1	2408	1	710	0
Bushland	24 935	13	34 251	16	24 020	13	26 312	11
Forest	2949	2	991	1	1042	1	86	0
Grassland	120 746	63	101 845	53	102 059	51	84 348	44
Settlement	10 350	5	18 002	9	21 060	11	24 599	12
Woodland	4026	2	5507	3	5293	3	5636	3
Water bodies	0	0	8	0	4	0	3	0
Wetland	777	1	944	1	2170	1	694	3

Kija *et al.* (2020) and Msofe *et al.* (2019)

4.1.2 Influence of Environmental and Anthropogenic Variability on Land Use and Land Cover

Human-elephant conflicts occurrence was high at low elevations (β = -0.02; $p < 0.001$), near settlements (β = -0.56; p = 0.039), close to farmlands (β = -1.15; p = 0.023) and near PA (β = -0.81; p = 0.006). Furthermore, based on interviews and existing reports, HEC occurrence across the entire study period was closely linked with higher average NDVI values (β = 15.43; p = 0.029), particularly in the wet season, confirming the elephants' preference for rich and productive vegetation. Distances from roads (β = -0.01; p = 0.125) and rivers (β < - 0.37; p = 0.232) showed no significant relationship with HEC occurrence in EWMA (Table 4). Elephant raids occurred most often in farmland within 20 km away from PAs (80% of incidents), concentrating on agricultural areas along the KWC and close to the villages of Tingatinga and Ngereyani; a small number of raids (20%) occurred between 21 km to 40 km away from the PA boundary (Fig. 3).

Table 4: Binary multiple logistic regression analysis results of variables influencing human-elephant conflict occurrences

Variable	Estimate	SE	*Z*	*P*
(Intercept)	23.02	1.39	4.67	0.001
Elevation	-0.02	-0.03	-4.26	0.001
Distance from farmland	-1.15	0.00	-2.84	0.005
NDVI	15.43	1.07	2.12	0.029
Distance from PA	-0.81	0.31	-3.09	0.006
Distance from river	-0.37	0.32	-1.10	0.232
Distance from settlement	-0.56	0.29	2.06	0.039
Distance from road	-0.01	0.25	-1.53	0.125
Distance from river * from road	0.01	0.01	0.92	0.359
Distance from farmland * from PA	0.01	0.01	2.31	0.021
Elephant home range	18.81	1.34	0.01	0.041

Note: * *interaction between two variables*

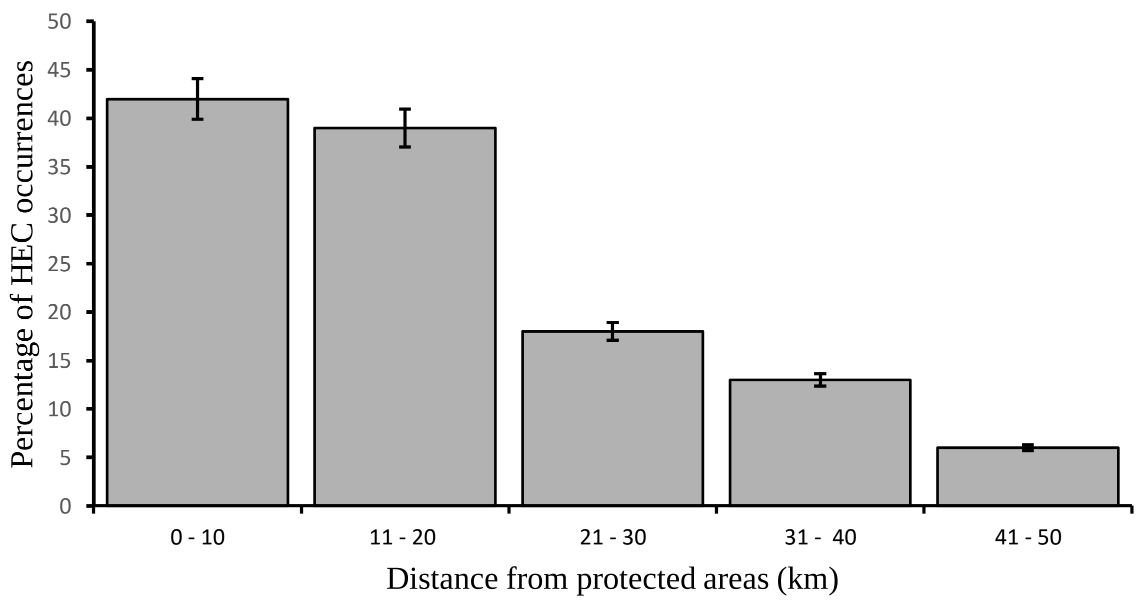

Figure 3: Proportional influence in percentage of distance away from the protected area boundary on human-elephant conflicts occurrence

4.1.3 Spatio-Temporal Patterns of Land Use and Land Cover and Hotspot Mapping

A total of $n = 923$ crop foraging incidents were recorded by Oikos East Africa between May 2016 and May 2020 across the eight villages in EWMA, with an annual mean (± SD) of 185 (± 173). The lowest ($n = 56$) and the highest ($n = 482$) number of incidents took place in 2016 and 2019, respectively, but there was no significant trend across the years ($p > 0.05$). Although crop losses caused by elephants occurred throughout the year, most incidents (55%) were recorded during the dry season, from June to November, when wild forage resources for elephants decrease in quality. There was a trend of more incidents being documented during the harvest periods of May (26%) and June (25%), while lower incidents were observed in April (3%) and October (2%), albeit not significantly different ($U = 10.50$, $Z = 0.42$, $p = 0.69$). Further, there was no significant trend across years 2016 to 2020 (H (4) = 5.55, $p = 0.24$). The majority (82%) of the recorded crop foraging incidents took place during the night, and were concentrated across six clusters within Tingatinga and Ngereyani, showing strong spatial autocorrelation (Moran's $I = 0.34$, Z-score = 33.8, $p < 0.0001$; Fig. 4).

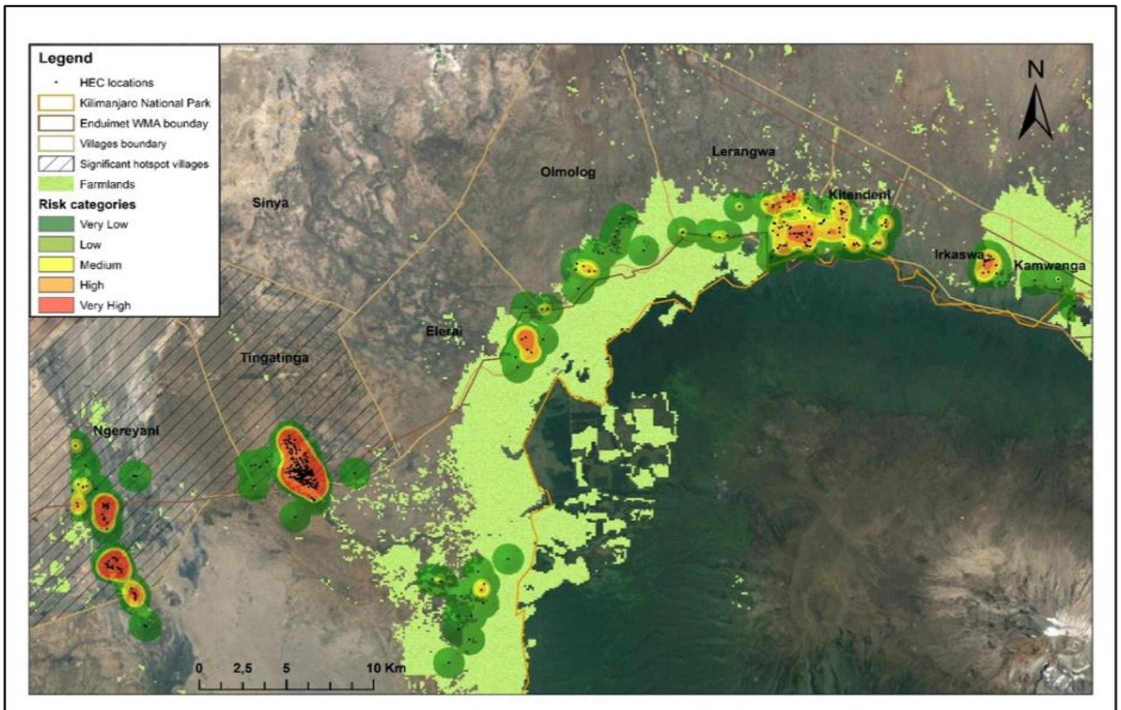

Figure 4: Heat map of areas with a high risk of being a crop foraging hotspot for elephants in the close farmlands adjacent to the southern part of EWMA

4.1.4 Elephant Home Range and Habitat Use

From more than 52 488 GPS fixes collected from three male collared elephants known to the Amboseli Elephant Research Project between 2019 to 2020, male elephants spent most of their time (48% of total recorded fixes, $p < 0.05$) in Amboseli National Park (Kenya) and 10% of their time in the EWMA (Tanzania). In agreement with other studies, elephant home range sizes were highly variable between individuals and seasons but no significant pattern was visible ($p > 0.05$ for all variables; appendices 2-5). In the EWMA, 27% of elephant GPS fixes were recorded in agricultural areas, while 38% and 34% were found in grassland and bushland, respectively. Elephant home ranges overlapped with farmland in the villages of Tingatinga and Ngereyani, where 23% of the GPS fixes were less than 2 km away from settlements and farmlands, and 27% of the GPS fixes around Lerang'wa, and Kitendeni villages were recorded near farmland (within the buffer zones or 0-20 km from the park boundary) (Fig. 5).

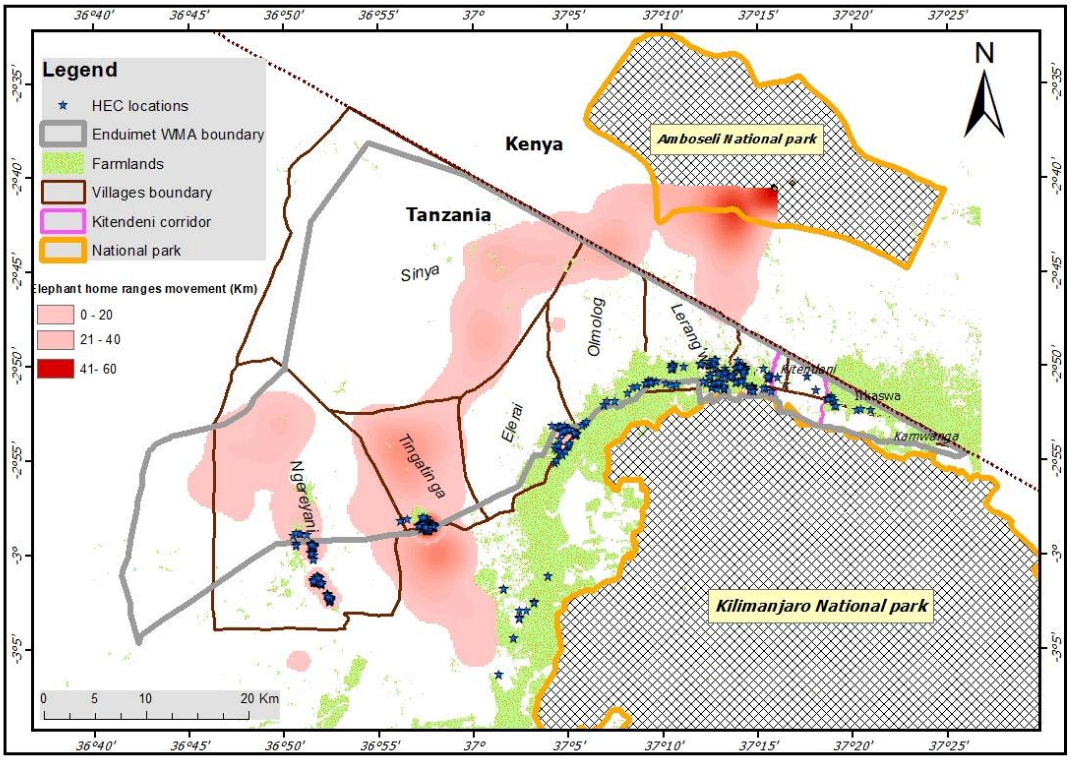

Figure 5: Home ranges for three collared male elephants (n = 52 488), calculated using Kernel density estimation, and farmlands in EWMA from July 2019 to September 2020

The study further found there was a statistically significant difference ($F = 5.543$, $p = 0.004$) in the average speed of elephants between farmland and settlements and other areas of EWMA. The collared male elephants moved almost 10% significantly slower in farmlands (0.83 km/h) compared to areas near settlements (1.08 km/h) or other areas of EWMA habitats (1.06 km/h) (Fig. 6).

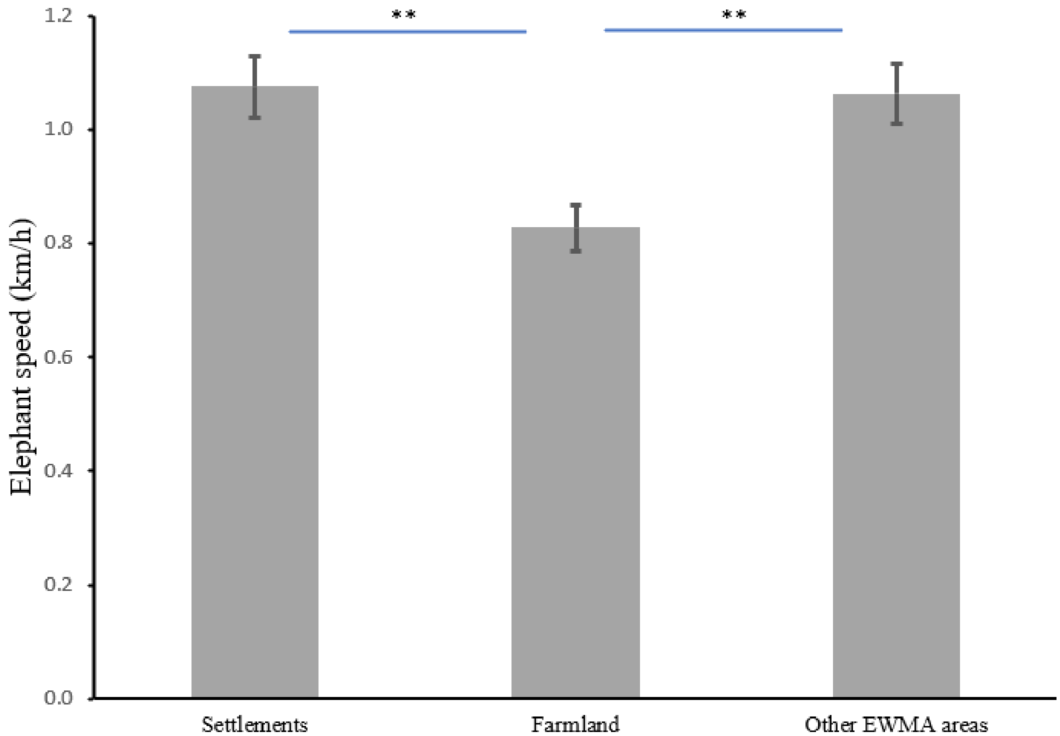

Figure 6: Average speed (±SE) of elephants collared in Amboseli National Park, Kenya, who also ranged in the Enduimet Wildlife Management Area in farmlands and settlements from 2016 to 2020

*Bar plots with an asterisk are significantly different at $p<0.05$

4.2 Discussion

4.2.1 Land Use / Land Cover Change Effects on Elephants in Enduimet Wildlife Management Area

The first two cover classes experienced the greatest reduction to 84% in 1999, 82% in 2009 and finally 72% in 2019. Agriculture experienced a rapid increase during the same years (13%-26%), doubling in the area from 1989 (25 999 ha) to 2019 (50 685 ha). The slight increment of 51 ha of forest area between 1999 and 2009 was likely due to a compensatory afforestation and plantation program (Mbane *et al.*, 2019). The findings that a large proportion of natural vegetation (152 656 ha in 1989 to 116 382 ha in 2019 or 79% in 1989 to 60% in 2019) was transformed to farmland and settlements are consistent with other studies in eastern Africa (Bullock *et al.*, 2021), indicating that anthropogenic activities are the main driver for LULC changes (Kija *et al.*, 2020; Mmbaga *et al.*, 2017). The total human population of the EWMA was around 47 103 people in 2012, with an average annual growth rate of 3% (Kulindwa *et al.*, 2003), which might have led to an increased demand for natural resources and land. The establishment of farmlands and settlements in the EWMA, as well as intense livestock grazing practices, might have blocked the traditional migratory route of elephants from east to west (Dekker, 2018; Mariki, 2015; Noe, 2003). However, even if elephants can navigate these obstacles, these practices usually increase the contact between elephants and people and, thereby, enhance the potential for damaged livelihoods (Nyirenda *et al.*, 2018; Nyumba *et al.,* 2020; Shaffer *et al.,* 2019). In addition, agriculture supporting policies encouraged the expansion of agriculture between 2009 and 2019 in the EWMA (Nduwamungu, 2008), in addressing food insecurity causing changes in grasslands and forest cover. Globally, the human population is projected increase in the coming decades, particularly in Africa (United Nations, 2019) and likely also in the EWMA (URT, 2019), threatening the survival of the elephant populations and their habitats. Wildlife tends to disappear when anthropogenic activities cover 25–50% of savanna landscapes (Thompson *et al.*, 2022), and the results revealed that settlement and agriculture together encompassed about 37% of the EWMA land in the year 2019. In Ghana, savanna reserves surrounded by human settlements have lost a large number of wildlife species over time (Abukari & Mwalyosi, 2018), and similar trends might be seeing in EWMA. The growth of human populations around PAs may further have strong negative impacts on large mammals and biodiversity through poaching, deforestation, and habitat encroachment, as was shown recently in a human-dominated landscape in North Bengal (Naha *et al.,* 2020), Mole National Park in Ghana and Tarangire National Park in Tanzania (Abukari & Mwalyosi, 2018).

4.2.2 Environmental and Anthropogenic Variability Determines Human-Elephant Conflicts

The study found a strong positive and significant relationship between NDVI and HEC occurrence, in line with other studies (Bohrer *et al.,* 2014; Duffy & Pettorelli, 2012) as both elephants and farmers select areas of higher rainfall, and farmers effectively create new foraging opportunities for elephants within these already preferred areas (Bohrer *et al.,* 2014; Caprivi *et al.,* 2000; Matt Walpole, 2020). Moreover, The study found that HEC decreased with increasing elevation, likely as elephants prefer flat lands and lowland forests compared to highlands (Naha *et al.,* 2019). In contrast to other studies (Dublin & President, 2006; Tsalyuk *et al.,* 2019), who claimed that decreased water and food availability in protected areas could lead to higher HEC, This found a non-significant relationship between HEC occurrence and water bodies distribution in EWMA. The spatial resolution at which sampled might have been too coarse and did not take artificially added water holes or seasonal water bodies into account (Harris *et al.,* 2008). While roads and small pathways open up areas for human passage and increase the probability of contact between humans and elephants (Mann *et al.,* 2019), there was no any significant positive or negative relationship of HEC with roads. This might be due to the fact that EWMA vegetation is open, and there is no need for elephants to use roads and inaccessible terrain (Minwary, 2009).

4.2.3 Spatio-Temporal Patterns of Human-Elephant Conflicts

The results showed the tendency of increasing HEC incidents into the dry season in June, when crops such as *Zea mays* (maize), *Phaseolus vulgaris* (beans), *Solanum lycopersicum* (tomatoes) and *Triticum spp.* (wheat) are maturing and to harvest stage (Thompson *et al.,* 2022) (Appendix 6). At this time, elephants raid farmlands for nutritious and palatable crops despite the availability of natural forage resources within protected areas (Chen *et al.,* 2016; Pozo *et al.,* 2017). Additionally, spatially clustered HEC incident areas were observed, mainly close to protected area boundaries in the EWMA, as has been widely reported across Africa's protected areas (Chibeya *et al.,* 2021; Ly *et al.,* 2020; Nyumba *et al.,* 2020; Shaffer *et al.,* 2019). The recorded human-elephant conflicts (HECs) hotspots in Ngereyani and Tingatinga villages reflect the proximity of vast plantations of maize and beans as well as bushlands, a mixed tree and grass system dominating the southern parts of the EWMA, which represented an attractive habitat for elephants, which potentially increased the HEC incidences in the area. The presence of dense vegetation and open grassland near farms and settlements, along with available patches of forest outside the PA in the study, may have assisted elephant movements and facilitated crop raiding (Kitratporn & Takeuchi, 2020; Pringle, 2008).

4.2.4 Influence of Elephant Home Ranges on Human-Elephant Conflicts

Elephants using EWMA demonstrated less constrained movements during the wet season, albeit not significant, but has an influence on HEC as male elephants do not have to stay close to surface water bodies to drink, which is crucial for lactating females and contributes to sexual segregation in elephants during the dry season (Stokke & Du, 2002). Although elephants mostly used protected areas' habitats on both sides of the country border, the foraging opportunities in farmland were reflected by the proportion of elephant GPS fixes in agricultural areas and by the relatively low walking speed (Hemson *et al.,* 2005; Troup *et al.,* 2020). This cluster of low elephants moving speed likely reflects foraging opportunities available in farmland, but as these data were not overlaid with crop availability data due to different resolutions, the study could not identify if any of the collared elephants were involved with identified crop foraging events.

On the other hand, elephants travelled at the same speeds in settlement areas and in other EWMA areas. Generally, male elephants have higher risk tolerance and a higher payoff for crop foraging (Chiyo *et al.,* 2011), and this trend was visible in the collar data. Understanding that crop foraging is only a small part of an elephant's ranging behavior is important for developing sustainable solutions as collared elephants spent 90% of their time in other areas (the rest of EWMA that is neither settlement nor "farmland" rather than near farms. However, the little time, they spent in areas near farmlands has been associated with destructive actions such as crop foraging (Danquah, 2016). The results are further in line with (Mmbaga *et al.,* 2017), who found HEC in Rombo district close to Kilimanjaro National Park mainly occurring during the night. In addition, the study revealed cold spots for HEC in areas that were cultivated with crops less preferred by elephants, such as Taro (*Colocasia esculenta*), Tumeric (*Curcuma longa*), Chili (*Capsicum spp.*), Eggplant (*Solanum spp.*) (Thompson *et al.*, 2022), highlighting a potentially solution against HEC. Areas of high human population and a decrease of suitable land were the best predictors of HEC in Mozambique (Ntumi, 2012), which found that areas with a human population density of < 60 people/km^2 had lower HEC incidences than areas with higher human population densities. At low population densities, there would be less interaction between humans and elephants, but also human driven destruction on elephant habitats and migratory routes might be lower (Thompson *et al.*, 2022). Unfortunately, the time span for land cover change and GPS collar in this study data did not cover exactly the same time span, during which conflict occurrences were assessed, making it difficult to relate changes in LULC to HEC incidences over time. Further, reports and interviews might have exaggerated damage extent as farmers receive reimbursement only for certain damages to their crops. Nevertheless, the socio-ecological approach is considered highly valuable in identifying spatial and temporal conflict risk zones and finding underlying factors, which can be applied for further land management actions.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study has shown that human-induced LULC changes and the encroachment into elephant habitats have resulted in spatially and temporally predictable increases in HEC in EWMA. Particularly forests and grasslands had been converted into agricultural land and settlements over the last three decades, which has increased the competition between elephants and humans for scanty resources such as water and forage. As the majority of farms in EWMA were located close to the protected areas, which likely stimulated crop foraging and escalated conflict situations, this study proposes to enforce buffer zones and effectively increase the distance of human settlements and farmland from protected areas and elephant habitats. Also, elephant speed based on collar data can be used as an indicator of a risk landscape for this species, and highlight potential conflict zones. This study further showed that the combination of cross boundary long term GPS elephant movement data and remote sensing imagery data provide a valuable resource for HEC predictions and land use planning strategies in northern Tanzania.

5.2 Recommendations

The study proposes the following to mitigate HEC adjacent to protected areas as indicated by the results:

(i) This study has shown that the majority of farms in EWMA were located close to the protected areas, which likely stimulated crop foraging and escalated conflict situations. Hence, the recommend that buffer zones, wildlife corridors and wildlife dispersal areas for elephants should be taken into consideration and given a high priority for protection. This will help avoid or minimize the conflicts that might arise between local communities and elephants, as correctly managed buffer zones outside PAs may be as important as wildlife reserves for the long-term viability of wide-ranging species.

(ii) The GPS collaring of elephants should be continued for a more in-depth understanding of elephant movement patterns and the use of certain migratory routes when moving through human-inhabited areas. The GPS locations can act as an early warning system before conflicts arise. Also, the assessment, of whether other wildlife species are using the corridor might be of interest in the future.

(iii) More detailed trans-boundary wildlife surveys should be conducted synchronically along both sides of the country boundaries since the Enduimet WMA (Tanzania) and Amboseli national park (Kenya) are one ecosystem, and wildlife migrates from one side to another. By protecting large-bodied migratory species i.e., elephants, and their habitat, some other endangered species e.g., Gerenuk (*Litocranius walleri*), will also have better habitat conditions.

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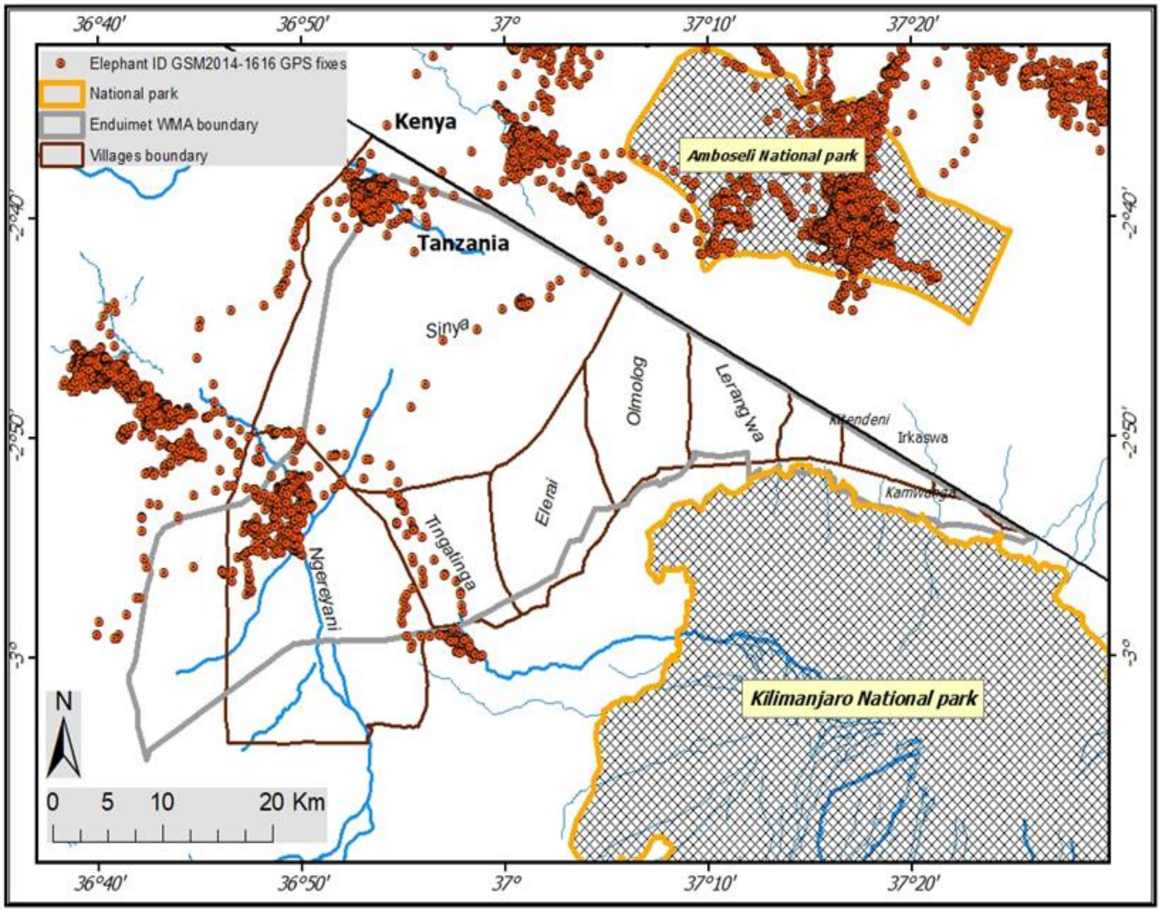
APPENDIXES

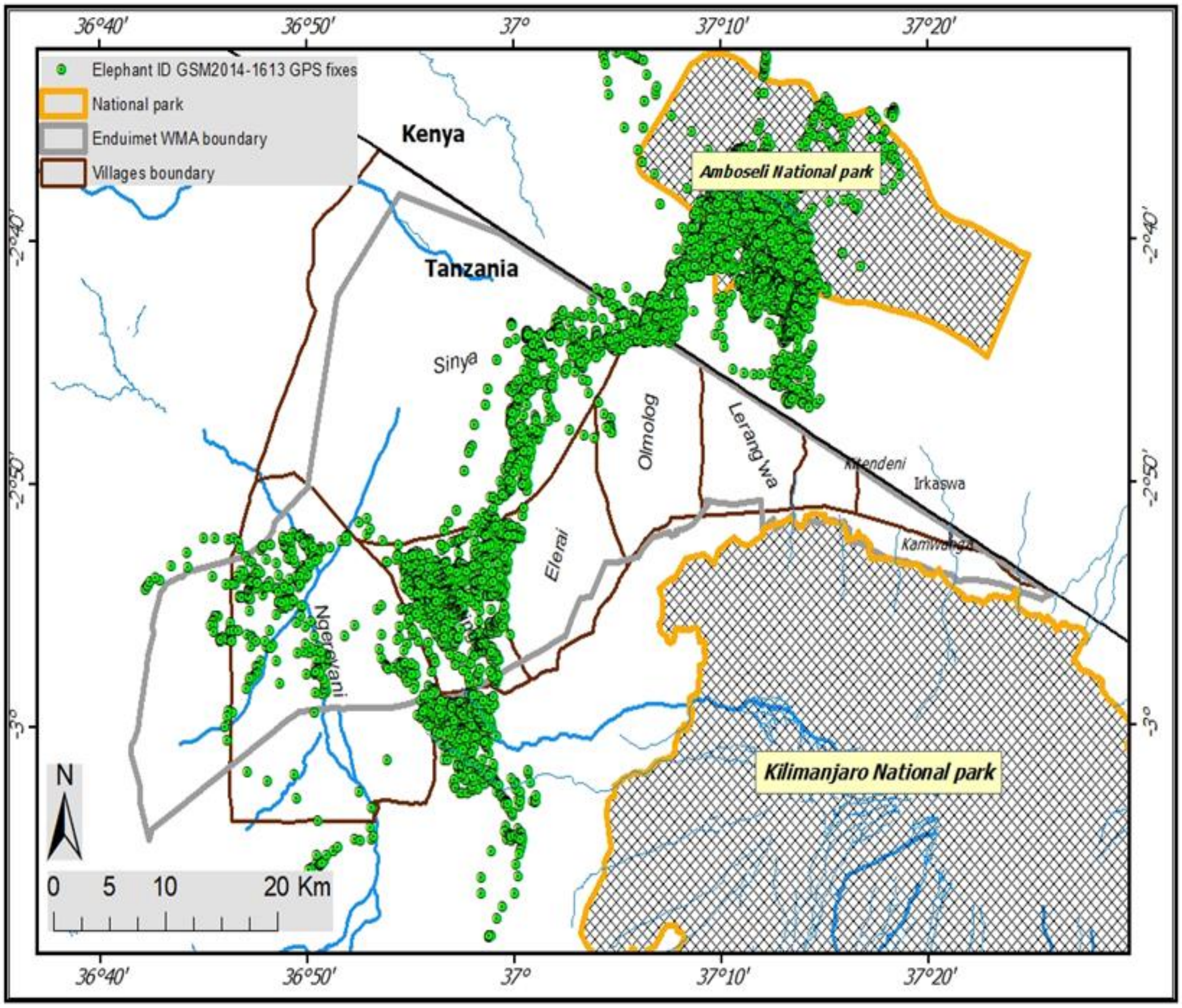
Appendix 1: Details of the Landsat images used for land use/land cover mapping during research in the Enduimet Wildlife Management area for the years 1989, 1999, 2009 and 2019 (source: http://www.usgs.gov)

Acquisition date	Scenes (path/row)	% Cloud cover	Sensor	Data source
8/24/1989	139/42	<10%	TM	USGS
7/2/1999	138/42	<10%	ETM+	USGS
7/11/2009	137/062	<10%	ETM+	USGS
8/7/2019	138/062	<10%	OLI & TIRS	USGS

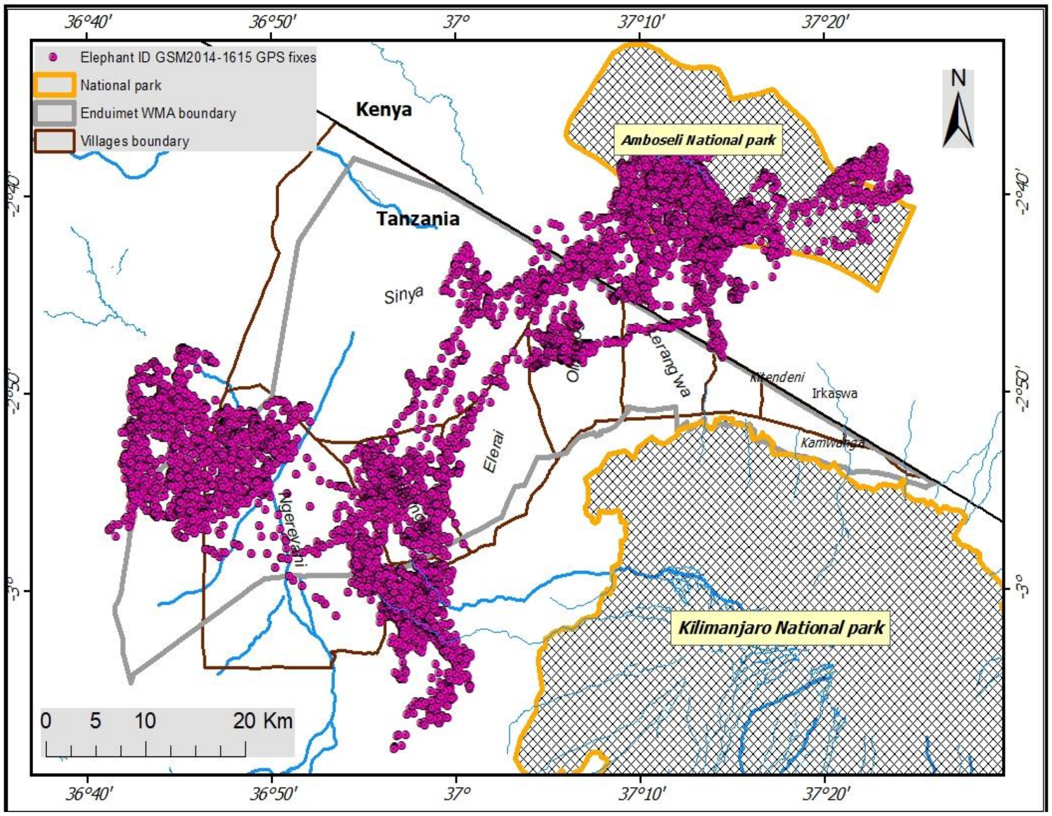
Appendix 2: Spatial distribution of one collared elephant with the ID GSM2014-1616 (n = 17 452) in the Amboseli National Park in Kenya, in the Kilimanjaro National Park and Enduimet Wildlife Management Area (EWMA) in Tanzania (Amboseli Trust for Elephants)



Appendix 3: Spatial distribution of one collared elephant with the ID GSM2014-1613 (n = 17 472) in the Amboseli National Park in Kenya, in the Kilimanjaro National Park and Enduimet Wildlife Management Area (EWMA) in Tanzania (Amboseli Trust for Elephants)



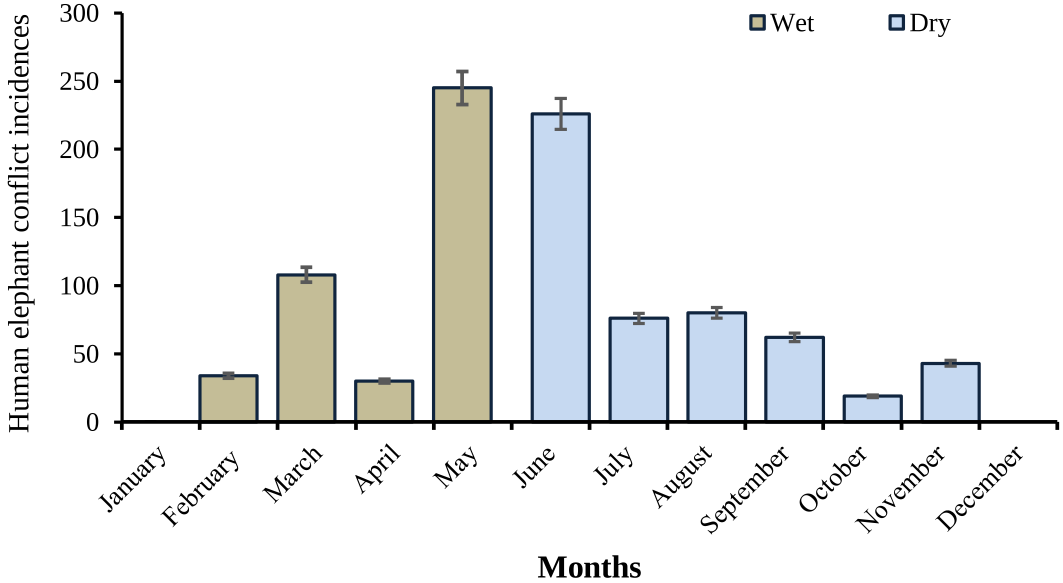
Appendix 4: Spatial distribution of one collared elephant with the ID GSM2014-1615 (n = 17 478) in the Amboseli National Park in Kenya, covering the Kilimanjaro National Park and Enduimet Wildlife Management Area (EWMA) in Tanzania (Amboseli Trust for Elephants)



Appendix 5: Annual and seasonal 100% maximum convex polygon (100% MCP), and Seasonal 95% Fixed kernel density (KDE) home range sizes (km^2) for three male elephants monitored via GPS collars in Amboseli, Kenya, and in northern Tanzania from (2019-2020). Wet = wet season (Jan - May; dry = dry season (Jun - Nov)

100 % MCP	Sex	No	Annual	Wet	Dry
	Male	1	552	368	368
		2	1,278	1,066	704
		3	819	816	169
		Mean ($\bar{x}$)	**996**	**756**	**644**
95% KDE		No		**Season**	
				Wet	**Dry**
	Male	1		981	700
		2		816	269
		3		568	472
		Mean ($\bar{x}$)		**740**	**466**

Appendix 6: Temporal distribution of average (±SE) human elephant conflict (HEC) incidences reported in the Enduimet Wildlife Management Area across the year, averaged for the years 2016 and 2019 (Note; no data were collected in the months Dec and Jan, likely indicating no HEC occurrence)



Appendix 7: Questionnaire for local respondents

A. PERSONAL INFORMATION

1. Age

- 25-35 ( )
- 36-46 ( )
- 47-57 ( )
- above 57

2. Sex:

- Male ( )
- Female ( )

3. Education Level

- Informal education ( )
- Primary education ( )
- Secondary education ( )
- College / technical education ( )
- University education ( )

4. Are you a resident of this village?

- Yes ( )
- No ( )

5. If yes, how long have lived in this village

- 1-5 ( )
- 6-10 ( )
- 11-15 ( )
- iv) Above 15

6. What are the main sources of your income? (Preferences)

- Employed ( )
- Agriculture ( )
- Business ( )
- Others ( )

B. HUMAN-ELEPHANTS CONFLICTS

1. Have you ever encountered with elephants in your area or village?

- Yes ( )
- No ( )

2. How often do they visit?

- Daily Once a week ( )
- Twice a week ( )
- Any time ( )

3. Which time of the day?

- Day time ( )
- At night ( )
- Any time ( )

4. What season of the year?

- Wet ( )
- Dry ( )

5. Is there any Game officer in your village?

- Yes ( )
- No (   )

6. If yes, what is his / their roles or duties?

i. ……………………….

ii. …………………………

iii. …………………………..

7. What is your opinion on the presence or absence of game officers at your village?

………………………………………………

C. MITIGATIONS MEASURES

1. What are your suggestions to control or mitigate Elephant impacts in your village areas?

   ………………………………………

2. Do you chase or repel elephant approaching your house or farm land?
   - Yes ( )
   - No ( )
3. If yes which method are frequently used.
   - Torch & Horn
   - Torch, Horn and Chili-crackers
   - Torch, horn, Chili and Flashflash
   - Other (explain)

5 Could you suggest how this problem of human- Elephant can be solved?

6 Do you think Human-Elephant conflict will increase in the near future?

- Yes ( )
- No ( )

If yes, what are the reasons ….?

D. CROP RAIDS

Put ✗ - if the method failed

Tick ✓ - if the method succeeded

Put ✗✗- if the method was not used

Time of raid	Incident (GPS	Wildlife animal specie	No. of Wildlife specie	crop damaged	Size of plot damaged (Acres)	Other damage (E.g., House, food store, other properties.)	Prevention Methods - used 1. Torch 2. Torch & Horn 3. Torch, Horn and Chili-crackers 4. Torch, horn, Chili and Flashflash 5. Other (explain)
	X: Y:						☐ 1. ☐ 2. ☐ 3. ☐ 4. ☐ 5.
	X: Y:						☐ 1. ☐ 2. ☐ 3. ☐ 4. ☐ 5.
	X: Y:						☐ 1. ☐ 2. ☐ 3. ☐ 4.

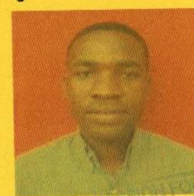
							🗀 **5.**
	X: **Y:**						🗀 **1.** 🗀 **2.** 🗀 **3.** 🗀 **4.** 🗀 **5.**
	X: **Y:**						🗀 **1.** 🗀 **2.** 🗀 **3.** 🗀 **4.** 🗀 **5.**

*******************The end, thank you for your cooperation*************************

Appendix 8: Student introduction letter from Tanzania Commission for Science and Technology (COSTECH) and The Nelson Mandela African Institution of Science and Technology

UNITED REPUBLIC OF TANZANIA

TANZANIA COMMISSION FOR SCIENCE AND TECHNOLOGY (COSTECH)



RESEARCH PERMIT

Permit No.	2020-148- NA-2020-05
Date	10th March 2020
Researcher's Name	John Sanare
Nationality	Tanzanian
Research Title	Human-Elephant interactions and community attitudes in Kitendeni Wildlife Corridor, Tanzania
Research Area(s)/Region(s)	Arusha, Kilimanjaro
Validity	From:10th March 2020 to 9th March 2021
Local contact/collaborator *(with affiliated institution)*	Dr. Julius Keyyu, Tanzania Wildlife Research Institute, P.O. Box 661, Arusha

TANZANIA COMMISSION FOR SCIENCE AND TECHNOLOGY P.O. Box 4302 DAR-ES-SALAAM

PROGRAM OFFICER

FOR: DIRECTOR GENERAL

IMPORTANT REQUIREMENTS

- *Research permit that involve collecting human, plant or animal materials / data that will be exported outside Tanzania must submit a signed Material Transfer Agreement (MTA), Data Transfer Agreement (DTA) between Tanzania host institution and the foreign counterpart. The MTA/DTA will indicate terms for collecting, storing/managing, transporting, disposal or returning of the materials/DATA to Tanzania after the closure of the research project.*
- *Any patent or intellectual property and royalty emanating from any research approved by the National Research Registration Committee (NRRC) shall be owned as stipulated in the research proposals and in accordance with the IP policy of the respective research institutions.*
- *All researchers are required to report to a Regional Administrative Secretary (RAS) of the study area and present the introduction letter and activity schedule(plan) prior starting any research activity.*
- *All researchers are required to submit quarterly progress reports and all relevant publications made after completion of the research.*
- *All communications should be addressed to COSTECH Director General through rclearance@costech.or.tz; dg@costech.or.tz or +255222700749; +255 (022) 2771358. Terms and conditions of the permit are found at www.costech.or.tz*

TANZANIA COMMISSION FOR SCIENCE AND TECHNOLOGY
(COSTECH)

Telegrams: COSTECH
General Line: +255 (022) 2771358
Director General: +255 (022) 2774023
Research Clearance: +255 (022) 2700749
Email: dg@costech.or.tz
Website: www.costech.or.tz

Ali Hassan Mwinyi Road
P.O. Box 4302
Dar es Salaam
Tanzania

In reply please quote: **RCA 2020/05**

Date 10th March 2020

Permanent Secretary
President's Office,
Regional Administration and Local Government,
P.O. Box 1923
DODOMA

Dear Sir/Madam,

INTRODUCTION LETTER ON RESEARCH PERMIT

I wish to introduce **John Sanare** from **Tanzania** who has been granted Research Permit **No. 2020-148- NA-2020-05** dated **10th March 2020.**

The permit allows him/her to conduct research titled **"Human- Elephant interactions and community attitudes in Kitendeni Wildlife Corridor, Tanzania"** under the terms and conditions as per the National Research Registration and Clearance guideline of 2018. The research will be conducted in **Arusha, Kilimanjaro** regions.

COSTECH is therefore kindly requesting you to introduce the researcher(s) to relevant Regional Administrative Officer(s) and support with any necessary assistance and guidance under national laws and regulations.

Yours faithfully

FOR: DIRECTOR GENERAL

CC:

1. Regional Administrative Secretary: **Arusha, Kilimanajro**
2. Local Contact/affiliated Institution: **Dr. Julius Keyyu, Tanzania Wildlife Research Institute, P.O. Box 661, Arusha**
3. Co-Researcher: **none**

RESEARCH OUTPUTS

(i) Publication Paper

Sanare, J. E., Valli, D., Leweri, C., Glatzer, G., Fishlock, V., & Treydte, A. C. (2022). A Socio-Ecological Approach to Understanding How Land Use Challenges Human-Elephant Coexistence in Northern Tanzania. *Diversity*, 14(7), 513. https://doi.org/10.3390/d14070513

(ii) Poster Presentation