

**MASAI GIRAFFE POPULATION DISTRIBUTION, THREATS, HABITAT
SUITABILITY AND CONNECTIVITY IN SOUTHERN KENYA AND
NORTHERN TANZANIA**

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DECLARATION

I, Amos Chege Muthiuru hereby declare that this thesis is my original work and has not been presented for a degree or any other award in any other institution of higher learning.

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DEDICATION

To my wife Stella and my son Hannington Chege. I also dedicate this study to my parents, Jesse Chege, and Mary Muthiuru who built the foundation of my life and my career. Most of all, I dedicate thesis to my uncle Sammy Chege and aunt Alice Chege who have been the greatest motivation in my academic journey. “You both believed in me”!

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ACRONYMS AND ABBREVIATIONS

AWF	African Wildlife Foundation
CHNP	Chyulu Hills National Park
EVI	Enhanced Vegetation Index
GEE	Google Earth Engine
KWCA	Kenya Wildlife conservancy Association
KWS	Kenya Wildlife Service
MAXENT	Maximum Entropy
NDVI	Normalized Difference Vegetation Index
TCA	Tsavo Conservation Area
TENP	Tsavo East National Park
TME	Tsavo Mkomazi Ecosystem
TML	Tsavo Mkomazi Landscape
TTWC	Taita Taveta Wildlife Conservancies Association
TWNP	Tsavo West National Park
SPSS	Statistical Package for the Social Sciences

ABSTRACT

Over the last three decades, the giraffe population in Africa has experienced a significant decline of nearly 40%, attributed to various threats such as severe poaching for bushmeat, human-wildlife conflicts, diseases, habitat fragmentation, and loss due to the increase in human settlement and associated land use changes and linear infrastructure. To be able to institute and prioritize effective conservation measures for the giraffes, it is necessary to identify population distribution, threat hotspots, suitable habitats, and their connecting corridors especially in multiple use landscapes. This study aimed to characterize Masai giraffe habitat and distribution in Southern Kenya and Northern Tanzania in the transboundary Tsavo-Mkomazi Landscape: identifying threats, suitable habitats and their linkage zones and population structure distribution under different land uses. Road surveys, ranger patrols, aerial surveys and remotely sensed data were integrated into Google Earth Engine (GEE) to develop species distribution models. The Suitability index obtained from this analysis was used as resistance surface to model landscape connectivity using Circuitscape in Arc GIS 10.5. Threats and location of occurrence were mapped from ranger's patrol data and road surveys. Group associations were analyzed using SPSS. The results showed that land uses did not influence mean giraffe herd sizes and herd types significantly ($p > 0.05$). However, age composition and herd types were significantly different between conservancies and small-scale farms during the wet season respectively ($p < 0.05$). Poaching was the main threat to Masai giraffes accounting for 49% of total deaths of the identified carcasses in the landscape. Although ranches and conservancies were the most affected by the threats, they remained the least cost paths and corridors of high importance with low resistance to giraffe movement connecting from Mkomazi National Park (Tanzania) to South Kitui National Reserve (Kenya). The potentially suitable giraffe habitat was 15,002 km² within the landscape with 17% of it being outside protected areas. Capacity building of ranch owners is recommended to address giraffe poaching. Transboundary collaborations, participatory land use planning, spatial planning at County, ranches/conservancy level should be done to ensure corridors and dispersal areas are included in land use planning and integrated with other conservation compatible land use practices to safeguard giraffes in the Tsavo-Mkomazi Landscape. Additionally, equal security measures should be deployed in protected and non-protected areas to deter poaching and reclaim South Kitui National reserve. Since climate change mediates Masai giraffe movement and group organization, this study recommends deep understanding of climate impact on the Masai giraffe distribution and future use of the community dominated landscapes and designed underpasses with the major infrastructure in their entire range.

CHAPTER ONE: INTRODUCTION

This chapter gives a broad overview of the giraffes, discusses the broad and specific objectives of the project, research questions, predictions and hypotheses being tested. It summarizes the contextual framework of the study, justifying the study and explicitly elaborating its significance and provides a background of the study.

1.1 Background Information

Nine extant sub-species of the *Giraffa camelopardalis* belonging to four species exist in Africa (Dagg and Foster, 1976), Winter *et al.*, 2018). The four species include: Northern giraffes (*Giraffa camelopardalis*) which consist of *G.C. peralta*, *G.C. camelopardalis* and *G.C. antiquorum* occurring in the northern part of the continent including Kenya, South Sudan and Chad. The Southern Giraffe (*Giraffa giraffa*) has two sub-species: *Giraffa giraffa* and *G. g. angolensis* occurring in South Africa, Angola and Namibia. The Masai giraffe has two subspecies: *Giraffa tippelskirchi* and *G.t. thornicrofti*. The subspecies *Giraffa tippelskirchi* are only found in Kenya and Tanzania with extralimital introduction in Rwanda and Congo (KWS 2018). The *G.t. thornicrofti* is found in Southern part of the continent including South Africa and Namibia among other countries. The reticulated giraffe has one subspecies *Giraffa reticulata* which is found mainly in East Africa; Kenya, Ethiopia and possible distribution in Somalia (Crego *et al.*, 2023).

Despite their continental distributions, over the last three decades, the giraffe species populations in Africa have experienced a significant decline of nearly 40%, attributed

to various threats such as poaching for bushmeat, human-wildlife conflicts, habitat fragmentation, and loss due to the increase in human settlement and associated land use changes. The management of wildlife habitats and land utilization practices play crucial roles in influencing giraffe distribution and population structure. For instance, research by Muller (2018) demonstrated that giraffe populations in Lake Nakuru National Park are influenced by management practices and the presence of predators. Moreover, the size and distribution of giraffe populations vary across different landscapes, habitats, and seasons (Bonenfant *et al.*, 2023; Okello *et al.*, 2016) while distribution and structure of giraffe populations is also influenced by the habitat risks within the landscape (Ihwagi, 2018, Levi *et al.*, 2022).

Anthropogenic activities can trigger behavioral changes in giraffes while vegetation density and predation risk influence their distribution (Bond *et al.*, 2021; Knüsel *et al.*, 2019; Levi *et al.*, 2022). On the other hand, increased illegal hunting of giraffes affects gender bias, skewing population to one gender (Stokke *et al.*, 2010) while proximity to humans affects local social structure in a giraffe metapopulation (Bond *et al.*, 2020).

The Tsavo-Mkomazi Landscape (TML) is a transboundary landscape encompassing protected National Parks, along with surrounding ranches and conservancies forming key habitats for the Masai giraffes (*Giraffa tippelskirchi*). Within the national parks, human activities are restricted to conservation and tourism. In recent years, some ranches in landscape have begun adopting the "conservancy model," mimicking the national parks, although full implementation remains pending. While certain ranches operate under directed agriculture mandates (with 1% government ownership), others

function as individual, family, cooperative, or communally owned entities. South Kitui National Reserve (SKNR) forms the northern boundary of the Tsavo-Mkomazi Landscape and is co-managed by the County Government of Kitui and Kenya Wildlife service (KWS).

The ranches, conservancies and community owned areas form key wildlife dispersal and connecting corridors, grazing and home ranges for the Masai giraffes among other species. Forty five percent of the total Masai giraffes in the Tsavo-Mkomazi Landscape (TML) are found outside protected areas (Waweru *et al.*, 2021). These linkage zones between the protected (Tsavo West, Tsavo East, Chyulu hills and Mkomazi national parks) have been subjected to land use changes, giraffe poaching, livestock incursions, unpredictable rainfall patterns, and climate change related threats. The suitability of the giraffe resources in these landscapes which comprise more than one million acres has not been assessed and neither the distribution nor threats to giraffes in these landscapes carefully examined.

1.2 Statement of the Problem

The global population of giraffes has plummeted by 40% in the last three decades due to poaching, diseases, habitat loss and electrocution by the fences (Bolger *et al.*, 2019; Brown *et al.*, 2019; Muller, 2018). In the TML, unprotected areas serve as crucial connecting corridors between the protected areas. These communally owned conservancies and ranches are the most affected by threats to giraffe, including habitat loss due to land use changes and land subdivisions which impact their habitats and connectivity (Waweru *et al.*, 2021, Bond *et al.*, 2021). This compounding threats may

significantly influence social and ecological behavior of the giraffes as documented by Bond *et al.*, (2021). Further aerial surveys in TML have shown static population while climate change, human settlement and agriculture increasingly confine giraffes to smaller and more isolated patches of protected areas. Although these changes could have detrimental impacts on giraffe populations in the landscape, they have not been fully assessed (KWS, 2018). The emerging fences within the landscape have resulted in electrocution of giraffes accounting for over 30% of the total giraffe carcasses recorded in the year 2021 within the TML (AWF, 2021). The increasing land subdivision continues to create opportunities for more fences thereby jeopardizing the conservation efforts. Given these current threats, it is crucial to assess the suitability and sustainability of these habitats to wild ungulates, particularly giraffes which have been listed as endangered by IUCN. This study aimed to characterize Masai giraffe population, threats, distribution, habitat suitability and connectivity within Tsavo-Mkomazi Landscape. This information will be used to prioritize suitable unprotected giraffe' habitats for conservation, designing land use plans as well as infrastructural development to avoid destruction of Masai giraffe's suitable habitats.

1.3 Justification of the Study

Giraffes are increasingly imperiled in the Tsavo-Mkomazi Landscape where limited attention has been paid to their habitat as well as their population size, structure, and distribution earning them the term “forgotten giants” by Giraffe Conservation Foundation (Giraffe Conservation Foundation, 2018) globally. The commercialization of giraffe meat, unprecedented land use changes, climate variations and increased human activities and the demand for linear infrastructure development put Masai

giraffes in the landscape at crossroads. The trade-off between development and conservation cannot be overlooked. A balance, therefore, needs scientifically informed decisions to get a win-win situation between conservation and development. However, most studies have been undertaken within the protected areas and are inclined to giraffe ecology (Leuthold and Leuthold, 1978) with populations outside remaining less known and habitats uncharacterized. The population structure of Masai giraffes specifically in this multiple-use landscape remains poorly understood. Little attention has been paid to habitat suitability and connectivity, population structure, factors influencing their population structure and distribution and the interaction with environmental variables which is key to maintain genetic variability and viable population (Haddad *et al.*, 2015). This study describes Masai giraffes' population, distribution, habitat suitability and connectivity and threats facing them within protected and unprotected areas. The study provides information relevant to management, planning, and land use practices in giraffes' habitats where the species is of ecological socio-economic and heritage value.

1.4 Research Questions

- i. How are Masai giraffes distributed within the Tsavo-Mkomazi Landscape in relation to habitat types and population structure.
- ii. What threats do giraffes face in the Tsavo-Mkomazi Landscape?
- iii. Where are the suitable habitats and connecting corridors for Masai giraffes' habitats in Tsavo-Mkomazi Landscape?

1.5 Hypotheses

This study hypothesized that Masai giraffe's population and structure are randomly distributed in habitats with low threats but utilize areas with suitable forage and

favorable climatical and topographical conditions. The study had the following null hypotheses.

- i. Giraffes are randomly distributed, and the population structure does not differ between land uses in the Tsavo-Mkomazi Landscape.
- ii. Giraffes and their habitats face no threats in the Tsavo-Mkomazi Landscape.
- iii. The whole of Tsavo Mkomazi landscape is suitable and well connected for Masai giraffes' utilization.

1.6 Objectives

1.6.1 General Objective

To characterize Masai giraffe's population, threats and distribution and assess habitat suitability and connectivity in the Tsavo-Mkomazi Landscape.

1.6.2 Specific Objectives

- i. To document Masai giraffe population structure and distribution within Tsavo-Mkomazi Landscape
- ii. To map threats facing Masai giraffes within Tsavo-Mkomazi Landscape.
- iii. To model Masai giraffes' habitats suitability and connectivity within the Tsavo-Mkomazi Landscape.

1.7 Significance of the Study

Habitat loss and modification coupled with global climate change plays a key role in determining wildlife distribution. The need to predict wildlife population occurrence and habitat suitability and viability is paramount in decision making on wildlife management while threats mapping can help institute management actions at site level.

This study mapped the current threats and their impacts on Masai giraffe's population and distribution, identified suitable habitats and their connecting corridors within the Tsavo-Mkomazi Landscape. The results obtained are instrumental in identifying critical habitats for Masai giraffes in the landscape, their connecting corridors and associated threats and give relevant recommendations to conservation of this endangered species. This data is critical to conservation managers, donors, local communities, county government and government agencies as they prioritize management actions and areas of high conservation value to secure the already endangered giraffe populations and other wildlife outside protected areas.

1.8 Theoretical Framework

This study adopts the niche theory of habitat use, which is governed by three constraints outlined by (Peterson *et al.*, 2008; Soberon & Peterson, 2005): (i) the local environment must support population growth (Grinnellian niche), (ii) interactions with other local species (such as predation, competition, and mutualism) enable species persistence (Eltonian niche), and (iii) the location must be accessible considering the species' dispersal abilities. These constraints collectively determine the geographical distribution of the species.

Like other organisms, giraffes respond to a complex array of factors, including environmental variables and human disturbances within their niches, as well as biotic interactions (Hirzel and Lay, 2008; Muller, 2018). Theoretically, giraffes tend to avoid areas with high human population densities, Bond *et al.* (2020), as well as high altitudes and with high predation risks and threats (Stabach *et al.*, 2016, Kimuyu *et al.*, 2021). Conversely, giraffes prefer habitats with ample forage and water resources (Caroline *et*

al., 2013). Consequently, the presence of threats can drive giraffe populations towards extinction.

1.9 Conceptual Framework

The Masai giraffe's habitat suitability, connectivity and utilization is influenced by land use and management, human activities, topography and climate (Bond *et al.*, 2020, 2023; Bond & Farine, 2021; Knüsel *et al.*, 2019). Poaching and habitat modification accelerate the threats to giraffes resulting in spatial displacement and alteration of population structure and growth within the landscape. Fig. 1 below shows the relationship between these variables and how they affect the Masai giraffes' population structure, movement and distribution in multiple use landscape of Tsavo-Mkomazi Landscape.

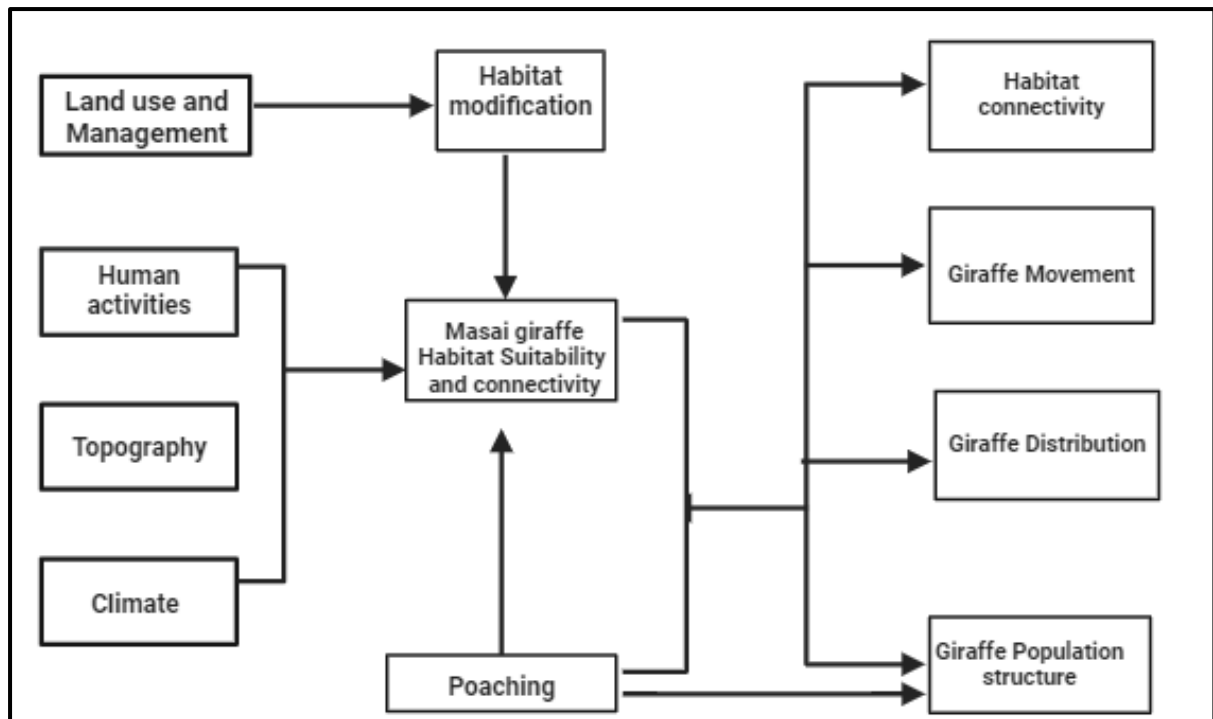


Fig. 1.1: Conceptual Framework

Climate and weather anomalies have been shown to influence giraffes' movement and habitat use in Southern Africa (Bond *et al.*, 2023), while topography determines giraffes' habitats utilization as they avoid highly elevated areas (Kimuyu *et al.*, 2021). Further, increased human occupancy in landscapes displaces large mammals such as giraffes (Bhola *et al.*, 2012; Brown *et al.*, 2023) while land use and management influences population's structure (Muller, 2018). The combination of these factors accelerated by human habitat modification threatens population structure, occurrence, distribution and movement of Masai giraffes in Tsavo-Mkomazi Landscape.

CHAPTER TWO: LITERATURE REVIEW

This chapter provides background information to giraffes and specifically the Masai giraffes, their population, ecology, and distribution as well as global threats facing them in their natural habitats. The chapter concludes by identifying research gap highlighting the importance of investigating the threats, distribution and identifying critical habitats and connecting corridors at landscape level in multiple use landscapes.

2.1 Masai giraffes' Biology

The giraffe is known as the tallest land mammal, distinguished by its elongated neck, long legs, patchy coat pattern, short "horns" called ossicones, a short stiff mane, and a long tuft of hair on the tail. Despite its remarkable neck length, giraffes possess the same number of cervical vertebrae (seven) as other mammals, albeit elongated. On average, male giraffes can reach heights of up to 5.5 meters (18 feet), while females typically reach heights of around 4.5 meters (15 feet). In terms of weight, males can weigh up to 1,200 kilograms, whereas females typically weigh around 830 kilograms (Kingdom, 1979)

Giraffes are known for their remarkable speed, capable of running at a speed of up to 50 kilometers per hour for sustained periods. They also possess the ability to kick in all directions, which serves as a defense mechanism against predators. Typically, giraffes reach maturity at around three to four years old, although this may occur later for males. In the wild, giraffes are estimated to have a lifespan of approximately 25 years, although it is likely they live longer given the absence of long-term studies (Kingdom, 1979; Dagg, 2014). Giraffes are selective browsers, meaning they carefully choose their food.

One of the distinctive features of giraffes is their long prehensile tongue, which they use in conjunction with their upper lip to feed selectively in their habitats.

In 2018, *G. tippelskirchi* which is distinguished by its unique jagged spots, distinctive geographic range, and genetic characteristics, setting it apart from other giraffe subspecies was included in the list of endangered species by the International Union for Conservation of Nature (IUCN) due to high rate of decline of its population and habitat loss (Muller *et. al*, 2016). The Convention on International Trade on Endangered species (CITES) lifted Masai giraffe to Appendix II, warning that its sale or trade of its products may threaten its survival (Bolger *et al.*, 2019). In 2008, the giraffe was listed on Appendix II of the Convention on Migratory Species (CMS, Appendix II)(Convention on Migratory Species, 2020).



Plate 1: A male Masai Giraffe in Tsavo West National Park April 2021

2.2 Distribution of Masai Giraffe

Masai giraffe occurs in Kenya and Tanzania with extralimital introductions to Rwanda (KWS, 2018). In Tanzania, the species is distributed in northern and central parts of the country where approximately 25,000 individuals roam (CMS, 2020). In Kenya, Masai giraffe is the most distributed subspecies occurring in three regions: Southern part of the rift Valley, Tsavo Conservation Area, and central rift valley (Bolger et al., 2019), Fig. 2.1 shows the distribution of the Masai giraffes in Kenya and Tanzania.

Waweru *et al.* (2021) estimated a population of 13,732 individuals distributed in these three regions in Kenya with Tsavo Conservation Area (TCA) hosting about 31% (4,314) of the total country population. Tanzania Wildlife Research Institute estimated a total of 255 individuals in Mkomazi National Park in the large mammal survey of the year 2017 (Ngene *et al.*, 2017). Although, the Masai giraffe numbers in Kenya has been on increasing trend since 2005, owing to increased surveillance, a slight decline in population was recorded between 2020 and 2021 June from 15,807 (Brown *et al.*, 2021) to 13,732 (Waweru *et al.*, 2021) which can be attributed to drought and increased poaching countrywide.

In Tsavo-Mkomazi Landscape, the population indicates a 0.2% decrease between 2017 and 2021 (KWS 2018, Waweru *et al.*, 2021). However, the 2021 census did not include Mkomazi National Park which may account for the difference. Forty five percent of the total Masai giraffes in Tsavo Landscape are found outside protected areas (Waweru *et al.*, 2021), this distribution is not well documented why Masai giraffes would occupy livestock dominated areas neither the frequency nor suitability of these habitats.

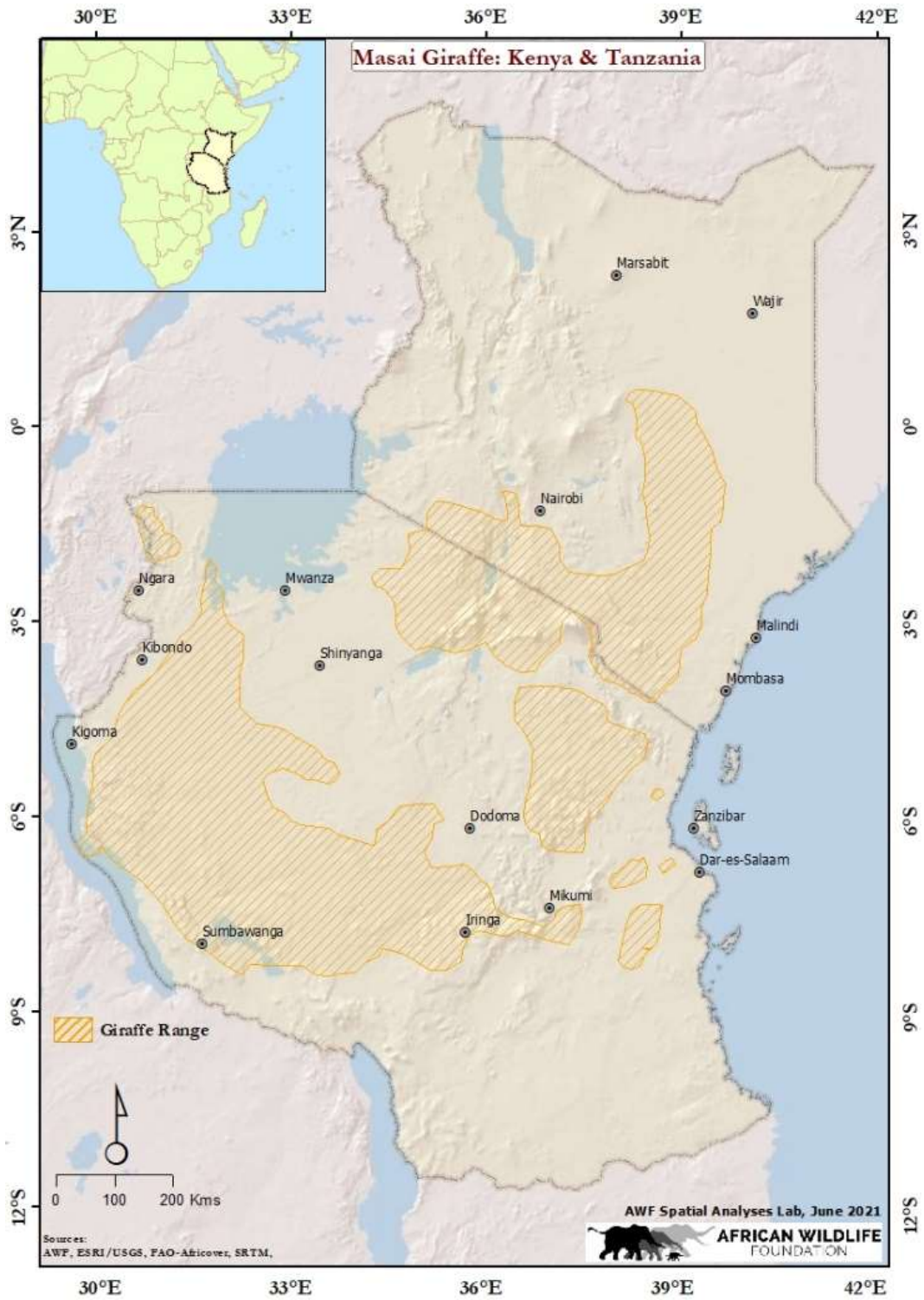


Fig. 2. 1: Masai giraffe range in East Africa

2.3 Historical giraffe Population trends in Tsavo-Mkomazi Ecosystem

The Masai giraffes in Tsavo-Mkomazi Landscape have been on an increasing trend since 1999. The population increase can be attributed to increased surveillance where earlier surveys did not include either giraffes or some areas were not surveyed up to the year 2014 specifically the ranches and community dominated areas such as Rombo. The 2011 decline was associated with the 2009 drought, however, since then, the population has been on an increasing trend. The trend can be attributed to increased surveillance and improved census coverage in the landscape. In 2021, the population did not record a substantial growth. Fig. 2.2 below shows the historical population changes. The distribution of the Masai giraffes have been skewed to Tsavo West National Park and Chyulu west specifically in 2017 as shown by Fig. 2.3. which can largely be associated with forage availability and seasonality changes compared to 2021 census.

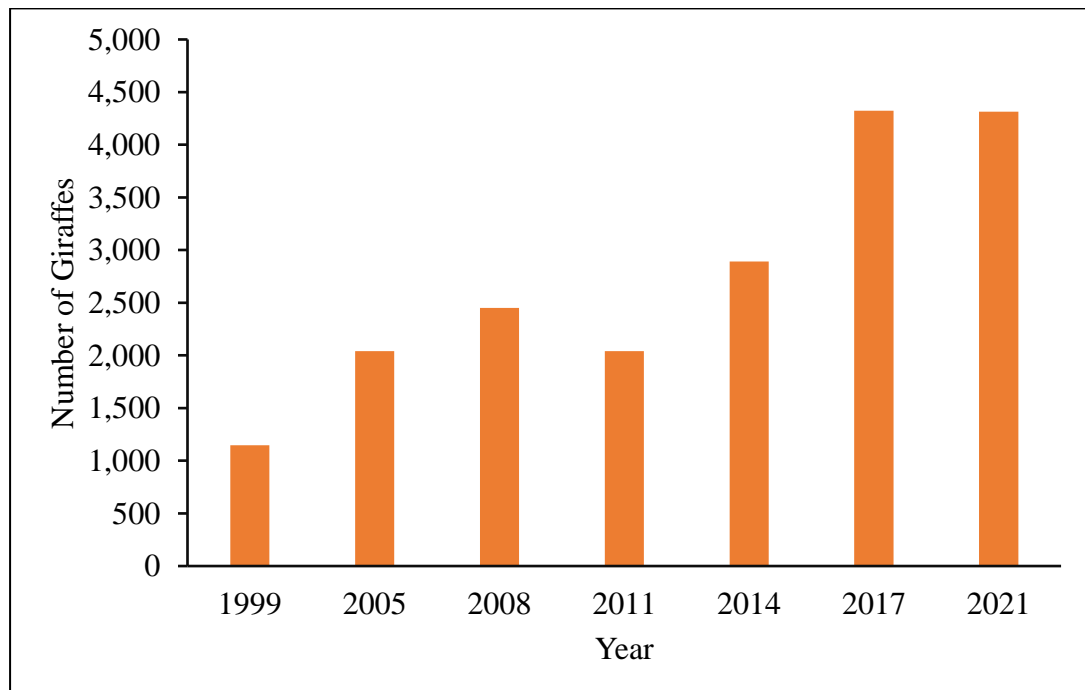


Fig. 2. 2: Historical Masai giraffe population in Tsavo-Mkomazi Landscape

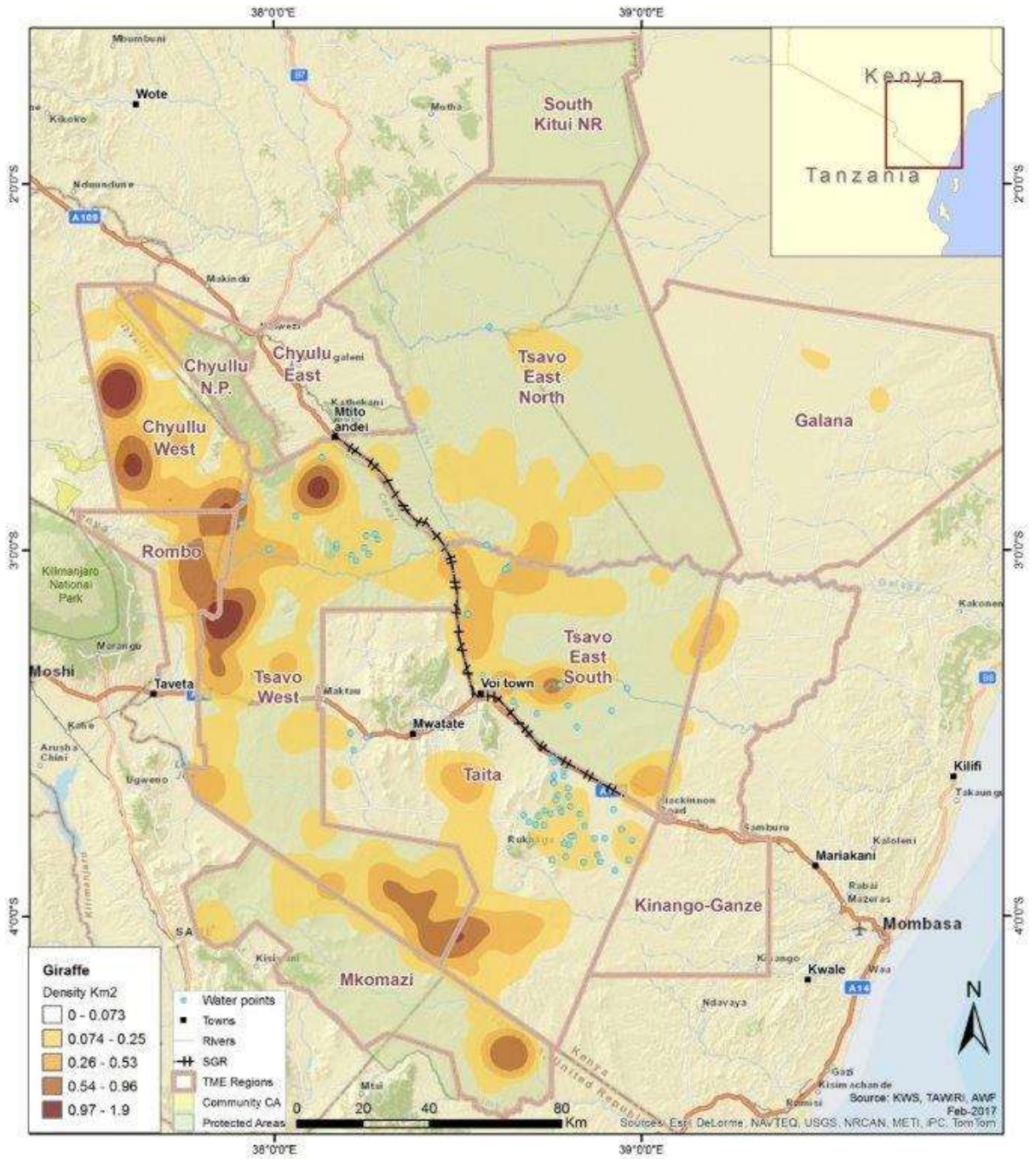


Fig. 2. 3: Distribution of Masai giraffes in Tsavo-Mkomazi Landscape in 2017 (Source KWS 2017).

2.4 Ecology of the Masai Giraffes

Giraffes are social beings, engaging in interactions through fission and fusion, without forming lasting bonds with their companions, and their associations are largely casual (Bond *et al.*, 2021; Muller, 2018). In attaining their energy requirements, giraffes spend a large portion of their day foraging and moving between foraging areas, particularly in times of limited resources (Pellew, 1984). Compared to other ruminants, giraffes spend a disproportionate amount of time feeding, averaging around 13 hours per day, as opposed to approximately 4.5 hours per day spent ruminating (Pellew, 1984).

Female giraffes have smaller home ranges than those of males (Knüsel *et al.*, 2019), with their ranging patterns indicating residency within a defined geographical area, even in unfenced ecosystems, whereas males exhibit dispersal and migration (Brown and Bolger, 2020). Male giraffes form flexible social connections, adapting their social structures from solitary to being part of large mixed herds (Bond *et al.*, 2021). This phenomenon is termed fission-fusion, where individuals or smaller groups easily join or separate from the herd, although this behavior varies among different populations (Shorrocks, 2016; GCF, 2017; Bond *et al.*, 2021).

Typically, males have large home ranges compared to females. These large home ranges are influenced by mating and vary with seasons (Knüsel *et al.*, 2019). After mating seasons, mainly the males will re-unite with bachelor herds while female nurse the young with weak bonding between themselves (Bond *et al.*, 2021). During lactation, females will utilize open bushlands to avoid losing their young and predation (Stabach *et al.*, 2016).

Giraffes feed on tree leaves, shoots, pods, and fruits and in rare instances they feed on grass. They have been observed preferring different species of plants depending on habitat types. More than a hundred plant species have been documented in the giraffe diet, with the selection of plants influenced by their local and seasonal availability. However, most of their forage comes from the numerous species of *Mimosaceae* (Kingdon, 1979). Caroline *et al.*, (2013) observed a high preference of giraffes to *Vachellia spp.* and *Balanites* species in Ruma National Park feeding on over 40 species of plants in the park.

2.5 Threats to Giraffes

Giraffes have been subjected to silent extinction as less attention has been paid to their declining populations globally until the recent past. Contrary to elephant populations in Tsavo-Mkomazi Landscape, giraffe populations have remained relatively static for the last 20 years in areas where consistent data has been collected. Whereas distribution continues to shrink, a high concentration of giraffes has been recorded in Tsavo West, Chyulu National Parks and in the ranches. Poaching, unpredictable weather patterns, change in land use and frequent livestock incursions have continued to jeopardize conservation efforts for the Masai giraffes in Tsavo-Mkomazi Landscape.

2.5.1 Poaching and Bushmeat Trade

Although global assessment of giraffe poaching has not been documented, scientists have highlighted poaching as the key threat to giraffes (Muller 2018, Bolger *et al.*, 2019). Data obtained from courts within Tsavo conservation area indicates high giraffe poaching where giraffe bushmeat could be commercialized (Waweru *et al.*, 2021). Additionally, huge consignments of giraffe meat have been confiscated within Tsavo landscape with over 70% of giraffe poaching occurring outside protected areas.

2.5.2 Climate Change

Climate change has been listed as the next worst threat to wildlife and wild lands, unpredictable rainfall patterns, prolonged drought and change in temperatures could have detrimental impacts on giraffe populations and distribution. Although long term effects of climate change have not been shown to affect giraffe distribution; Knüsel *et al.*, (2019) showed that mean annual rainfall led to 74% variance in home ranges of the giraffes across landscapes due to increased productivity, providing additional evidence that access to critical resources mediates home range size of this megaherbivore (Knüsel *et al.*, 2019).

2.5.3 Habitat Loss and Fragmentation and Electrocution

One of the major threats to wildlife conservation is land use changes; like other ungulates, giraffes' habitats have been affected by land use practices and changes. This has resulted in loss of habitats and isolation of populations and formation of habitat patches (Bolger *et al.*, 2019; Brown *et al.*, 2021). Charcoal production, clearing land for agriculture, fencing and settlement have formed a compound effect on giraffe populations and their habitats (Muller 2018).

2.5.4 Habitat Incursions

Although, the temporal and spatial effects of livestock occupancy on Masai giraffe distribution have been relatively understudied; giraffes' occupancy is affected by livestock in various ecosystems. Crego *et al.* (2020) found that giraffes temporarily avoided areas with high livestock densities while Masiaine *et al.* (2021), demonstrated that the presence of livestock significantly influenced the spatial utilization of habitat

by giraffes in Laikipia North, Kenya. Furthermore, they observed that increasing livestock occupancy competitively displaced giraffes from their habitats.

Giraffe suitable habitats in the Tsavo-Mkomazi Landscape remain less known, although the distribution shows preferences in some areas of western side of Tsavo West and less elevated plains of Chyulu National Parks, the 45% of the total population occur in unprotected areas whose vegetation and composition has not been assessed. High poaching of giraffes has been documented in the unprotected areas while land use changes continue to decrease the range of giraffes in the landscape.

2.6 Masai Giraffe Habitat Connectivity

Habitat loss, fragmentation and loss of connectivity are major threat to genetic flow between giraffe individuals and populations (Haddad *et al.*, 2015), specifically the Masai giraffes (Bolger *et al.*, 2019). The need to protect, restore and designate viable corridors and dispersal areas becomes paramount. To maintain landscape connectivity requires understanding of species dispersal within a landscape and its requirements and constraints (Diniz *et al.*, 2020). The use of resource selection has been used to analyze connecting linkage zones to suitable habitats at landscape and ecosystem levels (Cushman *et al.*, 2013; Riggio *et al.*, 2022), integrated with movement data obtained from telemetry data (Crego *et al.*, 2021).

Habitat suitability analysis can be used to complement the existing telemetry data to analyze resource selection and habitat connectivity. Presence data obtained from ground surveys or aerial surveys and the satellite data can be used to model suitability. The current advancement of remotely sensed information and integration with landscape environmental variables have revolutionized the studies of giraffes. Such

advancement has led to fine-scale predictions of species and their habitats at range levels (Crego *et al.*, 2022).

Giraffes have been observed to move to more suitable areas (Hart *et al.*, 2020; Mcqualter *et al.*, 2016; Zeller *et al.*, 2012). This selection of highly suitable areas is a reasonable proxy for landscape resistance (Riggio *et al.*, 2022) and can be used to analyze habitat connectivity especially in large habitats.

2.7 Research Gap

Increased habitat destruction, fragmentation and human development have led to isolation of giraffe's population in few patches of the protected and unprotected areas. Threats to giraffe species have been generalized due to lack of specific studies addressing landscape or ecosystem threats particularly for Masai giraffes (Bolger *et al.*, 2019). As a result, Masai giraffe's ecosystem threats have remained less understood. Further, the effect of increased human activities, climate change and poaching on population, movement and habitat suitability have not been assessed. Giraffe corridors and habitat linkage zones have not been assessed and therefore other species such as elephants have been used as proxies in corridor mapping such as (Crego *et al.*, 2021). Tsavo-Mkomazi ecosystem is a global stronghold of the species that is range restricted between Kenya and Tanzania presenting a unique transboundary space of study where diverse land use occur and developments are shaping these endangered species habitats as climate change complicates the conservation efforts in these arid and semi-arid areas (Githinji *et al.*, 2019; Nyambariga *et al.*, 2023). This study explores a nexus between human development, land use patterns, population threats and climate and how they affect the Masai giraffes' population structure and distribution, habitat suitability and

connectivity. The existing studies on these populations investigated population ecology (Leuthold & Leuthold, 1978) with little attention on habitat and connectivity and interaction with environmental variables where this study explores.

CHAPTER THREE: MATERIALS AND METHODS

This chapter identifies and characterizes the study area, methods used as well as their justification. Further the chapter describes variables used in the analysis as well as data collection methods and their analysis. It also outlines the software used in each analysis of the data together with their justification.

3.1 Study Area

3.1.1 Location

This study was conducted within the transboundary Tsavo-Mkomazi Landscape (TML) with an estimated area of 49,000km². Situated in Southeastern Kenya, 250Km South of Nairobi, the landscape spans from, 1⁰⁴' to 3⁰⁵⁵' south and 37⁰⁰⁴' to 39⁰⁴³' east (Fig. 3.1) with altitude ranging from 200 to 1000 meters above sea level. The transboundary landscape comprises of 4 national parks (Tsavo West, Tsavo East and Chyulu Hills), Mkomazi National Park (Tanzania), South Kitui National Reserve and the surrounding ranches and conservancies and other public and private lands. The area is characterized by non-sedentary pastoralism and sedentary livestock farming combined with small-scale agriculture. Regions adjacent to Tsavo East National Park (TENP) are semi-arid, with local communities predominantly non-sedentary pastoralists.

On the contrary, ranches predominantly prioritize livestock production, although some also participate in conservation efforts, tourism, mining activities, and initiatives related to carbon offsetting. Small scale farming is practiced in Wundanyi areas, Kasigau, Rombo and Mwatate where commercial sisal production is done. The local inhabitants are mainly the Taita community who prefer living at the high altitude of Wundanyi and

Sagalla. Urbanization has led to high population growth in the towns of Mwatate, Voi and Taveta, increasing the urban population threefold from year 2000 (KNBS 2020).

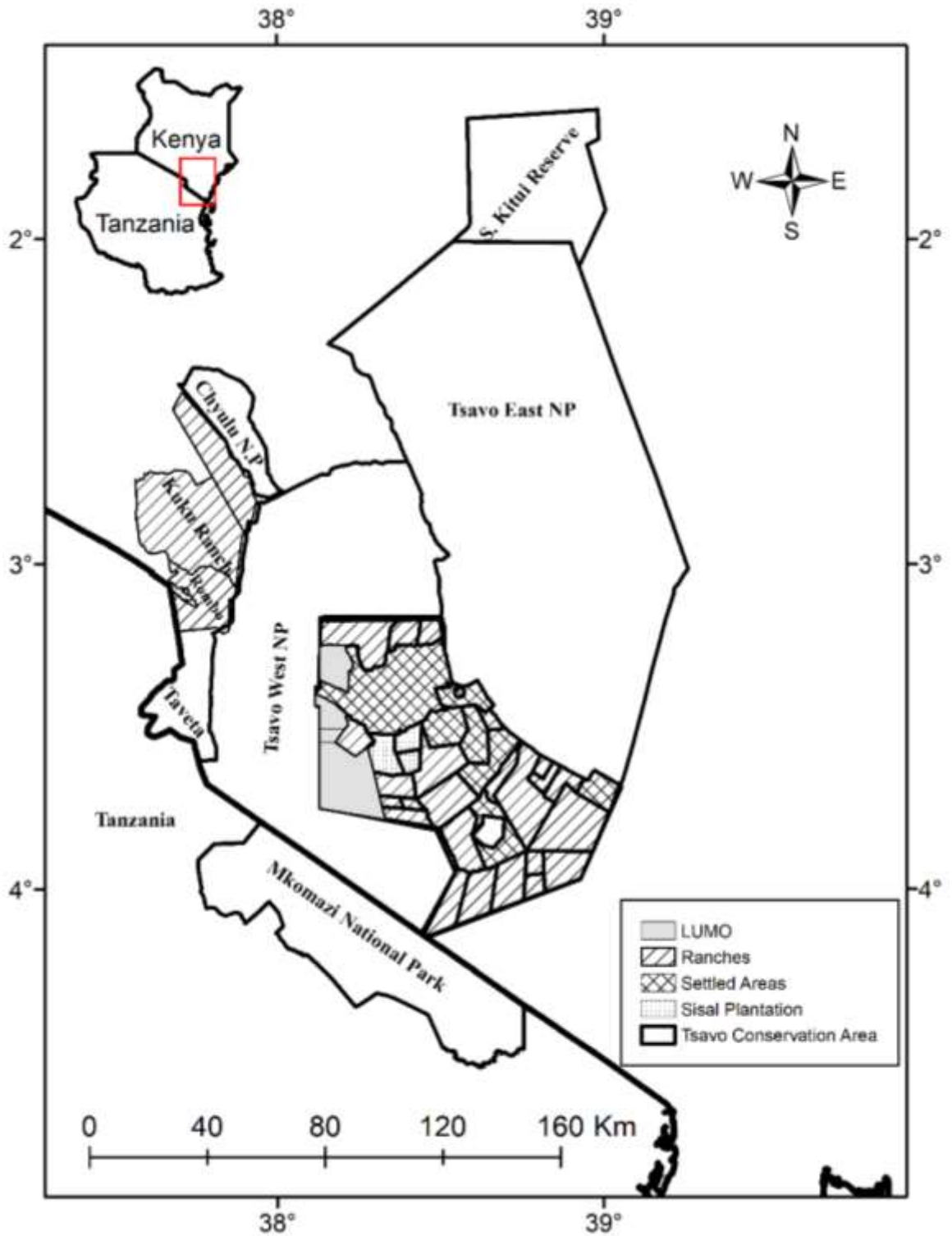


Fig.. 3. 1: Map of the Tsavo-Mkomazi Landscape showing study area.

3.1.2 Climate

According to Kenya Meteorological Department (Githinji *et al.*, 2019), rainfall in Tsavo-Mkomazi Landscape is erratic, ranging from 250mm to 700mm annually depending on the altitude. However, rainfall changes with change in climatic zones where higher areas such as Wundanyi receive up to 1000mm annually with ranches receiving an average of 350mm- 700 annually. Rainfall in Tsavo East National Park is unpredictable and bimodal according to (Githinji *et al.*, 2019) with long rains expected in March-April. Tsavo West National Park falls under Agroclimatic Zone IV, the rainfall is generally higher, less erratic, and spatially differentiated with Mt. Kilimanjaro having an influence (Leuthold and Sale, 1973, Wijngaarden, 1985). On average, temperatures vary between 24°C and 33°C in the ranches but can be as low as 20⁰ C in the highlands of Wundanyi. Tsavo East experiences higher temperatures of up to 35°C (O'Rourke and van Wijngaarden, 1987) especially during dry season.

3.1.3 Geology and soils

The Tsavo-Mkomazi Landscape is characterized by the dominance of Eastern Arc Mountains, including Sagalla, Taita, Kasigau, and Marungu Hills. Rocky outcrops emerge from the soil, forming hills, particularly within the national parks. The geomorphology of the Tsavo National Parks is marked by extensive planation levels of sedimentary and erosional origin (Wijngaarden, 1985). The northern side of both Tsavo East and Tsavo West national parks is dominated by the Yatta Plateau and Chyulu Hills, respectively. Red laterite soil prevails, especially in the ranches. The geological formation of the Mozambique gemstone belt, which extends to the Kasigau area, is rich

in various minerals, including gemstones like green garnet, tourmalines, rubies, red garnets, and spinel, as well as industrial minerals.

The Chyulu Hills are relatively new geological formations, characterized by volcanic activity, composed mainly of basalts or coarse pyroclastic deposits in certain areas. On the other hand, the Yatta Plateau is composed of Miocene phonolites of about 10 meters thick and sits atop gneisses of the basement system rocks. Erosional plains in the area have been formed on various rock types, including basement system rocks and sandstones.

3.1.4 Vegetation

Vegetation in Tsavo-Mkomazi Landscape is dominated by *Vachelia commiphora* woodland. Specifically, the northern part of Tsavo west and Tsavo East are dominantly *Vachelia* woodlands. However, in the southern part of Tsavo East and Tsavo west National Parks, open grasslands are interspersed with the *Vachelia tortilis*, *nilotica* and *hockii*. Tall hardwood trees such as *Terminalia spinosa* (Robecchii Chiov), *Melia volkensii* (Guerke), *Boscia coriacea* Pax, *Cassia abbreviata* can be spotted in areas bordering in Lumo conservancy and Tsavo West to the East National Parks (O'Rourke and van Wijngaarden, 1987). At the lower elevations of the ranches, the dense *Vachelia commiphora* forest gradually thins out, transitioning into patches of grassland. This grassland layer consists of native savannah grasses and shrubs, occasionally interspersed with *Vachelia zanzibarica*. Main grass species include *Brachiaria deflexa*, *Brachiaria leersoides* and *Cenchrus ciliaris* (L.).

3.1.5 Wild Animals

Tsavo Conservation Area (TCA) is well known for “man-eaters of Tsavo”, lions that attacked and fed on humans. The lions dominated history in 1900s during the construction of the Mombasa-Nairobi-Uganda railway by the British Government Indian laborers. The landscape hosts Kenya’s largest population of ‘red elephants’ (*Loxodonta africana*). The largest population of the black rhinos (*Diceros bicornii*) in the country is also found in the Tsavo Conservation Area while Mkomazi national Park is breeding site for black rhinos in Tanzania. Other endangered, threatened and vulnerable species such as pangolins (*Smutsia gigantea*), Masai giraffes (*Giraffa tippelskirchi*), wild dogs (*Lycaon pictus*), hyenas (*Crocuta crocuta*), caracals (*Felis caracal*), cheetahs (*Acynonix jubatus*), leopards (*Panthera pardus*) and other key carnivores are also common. Key herbivores found in the landscape include zebras (*Equus guagga*), buffaloes (*Syncerus caffer*), hartebeest (*Alcelaphus buselaphus*), elands (*Taurotragus oryx*), wildebeest (*Connochaetes taurinus*), impalas (*Aepyceros melampus*), Thomson gazelles (*Eudorcas thomsonii*), grant gazelles (*Nanger granti*), gerenuk (*Litocranius walleri*) and endangered hirola (*Beatragus hunteri*). The endangered grevy’s zebras (*Equus grevyi*) have also been introduced in the landscape. Other smaller mammals such as dik diks (*Genus madoqua*), duikers (*Cephalophus monticola*), klipspringer (*Oreotragus oreotragus*) and warthogs (*Phacochoerus africanus*) are also present. Over 450 species of birds have been recorded in the landscape.

3.1.6 Land Use Types

Land use encompasses various human activities that modify the land surface and its processes, including agriculture, forestry, and urban development (Ellis, 2010). In the study area, land use can be classified into five distinct categories based on management practices and predominant land use activities. These categories include a) Parks: 62% of Taita Taveta county), b) ranches: livestock production areas, c) conservancies: communally managed protected areas mimicking national parks, d) small scale farms: Areas within the study area where wildlife interact with agriculture specifically in the Western side of Tsavo West National Park (Rombo), and e) National reserve (South Kitui National Reserve) managed by the county Government of Kitui.

Table 3.1: Land use and management type

Land use	Management type	Area name	Size
Parks	Kenya through KWS	Tsavo East & Tsavo West, and Chyulu National Parks.	22,812 Km ²
Community conservancies	Shareholding company	LUMO conservancy	4,800Km ²
Ranches	Shareholding companies	Maungu, Kasigau, Taita, Mgeno Ranches	25,447K m ²
Reserves (conservation)	Kitui County government	South Kitui National Reserve	1,833Km ²
Small scale farms (farming and pastoralism)	Community/individual farms	Rombo Group Ranch	9,500Km ²

3.2 Mapping Masai giraffes' distribution in Tsavo-Mkomazi Landscape

3.2.1 Marking and layout of transects.

Forty-nine transects were designated across various locations in different land uses, including Tsavo West and Tsavo East National Parks, South Kitui National Reserve, 4 ranches (Mgeno, Maungu, Kasigau, Taita Ranches), one conservancy (LUMO), and in Rombo Group Ranch. However, due to complication in data collection Tanzania, transects were not conducted in Mkomazi National Park. Existing roads networks were used as transects to avoid vegetation destruction. Further, off-road driving is not allowed in the national parks and therefore surveys were restricted to road networks available. Since the parks are massive and financial constraints, roads that showed higher distributions informed by the 2017 large mammal census were selected. Figure. (3.2) shows the distribution of the transects within the landscape. The counts were conducted in April-May 2022 (rainy season) and September-October 2022 during the dry season.

Surveys were conducted between 0600hrs and 1100hrs, a period when animals are typically active where three people conducted surveys by driving along the transects at a speed of 20 km/hour searching for giraffes on each side of the transect to a maximum distance of 1km on both sides of the transect. Furthermore, data from the census was utilized to complement the study.

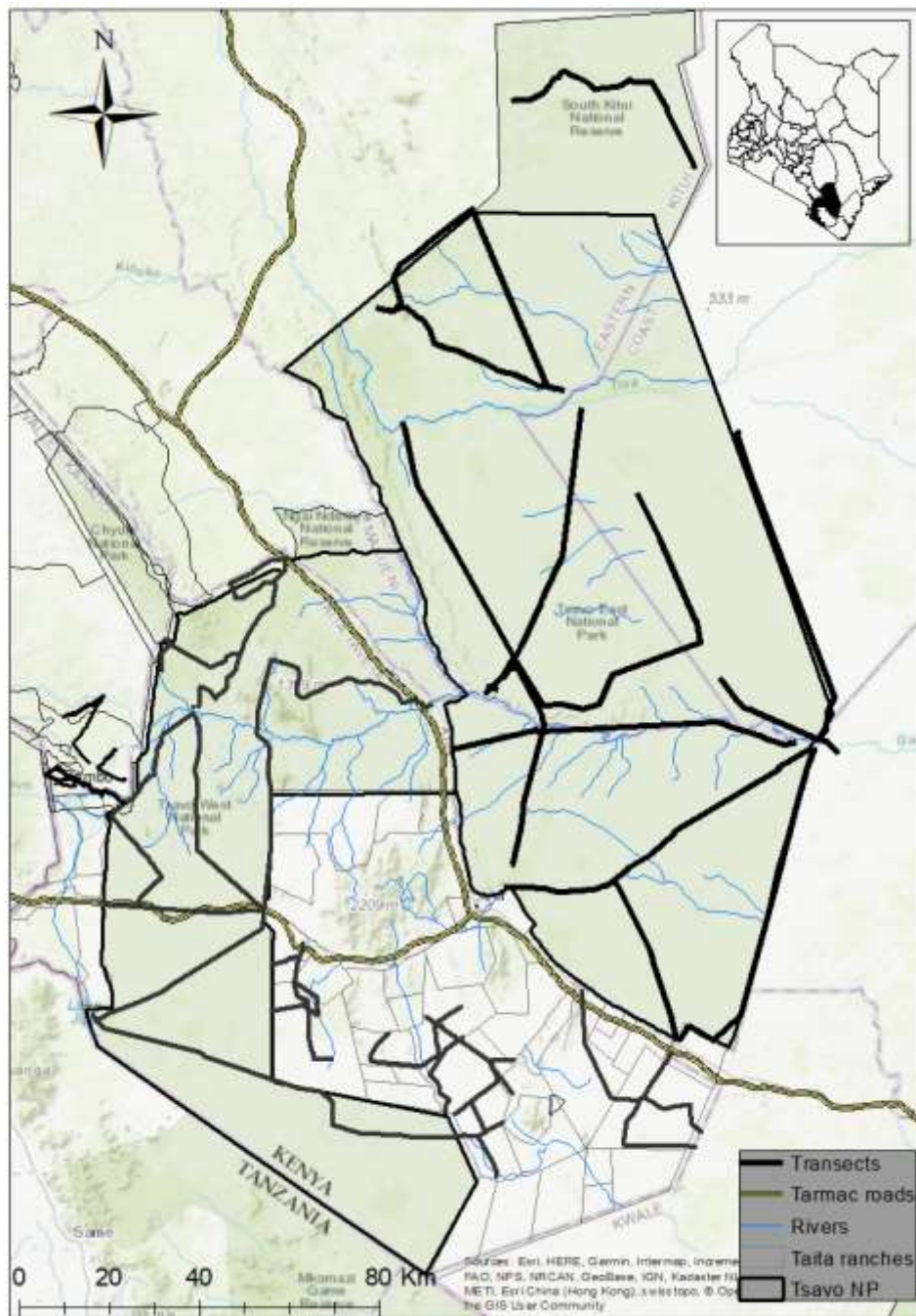


Fig. 3. 2: Transects distribution in the Tsavo-Mkomazi Landscape.

3.2.2 Masai Giraffe Distribution Mapping

The study employed an observational method where the researcher drove along transects looking out for giraffes and recording relevant information about them. The surveys were conducted between 0600hrs and 1100hrs when giraffes are active. Three observers used binoculars to scan giraffes along the transect. GARMIN GPS map 62 receiver was used to generate GPS coordinates for each giraffe/group sighted. The distance from the observer location and sighting angle were determined using a range finder. Further, data on number of individuals, population structure and age groups were recorded. The vegetation type within which the animals were found was also documented.

Once giraffes were sighted, distance between the group and the observer, angles to the center of the group, group type (mixed, bachelors, female and young), GPS coordinates and the sex and age of the giraffes were recorded. Age categories were determined based on physical characteristics such as body shape, neck, leg length, and ossicone and morphological characteristics, following the classification outlined by Struss (2014) and Muller (2018). If identification was not possible, individuals were recorded as 'unsexed', particularly for calves and sub-adults. Adults (> 3 years for females and > 6 years for males), sub-adults (1-3 years), and Juveniles (< 1 year). Groups were classified into different types, including lone males, bachelor herds (comprising 2 or more sub-adult and adult males), mothers with calves, mixed herds (consisting of males, young, sub-adults, and females), and lone females. Sightings were restricted to one kilometer to avoid uncertainties and allow for sexing the giraffes. Individuals within a 500-meter radius were grouped together.

All the information collected was entered into the data sheet and later used to generate a distribution map of the giraffes' distribution. Data on habitat covariates such as water pans, settlement/infrastructure and their condition were recorded. The presence of predators such as hyenas and lions were also documented. Complementary data was obtained from WRTI on wildlife census conducted in 2021 June.

3.2.3 Mapping Threats to Giraffes

Data on threats to giraffes such as evidence of poaching, carcasses, agricultural activities, or habitat destruction were recorded during road surveys. Secondary data on threats was obtained from scouts and rangers in the ranches under the African Wildlife Foundation's Spatial Monitoring and Reporting Tool (SMART) database. The rangers recorded information on poaching incidents, habitat destruction such as wood collection, charcoal production, livestock incursions, snares, and carcasses among others. Similar threats were recorded in the protected area during the road survey exercise. Areas under mining were also mapped during the surveys. Human activities data was supplemented with remote sensing data as described in section 3.3.4.

3.2.4 Mapping Habitat Suitability

Data collected during road surveys and through Systematic Reconnaissance Flight (SRF) (Waweru *et. al*, 2021) during the national wildlife census were used. The 7 days survey deployed several aircraft flown systematically over pre-defined blocks in the landscape at an altitude of between 280-350 ft above the ground and 1km spacing. Crews positioned on the front, left and right seats searched for animals, recording GPS position and audio of the sightings as described by Ngene *et al.*, (2013) and Douglas-Hamilton I. (1996). The data was transcribed to an excel database. The giraffe's

sightings were filtered from the total aerial census and imported into Google Earth Engine. A spatial resolution of 250m resolution was set for analysis. To reduce the potential bias of having multiple occurrence points in the same location (Fourcade *et al.*, 2014), duplicates per pixel were removed reducing the sightings from 1288 to 1208.

3.3 Data Analysis

Three sets of data were analyzed. a) data obtained from road counts along the transects and b) aerial survey data obtained from Systematic Reconnaissance Flights (SRF) through WRTI and c) threats data obtained from scouts' patrol in the landscape. Field data was processed in excel spreadsheets and shapefiles in Arc GIS 10.5 and analyzed in both Arc GIS and Google Earth Engine.

3.3.1 Giraffe Population Structure and Distribution

The collected data, including GPS locations of giraffes and their group compositions, was entered, collated, processed, and stored in Microsoft Excel. Subsequently, the GPS data was imported into ArcGIS 10.5 for distribution analysis. To test whether the group herds of giraffes differed significantly between land use types and between seasons, a Two-way Analysis of Variance was performed. Chi-square was used to test the association between group types and different land uses.

Using density tool in Arc GIS 10.5 and search radius of 5 Km (Knüsel *et al.*, 2019), a density distribution of the giraffes was developed based on the ground points collected during the survey. Ripley's K-function was used to test the randomness of giraffe distribution in the study sites. The function analyzes spatial pattern of incident point data and summarizes spatial dependencies over a range distance. Ripley's K-function

illustrates how the spatial clustering or dispersion of feature centroids changes when the neighborhood size changes. When the observed K value is larger than the expected K value for a particular distance, the distribution is more clustered than a random distribution at that distance (scale of analysis) and vice versa. When the observed K value is larger than the upper confidence envelope (HiConfEnv) value, spatial clustering for that distance is statistically significant. When the observed K value is smaller than the lower confidence envelope (LwConfEnv) value, spatial dispersion for that distance is statistically significant.

3.3.2 Threats facing Masai Giraffes in Tsavo-Mkomazi Landscape

Two sets of data were sorted for analysis. Habitat threats recorded during the surveys and Spatial monitoring data (SMART) obtained from AWF database from the scout's data collected in Mgeno, Kasigau, LUMO, Taita ranch and Toloha in Tanzania. Main threats analyzed included poaching, habitat destruction, charcoal production, wood collection, snares, timber harvesting and agriculture. Livestock presence was also recorded specifically in the Parks. Data acquired from surveys and SMART was combined as a single file and analyzed in Arc GIS 10.5 to identify the type and distribution of threat facing giraffes in the landscape. A threat index was generated using a 1km search radius on ArcGIS 10.5 and the results mapped as threat index from low to high. The density tool in Arc GIS 10.5 was used to create a density threat index map.

3.3.3 Habitat Suitability

Giraffe sightings data was sorted in Excel, combined, and processed in Arc GIS 10.5, then analyzed using Google Earth Engine (GEE) for habitat suitability. Remotely sensed data was used to model habitat suitability for giraffe's using rainfall, elevation, human settlement, agricultural expansion, and human development as well as linear infrastructure. Terrain characteristics, Normalized Difference Vegetation Index (NDVI), climatic and anthropogenic variables were acquired from the GEE catalog which is a cloud-based data access and analysis tool. To account for giraffe forage which are browsers, Advanced Land Observation Satellite Phased Array L-band Synthetic Aperture Radar (ALOS -PALSAR) aboard ALOS-1 image which characterizes vegetation was used. Human modification of the habitats was also acquired from the Global Human Modification index (GHM) imagery (Kennedy *et al.*, 2019). Using random forest classifiers in GEE, the analysis was conducted following Crego *et al.*, (2022) framework as described below.

3.3.3.1 Predictor/ Environmental Variables

A set of predictor variables that were thought to be a-priori would affect giraffe habitat suitability were chosen. They included rainfall, Enhanced Vegetation Index (EVI), terrain, Surface roughness, Human habitat modification and woody vegetation using the Advanced Land Observation Satellite, Phased Array type L-band Synthetic Aperture Radar (ALOS-PALSAR) (Shimada *et al.*, 2014). To avoid modelling highly correlated variables, a correlation matrix was run, and the variables confirmed to be less correlated ($r= 0.7$). These data files were clipped to extent of the study area and analyzed using random forest implemented in GEE following Crego *et al.*, (2022) framework.

Vegetation indices have been proved to explain giraffes' distribution (Crego *et al.*, 2020; Mcqualter *et al.*, 2016). Enhanced Vegetation Index (EVI) was obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) 16 days 250m resolution terra image (Didan *et al.*, 2015) corresponding with the period of survey May and June 2021. EVI was selected due to its capability to minimize canopy background variations, residual removal and maintaining sensitivity over dense vegetation conditions (Didan *et al.*, 2015).

Additionally, ALOS-PALSAR which has Horizontal and Horizontal (HH), and Horizontal and Vertical (HV) polarization bands identifying woody vegetation which forms the major forage for giraffes was included (Shimada *et al.*, 2014). This image has been used to characterize forest diversity (Martinuzzi *et al.*, 2009) and habitat variations (Rada *et al.*, 2022; Yu and Saatchi, 2016). ALOS-PALSAR was filtered to retain mosaics of year 2021 when the survey was conducted.

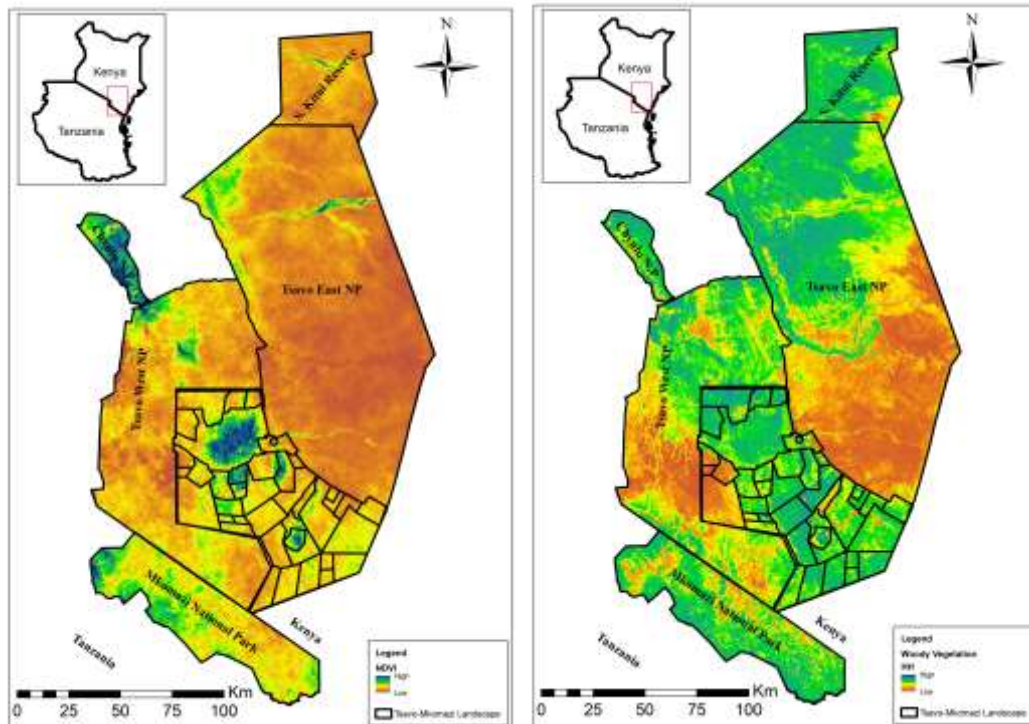
Elevation and surface roughness data was obtained from the Shuttle Radar Topography Mission (SRTM) image USGS/SRTMGL1_003 (Hennig *et al.*, 2001). Surface roughness was calculated as the standard deviation of elevation in a moving window of a 10-pixel radius. Highly rugged terrain has high deviation in elevation while closer to zero values show smoother terrain. Rainfall variance have proven to have a positive correlation with home range of the giraffes and hence resource selection (Bond *et al.*, 2023; Knüsel *et al.*, 2019; Martínez-Freiría *et al.*, 2016); and since the study area fell under different climatic zones and have shown rainfall variations (Githinji *et al.*, 2019; Ministry of Agriculture, 2019), rainfall data was obtained from UCSB-

CHG/CHIRPS/PENTAD at a 5km² resolution (Funk *et al.*, 2015) and clipped it to the study area for 5 years and filtered by mean.

Human habitat modification index has been shown to accurately describe habitat loss and modification (Bond and König, *et al.*, 2021; Fehlmann *et al.*, 2021). Human modification data commonly referred to Global Human Modification index (gHM) was obtained from (Kennedy *et al.*, 2019) and included in the model. The global Human Modification dataset (gHM) accounts for five major anthropogenic stressors mainly human settlement (population density, built-up areas), agriculture (cropland, livestock), transportation (major, minor, and two-track roads; railroads), mining and energy production, electrical infrastructure (power lines, nighttime lights) (Kennedy *et al.*, 2019) at a 1km² resolution. The final composite image used for modeling consisted of 7 bands: ALOS-PALSAR HH and HV, EVI mean composite, elevation, surface ruggedness, Global human modification and rainfall (Table 3.2). Figs 3.3-3.5 show the distribution of the variables within the landscape.

Table 3.2: Model Predictors Used in The Suitability Analysis.

Variable	Predictor	Product	Spatial resolution
Elevation	Elevation	USGS/SRTMGL1_003, (Hennig et al., 2001)	30 m
Vegetation condition	EVI	MODIS/061/MOD13Q1, (Didan et al., 2015)	250 m
Human Modification Index (GHM)	GHM	CSP/HM/Global Human Modification, (Kennedy et al., 2019)	1 km
Precipitation	Mean annual PPTN	UCSB-CHG/CHIRPS/PENTAD, (Funk et al., 2015)	5566 m
Surface Roughness	SR	USGS/SRTMGL1_003, (Hennig et al., 2001)	30 m
Woody Vegetation	HH	ALOS-PALSAR, (Shimada et al., 2014)	25 m
Woody vegetation	HV	ALOS-PALSAR, (Shimada et al., 2014)	25 m

**Fig. 3.3:** Mean EVI for the Month of May and June in 2021 and Woody Vegetation (HH) Band

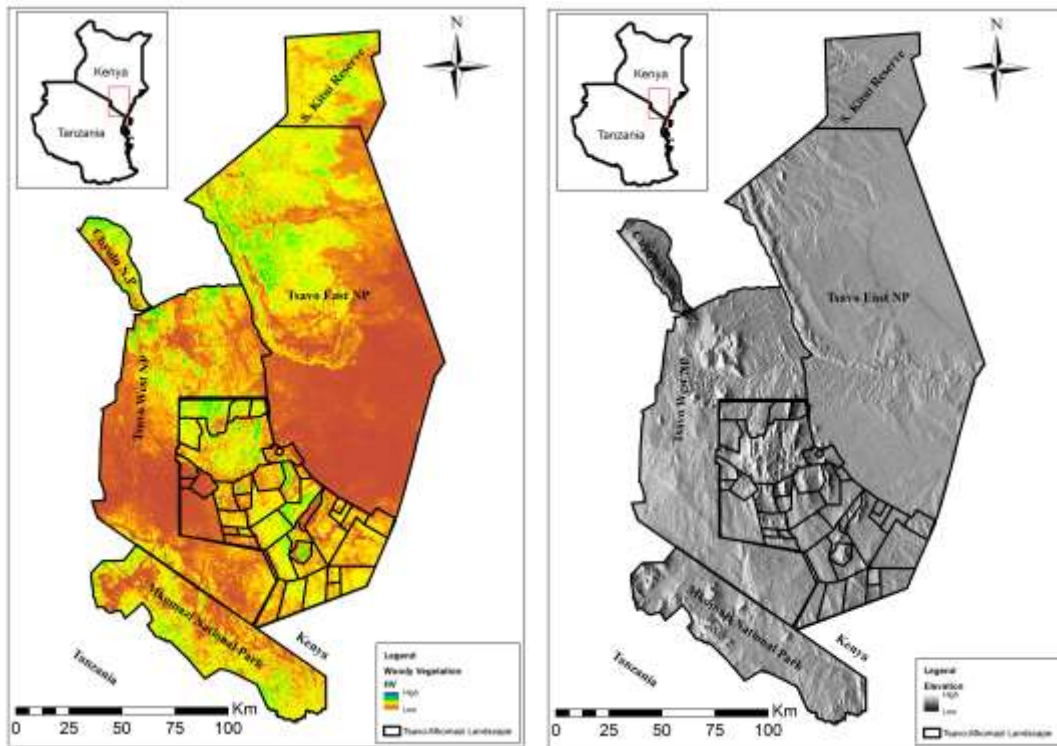


Fig. 3. 4: TML Woody vegetation HV band and Elevation

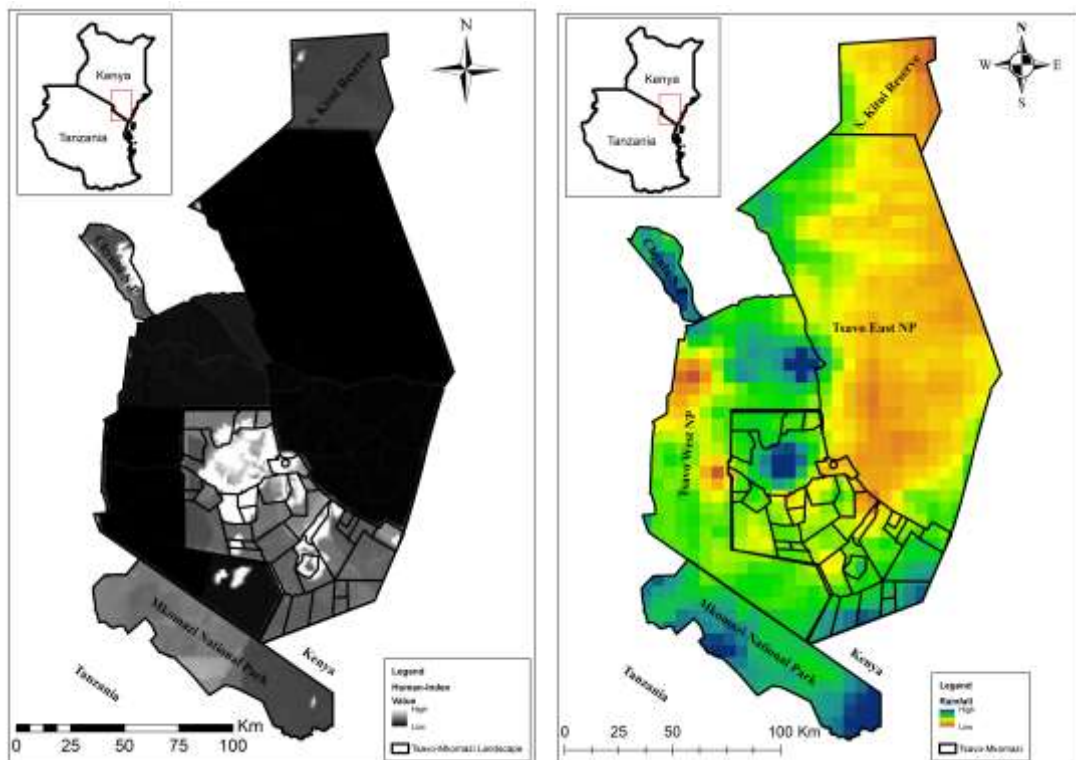


Fig. 3. 5: Human modification index and rainfall distribution in the Tsavo-Mkomazi Landscape

3.3.3.2 Model Fitting and Validation

Giraffe potential habitat suitability was modelled using random forest classifiers and a 10-fold spatial block cross-validation approach (Roberts *et al.*, 2017; Valavi *et al.*, 2022). The random forest classifiers select samples from the dataset and create a decision tree for each sample, aggregating a prediction for each of the 500 trees created (Evans *et al.*, 2011). For cross-validation 5 x 5 km spatial blocks across the Tsavo-Mkomazi Landscape were generated. Blocks were then randomly split into two groups, with 70% for model fitting and 30% for model validation. To account for absence data needed for modelling, at each of the 10 iterations, equal random pseudo-absences were created, resulting in different random pseudo-absences sets for each model iteration which have been proven to perform better with machine learning techniques such as random forests (Evans *et al.*, 2011; Fox *et al.*, 2017). The relative contribution of the seven predictors to each model fitting was assessed by calculating the average proportional contribution of each variable across the 10 iterations produced by each random forest classifier, as indicated by the Gini index.

Model accuracy was assessed using Area Under the Curve of Receiver Operator Characteristic (AUC-ROC) and Area Under the Precision Recall Curve (AUC-PR). Data contained within the 30% blocks was randomly selected for model validation at each iteration. The use of AUC-ROC as a measure of accuracy has been criticised specifically when no true absence data is provided and when species are narrowly distributed in relation to the extent of the study area (Li and Guo, 2021; Lobo *et al.*, 2008). In contrast, the AUC-PR is not influenced by the number of absences (Sofaer *et al.*, 2019) and can assess accuracy across large spatial extents (Li and Guo,

2021). Hence, both metrics were used as complementary accuracy assessments (Sofaer *et al.*, 2019). Both AUC-ROC and AUC-PR range between 0 and 1 with values closer to one indicating perfect data prediction (Sofaer *et al.*, 2019).

Additionally, models were validated based on ability to correctly predict occurrence (specificity) and ability to correctly predict absence (sensitivity) at a given threshold (Fourcade *et al.*, 2014). A threshold habitat suitability was calculated by maximizing the sum of sensitivity and specificity which is known to perform well with presence-only data (Liu *et al.*, 2016). The mean was calculated, standard deviation, and range AUC-ROC, AUC-PR, sensitivity, and specificity across the 10 model iterations.

Predictions were made for each model iteration and generated a final habitat suitability map by averaging pixel values. The final averaged suitability map was reclassified to binary potential distribution map using the average threshold estimated for each of the ten-fold model fitting. The binary distribution model was used to quantify potential suitable Masai giraffe habitat within the transboundary Tsavo-Mkomazi Landscape including Mkomazi National Park where the census was not conducted. The final images were run on batch mode to avoid memory lapse in GEE. All Google earth Engine analysis can be accessed here:

<https://code.earthengine.google.com/6453160d110474ad414d817e2d1e1012>.

3.3.4 Connectivity

The factorial pairwise least cost paths identify several routes that the giraffes can take from source to destination as has been described by Diniz *et al.*, (2020), contrary to Least cost Path analysis alone. Tsavo-Mkomazi Landscape is somehow contagious, the factorial pairwise matrix was coupled with Circuitscape and cost weighted distance (CWD) to identify critical least cost paths specifically within community dominated landscape. This method has been recommended especially where general corridor is to be delineated (Diniz *et al.*, 2020).

To model landscape functional connectivity, linker mapper toolkit embedded in ArcGIS 10.5 was used (McRae and Kavanagh, 2011). This method employs Circuitscape, cost weighted distances (CWD) and least cost paths analysis to identify and prioritize wildlife linkage zones and corridors (Howey, 2011; McRae and Kavanagh, 2011). The Circuitscape analysis mimics the electric current flow through a resistance surface from one node to the other producing a cumulative current density by combining and weighting all possible pairwise connecting corridors within the landscape (Mcrae and Shah, 2011). Corridors were identified by building the map network linkages as described by (McRae and Kavanagh, 2011) using Circuitscape, least cost paths and cost weighted distances in linker mapper toolkit.

To identify possible corridors and assess their relative importance, the Linkage Priority Tool from the Linker Mapper toolkit was utilized. This tool operates on a two-level analysis. Firstly, it estimates the relative priority of two core areas and each linkage based on shape, mean resistance value, and size. Then, it links each corridor to the

permeability of each linkage, mean resistance along the least-cost paths, proximity, and centrality, ultimately generating a relative priority value for each linkage corridor (McRae and Kavanagh, 2011). Corridors were subsequently mapped with priority values ranging from high to low. The analysis is predicated on the assumption that a linkage connecting two or more important core areas holds higher conservation priority than one linking two marginal core areas (McRae and Kavanagh, 2011).

Since these algorithms estimate connectivity as a function of source locations, landscape resistance and dispersal thresholds and requires the knowledge of destination points (Kumar and Cushman, 2022), model was run using seven core areas accounting for both suitability and availability of the core area(See appendix IV for the core areas) within the landscape from Mkomazi National Park to South Kitui National reserve using habitat suitability as a resistance surface. It was assumed that resistance decreases at a constant rate as suitability increases (Crego *et al.*, 2021; Killeen *et al.*, 2014).

Further, an assumption was made that giraffes move to more suitable areas as it has been observed (Hart *et al.*, 2020; Mcqualter *et al.*, 2016) and that habitat suitability is analogous to, or at least a reasonable proxy for, landscape resistance (Riggio *et al.*, 2022). Although this method can be used as a proxy (Huck *et al.*, 2011; Kumar and Cushman, 2022), it has shown to predict accurately the utilization of habitats and corridor delineation (Keeley *et al.*, 2016; Riggio *et al.*, 2022; Sawyer *et al.*, 2011; Zeller *et al.*, 2012). Fig. 3.6 summarizes the workflow and data analysis process.

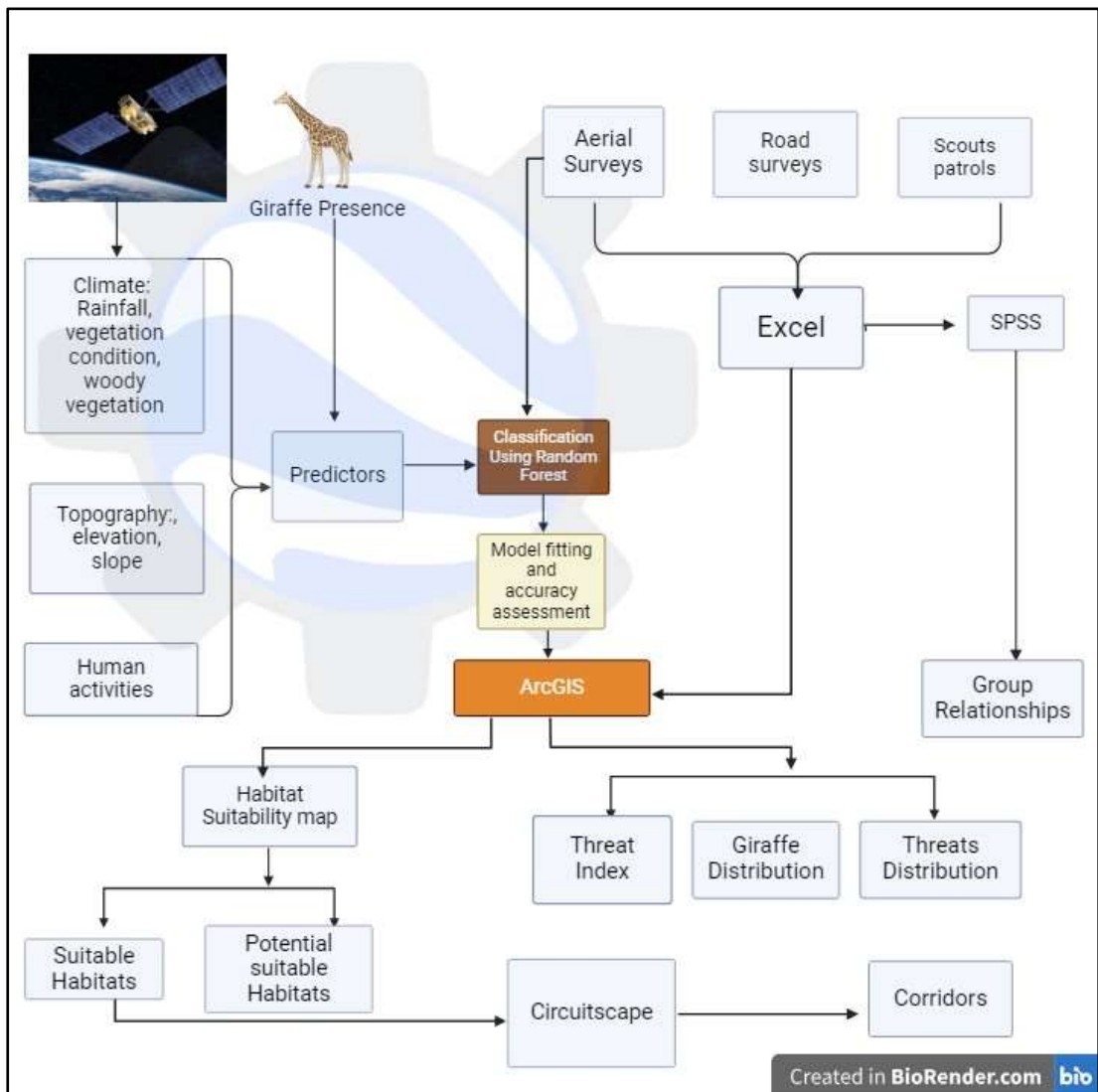


Fig. 3. 6: A summary modelling workflow and analysis for Masai giraffe habitat suitability, threats population structure and distribution.

CHAPTER FOUR: RESULTS

This chapter highlights key results and the findings of the study. The chapter explicitly outlines key findings and how the results were achieved using the described methods. The chapter provides graphical and visual interpretation of the results.

4.1 Masai Giraffe Population and Distribution in the Tsavo-Mkomazi Landscape

4.1.1 Population of Giraffes in Different Land Use Types

Masai giraffe population distribution was assessed using road counts. A total of 2,082 giraffes were sighted on 625 occasions. Parks had the highest number of sightings (80.3%), followed by ranches at 11%. Conservancies and small-scale farms had the lowest number of sightings at 4% each. No giraffe was recorded in South Kitui National Reserve. Herds of males and 'lone males' collectively comprised 37.7% of the groups observed out of a total of 590 sightings that were sexed. Conversely, 'lone females' were the least sighted, representing only 12% (n=72) of the total sightings. Mixed herds accounted for 24% of the grouped sightings, while 'families' (females and calves) constituted 26.7% of the total sightings (Fig. 4.1).

Out of the total giraffe population surveyed, 87% (1,818 individuals) were successfully identified by sex and age, while 12.84% (264 individuals) could not be positively sexed and aged. Of the sexed adults, 48.9% were adult females, 25.16% were males while juveniles and sub-adults accounted for 7.2% and 5.9% respectively. Age category (adult males, adult females, Sub-adult males and Subadults females and young) differed significantly between the land uses ($\chi^2= 46.76$, $df = 12$, $p=0.02$). Farms had proportionately more bachelor and mixed herds than family and lone females.

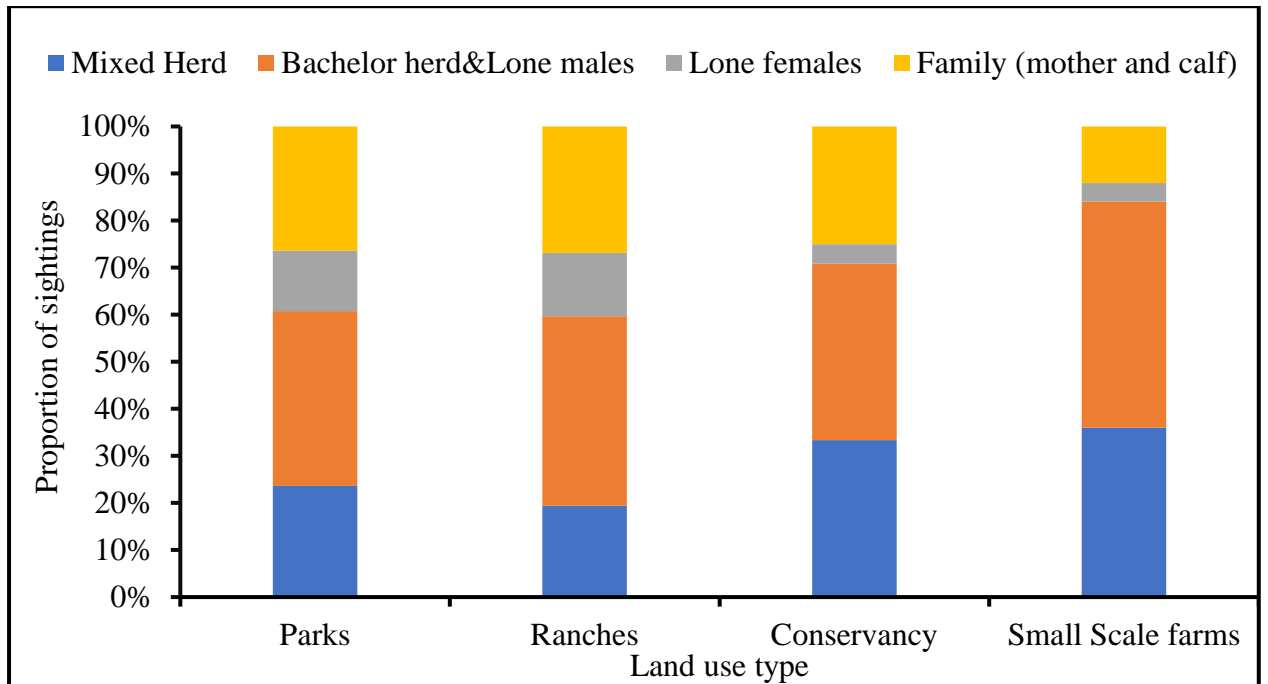


Fig. g 4.1: Proportion of sightings of different group types in different land use types within the Tsavo Conservation area

4.1.2 Association Between Giraffe Group Type and Land Use Type.

Chi-square was used to test the association between group types and different land uses.

There was no association between group types (Bachelor herds, mother, and young, mixed, lone females) land use type ($\chi^2 = 14.7$, $df = 7$, $p > 0.05$). This implies that the proportions of different group types were the same in the different land use types.

4.1.3 Spatial and Temporal Variation of Giraffes In Tsavo-Mkomazi Landscape

Giraffe size distribution in different habitats is shown in Fig. 4.2. The Fig. shows that median group size is about 3-6 individuals. The Fig. further shows that there were few groups with a very large number of individuals, especially in the parks. To test whether the abundance of giraffes differed significantly between land use types and between the wet and dry seasons, a Two-way Analysis of Variance was performed (Table 4.1). A

post-hoc analysis using Least Significant Difference (LSD) was done to test pairwise comparisons between the land uses.

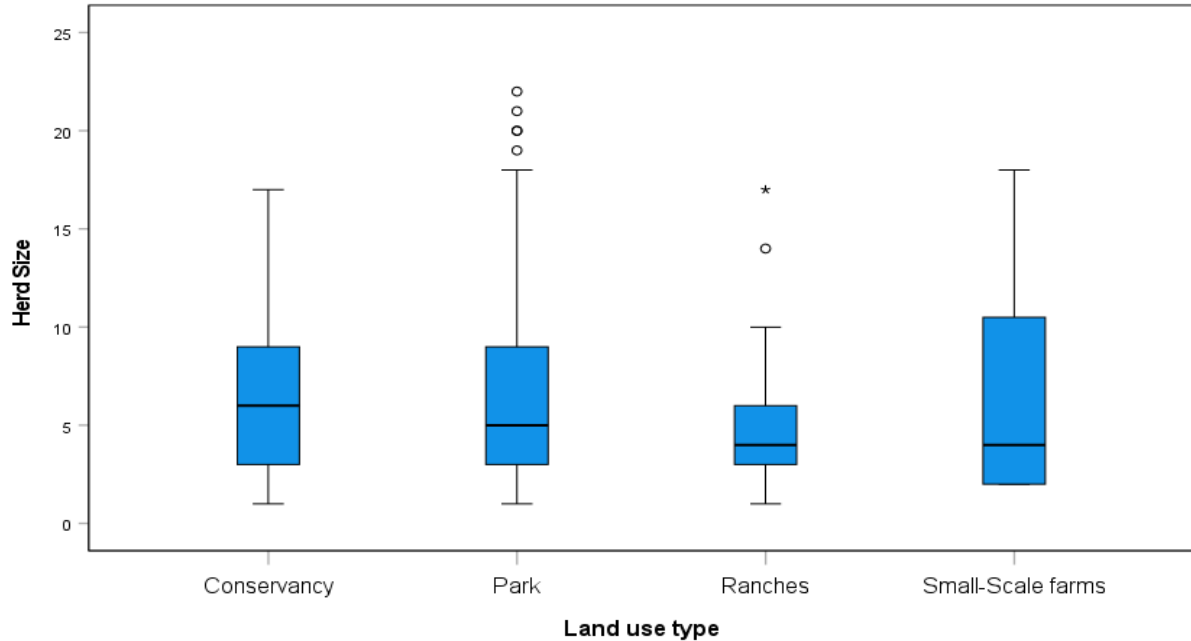


Fig. 4. 2: Giraffe herd sizes Distributions across Land uses.

Table 4.1: Mean Heard Sizes \pm SE Between Seasons and Across the Land Uses.

Season	Land use Type.			
	Mean (\pm SE) number of giraffes per herd			
	Parks	Conservancies	Ranches	Farms
Wet	3.2 \pm 1.2	6 \pm 3.3*	2.5 \pm 0.32*	4.8 \pm 1.1*
Dry	3.5 \pm 1.3	4.2 \pm 1.2	2.5 \pm 0.39	3.35 \pm 1.9
Anova	* p<0.05, df=3, F=2.696			

There was no significant difference between mean herd sizes in all the land use types ($p>0.05$) and between seasons. However, there was significant difference within the wet season ($p<0.05$) between the land uses. The post-hoc analysis showed significant differences between ranches and conservancies ($p = 0.026$) and small-scale farms and ranches ($p= 0.029$) during the wet season where giraffe herd sizes differed across the land uses.

4.1.4 Giraffe Density and Distribution

Giraffe densities were analyzed using the aerial census data obtained from Kenya Wildlife Service due to biasness of the road counts and limited coverage. The Point density tool in Arc GIS 10.5 was used to create a population density map using 1Km search radius. This analysis assumed that a giraffe has a minimum home range of 5Km² (Knüsel et al., 2019). High densities and occurrences were recorded on the western and southern side of Tsavo west and Tsavo East National Parks. The ranches at the southern part of the Tsavo West National Park, connecting Mkomazi and Tsavo East National parks also recorded high densities as shown in Fig (4.3a). Similarly, more Masai giraffes' sightings were recorded in the same areas Fig (4.3b).

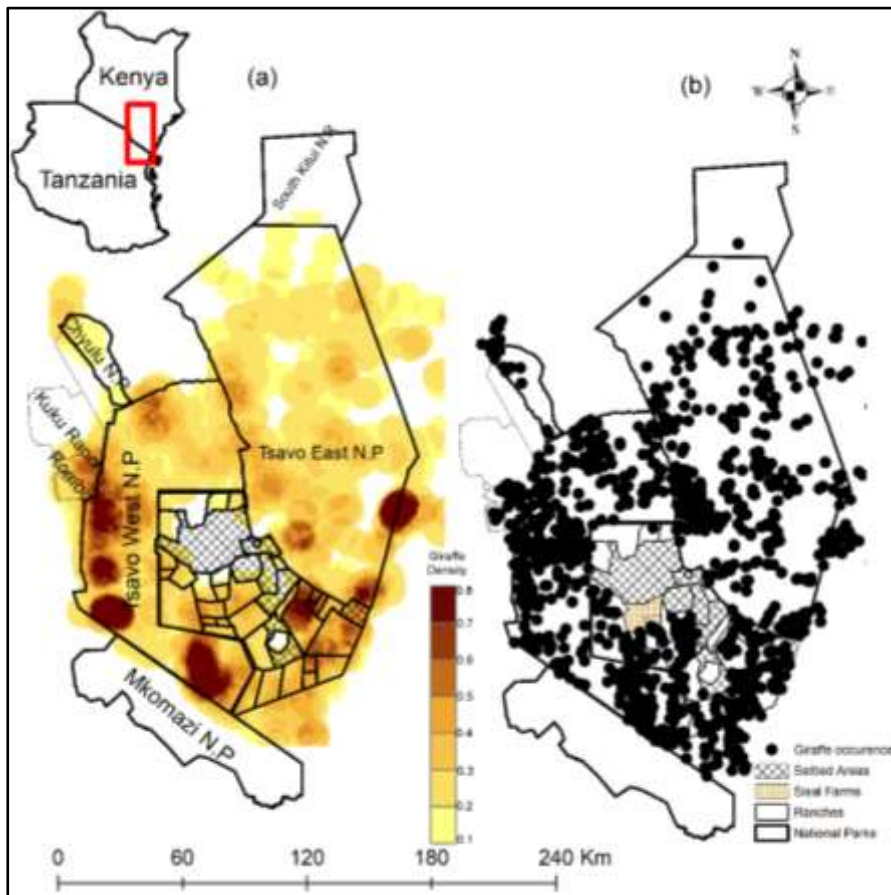


Fig. 4. 3: a) Masai giraffe density distribution b) Giraffe presence as recorded in June 2021 in Tsavo Conservation Area.

Using the Ripley-K function, the observed K value was larger than the expected K value at 10km spatial scale which indicated that the distribution is more clustered than a random distribution. Further, a larger observed K value than the upper confidence envelope (HiConfEnv) value, was recorded at less than 15Km indicating that spatial clustering for 15km was statistically significant as illustrated by Fig. 4.4 below. Overall, the giraffes recorded a clustered distribution as the observed K values were higher than expected.

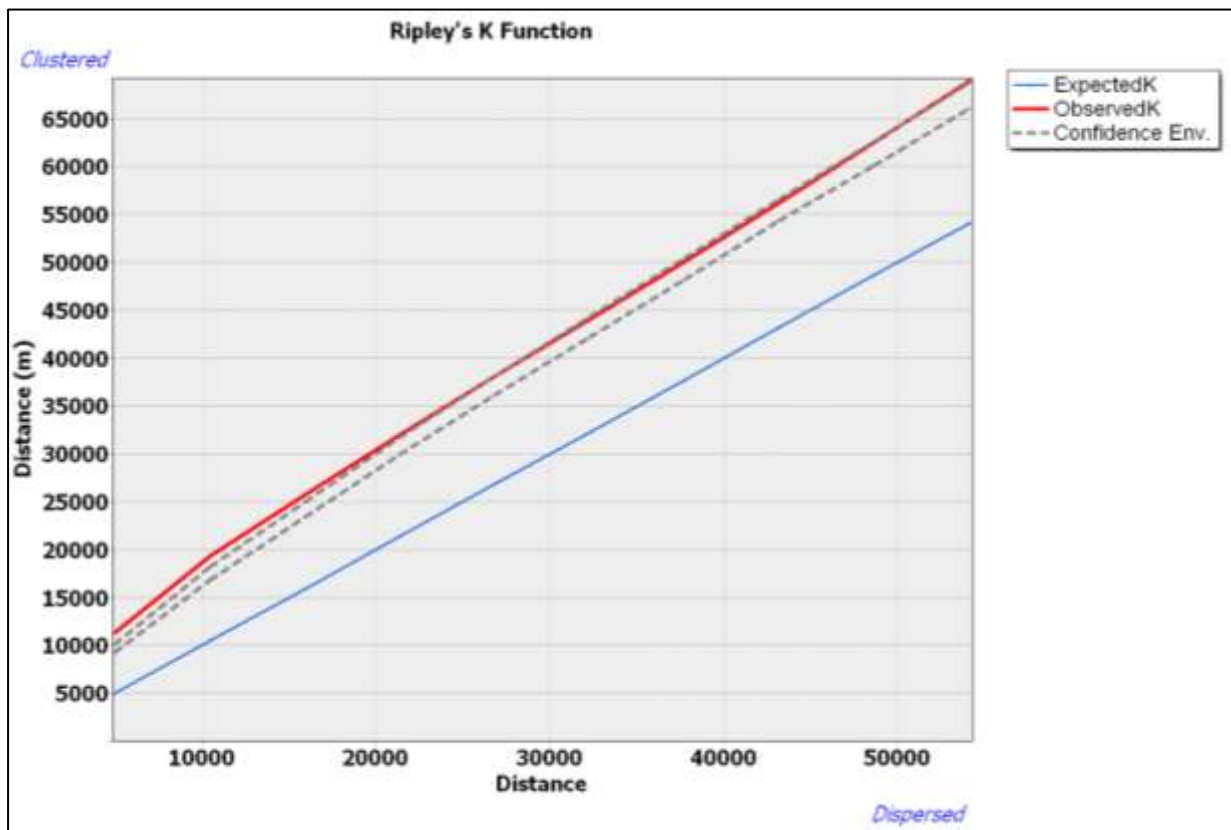


Fig. 4. 4: Results of Ripley's K function analysis showing significant clustering distribution at 15Km of the Masai giraffes in the TML.

4.2 Threats Facing Giraffes.

Key direct and indirect threats to giraffes included poaching, electrocution, wood collection/habitat destruction, charcoal burning, snares, illegal livestock incursions and wildfires. Data from scout's SMART database and field surveys for January 2021 to December 2022 was analyzed.

4.2.1 Threats To Masai Giraffes And Their Habitats In The Tsavo-Mkomazi Landscape

Habitat threats included livestock incursions, wood collection and charcoal production among others. Fire, mining and temporal settlement within the parks and ranches were also rampant. In total, 1128 illegal human activities involving habitat destruction, poaching or tree felling were recorded. Livestock incursions from local area and from eastern Kenya were the main threat to both ranches and parks. Large herds of cattle (10-3500 heads) were observed especially in the parks.

Wood collection accounted for 22% of the total threats recorded mainly in the unprotected areas. Snares also ranked among the top threats affecting giraffes and other wildlife in the TML (Fig 4.6). Fig. 4.7(a) shows the distribution of the carcasses while 4.7 (b) shows the threat index in the study area. High threat index was recorded in ranches specifically, Mgeno conservancy, areas around LUMO conservancy, Taita ranch, Rombo group ranch and at the boundary of Tsavo West National Park and communities in Tanzania near Lake Jipe.

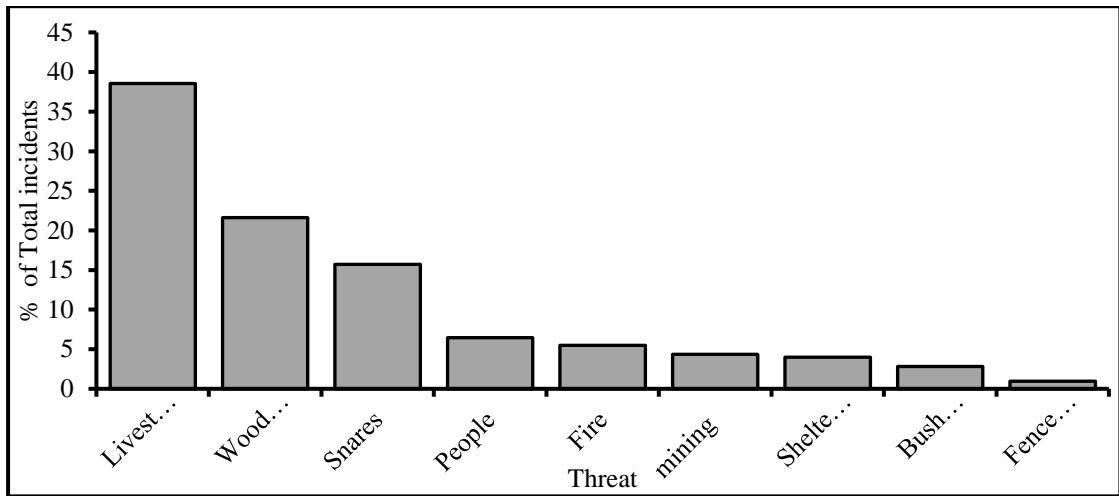


Fig. 4. 5: Frequency of habitat destruction activities recorded (2021) in Tsavo-Mkomazi Landscape

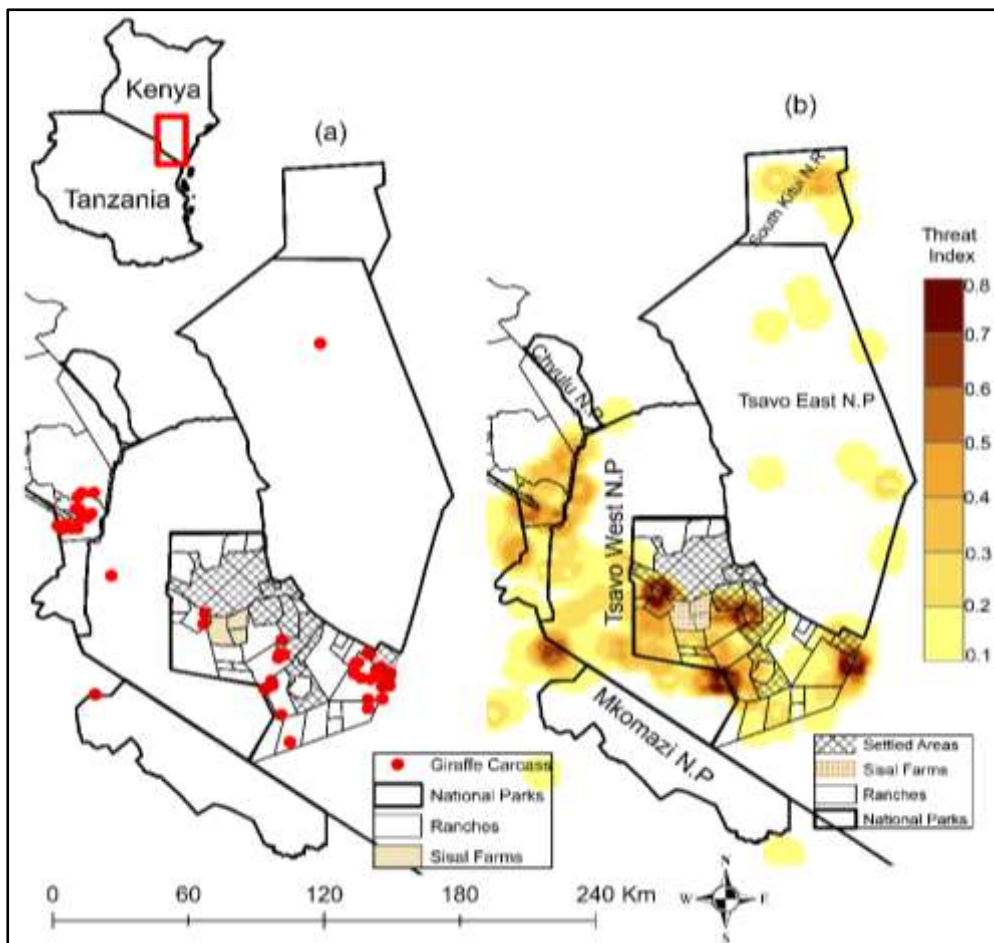


Fig. 4. 6: a) Masai giraffe carcass distribution between January 2021 and May 2022, b) Masai Giraffe threat index in Tsavo-Mkomazi Landscape

4.2.2 Cause of giraffe death in Tsavo-Mkomazi Landscape

A total of 64 giraffe carcasses were recorded between 2021 and 2022. Twenty carcasses were recorded during the field surveys and 44 by scouts working in LUMO, Kasigau, Taita ranch and Mgeno. The causes of death were classified as either killed by ‘traditional weapons’ whereby the poacher used machete or bows and arrows to kill the animal; ‘snaring’ where the poacher put any type of snare targeting the giraffe; ‘unknown’ when the cause of death could not be ascertained immediately. Other causes of death included predation, diseases or old age. If the giraffe was killed by powerlines or fences the cause of death was classified as ‘electrocution’.

Poaching using traditional weapons was the leading cause of death of giraffes accounting for 38% of the total deaths recorded. Use of snares accounted for 11% of the total carcasses. Hence, poaching contributed 49% of the total cause of death of giraffes in the landscape. Electrocution accounted for 14% of the total carcasses recorded. Fig. (4.4) shows the cause of death against the number of carcasses.

Of the 64 giraffe carcasses recorded during this study, 96% were outside the protected areas, in ranches. Rombo and Taita ranches had more carcasses, one carcass was found predated by lions in Tsavo East National Park and one along Voi-Taveta Road due to motor vehicle accident.



Plate 3: Confiscated giraffe meat by authorities in Tsavo Conservation Area and an electrocuted giraffe in Kasigau Ranch.

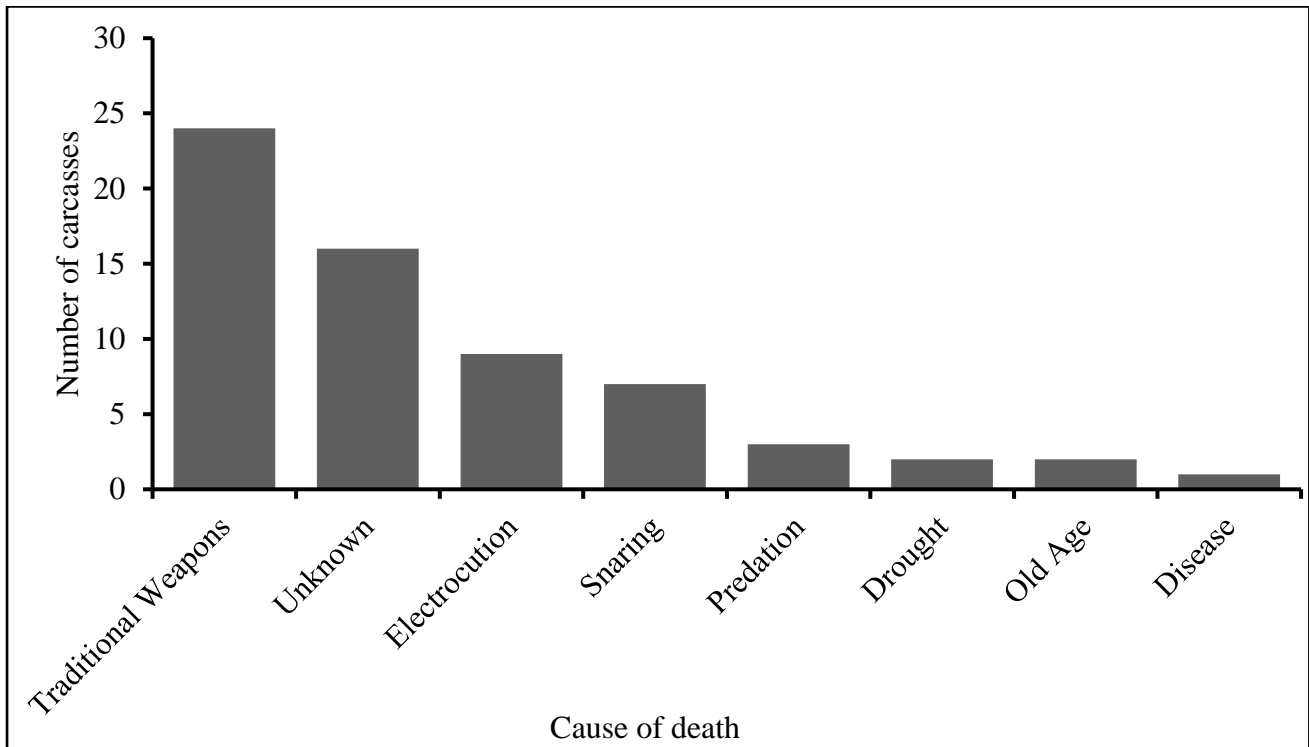


Fig. 4.7: Cause of death for giraffes whose carcasses were recorded in Tsavo-Mkomazi Landscape between January 2021 and December 2022.

Further, information on the body parts missing on the carcass was recorded (Fig 4.5).

Most of the carcasses (61%) had the meat missing, two had the skin missing and 9 had other parts such as tails and head missing.

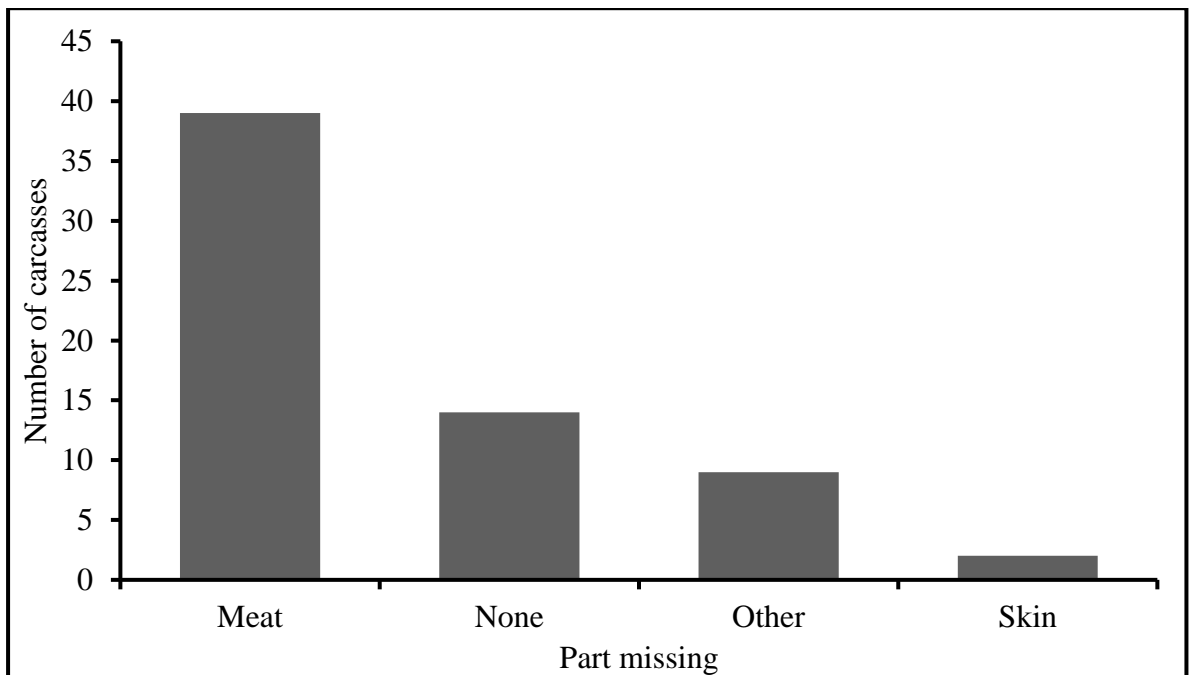


Fig. 4. 8: Body parts missing on giraffe carcasses.

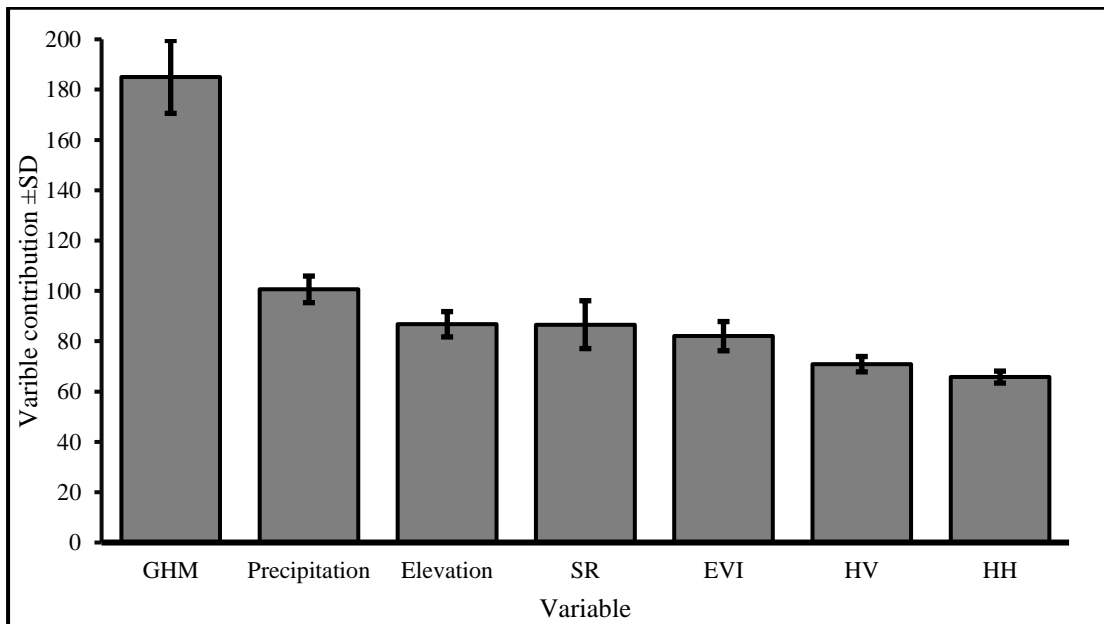
4.3 Masai giraffes' habitats' suitability and connectivity within the Tsavo-Mkomazi Landscape

4.3.1 Model Predictions.

On average, the models attained an average mean AUC-PR of 0.80 (SD = 0.01, Range = 0.79-0.83), the mean sensitivity of 0.83 (SD = 0.04, Range= 0.75-0.90) and the mean specificity was 0.73 (SD= 0.03, Range= 0.69-0.79) across the ten-fold model fittings (Table 4.2). The low standard deviations in accuracy metrics shows consistency among individual models run with different random sets of data.

Table 4.2: AUC-PR and AUC-ROC values obtained in 10 model fittings in TML.

Runs	AUC-PR	AUC-ROC
Run0	0.79	0.83
Run 1	0.80	0.85
Run 2	0.83	0.87
Run 3	0.79	0.82
Run 4	0.79	0.84
Run 5	0.79	0.86
Run 6	0.80	0.83
Run 7	0.81	0.88
Run 8	0.78	0.82
Run 9	0.78	0.82
Mean	0.80	0.84

**Fig. 4. 9:** Mean random forest predictor importance \pm Standard Deviation (SD)

The mean random predictor importance is shown in Fig. 4.8. Higher values indicate a better ability to identify suitable and unsuitable habitat based on the training data set. Human habitat modification was the most influential predictor on average across all the

model fittings (27.30%), followed by precipitation (14.84%) and elevation at 12.77% other variables varied between 9-12%.

4.3.2 Habitat Suitability

The model highlighted Tsavo West and Tsavo East National Parks as key suitable habitats for Masai giraffes in Tsavo-Mkomazi Landscape (Fig. 4.9a), predicting a total of 15,002 km² as suitable habitat. Over 17% (2600 kms²) of suitable habitat was found within community ranches. The *Vachelia commiphora* forest in Tsavo West National Park were the most suitable habitats. The Northern part of Tsavo East National Park recorded moderate suitability with South Kitui National Reserve and Chyulu Hills National Park recording small patches on the western side with medium suitability. Ranches at the southern part of Tsavo West National Park recorded high suitability (>0.5). Human settled and highly elevated areas recorded low suitability and consequently they were not potentially suitable for giraffes as shown in Fig. 4.9b.

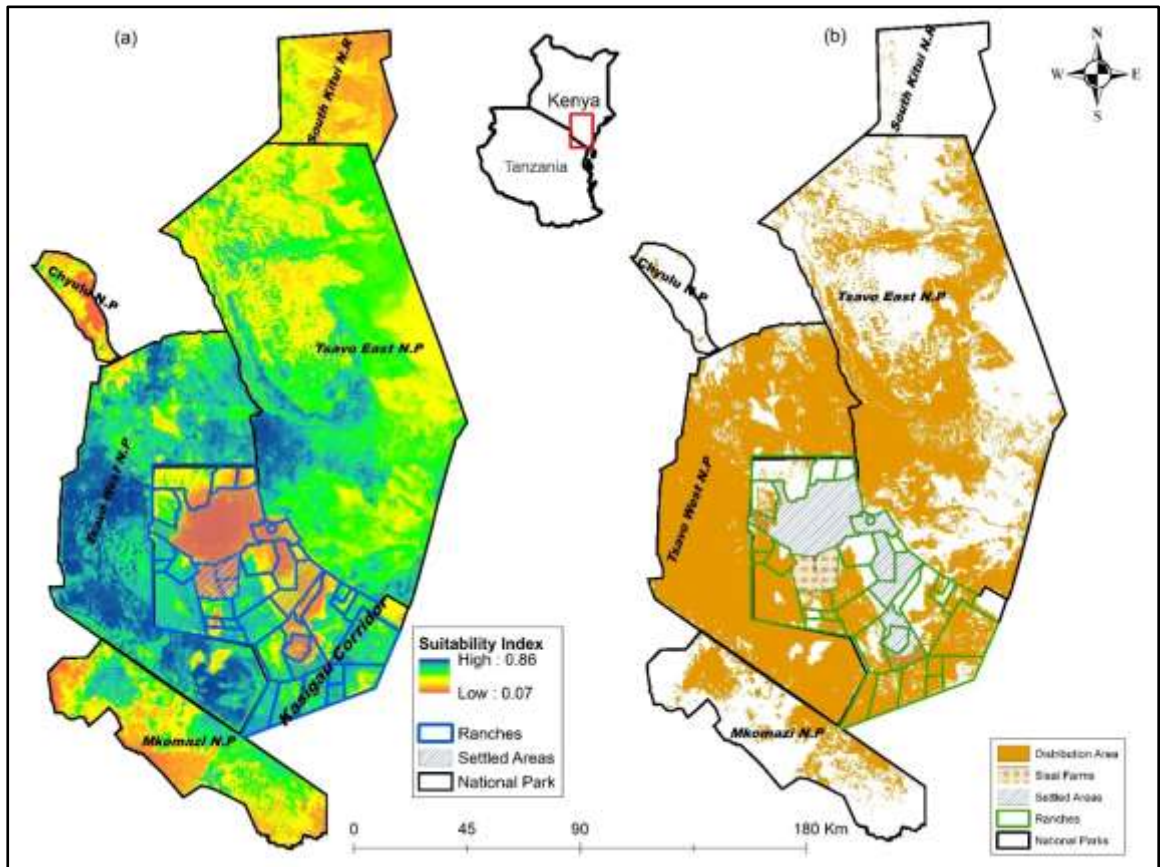


Fig. 4. 10: a) Masai Giraffe habitat suitability index and b) possible distribution map within Tsavo-Mkomazi Landscape

4.3.3 Habitat Connectivity

Results of this analysis showed three connecting corridors between the contiguous protected areas from Mkomazi National Park to South Kitui National reserve. Both Circuitscape and factorial pairwise matrix highlighted Tsavo West National Park's northern side as key corridor and two corridors at the southern part of Tsavo West National Park connected through community ranches and conservancies. These corridors include: Mkomazi-Tsavo West-Bura-Taita ranch-Rukinga and Tsavo East (Kasigau corridor), and the second corridor through Tsavo West-Maungu ranch-Sagalla ranch-Izera ranch and Tsavo East National Park. Rukinga conservancy formed the conduit to Tsavo East National Park. The third corridor Tsavo West-Maungu-Izera

ranch-Tsavo East recorded marginal suitability and low current due to increased infrastructure (See appendix III for names and locations of the ranches).

The model further identifies Tsavo West NP as a major Masai giraffe corridor, forming a key connecting zone between Mkomazi NP, community ranches, and Tsavo East NP. Human settled areas, South Kitui national reserve and Chyulu Hills NP had high resistance, potentially indicating lower use by the giraffes. Kasigau corridor located in the southern part of Tsavo West NP, which cuts across several livestock ranches, was also identified linking the ranches to Tsavo East NP through Rukinga conservancy and Taita Ranch (Fig. 4.10a). Further, ranches bordering Rukinga and forming Kasigau corridor were identified as of high importance in maintaining the connectivity of the landscape (Fig. 4.10b).

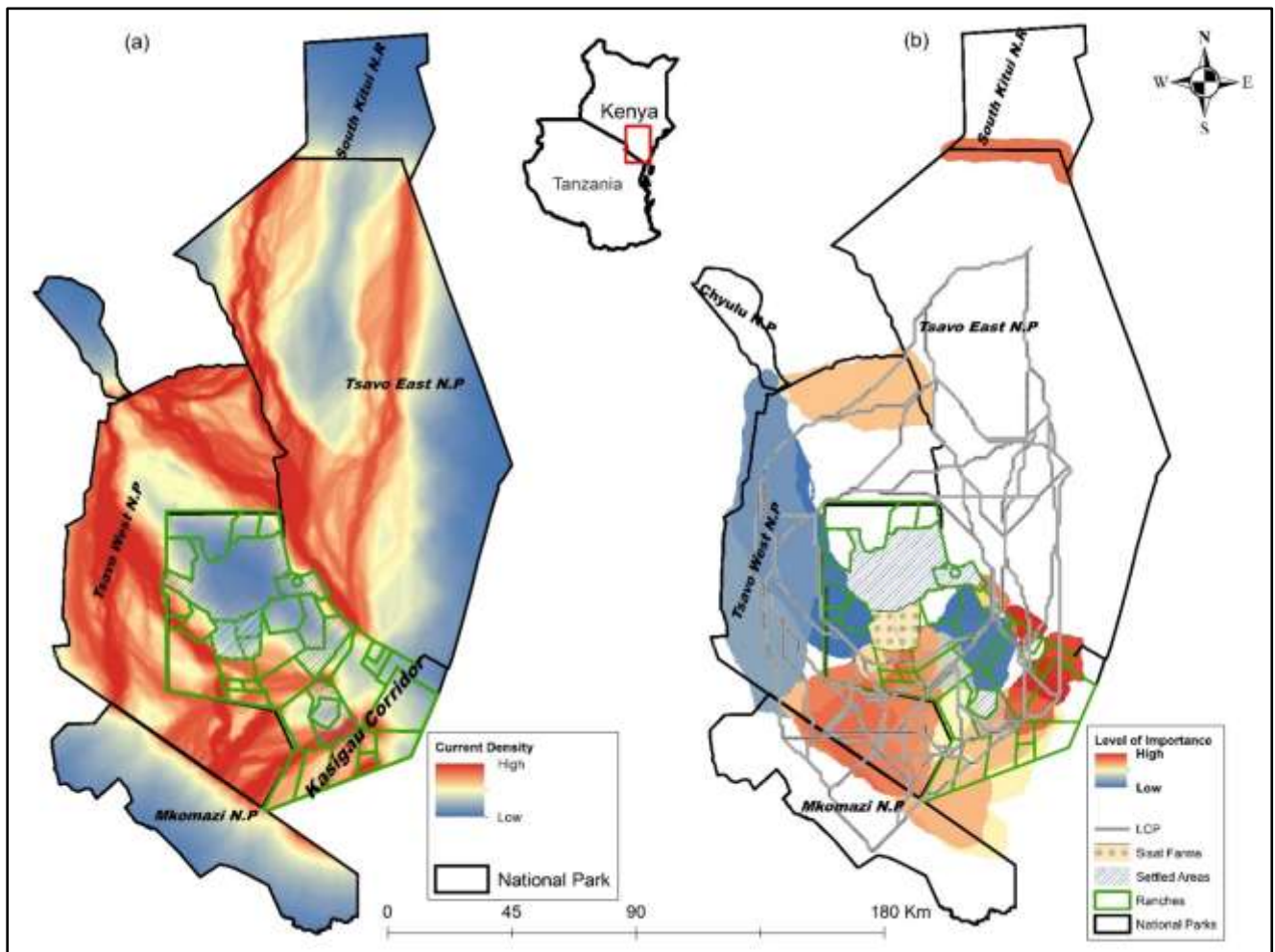


Fig.. 11: a) Current density flow between the core areas across the landscape (High density shows high permeability while low density indicates high resistance; b) Priority scoring of each corridor in keeping the overall landscape connectivity and the Least Cost paths (LCP) between the core areas.

CHAPTER FIVE: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This study characterized the Masai giraffe populations and their habitats in Tsavo-Mkomazi Landscape in Southern Kenya and Northern Tanzania, identifying Masai giraffe population structure and distribution under different land use types, threats and their habitats suitability and connectivity. This chapter describes the results and why the scenarios were observed in reference to available literature and similar studies.

5.2. Discussion

5.2.1 Masai Giraffe Population and Distribution

There were more giraffes sighted in the national parks than in ranches, small-scale farms, and conservancy. Although mean herd sizes and herd types did not differ between seasons and across the land use types during the dry season, significant differences were observed during the wet season (Table 4.1) with conservancies and farms having bigger group size during the wet season. Herd sizes are mediated by several factors such as security, social behavior and habitat variations and seasonality (D'haen *et al.*, 2019; Knüsel *et al.*, 2019; Levi *et al.*, 2022; Mcqualter *et al.*, 2016; Muller, 2018; Stabach *et al.*, 2016) and in the recent past, proximity to settlement and livestock densities have been found to mediate occupancy and social organization of the giraffes (Bond *et al.*, 2020; Bond and Farine, 2021; Hart *et al.*, 2020; Masiaine *et al.*, 2021). The behavior of the giraffes in TML could be attributed to resource variation and livestock incursions in different land use types agreeing with the findings of (Masiaine *et al.*, 2021; Mcqualter *et al.*, 2016) who observed giraffe displacement by

livestock incursions and seasonal movements between land uses respectively. Due to the prolonged drought during the surveys, the movement of giraffes could have been mediated by resource variations in these areas. Additionally, there were high incursions of livestock in the parks and could have impacted on the distribution of the giraffes outside protected areas during the dry season. This finding agrees with Masiaine *et al.*, (2021) who observed that giraffe's occupancy can be influenced by livestock densities.

Group sizes did not differ significantly between seasons (Table 4.2). Although studies have shown that seasonality plays a key role in determining the group size and structure (Knüsel *et al.*, 2019; Muller, 2018; Stokke *et al.*, 2010), this was not the case in this study. The surveys were preceded by long dry period in the years 2020 and 2021 (Mwui *et al.*, 2022) which could have had an impact on the social structure of the giraffes and movement between the land uses. Prolonged drought has been shown to mediate group sizes of large mammals (Sitati *et al.*, 2014) and specifically the giraffes (Knüsel *et al.*, 2019). This could be a possible explanation of the giraffe herd sizes not being affected by the seasonality but within seasons by not influencing their fission-fusion behavior.

There was a significant association between age groups and land use type (adult males, adult females, sub adults and juveniles). This could be attributed to social organization of the giraffes where dominant males lead a herd of females (Bond *et al.*, 2021; Brand, 2007; Burger *et al.*, 2020; Hart *et al.*, 2020). While female giraffes tend to have stronger social associations, Ferres *et al.* (2021) suggests that males are more socially connected, potentially explaining why bachelor herds are more commonly observed across different land uses. However, the differences in sexes among the group occurrences can

be attributed to environmental factors and social demands of individuals such as mate (Brown and Bolger, 2020), vigilance (Scheijen *et al.*, 2021), resources and predation (Muller *et al.*, 2018). Females with young were more sighted in the parks which could be attributed to vigilance and safety (Marealle *et al.*, 2020). In farmed areas, adult males outnumbered the adult females sighted; this could be attributed to illegal killing and increased human activities which have shown influence in family structure of giraffes in concurrence with the finding of Marealle *et al.*, 2020; and Stokke *et al.*, (2010).

Resources such as vegetation, water, climatical factors and landscape characteristics determine the occurrence of species in given habitats, (Kimuyu *et al.*, 2021; O'Rourke and van Wijngaarden, 1987). Rainfall could also be an influencing factor as it contributed 14.84% to model prediction. Given that giraffes prefer *Vachellia* species, which are abundant in the Rombo areas of small-scale farms and the western side of Tsavo West National Park, it's likely that these areas are highly favored by giraffes due to the combination of favorable vegetation and ample water sources. Additionally, Tsavo West National Park constituted over 50% of the total suitable habitat for giraffes in the landscape despite having the highest distribution of giraffes. Other areas such as community ranches recorded higher densities (Fig.s 4.9a and 4.9b). This explains the observed clustered distribution of Masai giraffes in the Tsavo-Mkomazi Landscape.

5.2.2 Threats to Giraffes

The main threat to giraffes in Tsavo Mkomazi landscape is poaching. This study found that 49% of the total giraffe deaths were due to poaching, induced either by snare or crude weapons. The main aim of poaching was meat consumption and sale for commercial gains or subsistence consumption since 61% of the carcasses recorded had

the meat missing. Most of the poached carcasses (98%) were found outside National parks. Poaching has huge impacts both on social structure of the affected species and its population as have been observed in large mammals such as elephants and rhinos (Mkuburo *et al.*, 2020). Illegal hunting may skew populations to one sex (Stokke *et al.*, 2010) which could be an attributing factor to male dominance in small-scale farms as poachers select easy target of females and sub adults. Results of this study agree with this observation as bachelor herds and lone males formed almost 50% of giraffes in small scales farms (Fig. 4.1).

Electrocution is an emerging threat to wildlife specifically in developing areas such as African savannas (Løvschal *et al.*, 2017). In Tsavo-Mkomazi Landscape, electrocution of giraffes was one of the observed threats to giraffes. Increased land subdivision in the landscape has resulted in fencing off individual parcels affecting historical utilization of such habitats by the giraffes. Additionally, hay production in ranches has led to fencing off the production areas to reduce access and destruction of hay by wild animals. Giraffes have been caught in these fences and electrocuted. Similar threats of the fences have been recorded in other landscapes such as Masai Mara ecosystem(Løvschal *et al.*, 2017). These new fences accounted for 14% of the total causes of death and was the third largest threat to giraffes. Similarly, such fences have been rated as one of the major threats to large mammals specifically the giraffes (Trouwborst *et al.*, 2016) despite reducing livestock production in some areas by at least 19% (Boone and Hobbs, 2004).

Habitat destruction is another threat to giraffes. This is mainly due to charcoal production, wood collection and generally felling of the trees which form major forage for giraffes. This accounted for 22% of the total threats identified. Giraffe habitat destruction is one of the leading causes of habitat shrinkage globally (O'Connor *et al.*, 2019). Illegal charcoal production in this area began in early 1970s (O'Rourke and van Wijngaarden, 1987), in the Southern part of Tsavo West National Park in Kilibasi and Lualenyi ranches. Currently, it is mainly in Rombo group ranch where parcels of land have been subdivided and opened for farming and irrigation following an ongoing land subdivision. If unchecked, charcoal burning can have negative consequences on giraffe populations.

Previous censuses from Ngene *et al.*, (2013) and Omondi *et al.* (2008) show that giraffes occupied South Kitui National Reserve. However, due to increased illegal human activities such as charcoal production and overgrazing, the giraffe population was either driven to extinction or dispersed from the reserve. High densities of livestock can also be a threat to giraffes. Livestock incursions in the protected areas accounted for 38% of the total threats identified. Although livestock do not necessarily compete with giraffes in terms of foliage, studies have shown that high densities of livestock decrease giraffes' occupancy (Masiaine *et al.*, 2021) and may trigger resource partitioning (Killeen *et al.*, 2014). Although this study did not evaluate the impact of livestock on giraffe's occurrence it is worth noting that ranches where giraffes and livestock occur together, the density and herd size of giraffes was low (Table 4.1, Fig 4.2). Additionally, during the year, a high number of livestock incursions were reported in the Tsavo West National Park. This may have led to giraffes moving further into the

conservancies leading to high densities in wet season and exposing giraffes to potential poaching.

5.2.3 Habitat Suitability and Connectivity

Tsavo West and Tsavo East National Parks were among the most suitable habitats for Masai giraffes; however, parts of Tsavo East National Park were unsuitable specifically, Northern part and South Kitui national reserve. The model projected a total of 15,002 km² as suitable habitats within Tsavo-Mkomazi Landscape, indicating a smaller than the historically described general range of the Masai giraffes in Tsavo-Mkomazi Landscape (O'connor *et. al.*, 2019). Community dominated landscapes are becoming increasingly important in conserving giraffes as they act as connecting corridors and dispersal areas (Brown and Yoder, 2015, Kiffner *et al.*, 2020, Crego *et al.*, 2021). This was evident as community ranches were not only suitable for giraffes but also had 17% of the total suitable habitat highlighting the importance of conserving them for the benefits of Masai giraffes.

Human settled areas and high-altitude areas such as Chyulu Hills National Park, Kasigau, Sagalla and Wundanyi had the lowest suitability index. Human habitat modification was the most influential predictor on average across all the ten-fold model fittings at 27.30%. The ranches at the southern part of Tsavo West National Park often referred to as Kasigau corridor, (Fig. 4.10) recorded low to high suitability index but declined towards the main infrastructure such as main road and railway lines towards Tsavo East National Park at the settlements near the boundary with Taita ranch (See Fig. 3.1 and Appendix V for locations of the ranches). This showed that human

dominated, and highly elevated areas were unsuitable for giraffes agreeing with the findings of (Kimuyu *et al.*, 2021, Bond *et al.*, 2021; Brand, 2007; Burger *et al.*, 2020; Hart *et al.*, 2020), who found that giraffes avoided human dominated landscapes and highly elevated areas.

Rainfall was the second most influential variable (14.84%). Knüsel *et al.* (2019) observed that mean annual rainfall led to 74% variance in home ranges of the Masai giraffes across Tarangire-Manyara ecosystem. Since Tsavo West National Park receive higher rainfall than Tsavo East National Park (Githinji *et al.*, 2021), this could have had an impact on distribution of the giraffes agreeing with the findings of Knüsel *et al.* (2019). As EVI is a factor of rainfall (Hao *et al.*, 2012), there exists high correlation between vegetation and rainfall which in turn influenced distribution of the Masai giraffes in Tsavo West National Park.

South Kitui national reserve recorded low suitability which could be attributed to high livestock incursions and vegetation destruction through charcoal production. Historically giraffes have utilised the reserve (Ngene *et al.*, 2013). However, in 2017 and 2021 large mammal census in the landscape no giraffe was recorded in the reserve (Ngene *et al.*, 2017; Waweru *et al.*, 2021). Additionally, no giraffe was sighted during the surveys. Livestock incursions, human settlement and cultivation were identified in the reserve. Such pressures could have led to fleeing of giraffes from the reserve leading to local extinction. Similarly, findings have been documented by Bond *et al.*, (2021) and Okello *et al.*, (2016).

Connectivity analysis showed three connecting corridors between the contiguous protected areas from Mkomazi National Park in Tanzania to South Kitui National Reserve. Both Circuitscape and factorial pairwise matrix highlighted: a) Tsavo West National Park Northern side, b) southern part of Tsavo West National Park connected through community ranches and conservancies: Mkomazi-Tsavo West-Bura-Taita ranch-Rukinga Tsavo East (Kasigau corridor), and c) through Tsavo West-Maungu ranch-Sagalla ranch-Izera ranch to Tsavo East National Park (Fig. 4.10 a and 4.10b, see Appendix V for names and location of the ranches). The Rukinga conservancy formed the conduit to Tsavo East National Park. High current flow was also obtained from Tsavo West National Park Northern side as the most permeable corridor allowing high flow of current with low resistance to giraffe movement. All the corridors recorded medium to high permeability. The Kasigau corridor also formed the least cost paths with low current resistance indicating permeability of giraffe movement between Mkomazi to Tsavo East National Parks.

Although habitat suitability does not necessarily account for habitat utilization (Scharf *et al.*, 2018) nor presence of other biotic factors such as predation, competition, and poaching, this analysis can be useful in prioritizing conservation areas and conservation strategy to save giraffes which are faced by habitat fragmentation, loss of dispersal corridors, populations decline, climate, and increased human-driven threats (Brown and Yoder, 2015). Moreover, the findings of this study can guide planning of infrastructure and land use to avoid destroying key suitable habitats and important corridors in the landscape which are threatened by wildfires, human pressure, and unpredictable weather patterns.

5.3 Conclusions

Using ground surveys, aerial surveys and ranger patrols, this study sought to test whether Masai giraffes are uniformly distributed in the Tsavo-Mkomazi Landscape, and whether the population structure differs between land uses. This study showed that giraffes exhibited a clustered population distribution in the landscape, hence rejecting the null hypothesis. Additionally, the mean herd sizes differed significantly across land uses during the wet season. Further, age structure was different across the land uses with small-scale farms having fewer lone females and family groups compared to other land use types. The study identified poaching and electrocution as major causes of Masai giraffe deaths accounting for 63% of the total carcasses recorded. The study further revealed that giraffes in the small-scale farms suggests an unhealthy population (skewed to male sex), likely constrained by anthropogenic activities and poaching.

Further, the study tested the hypothesis: “The whole of Tsavo-Mkomazi landscape is suitable and well connected for Masai giraffes”. This hypothesis was rejected as the total suitable habitats for Masai giraffes in the landscape is approximately 15,002 km² with 17% outside protected areas at least for the dry season. In addition, South Kitui National Reserve was found to be no longer suitable habitat for the Masai giraffes. Ranches and community conservancies form the least cost paths for the giraffe movement between Mkomazi National Park in Tanzania and South Kitui national reserve and are of high importance in maintaining landscape connectivity since they connect more than one giraffe core areas. High resistance was recorded in Chyulu Hills National Park and South Kitui National Reserve. Dispersal areas and corridors are being

lost to land subdivision and blocked by fences and linear infrastructure worsening the situation.

Moreover, livestock incursions and charcoal production like in South Kitui National Reserve may have led to local extinction of the giraffes. Rainfall patterns coupled with land uses mediate herd sizes and group composition as large herds were found in parks and smaller herds in ranches and small-scale farms differing within seasons. Prolonged drought seems to distort the fusion-fission social organization structure of giraffes while human habitat modification and rainfall shapes the suitable habitats and their connecting corridors.

5.4 Recommendations

This study recommends:

- a) Although the unprotected areas contributed 17% of the giraffe's suitable habitats, they are crucial as least cost paths and with low movement resistance for the population explaining high density of giraffes in the unprotected areas. These habitats should be delineated and protected with inclusion in the national corridors and the protection measures instituted sooner to avoid both loss of the corridors and the populations. Equal prioritization should be given to ranches and conservancies with critical emphasis on corridors to ensure landscape connectivity.
- b) Incompatible human development, agriculture and linear infrastructure are increasingly compounding threats to Masai giraffe population and other wildlife. A proper land use plan should be carried out or encouragement of

compatible wildlife practices to maintain the population in these critical linkage zones.

- c) The upcoming fences and the need to protect pastures for livestock production, which is the main business in the ranches, are threatening corridors and causing deaths of giraffes. The construction of such fences should be done in line with the laid down procedures and adherence to authorities' frameworks such as National Environment Management Authority (NEMA) guidelines and proper auditing done. Similarly, the authorities in charge of wild animals should oversee construction of the fences to ensure adherence to the set procedures. Land use planning should also be encouraged and be done in line with National policies and county guidelines to ensure corridors and dispersal areas of wildlife are safe.
- d) A multisectoral approach is required to manage giraffe poaching in the Tsavo-Mkomazi Landscape. As most of the poaching occurs outside the protected areas, it is important equally important to support both authorities, ranches and nascent conservancies to manage poaching within their jurisdiction. Training of scouts and community rangers and expediting on collaboration with governments should be done to reduce poaching. Additionally, poaching has been commercialized based on large seizures made by the authorities which has also been linked to sale of giraffe meat in Tanzania specifically in Rombo bordering Tsavo West National Park. To curb the threat, cross-border collaboration and community awareness is critical.
- e) Sustainable livestock production integrated with tourism has demonstrated complementary economic benefit (Genovese *et al.*, 2017) and ecological

sustainability (Allan *et al.*, 2017) and should be encouraged to ensure giraffes and other wildlife thrive in these communally owned ranches while drawing economic benefits. Ranches should be encouraged to practice sustainable livestock production as well as be supported to explore tourism opportunities in the area to maximize their income and accommodate livestock-wildlife integration as thriving ecosystem model.

- f) Active management of South Kitui National Reserve should be put in place to save the reserve from destruction and earn much needed revenues. During the surveys, species such as kudus, elephants and lions were sighted indicating the suitability of the reserve to other species. The reserve can be managed as part of the larger Tsavo East National Park and be included in the tourism circuits within the Tsavo-Mkomazi Landscape. This study reiterates the urgency to develop recovery strategies for South Kitui National Reserve as key habitat for giraffes and other wildlife in Kenya's largest contiguous landscape.

5.5 Suggestions for Further Studies

- a) A detailed study on the impact of human development and linear infrastructure on Masai giraffe populations and geographical range needs to be done while assessing the use of designated underpasses especially within the new Standard gauge railway.
- b) The change in climate would affect the human wildlife interaction and increase over-reliance on bushmeat as witnessed during the COVID and escalated drought of 2021. There is a need to investigate the effects of climate change on long-term viability and sustainability of the Masai giraffe habitats both at the landscape and range levels. Although this study utilized historical rainfall data

to model habitat suitability, long term evaluation of changes in temperatures and other environmental variables needs to be done to ascertain the future of giraffes and other wildlife increasingly human-dominated landscape.

- c) More research on social drivers of the increasing giraffe poaching in the landscape should be investigated to ascertain the causes of the increasing poaching trends in the landscape.

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APPENDICES

Appendix I: NACOSTI License



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Appendix II: Wildlife Research and Training Institute Permit



WRTI/RP/118.6

6th March 2023

Amos Muthiuru Chege
 Department of Zoological Sciences
 Kenyatta University
 P.O. Box 43844-00100
Nairobi
 Email: chege.amos2100@gmail.com

Dear *Amos,*

Research Permit No. WRTI-0280-02-23

We acknowledge your application for a permit to conduct your MSc. research approved by Kenyatta University, titled '**Habitat characterization, spatial distribution and threats to Masai giraffes (*Giraffa camelopardalis tippelskirchii*) in Tsavo conservation area**'. You are granted a permit to conduct your research in Tsavo Ecosystem from **March 2023 to February 2024** upon payment of the WRTI permit fee of **Ksh 6,000**.

You will submit your executed Prior Informed Consent (PIC) and Mutually Agreed Terms (MAT) within six months from the date of issue of this permit. You shall comply with Kenya Wildlife Service (KWS) guidelines on wildlife research within and outside protected areas. Before commencing your fieldwork, you will obtain a NACOSTI permit and discuss your research workplan with KWS Senior Assistant Director for Tsavo Conservation Area (TCA), and the WRTI Principal Scientist for the Savanna, Arid and Semi-Arid Ecosystems

You will submit a copy of the final report of your research findings to the undersigned.

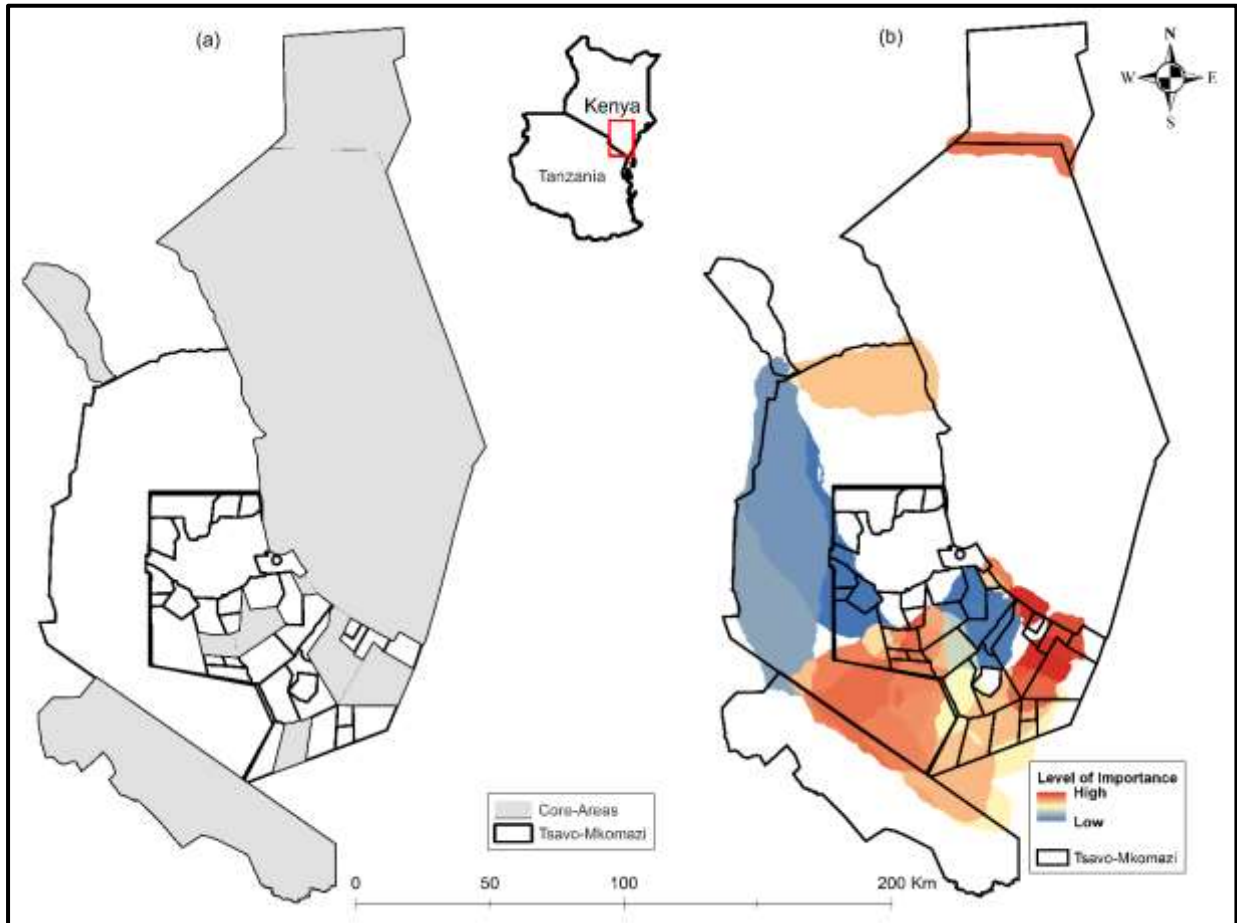
Yours

Patrick Omondi

DR. PATRICK OMONDI, OGW
DIRECTOR/CEO

Copy to: KWS Director, Wildlife and Community Service
 KWS Senior Assistant Director, Tsavo Conservation Area
 WRTI Principal Scientist, Savanna, Arid and Semi-Arid Ecosystems

**Appendix IV: Core Areas Used in Connectivity Analysis and The Corridors and
Their Importance Level**



Publication

1. **Muthiuru A.**, Ramiro D., Simbauni J., Muruthi P., Waiguchu G., Lala F., Kairu E, (2024) Human footprint and rainfall, shape Masai giraffe's habitat suitability and connectivity in multiple use landscapes. *Ecosphere Vol 15 (7): e4933*. <https://doi.org/10.1002/ecs2.4933>