MODELLING AND MAPPING THE PROBABILITIES OF LION-LIVESTOCK CONFLICT AREAS. A CASE STUDY OF MASAI MARA, KENYA

ANGIMA VELLA KWAMBOKA
February, 2015

SUPERVISORS:
Dr. A.G. Toxopeus
Dr. Ir. C.A.J.M. de Bie

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ANGIMA, VELLA KWAMBOKA
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SUPERVISORS:
Dr. A.G. Toxopeus
Dr. Ir. C.A.J.M. de Bie

THESIS ASSESSMENT BOARD:
Dr. Y.A. Hussin (Chair)
Prof. Dr. V.G. Jetten (External Examiner)
Dr. A.G. Toxopeus
Dr. Ir. C.A.J.M. de Bie

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ABSTRACT

Lions and livestock play an integral role culturally, socially and economically. They aid in ecosystem structuring and functioning. However, increased human settlements and livestock grazing in conservation areas has contributed to overlap between lion habitats, livestock grazing areas and human settlements. This overlap has augmented interactions between lions and livestock, fuelling conflicts which mostly result in loss of livestock, which is the key component for sustenance of pastoral livelihoods.

The main aim of this study therefore was to model and map the probabilities of livestock-lion conflicts at bomas and at livestock grazing areas, for the purposes of assessing the spatial likelihood of lion-livestock conflicts occurring within the study area.

To map vegetation cover types available for livestock grazing, hyper-temporal MODIS imagery were used, in combination with vegetation field survey data. Settlements were digitized from Google Earth imagery. This research made use of lion presence data and a set of six environmental predictors to predict lion presence probabilities using Maximum Entropy (MaxEnt) model. Model performance and accuracy was assessed using ROC Curve, Kappa and TSS statistics. Livestock kill count for one conservancy was used to validate the boma lion-livestock conflict probability map.

Two formal hypothesis were formulated. Null hypothesis 1 stated that the MaxEnt model performance will be equal to 0.5. Null hypothesis 2 stated that the boma lion-livestock conflict probability map is not valid, based on the 2013/2014 livestock kill count for one of the conservancies (Mara North).

The vegetation cover mapping exercise revealed that there were five grassland cover types in the study area, two of which could be easily differentiated from the rest. MaxEnt model for lions performed better than random. Analysis of model accuracy yielded TSS value of 0.497 and a Kappa statistic value of 0.733, indicating a fair model. Jackknife test results showed that wildlife density was the most important predictor of lion presence, followed by distance to bomas. Distance to roads, distance to rivers and vegetation cover types were on the other hand the least important predictors.

Two limitations were encountered when conducting this study. Actual lion-livestock conflict data for the entire study area was not available. Hence, validation of the lion-livestock conflict probability maps for the entire study area was not possible. Secondly, actual livestock grazing areas within the study area was lacking. Hence, mapping of lion-livestock conflict probabilities considered all grasslands, representing all potential livestock grazing areas.

In conclusion, the 71 classes, median, SD, and trend was not sufficient to differentiate all vegetation cover types. Grassland types situated in more conserved areas had more % grass cover and were more homogenous. Those situated near and in areas with anthropogenic activities were more heterogeneous. Wildlife and livestock densities are the best predictors of lion presence probabilities. Bomas located in areas with high lion presence probability have a very high likelihood of experiencing conflicts.

Key Words: African Lions, Maasai Mara, Habitat, NDVI, livestock, conflicts, Boma, Species Distribution Models, MODIS.

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LIST OF ABBREVIATIONS

CITES	: Convention on International Trade in Endangered Species
DRSRS	: Department of Resource Surveys and Remote Sensing
FAO	: Food and Agriculture Organization
GIS	: Geographical Information Systems
GoK	: Government of Kenya
ILRI	: International Livestock Research Institute
IUCN	: International Union for the Conservation of Nature
KWS	: Kenya Wildlife Service
LULC	: Land Use Land Cover
MMNR	: Maasai Mara National Reserve
NGOs	: Non-Governmental Organizations
RMSE	: Root Mean Square Error
WWF	: World Wildlife Fund

DEFINITION OF TERMS

The definitions below describe the terms used in this study.

Bare: "Un-vegetated patches including rock and bare earth" (D. N. Reed, Anderson, Dempewolf, Metzger, & Serneels, 2009).

Boma: **"**Structures consisting of a dense ring of thorn-scrub branches that contain and protect livestock overnight from theft and predation**"** (Augustine, 2003)**.**

Figure 1: An aerial view of a traditional Maasai boma. The outer thorn bush defines the extent of the boma i.e, the boundary. The inner circular thorn bush represents livestock enclosures.

Source: (Lichtenfeld, Trout, & Kisimir, 2014)

*Human-Wildlife Conflict***:** is the situation where by "the needs and behaviour of wildlife impact negatively on the goals of humans or when the goals of humans negatively impact on the needs of wildlife" (Madden, 2004).

Hyper-temporal: "Long-term, extensively repeated (daily) time series datasets of an area" (Ali et al., 2013).

*Complexes***:** "Different types, often belonging to different Main types, occurring in close conjunction, sometimes in a manner predictable according to the topography and ground-water conditions, sometimes irregularly and governed by surface geology, effects of human perturbations, e.t.c (Greenway, 1973).

Canopy cover: "The proportion of the ground area covered by the canopy when viewed vertically" (Allen et al., 2011).

Grassland: "This term is broadly interpreted to include grasses, legumes, forbs, and other herbs" (Allen et al., 2011; Greenway, 1973).

NDVI standard deviation: "the root mean square deviation of the NDVI time series values (annual) from their arithmetic mean" (FAO, 2015).

Herbs: In this study herbs were defined as non-wooded plants with soft stems covering the ground or having canopies rising a few centimetres from the ground.

High Shrubs: In this study, high shrubs were defined as above ground woody plants whose height is generally between 0.5 – 2m.

Low Shrubs: In this study, low shrubs were defined as above ground woody plant lying close to the ground with height ranging between ≤0.5m.

Tree: In this study, and during field work vegetation survey, a tree was described as above ground wooded vegetation of height ≥1.5m.

Vegetation Structure: "The spatial distribution pattern of growth forms in a plant community" (Di Gregorio & Jansen, 1998).

Vegetation Cover: "The vertical projection of the crown or shoot area of vegetation to the ground surface expressed as a fraction or percent of the reference area" (Purevdorj, Tateishi, Ishiyama, & Honda, 1998).

NDVI Classes: In this study, the term NDVI classes is used to mean the classes generated from the unsupervised classification of the stack of MODIS imagery.

1. INTRODUCTION

1.1. Worldwide Conservation of Carnivores

The scientific classification of animals places Carnivores under Kingdom Animalia, Phylum Chordata, Class Mammalia, Subclass Theria, Infraclass Eutheria, and order Carnivora. The order Carnivora is very diverse, consisting of about 226 mammal species, split to different branches of sub-orders, super-families and families (Treves & Karanth, 2003). One of the families under Superfamily Feloidea, is Family Felidae. This family comprises of cat-like carnivores, known as felids. Felids are apex terrestrial carnivores with specialized claws for preying, hunting, holding and handling prey. These distinct features differentiates them from the dog-like carnivores. Felids are excellent stalkers and killers. Their limbs are relatively long, with their fore feet having five digits and their hind feet having four digits. Examples of felids include; Cheetah, Tiger, Leopard, Puma, Jaguar and Lion, (Macdonald & Loveridge, 2010).

Unfortunately, global population trends of apex terrestrial carnivores indicate that they are rapidly declining (Schuette, Creel & Christianson, 2013). This decline has been attributed to a number of factors such as; illegal poaching, trophy hunting, declining wild prey populations, diseases, high human densities, trade in carnivore body parts, population increase, changing land use practices, habitat loss and fragmentation. According to Bauer, Nowell and Packer (2012), habitat loss, illegal killings and diminishing wild prey base are the key drivers of dwindling carnivore populations. Furthermore, the loss of habitats driven by increased competition for space and food resources, is the chief cause of human-felid conflicts (Mazzolli, Graipel & Dunstone, 2002).

One of the species recognized as an apex carnivore is the lion (Schuette et al., 2013). This species is one of the four big cats in the genus Panthera. With its males weighing between 150-225kg in weight, World Wildlife Fund (2014) indicates that it is the second largest living cat after the tiger. There are two known lion sub-species based on genetic analysis; the African Lion (*Panthera leo leo*) and the Asiatic lion (*Panthera leo persica*). Both sub-species have also experienced substantial range and population collapse.

Historically, lions lived in parts of Europe, Middle East, Asia and Africa. Nowell & Jackson (1996) link this broad historical geographical distribution of the lion, to its previous extensive home ranges, which varied from mountainous regions, semi-desert, to dense woodland. Unfortunately, during the 1st century AD, lions disappeared from Europe, and between 1800 and 1950, they disappeared from Middle East and Asia except for the Indian sub-species;- *Panthera leo persica* (Nowell & Jackson, 1996). In Africa, lions have been limited to savannah grasslands.

1.2. Status of Lion Conservation in Africa and Kenya

The extent of the African lion range is estimated to be 4,500,000 sq.km, which is only 22% of its historic distribution. Currently, Eastern and Southern Africa consist of 77% of the current African lion home range (Bauer et al., 2012).

Demographically, lion populations in Africa have experienced huge declines over the last 35 years. In 1980, it was predicted that there were about 75,800 (Bauer et al., 2012). In 2002, the estimates dropped to between 23,000 and 39,400 lions (Chardonnet, 2002). Estimations by Bauer and Van Der Merwe (2004) indicated a further drop to between 16, 500 - 30,000 free ranging lions in Africa, with the continent's largest populations being in Selous and Serengeti ecosystems in Tanzania. The Serengeti ecosystem forms part of the greater Serengeti-Mara Ecosystem. This ecosystem is a trans-boundary ecosystem, having its southern portion (Serengeti) in Tanzania, and the northern portion (the Mara) in south western Kenya. The Mara-Serengeti ecosystem supports a wide range of wildlife species and is a conducive hub for the annual wildlife migration (Ottichilo, Leeuw, & Prins, 2001). Other than the Masai Mara, large lion numbers in Kenya can also be found in the Tsavo complex and Laikipia region. The lion is one of Kenya's flagship species, and plays a significant role in the structuring and functioning of savannah ecosystems. In addition, it is a top tourist attraction that generates huge revenues for the country (Kenya's National Large Carnivore Task Force, 2008). Estimates showed that the country's lion population drastically declined from 2,749 in 2002 (Chardonnet, 2002), to 2,280 in 2004 (Bauer & Van Der Merwe, 2004) to 1,970 in 2008, (Kenya's National Large Carnivore Task Force, 2008), a decline of nearly 30% in almost 10 years (Schuette et al., 2013). There are now fewer than 2,000 lions left (Kenya's National Large Carnivore Task Force, 2008). This downward trend resulted in the IUCN classification of the African lion as a vulnerable species since 1996, to date (Bauer et al., 2012). In addition, this species has been listed under Appendix II by CITES (2014), as a species whose trade is highly controlled to ensure its long term survival, and is protected under the country's 1986 act schedule 1 part 1.

1.2.1. Behaviour and Ecology of the African Lion – *Panthera Leo Leo*

Lions are one of the most social animals in the cat family. They live in groups of two or more, which are otherwise known as prides. The pride is a matriarchal society (Packer et al., 1991), and Schaller (1972) describes it as the primary point of merging and splitting of a lion's social unit. These prides are made up of large lion families which vary in size and in structure, with most constituting of 5-9 adult females, their dependent cubs, and about 2-6 immigrant males (Packer et al., 1991). Large family prides may constitute an average of up to 30 – 40 individuals. These individuals are often scattered in subgroups all over their territory and each individual spends time alone. The smallest pride sizes are usually found in arid regions where prey availability is minimal (Schaller, 1972). The number of individual lions in a pride vary from one month to the other, simply because of a mixture of births, and the high death rate of cubs (Van Orsdol, Hanby, & Bygott, 1985). Activities undertaken by pride members include cooperative hunting to increase chances of hunting success, offering protection of lionesses and their offspring (Packer & Ruttan, 1988), to increase cubs' survival chances into adulthood (Pusey & Packer, 1978).

Lions are highly sedentary. Only few lions are known to be nomadic, and these are usually young or old males, which have been kicked out of their own prides. These nomadic lions can live single solitary lives or be part of an alliance with up to five or eight other male lions (Pusey & Packer, 1978). These male alliances often follow the movement patterns of prey, and can hunt and scavenge as a group (Van Orsdol et al., 1985). Once young nomadic male lions mature, they take charge of female lion prides, and father cubs born within these prides (Pusey & Packer, 1978). The males fight off challenges from their younger rivals, as they defend the pride's territory. Male lions spend up to two years in the pride, after which they are replaced by other younger male lions (Packer & Ruttan, 1988). On the other hand, most females stay with the pride through-out their life, and can even reach to about 15 in the pride. Females roam throughout the territory to hunt and look for food for the rest of the pride members, especially the cubs. The utilization of space within a pride's territory depends on resource availability e.g prey (Spong, 2002). Nomadic female lions are rare and are known to be philopatric, as they tend to return and settle near their natal pride (Packer & Ruttan, 1988).

A pride's territory does not easily change. It can be as small as 20 sq.km and as large as 500 sq.km (Van Orsdol et al., 1985). In some instances, a pride's territory may overlap with another pride's territory. In such cases, prides maintain their core area where most activities are carried out, and avoid interaction with the other pride groups (Schaller, 1972).

Figure 2: A group of lions in Masai Mara resting and taking advantage of the shade under trees, to cool off from the heat of the day.

Lions are mainly nocturnal (Packer, Swanson, Ikanda, & Kushnir, 2011). With eyes that are six times more sensitive to light, lions mostly prefer to hunt at night or in cooler daytime periods (Schaller, 1972), as a large part of their time during the day is spent sleeping, lying down, or sitting (Heinsohn, 1997) as shown in Figure 2. When active, lions spend their time taking care of their young ones, hunting and defending their territories (Heinsohn and Packer, 1995), with the latter being done through urine sprays and male vocalisations, which can also function as a way of communicating with the other pride members (Schaller, 1972). However, due to their opportunistic nature, they can even hunt in the heat of the day, especially during the dry season when prey is less available. It is also during the dry seasons that lions hunt in groups more than any other season. To obtain more food, groups of lionesses hunt together during the wet season (Stander, 1992). Selection of prey by lions is related to a number of factors such as seasonal weather patterns, prey migration patterns (Heinsohn, 1997). Hunting success on the other hand is influence by factors such as availability of grass cover 20 cm (Funston, Mills, & Biggs, 2001), lion group size, prey group size, terrain and moon light (during nocturnal hunts, to substitute for cover) (Van Orsdol, 1984). Female lions are more involved in hunting as compared to their male counterparts, although males can take advantage of kills made by females because of their indisputable strength (Packer et al., 1991). Lions usually feed on medium to large ungulates, with the most preferred prey weight being 350kg (Hayward & Kerley, 2005). To maintain normal basic metabolic requirements, a female lion requires an average of 5kg of meat per day (Schaller, 1972). Of this, cubs consume a third, sub-adult consume two thirds whilst the males consume twice as much (Packer et al., 1991).

Table 1 illustrates the wide range of prey across Africa that lions have been known to consume. According to Hayward & Kerley (2005) and Schaller (1972), the most favourable prey include Gemsbok, giraffe, zebra and wildebeest. However, lions have also been known to feed on larger mammals such as eland, buffalo, kudu, warthog, waterbuck, and young African Elephants (Stander, 1992) especially during the dry periods.

Table 1: A table describing the variety of wildlife observed and considered as Lion prey in different protected areas across the continent of Africa.

Country	Study Site	Prey	Reference
Botswana	Chobe National Park	Young elephants	(Power & Shem Compion, 2009)
Cameroon	Waza National Park	Gazelle, Ostrich, Roan Antelope	(Visser, Muller, Tumenta, Buij, & de Iongh, 2009)
Kenya	Masai Mara National	Buffaloes, warthog, topi, hartebeest, giraffe,	(J. O. Ogutu &

	Reserve	Zebra, wildebeest, Thompson Gazelle	Dublin, 2002)
Namibia	Etosha National Park	Wildebeest, Zebra	(Stander, 2011)
Tanzania	Serengeti National Park	Wildebeest, Zebra, Thompson's Gazelle, Warthog, Buffalo	(Hopcraft, Sinclair, & Packer, 2005)
Zimbabwe	Hwange National Park	Buffalo, Kudu, Giraffe, Zebra, Young elephants	(Davidson et al., 2013)

Africa today, lions are limited to savannah habitats, which are estimated to have reduced by 75% in the last century (Riggio et al., 2012), owing to dense human populations and extensive conversion of land. In these Savannah habitats, lions are found in open woodlands, thick bush, scrub, and grassland complexes. Altitude does not restrict lion's home range, as they can be found in mountains such as Mt. Elgon in Kenya which is 3,600m , and even Ethiopia's Bale Mountains which are 4,240m (Nowell & Jackson, 1996).

The Maasai Mara Ecosystem is known to have the highest lion densities in the world, of about 0.2-0.4 lions per sq.km (Elliot, Mogensen, Sankan, & Sakat, 2014). The lack of fences around wildlife habitats in Maasai Mara, means that part of the lion territories fall outside these areas. This brings lions into contact with the local Maasai. Conflict with people is a major cause of human-induced lion mortality and may speed up extinction of lions (Woodroffe & Ginsberg, 1998).

1.2.2. Past Human-Lion Interrelations in Kenya

The Maasai are one of the Nilotic communities who live in Kenya. They are nomadic pastoralists whose main source of livelihood is livestock keeping. One of the customs that best characterizes the Maasai community is their communal utilization and ownership of natural resources, as regulated and enforced under their traditional laws through a council of elders. This system ensured that there was minimal natural resource conflicts. Before the arrival of the first Europeans, the Maasai used to migrate from one region to another, grazing their livestock in accordance with climatic changes. Hence, for many centuries, this community co-existed well with wildlife, living in harmony side by side. (Rutten, 1992). However, this changed a lot after the arrival of the British, who in 1904 forcibly restricted the Maasai to the Laikipia area in the North and to the southern part of Kenya (Hughes, 2005).

During the colonial government by the British, and even the Kenyan Government after independence, there was a negative attitude associated with the nomadic ways of the Maasai. These traditions were viewed as a threat by these two governments. This led to the establishment of land subdivision policies by both administrations, which resulted in private ownership of lands, an effort that was aimed at eliminating the migratory behaviour of the Maasai, and this threatened their existence and way of life (Galaty, 1992). Seven years later in 1911 (Hughes, 2005), a treaty was signed between the British and the Maasai, which forced the Maasai to move out of the Laikipia area in the North and concentrate in the southern part of Kenya, where we have the Maasai Mara region. Unfortunately, their efforts in 1913 to contest this decision was futile.

The creation of conservation areas in southern Kenya by the colonial government further complicated Maasai livelihoods and lifestyle, as they found themselves inhabiting areas that were mostly wildlife habitats (Waithaka, 2004). It is not until 1961 that part of this communally owned land, was officially demarcated and gazetted as a national reserve, and owned by the Government of Kenya. This paved way for modern wildlife conservation programmes in this region. In 1976, the remaining communal land was sub-divided into group ranches to provide formal and legal land tenure for groups of Maasai clans (Asiema & Situma, 1994). The intention behind the formation of group ranches was to eliminate the communal ownership of land by the Maasai, to curtail their migratory behaviour, and to encourage the commercial livestock production system (Galaty, 1992). In order to efficiently administer wildlife revenues to members of these group ranches, wildlife associations were formed as from 1994. However, increased land sub-division coupled with internal political wrangles resulted to increased fragmentation of these wildlife associations, paving way to the establishment of privately owned wildlife conservancies (Bedelian, 2012).

Both the reserve and its surrounding conservancies, are governed by regulations which restrict land use types to wildlife conservation and tourism. With the conservancies allowing to some extent, settlement and livestock grazing. However, a lot of development has since taken place in this Maasai land, transforming this landscape completely. Rapid population growth, increased cultivation, increased fencing, increased livestock keeping, have led to accelerated land use changes, leading to an alarming 70% decline of wildlife populations in 20 years (Ottichilo, 2000). These anthropogenic activities have also led to the continued loss of wildlife habitat, and have increased human-wildlife interactions, particularly between humans and lions (Ogutu & Dublin, 2002).

1.3. Problem Statement

Historically, the area covered by Masai Mara was regarded as dry-season grazing reserves for livestock, which are heavily relied on for provision of sustenance to pastoral livelihoods. The continued changes in Mara have resulted in declining pasture resources and have led to less and less land available for livestock mobility (Mwangi & Ostrom, 2009). This has increased legal and/or illegal livestock grazing in the reserve and conservancies, and this is taking place regardless of seasonality (Reid, Rainy, & Ogutu, 2003), and despite the restricted access, disciplinary measures and heavy fines (Bedunah & Schmidt, 2004; Hazzah, Dolrenry, Kaplan, & Frank, 2013). And as Butt, Shortridge and WinklerPrins (2009) and Schuette et al. (2013) state, one of the strategies used by pastoralists especially during the dry season is the relocation from far away settlements to temporary settlements near or even inside these wildlife habitats, to reduce distance and duration of travel to grazing areas.

Given that the Mara region is home to one of the largest lion densities in Africa (Ogutu & Dublin, 2002; Reid et al., 2003), increased livestock grazing together with the presence and expansion of settlements, is amplifying the likelihood of livestock depredation by lions (Ogada & Woodroffe, 2003).

1.4. Relevance of the Study

A lot of research has been conducted on the recent land use/cover (LULC) changes within the Maasai Mara ecosystem (Bhola, Ogutu, Said, Piepho & Olff, 2012; Butt, Shortridge & WinklerPrins, 2009; Groom & Western, 2013; Kolowski & Holekamp, 2006; Mogensen, Ogutu & Dabelsteen, 2011; Ogutu, Piepho, Dublin, Bhola & Reid, 2009; Oindo, Skidmore & de Salvo, 2003; W.K. Ottichilo, 2000; Wilber K Ottichilo et al., 2000; Salvatori & Egunyu, 2001; Serneels, Said & Lambin, 2001; Toxopeus, Bakker & Kairuki, 1996; Waithaka, 2004; Walpole, M., Karanja, G., Sitati, N. & Leader-Williams, 2003).

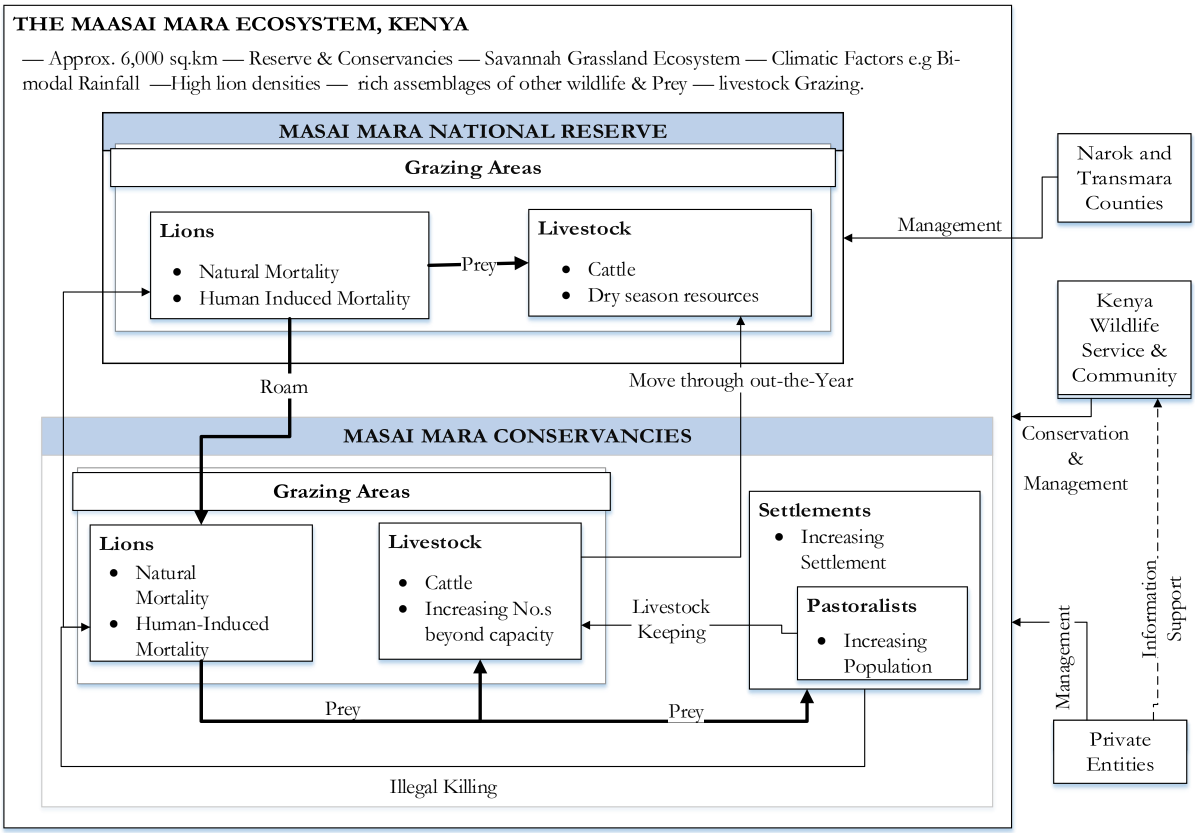
These changes, particularly on vegetation, have been related to habitat loss and modification, decline in wildlife populations and has as a result, influenced the distribution of species. The impacts of these changes on the distribution of species such as the *Panthera leo*, have been under-studied. Very few researchers e.g (Ogutu & Dublin, 2002) and entities (The Mara Lion project and Mara Predator Project) have focused their work on this species in this region, with the Mara Lion Project having just been formed recently in October 2013.

With the continued LULC changes in the Mara, modelling the probabilities of lion presence is vital for the conservation of this species and its habitat. The results of mapping the probabilities of lion-livestock conflict areas will provide key information that will complement the on-going efforts that are aimed at minimizing these conflicts. This study also aims to demonstrate the power of GIS and use of hyper-temporal data from Remote Sensing in achieving this objective.

1.5. Conceptual Diagram

The conceptual diagram in Figure 3 below provides a visual representation of the linkages between the Maasai people, their livestock and lions in the Mara region. The diagram forms the basis from which the hypothesis and research questions were formulated.

Figure 3: Conceptual diagram illustrating the existing relationships between the Maasai people, their livestock and lions in the reserve as well as the surrounding conservancies.



1.6. Research Objectives

1.6.1. Main Objectives

The main objective of this study is to model and map the probabilities of lion – livestock conflict areas (boma and grazing areas) in Maasai Mara. In order to achieve this objective, the following specific objectives were formulated;

1.6.2. Specific Objectives

1. To map vegetation cover types suitable for livestock grazing areas within the study area.

   Q1. Which vegetation cover types are suitable for livestock grazing areas within the study area?

2. To predict lion presence probability in the study area.

   Q3. What is the lion presence probability within the study area?

3. To map lion-livestock conflict probabilities at bomas and at livestock grazing areas.

   Q4. What are the probabilities of lion-livestock conflicts at bomas?

   Q5. What are the probabilities of lion-livestock conflicts at livestock grazing areas?

4. To validate the boma conflict map for Mara North conservancy.

   Q6. Can livestock kill count be used to validate the boma conflict map?

1.7. Research Hypothesis

Hypothesis 1:

1-H_0: The MaxEnt model performance for *Panthera leo* will not perform significantly better than 0.5.

1-H_1: The MaxEnt model for *Panthera leo* will perform significantly better than 0.5

Hypothesis 2:

1-H_0: The lion-livestock conflict probability map is not valid, based on the livestock kill count for one conservancy.

1-H_1: The lion-livestock conflict probability map is a valid, based on the livestock kill count for one conservancy.

1.8. Assumptions

For analysis of lion-livestock conflict probabilities at grazing areas, all grassland areas within the study area were considered. This notion was further supported by results from research conducted in the Mara which revealed that legal and/or illegal livestock grazing is common in the reserve and its surrounding conservancies. The results further states that livestock grazing takes place throughout the year regardless of seasonality, and there are no defined grazing zones (Bilal Butt et al., 2009; Bilal Butt, 2011; Reid et al., 2003).

1.9. Thesis Outline

This thesis is sub-divided into 5 chapters, namely; Introduction, Materials and Methods, Results, Discussion and, conclusion & Recommendations.

Chapter 1: Introduction

This chapter reviews available literature and provides an overview of the global status and conservation of carnivores, with an insight in to the conservation status of the African lion in Kenya. The chapter also provides a detailed description of the behaviour and ecology of the African Lion is provide, and lastly, it looks at the linkages between the African lion, the Maasai community and their livestock. This forms the basis of the main and specific objectives of this study.

Chapter 2: Materials and Methods

This chapter defines the study area, available data and software, provides a brief literature review on methods used and describes the steps taken to analyse the data.

Chapter 3: Results

The output of the analysis conducted in Chapter 2 for all the objectives is provided and explained here using maps, graphs, images and tables.

Chapter 4: Discussion

This chapter provides meaning to the results obtained, by putting them into context. It relates these results to those of similar studies and illustrates on the significance of these findings.

Chapter 5: Conclusion and Recommendations

In this final chapter, conclusions are made from the discussions provided in Chapter 4, and based on these conclusions, recommendations are made on the kind of contribution required from other researchers, and to NGO's for implementation to minimize human-lion conflicts.

2. MATERIALS AND METHODS

In this chapter, I would like to formally acknowledge the contributions made by the 'Masai Mara group' (Jared Buoga, Dennis Ojwang', Benson Maina and I), who worked tirelessly as team to ensure the completion of sections 2.3, 2.4 and 2.5 of this study, under the strong leadership and guidance of Dr. Ir. C.A.J.M. de Bie and Dr. A.G. Toxopeus.

2.1. An Overview of the Study Area

The Maasai Mara region is located in Narok district in the south western part of Kenya (Ottichilo et al., 2000). It consists of Maasai Mara National Reserve (MMNR) which covers 1,530 km2 (Salvatori & Egunyu, 2001), and is managed by the Narok and Transmara county councils (J. O. Ogutu, Owen-Smith, Piepho, & Said, 2011). Surrounding the Mara reserve are privately-owned conservancies of varying extents namely; Enonkishu, Ol-Chorro, Lemek, Mara North, Olare-Motorogi, Naboisho, Ol-Kinyei, Isaaten, Siana, Leleshwa Olarro Conservancies. To the north-east of this region we have the Loita plains, the Siria Escarpment to the west, Serengeti National Park to the south and the Laleta hills to the east (Morgan-davies, 1996) see Figure 4.

Rainfall in the Mara is bi-modal varying from 800-1,200mm per year, whilst the mean monthly temperatures vary from 14.7-30 ^{0}C. The area receives rainfall from the months of February to April, and the rains peak in November. The dry season spans from mid-June to mid-October (Salvatori & Egunyu, 2001).

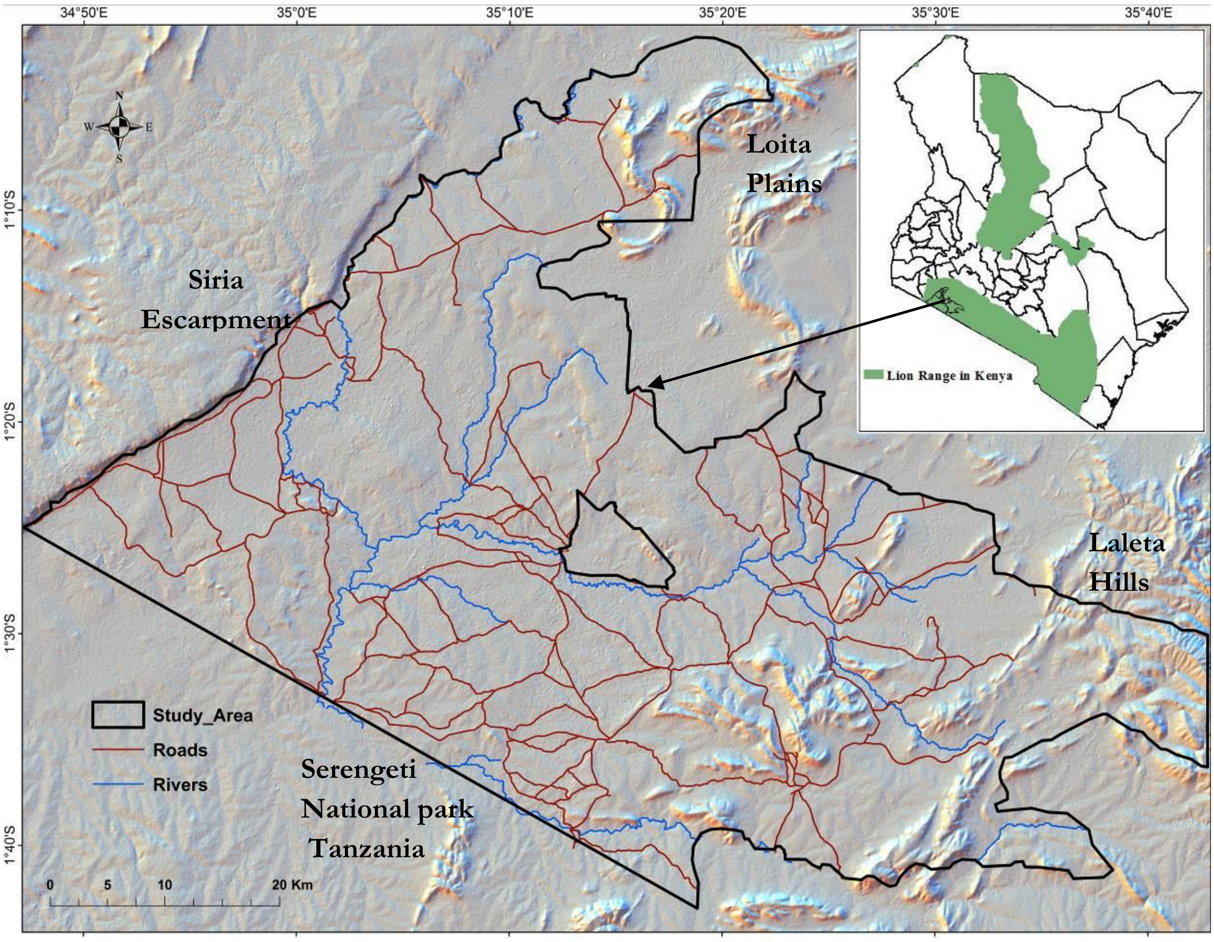
Altitude in MMNR varies, from 1,450 m.a.s.l in the low regions near the Kenya Tanzania border, to a high of 1,950 m.a.s.l at the top of Siria Escarpment to the west, and the Ngama hills to the east of the study area (Oindo, Skidmore, & de Salvo, 2003a).

Grasslands, Shrub-lands, wooded (Acacia) grasslands and riverine forests characterise the Mara region. The rolling grasslands are mainly *Themeda triandra* type which grows on poorly drained black cotton soils. There is scattered bush land which is mainly *Croton sp.* and *Euclea sp*. The riparian forests can be found along the water ways (Oindo et al., 2003a).

The study area is well intersected by many drainage lines and rivers. These water sources include the Mara, Talek and sand rivers which cut across the grasslands (Morgan-davies, 1996). The Mara River is a trans-boundary drainage system which originates from the Mau forest, passes through Mara and Serengeti ecosystems, and empties into Lake Victoria.

The Masai Mara forms the northern part of the greater Mara-Serengeti ecosystem and has one of the richest collections of wildlife. The combination of relatively high rainfall, high productivity of grasslands and the availability of a permanent water source, makes this region to be an important dry season refuge for migratory wildlife and for livestock (Morgan-davies, 1996). Its annual wildebeest migrations make it one of the highest visited reserves in the East African region (Waithaka, 2004).

Figure 4: An overview of the location of the study area as part of the African Lion ranges in Kenya



2.2. Data Description

This study relied on data from both primary and secondary sources. Primary data was collected through field work, whilst secondary data was obtained from various sources. Table 2 below lists and describes all the data used in this study.

Table 2: Description of data utilized in this study to achieve the set objectives listed in section 1.6.

No.	Data	Format	Spatial Resolution	Temporal Resolution	Survey Method	Source
1.	MODIS NDVI	Raster	250 m	Feb 2000 - Nov 2013	-	http://glovis.usgs.gov
2.	Google Earth	Image	-	2014	-	Google Earth
3.	Roads	Vector	-	-	-	Google Earth
4.	Rivers	Vector	-	-	-	WWF

5.	Boma	Vector	-	-	-	Google Earth
6.	Lion Presence Points	Vector	-	1st May – 31st July 2014	Field Observation	Mara Lion Project Report
			-	2010	Aerial Census	DRSRS
7.	Wildlife Count	Vector	5 km	2010	Aerial Census	DRSRS
8.	Livestock Count	Vector	5 km	2010	Aerial Census	DRSRS
9.	Vegetation Survey Data	Vector	-	7th - 31st Oct. 2014	Field Observation	Field Work
10.	Study Area Shape file	Vector	-	-	-	Mara North Conservancy
11.	Livestock Kill Count Data	Vector	-	2013 & 2014	Field Observations	Mara North Conservancy

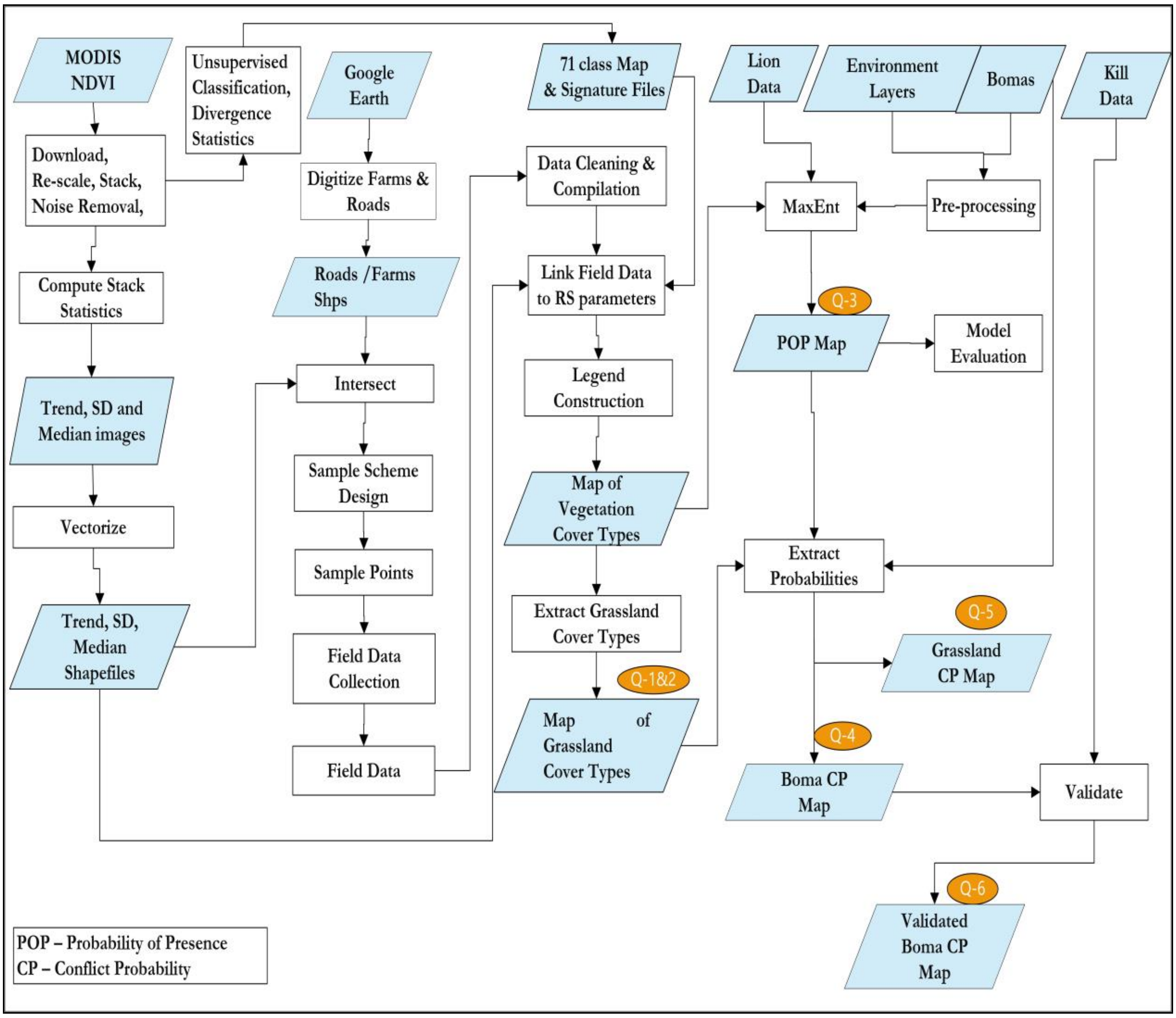
In order to be able to pre-process and analyse data for this research, six software were available. Table 3 provides a list of software used, and their applications.

Table 3: A list and description of software used in this study.

No.	Software	Application
1	Hp Arcpad & GPS	To ease navigation in the field and for field sample point digitization.
2	ArcGIS 10.2.1	Data preparation, analysis and mapping
3	ERDAS IMAGINE 2013	Image processing
4	Microsoft Excel	To generate databases and conduct simple calculations
5	R Statistical Software	Statistical Analysis
6	MaxEnt	Species Distribution Modelling

In order to achieve the set objectives listed under section 1.6, a set of logical steps as shown in Figure 5 below were taken to pre-process and analyse data.

Figure 5: General flow chart showing logical steps taken to analyse data to achieve results for set objectives.



2.3. Field Work Preparation

- **Downloading Images**

In this study, MODIS (Moderate Resolution Imaging Spectroradiometer) satellite imagery was used. The images were obtained from United States Geological Survey website (www.usgs.gov/) and were gridded in Sinusoidal projection, WGS 84 datum and WGS 84 Spheroid. The MODIS satellite has been in operation since the year 2000 to date, and has a swath of 2330 km (cross track) by 10 km along track at nadir (Xie, Sha, & Yu, 2008).

The acquired images were collected by the MODIS Terra sensor at a spatial resolution of 250m. Despite its course spatial resolution, MODIS presented a number of significant advantages that made it highly suitable for this research. MODIS has got 7 spectral bands, which enable it to be highly suitable for land remote sensing (Xie et al., 2008). Out of the seven spectral bands, band 1 and 2 have a spatial resolution of 250m, while bands 3-7 have a spatial resolution of 500m (Wessels et al., 2004). MODIS sensor orbits the earth every 1 or 2 days, meaning the sensor can provide almost daily images of the earth's surface, and thus has got a high temporal frequency. The sensor's high temporal resolution makes it ideal for monitoring vegetation dynamics. The sensor's MOD13Q1 products comprise of 16 day Maximum Value Composite (MVC) imagery, which correspond to the Normalized Difference Vegetation Index (NDVI). NDVI is an index calculated from observed radiances of red and infra-red reflectance measurements using the formula NDVI = (NIR-R) / (NIR+R) (Roderick, Smith, & Cridland, 1996).

In MVC, NDVI values are aggregated temporally or spatially, and pixels are assigned the highest NDVI value for the period and area (Pettorelli et al., 2005). The NDVI image data comprises of the red and the Infra-Red bands, which are the main bands used for deriving the NDVI. NDVI is very sensitive to the amount of green vegetation and is hence related to the chlorophyll /photosynthetic activity. In addition, MODIS imagery products are available for download for free online. Imagery obtained represented the period from 18th February 2000 to 2nd December 2013. Since decadal MODIS imagery span from the 1st to the 16th, a year therefore has 24 dekads (2 dekads per month). Therefore, 317 dekads correspond to the 14 year period.

- **Re-Scaling**

The downloaded hyper-temporal MODIS images were re-scaled from -1 to 1 range of values to the Digital Number (DN) range of 0-255 using the re-scale tool in ERDAS. Re-scaling NDVI values helps to stretch the contrast or information contained in the images, and this helps to facilitate data processing without degrading essential information (Roderick et al., 1996). Additionally, this process helps in getting smaller image files (unsigned 8bit), and thus save disk space. After re-scaling, the images were then stacked and geo-referenced.

- **Noise Reduction**

Satellite images are associated with many sources of errors due to factors such as sensor malfunctions and poor atmospheric conditions. The most common type of noise that characterise satellite images include haze, cloud cover, snow and shadow. All these factors affect analysis as they tend to lower NDVI values. Images can also contain false high NDVI values caused by solar reflection off clouds, although this is less frequent. To reduce many of these errors, satellite images are usually pre-processed to improve their quality before they are made available for download. For instance, the Maximum Value Compositing (MVC) method is applied to NDVI images to reduce noise effect. However, one of the disadvantages of this method is that even after pre-processing, NDVI images might still be contaminated by the above named factors (Pettorelli et al., 2005). More cleaning therefore needs to be done before these images can be used.

For this study, the Savitsky Golay Filter was used to develop an upper envelop filter to smoothen, clean and re-construct the NDVI time series by minimizing effect of clouds and outliers. The filter cleans the temporal NDVI values on a pixel by pixel basis to remove relatively low and relatively high NDVI values, from the hyper-temporal NDVI stack (Bie & Gallego, 2012). This filter was chosen because its application in so many previous studies has been successful.

- **Unsupervised Classification**

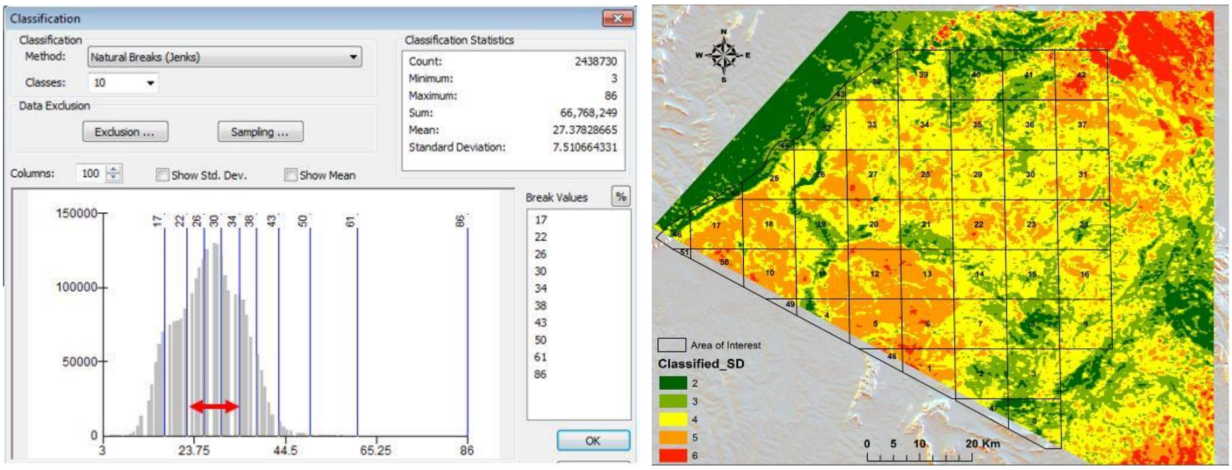
An unsupervised classification was performed on the image stack using ISODATA clustering algorithm in Erdas Imagine software. In an unsupervised classification, no additional data or expert's knowledge is used to influence classification outcome. ISODATA clustering algorithm is an unsupervised method of clustering that uses the minimum spectral distance method to form clusters (ERDAS, 2003). The classification was started at 10 to 100 classes. The maximum number of iteration was set at 50, which is the general rule for setting iterations to half number of classes. To prevent the classification stopping before 50 iterations or from running indefinitely, the convergence threshold was set at 1. For each ISODATA run, the signature file was evaluated for the divergence distance measures. The minimum and average statistics from the signature files were exported to excel to compare seperability between classes and to find optimum number of classes. The best number of classes were chosen based on a clear and distinct peak of the highest positive deviation from the trend in average and minimum divergence statistics and indicated the optimal number of classes that can be obtained from the time series (Nguyen, De Bie, Ali, Smaling, & Chu, 2012). For this study the optimal choice was 71 classes. Classes derived from a MODIS unsupervised classification were used as the strata for the random selection of field sampling sites. Stratification ensures representation of the full variation of all possible vegetation types across the study area. The total number of classes and samples selected depended on vegetation variability, extent of study area, time available for field work and accessibility of sample areas.

- **Computing NDVI Median, Standard Deviation and Trend**

The use of NDVI provided insight as to the distribution of green vegetation cover. Calculation of NDVI median and standard deviation was performed using the model builder tool in ERDAS Imagine. Here, under the function definition tool, the stack statistics option was used to select and compute the NDVI Standard Deviation and the NDVI Median from the stack of MODIS images. The outputs of this process were two raster images, one containing the standard deviation (see Figure 6) and the other the median (see Figure 7) of each pixel over the 14 year period.

The NDVI standard deviation image illustrates the heterogeneity of vegetation cover across the study area. The natural breaks (jenks) classification method was used to divide the SD image histogram into 10 classes. These classes were counter checked on Google Earth imagery and re-classified into classes 2, 3,4,5,6.

Figure 6: NDVI Standard Deviation map generated using Erdas Imagine software from MODIS Time Series data



The median NDVI image was selected as a representative NDVI image stack. The standard deviation classification method was used to generate 21 classes from the image histogram, and counter checks with Google Earth imagery led to re-classification of these classes to class 10 – 18.

Figure 7: NDVI Median map generated using Erdas Imagine software from Modis Time Series data

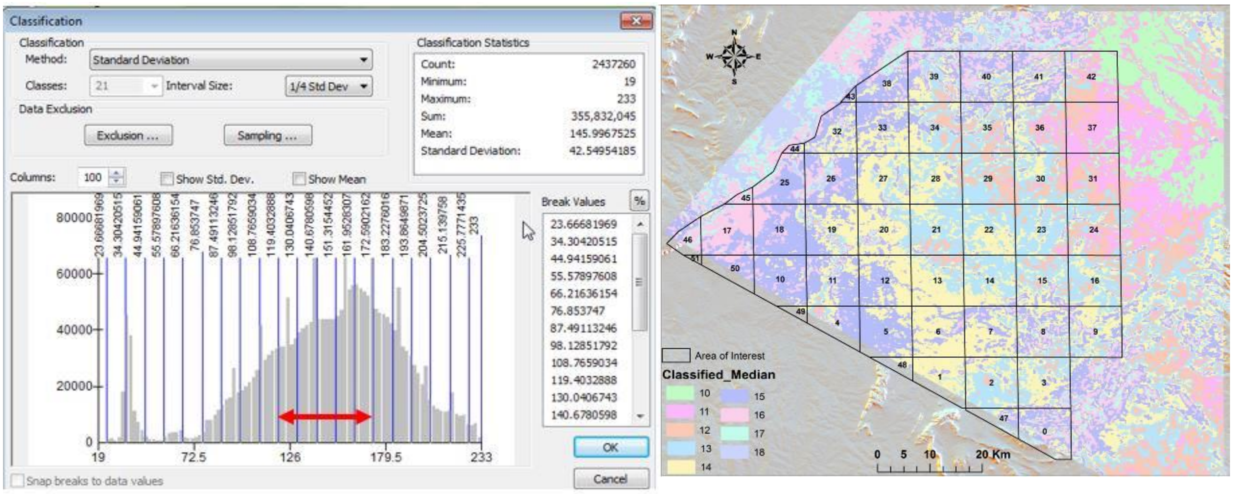
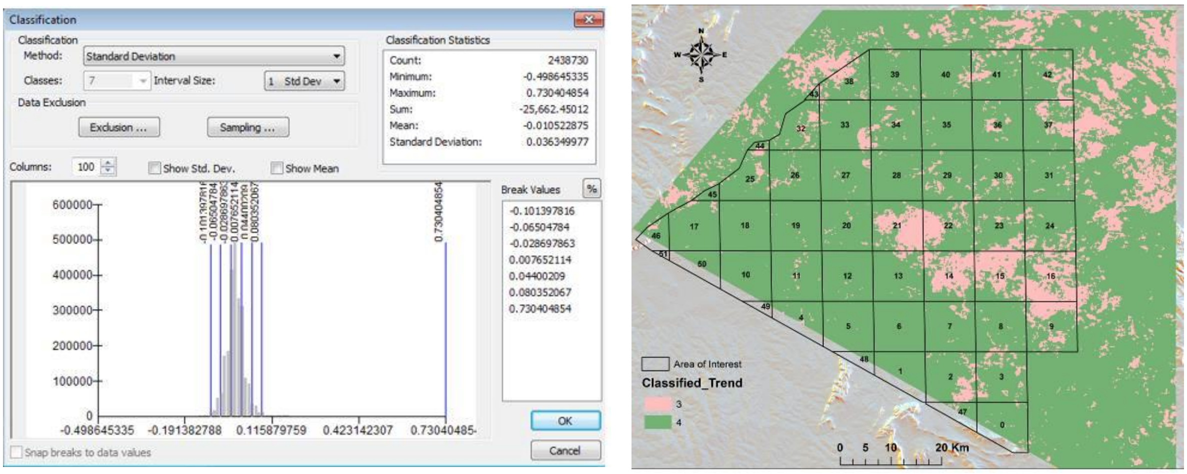


Figure 8 was used to differentiate areas experiencing NDVI trend versus areas with no trend. This was done in ENVI Integrated Data Language (IDL) to provide users with options of input, output specifications and the choice of producing change and trend maps. The program computes mean values by polygon using historical time series data set. It then establishes a range of pooled standard deviation around NDVI values. In this case, the change probability was summed and values falling below the range of pooled standard deviation were considered to be degraded rangeland whiles values falling above the range of pooled standard deviation were considered to be stable rangeland. The standard deviation classification method was used to classify the map's histogram into 7 classes, and for simple interpretation of trend/no trend, the histogram was re-classified to two classes (3 and 4).

Figure 8: NDVI Trend map generated using ENVI IDL from Modis Time Series data



- **Designing a Field Sampling Scheme**

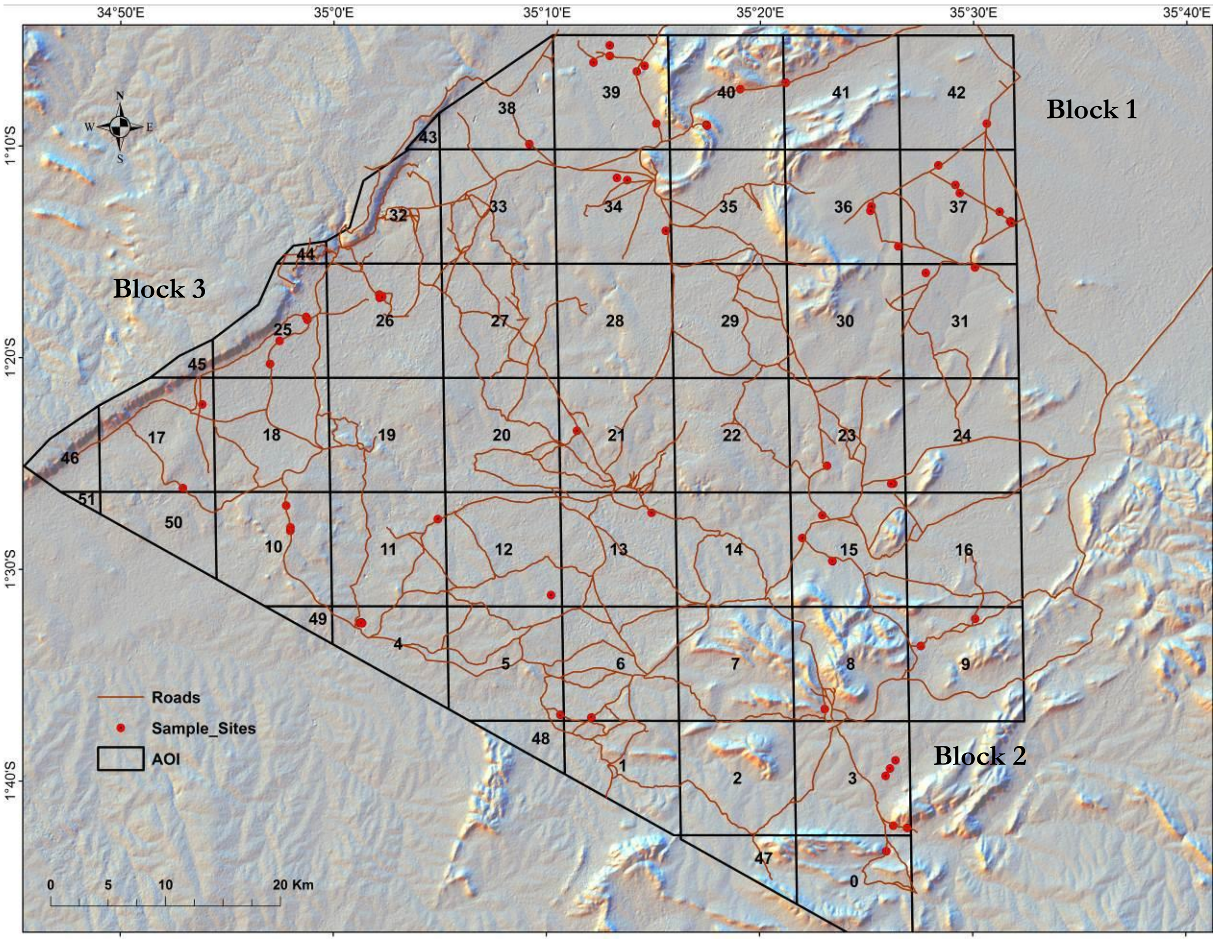
In this study, Stratified Random Sampling approach was used to conduct vegetation survey. Agricultural farms and roads were digitized from Google Earth imagery. Agricultural farms and the ridge on the western boundary of the study area were excluded from areas to be sampled. The roads shape file was intersected with the Median, Trend and SD maps. For accessibility and safety purposes a buffer of 500m from the roads was created, in which all areas to be sampled were to be located. 6000 polygons were generated based on variability of the Standard Deviation map. Polygons of less than 20 hectares were excluded. Small polygons of the same classes located near each other were merged using the single part procedure. Random selection was performed, resulting in 50 final sample points. The Google earth imagery also helped to provide an overview of how the study area looked like as well as to provide labels for the classified images.

Materials and equipment needed for field work were also prepared. First, relevant maps were produced for easy navigation on the ground and identification of vegetation sample sites. This was followed by designing of questionnaires required for conducting interviews. A field work plan was afterwards drawn, indicating when and where data was to be collected. Field work equipment (IPAQ, hand held GPS, Digital Camera, Binoculars and releve` sheets) were obtained, and the IPAQ tested for accuracy. Lastly, literature review related to the study topic and area was undertaken.

2.4. Field Data Collection

Field work was carried out from the 7th October to 31st October, 2014 in Masai Mara, Kenya. Figure 9 shows the location of all sample sites visited during field work.

Figure 9: Location of field sample points in Masai Mara. The AOI represents the area of interest divided into equal area squares labelled with numbers.



The study area was first divided into three blocks. Block one was area around Narok town, block two was area around Sekenani, which is located on the Eastern section of MMNR, while block three was area surrounding Aitong, on the Western part of MMNR.

The first few days were spent visiting sample sites near Narok town, to test the releve` sheets, after which the forms were rectified, before continuing with field data collection of other sample sites in the study area. At each sample site, one plot per polygon was sampled if the vegetation cover was rendered to be homogenous. More than one plot was taken for polygons consisting of complex and heterogeneous vegetation cover, to ensure proper polygon representation.

Information collected at each plot include broad vegetation structure, floristic information (height of strata, %cover, and dominant species), presence/absence of lions, livestock and settlements, Site ID, Sample plot Code, GPS Coordinates, plot images, altitude, and topography. % canopy cover of vegetation was decided based on visual assessments, expert judgment and consensus amongst team members. All photos and GPS Coordinates were downloaded regularly and stored into the computer system, and a back-up of the same made on a hard drive. Figure 10 shows images of lions, settlements, livestock and people observed during field work.

Figure 10: The images below illustrate the presence of humans, livestock, lion and other wildlife, as observed during field survey in the Mara.

(A) Fencing and settlement presence (B) Maasai grazing livestock in wildlife area

(C) Lion feasting on a recently killed cow.

2.5. Field Data Compilation

All data collected using IPAQ and GPS was downloaded and saved into a folder. This data, together with data collected using releve` sheets, was entered into an excel spreadsheet to form one database for easy manipulation. Sample site photos were also downloaded and saved in a separate folder. GPS Coordinates and dates of sample site photos provided a linkage to the data entered into the excel database. The data was reviewed to check for completeness and typographic errors. It was also cleaned to remove duplicate, incomplete and erroneous entries. Metadata relating to description of vegetation type, codes used, date of database creation, species cover and database reviewers was also created in the database.

2.6. Mapping Areas suitable for livestock grazing

2.6.1. Introduction

There are numerous methods used for classifying satellite imagery. Selection of satellite imagery classification method is influenced by factors such as data sources. Studies which consider use of training samples, mainly use the supervised and unsupervised classification approaches. Under the supervised approach, the analyst influences the classification process, as he uses samples to train the classifier on how to classify spectral data into a thematic output map. As for unsupervised approach, clustering algorithms divide the image into a number of spectral classes, and this process is not influenced in any way by the analyst. The success of satellite image classification can be influenced by factors such as landscape complexity of the study area, selected satellite imagery as well as classification approach used. Different remote sensed data vary in relation to their spatial, temporal and spectral characteristics. One way of improving classification accuracy is to make full use of satellite data feature characteristics such as spatial, spectral, radiometric or temporal features (Lu & Weng, 2007).

2.6.2. Satellite Image Classification Using Hyper-Temporal NDVI

The behaviour of vegetation across time is an important aspect for successful classification of satellite imagery (Reed et al., 1994). Vegetation conditions are best mapped using vegetation indices and in particular NDVI (Teillet, Staenz, & Williams, 1997). NDVI Time series is regarded as an excellent spectral indicator of vegetation activity and phenological characteristics. It is a powerful phenology based method to carry out vegetation cover classification (Wardlow, Egbert, & Kastens, 2007). One of the most popular methods for classifying composites of NDVI time series data is through unsupervised classification (Geerken, Zaitchik, & Evans, 2005).

Different types of vegetation vary in terms of phenological and growth characteristics, and therefore using remotely sensed time series data helps in correctly classifying them based on spectral variables. Pixels that demonstrate similar characteristics of NDVI time series are considered to belong to the same vegetation cover type (Song, Chen, Wan, & Shen, 2008). The use of MODIS NDVI products for classification of vegetation types has been widely used over the recent years as they have a high spectral resolution, are freely downloadable, are of high quality and in addition, they have a high temporal resolution (Yan, Wang, Lin, Xia, & Sun, 2015).

The high temporal resolution of MODIS images provide good opportunities for capturing high quality images. The use of multi/hyper-temporal images allows for a better classification accuracy as compared to using a single data imagery (Jia et al., 2014).

As an indicator of green biomass, NDVI is based on vegetation spectral properties, and has been used to assess ecological responses to environmental changes. It is these changes which ultimately affect the distribution and dynamics of vegetation, and inform about habitat degradation (Pettorelli et al., 2005). These dynamics in vegetation are especially experienced in savannahs, as these ecosystems are highly influenced by climatic factors such as rainfall, which is extremely variable over time. This variability affects the growth and distribution of plant communities across landscapes (Ogutu, Piepho, Dublin, Bhola, & Reid, 2007). This is the case in East Africa. In this region, rainfall is bimodal and varies inter-annually. It is less predictable, and is subject to great fluctuations. There is successive occurrence of poor and erratic rains and the interval between drought periods is becoming shorter and shorter. The combination of low rainfall and high temperatures result in high evapotranspiration rates, which exceed precipitation (Clinic & Hospital, 1997; Newman et al., 2006). The result is vegetation that is highly heterogeneous, both in structure and in productivity. Most savannahs are rangelands which are mainly characterised by natural and semi-natural vegetation, which is a source of forage for wild ungulates as well as pastoral grazing lands for domesticated animals (Homewood, 2004). Apart from climatic factors, savannah rangelands are also affected by human perturbations such as loss of wildlife habitat, degradation, increased expansion of human settlements, cultivation, and overgrazing, all of which shape the structure and diversity of the savannah vegetation (Vuorio, Muchiru, Reid, & Ogutu, 2014).

Stacks of NDVI values are too rich in information. One way of exploring this data is through the use of NDVI stack statistics. For instance, computing NDVI Standard deviation is extremely helpful in capturing vegetation heterogeneity/variability (Walker et al., 1992). In image classification, pixels with a high standard deviation within a geographic area would likely contain high temporal dynamics at the location (Begon et al., 1990). Also, the use of median NDVI measurements considerably helps to provide suitable annual representative image-stacks, and is a baseline of more stable NDVI estimations of the study area (Bie & Gallego, 2012; Terehov, Muratova, Arkhipkin, & Spivak, 2000).

2.6.3. Linking Field Data to RS Parameters

The cleaned database was imported into ArcMap and displayed as a point shape-file. Class values from the Median, trend, Standard deviation and the 71 class maps were extracted to this point shape-file. The resultant attribute table of this point shape-file was exported and saved as dbf, and later opened using excel to be used to construct a legend.

2.6.4. Legend Construction and Map Interpretation

In excel, weighted averages were computed for all cover characteristics of sub-samples taken in same locations to form representative sample site information. The weighted database was then sorted based on the 71 classes, and percentages of vegetation cover types were averaged for each class. This average percentage summary of the vegetation cover represented our legend, which described the 71 class image in terms of vegetation cover observed on the ground.

2.7. Species Distribution Modelling

2.7.1. Introduction

For efficient management and conservation of wildlife species and their habitats, maps of actual or potential species distribution are vital. These maps utilize methods which combine biological or environmental information with statistical tools (Franklin, 2009). One such method is the Species Distribution Models (SDMs). SDMs relate species occurrence to environmental factors at given sites, to provide insight as to the distribution of species either on land, in water or in the atmosphere. Examples of such models include Boosted Regression Trees (BRT), Generalized Linear Models (GLM), Generalized Additive Models (GAM), Genetic Algorithm for Ruleset Prediction (GARP), Random Forests (RF) and MaxEnt. These models differ in terms of their predictive performance and how they work. GLM, GAM, BRT, RF require both presence and absence species occurrence data. However, most of the species data available consist of presence only data sets, and so require use of methods such as GARP and MaxEnt, which use presence only data (Elith & Graham, 2009). Sérgio, Figueira, Draper, Menezes, & Sousa, (2007) conducted research using observation points from herbarium collection data to compare performance of these two methods and found that MaxEnt outperformed GARP.

2.7.2. Maximum Entropy

Modelling species distributions with Maximum Entropy (MaxEnt) offers several advantages. It is a very user-friendly statistical software which computes probability of species distributions from incomplete information (Baldwin, 2009). Since species biological survey data of both presence and absence tend to be sparse, MaxEnt helps to model species distribution using only presence data. (Merow, Smith, & Silander, 2013). It is less sensitive the number of species occurrence locations required to run a useful model. In some instances only five locations have been used to develop a useful model. However, it is recommended that >30 presence locations be used to run a model (Baldwin, 2009).

MaxEnt has a superior predictive accuracy which is highly comparable to other high performing models (Phillips, Anderson, & Schapire, 2006). The model algorithm utilizes both continuous and categorical data and takes into account inter-variable relationships. It is insensitive to spatial errors associated with species locational data. The program contrasts species occurrence against its background locations where occurrence/absence is unmeasured. By generating these pseudo-absences, the software is able to predict in terms of probabilities, locations of species occurrence (Baldwin, 2009).

The performance of MaxEnt model depends on the tuning of model parameters. Phillips & Dudı (2008), recommend the use of MaxEnt default settings, which have been tuned and validated on a wide range of data sets. Their findings indicate that the program's default settings produce models whose performance are almost as good as if the settings had been tuned to the data itself.

MaxEnt offers two ways of assessing the significance of variables being used. The first is a table indicating percent contribution of each variable to the final model, and this contribution is illustrated by increase in gain in the model, provided by each variable. The second method is through the use of Jack-Knife feature. This feature excludes one variable at a time when running the model, to provide information on the importance of each variable in explaining the distribution of species, and how much unique information is provided by each variable (Baldwin, 2009).

As an exponential model, MaxEnt allows the creation of response curves, which illustrate the effect of predictor variables on species probability of occurrence. Response curves greatly facilitate the interpretation of a species ecological niche and its defining or limiting environmental factors (Jiang et al., 2014). Upward trends for variables indicate a positive association, downward movements represent a negative relationship. The magnitude of these movements indicates the strength of these relationships. MaxEnt model outputs are provided in three formats; logistic, raw and cumulative formats. Of these three formats, the logistic format is highly recommended as the outputs allow for easy and more accurate interpretations. The logistic format provides estimates of species probability of occurrence and these estimates range between 0-1(Baldwin, 2009).

To determine the relevance of MaxEnt models, fit for accuracy can be conducted in two ways; through receiver operating characteristic (ROC) plots and by defining thresholds. ROC plots are plots of sensitivity (how well the data correctly predicts presence) and 1-specificity (a measure of correctly predicted absences). For evaluation, MaxEnt splits data into two sets; the training set and the test set. The test set is used to evaluate model performance. A good model is defined by a curve that maximizes sensitivity for low values of the false-positive fraction. The significance of this curve us quantified by the area under the curve (AUC)(Baldwin, 2009). Numerous published studies have shown the utilization of MaxEnt in a wide range of applications such as to predict the distribution of animal species, invasive species, forecast species distributions in relation to climate change, as well as test model performance against other method outputs (Elith et al., 2011)

2.7.3. Environmental Variables

The selection of environmental variables was based on two considerations; (a) The availability of data and, (b) Factors which influence the presence and/or absence of lions. Six environmental predictors as described in Table 4, were considered for running MaxEnt model. The variables were selected based on expert knowledge and documented literature.

The wildlife density layer contained total counts of several species which include; Buffalo, Giraffe, Zebra, Elephant, Wildebeest, Thomson Gazelle, Impala, Waterbuck, Ostrich, Eland, Grants Gazelle, Kongoni. The livestock density layer on the other hand consisted of sheep, goats, cows, donkeys and camels.

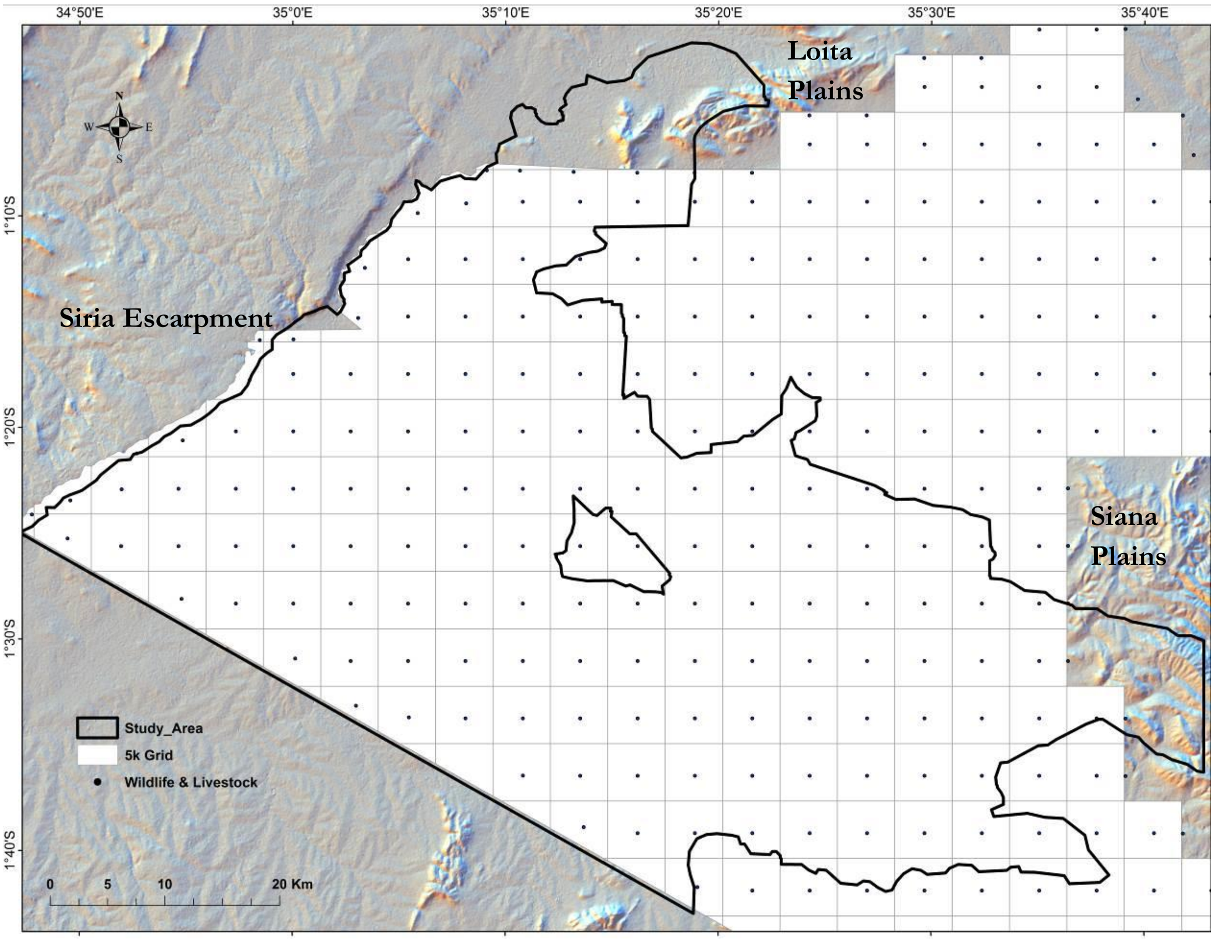
Table 4: Description of environmental variables considered for running MaxEnt model for the prediction of lion presence in the study area.

No	Full Names	Data Type	Resolution	Format	Ranges
1.	Distance to Rivers	Continuous	500m	ASC	0 - 23162.5 m
2.	Vegetation Cover Types	Categorical	500m	ASC	1 -7 classes
3.	Distance to Bomas	Continuous	500m	ASC	0 – 36003.5m
4.	Distance to Roads	Continuous	500m	ASC	0 - 18607.8 m
5.	Wildlife Density	Continuous	500m	ASC	0 – 504 (Numbers)
6.	Livestock Density	Continuous	500m	ASC	0 – 189 (Numbers)

The wildlife and livestock density data was obtained from DRSRS, who collect their data through aerial censuses. The method for collecting animal census information through aerial surveys is well documented and data obtained using this method has been proven to be reliable (Bhola, Ogutu, Said, et al., 2012; Bhola, Ogutu, Piepho, et al., 2012; Oindo et al., 2003b). Figure 11 illustrates the gridded wildlife census data obtained from DRSRS.

These environmental layers were pre-processed in ArcGIS. The Euclidean distance tool was used to create distance to roads, distance to rivers and distance to boma maps, and later rasterized. The kernel density tool was used to generate wildlife and livestock density maps. All the layers were then resampled to 500m resolution, masked to the extent of the study area, projected to WGS1984 UTM Zone 36S and converted to ASCII files for use in MaxEnt.

Figure 11: 5x5 km Grid of Wildlife/Livestock Census data collected through aerial census by the Department of Remote Sensing and Resource Survey (DRSRS) in Kenya.



2.7.4. Species occurrence data

Seventy nine presence points were obtained from DRSRS and 113 points were digitized from the lion distribution map in the Mara Lion Project May – July 2014 quarterly report. The Root Mean Square Error (RMSE) of the digitization exercise was calculated in ArcGIS. The RMS error refers to the difference between the desired output coordinate for a ground control point and the actual coordinates on the ground and is used to determine the accuracy of coordinate transformation. The error is measured in pixels and the rule of thumb is that the RMSE should be less than one pixel (Moses & Devadas, M, 2012). In this case, the RMSE was 235m, which is less than the environmental predictors' cell size of 500m. In total, this study made use of 192 lion presence points, which were saved in a .csv format, as required by MaxEnt.

2.7.5. Building MaxEnt Model

Before running the model, minor modifications were made to MaxEnt's default settings. The number of replicates was set to 10, and the background predictions option was checked to enable for calculation of TSS and Kappa statistics in R software. Table 5 below provides a description of all settings used in MaxEnt.

Table 5: A list of the regularization parameter settings used in running MaxEnt model

1.	Convergence Threshold	0.00001
2.	Replicates	10
3.	Random Test Percentage	30
4.	Regularization multiplier	1
5.	Maximum iterations	500
6.	Output format	Logistic
7.	Maximum number of background points	10000
8.	Make Background Predictions	Yes

2.7.6. Evaluating Model Performance and Accuracy

The Area under the ROC Curve (AUC) was used to evaluate model performance. To assess the significance of each variable and its contribution to the prediction of lion presence, the Jack-knife test was conducted. The option of response curve generation were selected to provide insight as to how each environmental variable affects the prediction of the model. The accuracy of the model was assessed using Kappa and TSS statistics in R software.

2.8. Mapping Probabilities of Lion-Livestock Conflict Areas

The lion presence probability map generated from MaxEnt was masked using the grassland cover types map to generate an output of areas of overlap between lion habitats and livestock grazing areas. These areas of overlap represented areas of lion-livestock conflicts.

The boma point shape file was overlaid on top of the lion presence probability map and the probability values were extracted to these points. The boma conflict probability values were then classified into five classes to show variation in conflict probabilities.

2.9. Validating the Boma Conflict Map

To validate the boma conflict map, livestock kill count data was used. This data was only available for one conservancy i.e Mara North conservancy. Mara North conservancy is one of the conservancies found in the Masai Mara, and borders the Masai Mara National Reserve on the north-western section. The conservancy was established in 2009 and it covers an area of 74,000 acres (MNC, 2015).

The database contained livestock kill data for 2013 and 2014. The databases were mMODELLING AND MAPPING THE PROBABILITIES OF LION-LIVESTOCK CONFLICT AREAS. A CASE STUDY OF MASAI MARA, KENYA erged, cleaned, exported into ArcGIS and displayed as a point shapefile. Values were then extracted from the lion presence probability map to these points and the resultant attribute table exported and saved in excel. A frequency table was then created to show the number of bomas per probability value range.

3. RESULTS

In this chapter, the results from the data analysis steps conducted in Chapter 2, are presented and discussed in accordance with the study objectives outlined in Chapter 1. Firstly, the results relating to the first objective of mapping areas suitable for livestock grazing within the study area are presented under Section 3.1. This section illustrates the outputs of the field data compilation process, the database linked to RS parameters, the constructed legend and the final output map. This is followed by section 3.2 which highlights the outputs generated from the MaxEnt modelling exercise, in relation to the second objective of predicting lion presence probabilities. The results of which are; lion presence probability map, jackknife test results, response curves and model performance. Thirdly, section 3.3 presents the mapping results of lion-livestock conflict probabilities at bomas and at livestock grazing areas. These outputs are linked to the third objective of this study. Finally, section 3.4 indicates the results of validating the boma conflict map for Mara North Conservancy.

3.1. Mapping Areas Suitable for Livestock Grazing

3.1.1. Field Data Compilation

Table 6 illustrates a section of the database which contained the compiled raw data from the field. It shows the kind of information collected during the field vegetation survey. Eight different types of cover percentages were recorded at different sample site locations.

Table 6: Section of database containing raw information collected during the vegetation field survey in the Mara.

X	Y	SN	SC	T	HS	LS	H	G	L	B	S	Cx	DT
35.48584	-1.19685	s-10a	37/10/1	0	1	0	0	40	0	89	0	15	10/10/2014
35.48584	-1.19685	s-10b	37/10/2	0	20	0	0	15	0	15	0	85	10/10/2014
35.48924	-1.20322	s-11	37/11	0	5	0	0	10	0	30	0	100	10/10/2014
35.022418	-1.54213	s-13a	45/2	40	40	0	0	45	0	40	0	40	10/10/2014
35.022418	-1.54213	s-13b	45/2	0	2	0	0	0	0	65	0	60	10/10/2014
35.25202	-1.14869	s-14	39/14	0	0.5	0	0	25	0	65	0	100	10/10/2014
35.24857	-1.45501	s-15a	15/2	0	0	0	0	52	0	30	0	70	10/10/2014
35.36636	-1.47478	s-16	15/16	0	0	0	0	10	0	50	0	100	10/09/2014
35.22935	-1.19332	s-17	34/17	0.5	0	0	0	65	0	30	0	100	10/09/2014
35.47245	-1.18142	s-18a	37/18/2	2	15	0	0	65	1	20	0	80	10/09/2014
35.47245	-1.18142	s-18b	37/18/1	0.5	5	0	0	15	0	0	0	20	10/09/2014
35.42026	-1.21373	s-1a	36/1/2	0	3	1	0	75	0	85	0	30	10/09/2014
35.42026	-1.21373	s-1b	36/1/3	0	0	5	0	10	0	50	0	60	10/12/2014

X- X-Coordinate **Y-** Y-Coordinate **SN** - Sample Number **SC** – Sample Code **T**- Tree % Cover
HS - High Shrubs **LS** – Low Shrubs **H**-Herbs **G**-Grass **L**- Litter
B - Bare **S** - Stony **Cx_** Complex **DT** - Date

Sites that were deemed to be homogenous were represented by single entries, while sites that were part of complex units were represented by multiple entries. Multiple entries of same sample sites had similar x-y coordinates. Their sample numbers were denoted by letters a, b and/or c. In total, the database had 77 entries.

3.1.2. Linking Field Data to RS Parameters

Table 7 shows a section of the database containing field data that have been linked to RS parameters. There were seven classes from the 71 class image that characterised the field data. The median values ranged from a low of 10 to a high of 18, while the least SD value was 2 and the highest was 6. The trend values for each site was either 3 or 4. Every row characterized a single sample site that was representative of a single pixel. The database had 53 entries in total.

Table 7: A section of database containing % vegetation cover linked to Remote sensing parameters (Median, SD, and Trend).

71_Class	Median	SD	Trend	Tree	HS	LS	Herbs	Grass	Litter	Bare	Stony
18	10	5	3	1	4	1	0	27	0	71	0
18	10	3	4	0	1	3	0	30	0	67	0
25	11	2	4	8	10	0	0	27	0	73	0
25	11	3	4	0	25	8	0	27	0	65	0
35	14	2	4	1	25	0	0	21	6	70	3
35	13	3	3	1	21	4	0	21	0	63	12
35	13	4	3	0	0	0	0	41	0	59	0
39	15	2	4	0	50	0	0	21	0	75	4
39	14	3	4	1	20	0	6	31	0	63	0
39	14	3	3	8	17	2	0	42	0	56	0
39	13	5	3	1	2	0	0	55	0	45	0
48	14	6	4	0	0	3	0	57	35	5	0
48	15	4	3	0	1	0	0	70.4	29.6	0	0
57	18	2	4	48	27	20	0	48	8	15	0

SD – Standard Deviation **HS** – High Shrubs **LS** – Low Shrubs

3.1.3. Legend Construction and Map Interpretation

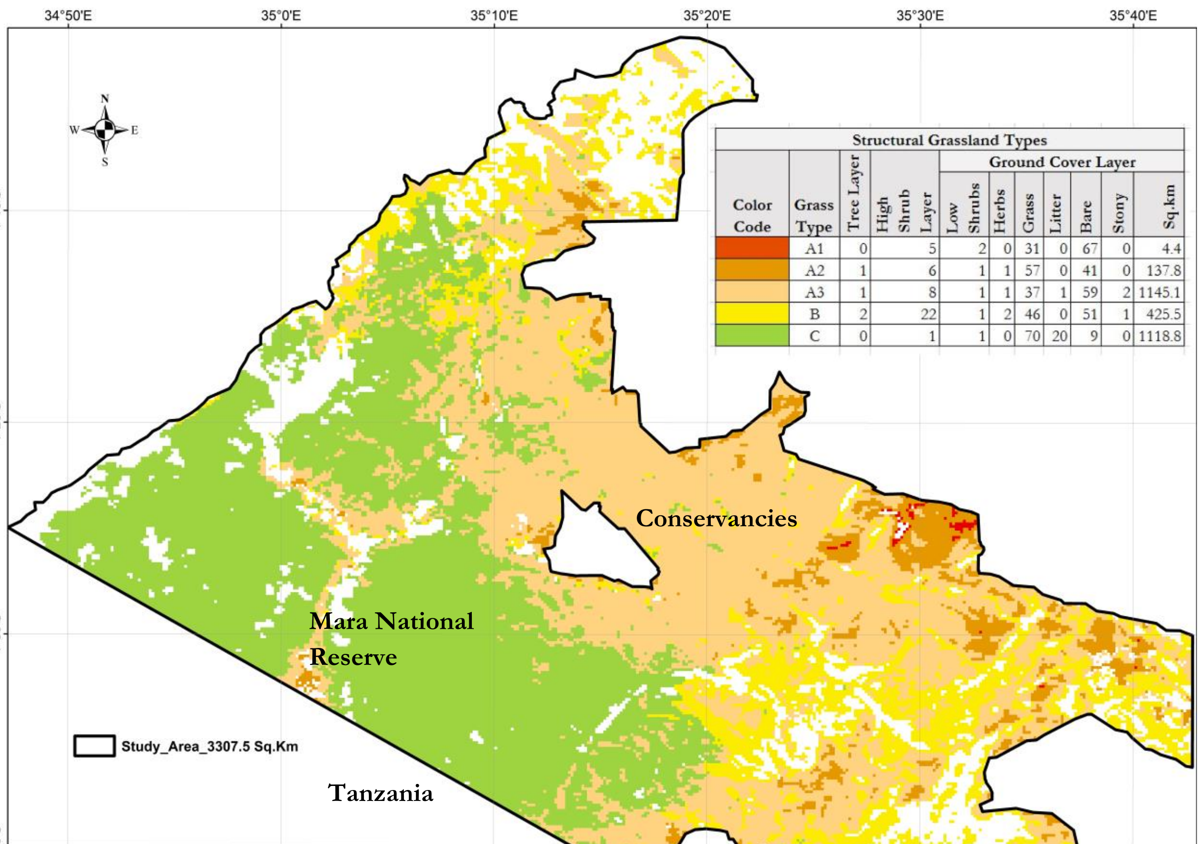
Table 8 below is the legend created to describe % canopy cover of vegetation within the study area. The percentages represented below are the average % of vegetation cover per class. Each class was characterized by its own unique combination of median and SD values. Class 52 and 57 represented trees and high shrub layers. Classes 18, 25, 35, 39 and 48 represented grassland cover types. Class 48 was easily differentiated as it had the highest % grass cover i.e 70%. Class 39 could also be differentiated from 18, 25 and 35, as it had significant amount of high shrub layer.

Table 8: A legend describing the average % of structural vegetation cover in the study area.

Average % of Structural Vegetation Cover											
						Ground Cover Layer					
71 - Class	Median	SD	Trend	Tree Layer	High Shrub Layer	Low Shrubs	Herbs	Grass	Litter	Bare	Stony
18	10	3,4,5	3,4	0	5	2	0	31	0	67	0
25	11,12	2,3,4,5	3,4	1	6	1	1	57	0	41	0
35	12,13,14	2,3,4,5	3,4	1	8	1	1	37	1	59	2
39	13,14,15	2,3,4,5	3,4	2	22	1	2	46	0	51	1
48	12,14,15,16	3,4,5,6	3,4	0	1	1	0	70	20	9	0
52	15,16,17	2,3,4	4	4	46	0	4	27	15	53	2
57	17,18	2,3	4	25	61	10	0	24	22	32	6

Figure 12 below is a map of grassland cover types found within the study area. These grassland cover types were represented by classes 18 (A1), 25 (A2), 35 (A3), 39 (B) and 48 (C). Cover type A3 and C were the most dominant cover types. Out of the 3307.5 sq.km, grasslands covered 2831.7 sq.km, which is 85.6% of the study area, indicating that grassland is the dominant vegetation cover type.

Figure 12: A map of the grassland cover types found within the study area.

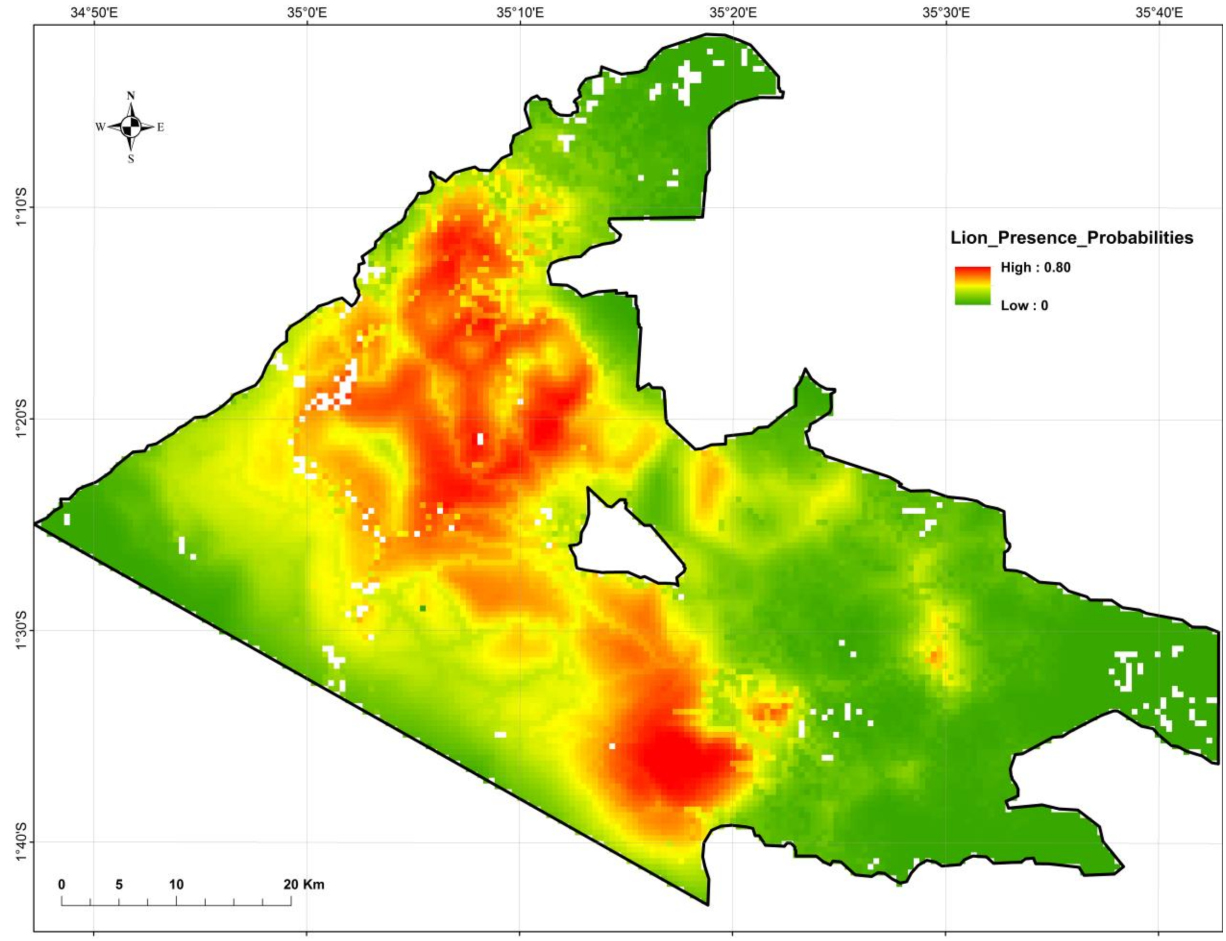


3.2. Species Distribution Modelling

3.2.1. Lion Presence Probability Map

Figure 13 shows lion probability of presence map generated by MaxEnt model. The predictive map had probability values ranging from 0.0 – 0.8, indicating different levels habitat suitability and hence different lion presence probabilities. Warmer colours i.e red and orange, represented areas with better predictions and signified suitable habitat conditions. Yellowish areas were of moderate predictions and represented habitats of moderate suitability. Greenish areas were area of low predictions and represented unsuitable lion habitats.

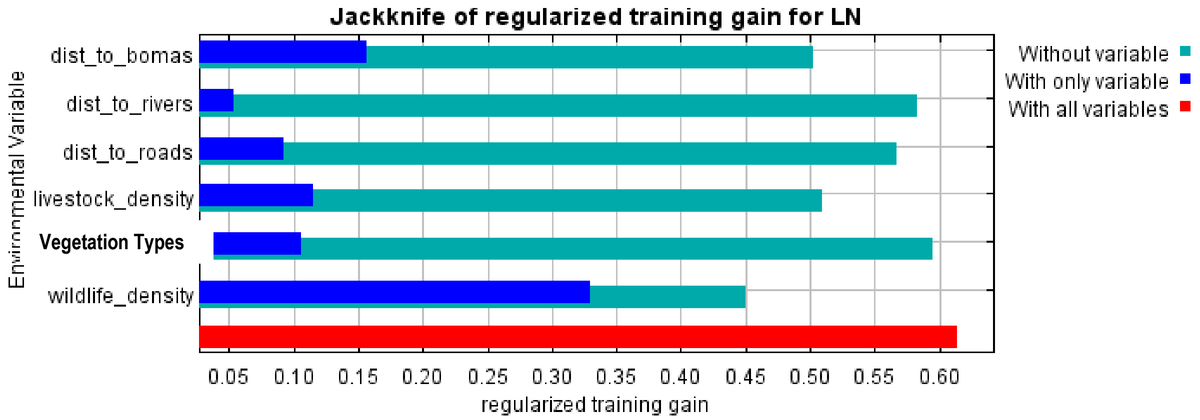
Figure 13: A map of the lion Presence Probabilities, as generated by the MaxEnt model



3.2.2. Jackknife Test

Figure 14 shows the Jackknife test results of the six environmental variables fed in to the MaxEnt model. The Jacknife test results show the training gain when the model is run with and without each variable. This test helps to identify variables which have significant contribution to the model. In this case, wildlife density is the variable with the highest gain when used in isolation. This indicates that it is the variable which appears to have the most useful information by itself. It is also the variable the gain the most when excluded from the model. This means that it is the variable that holds a lot of information that cannot be found in any other variable. The second most important variable for model when used in isolation is distance to bomas. The model has no significant decrease in the overall training gain when distance to rivers, distance to roads and NDVI class variables are excluded from the model.

Figure 14: Jackknife of Regularized Training Gain for Lion Species, based on the six environmental variables.



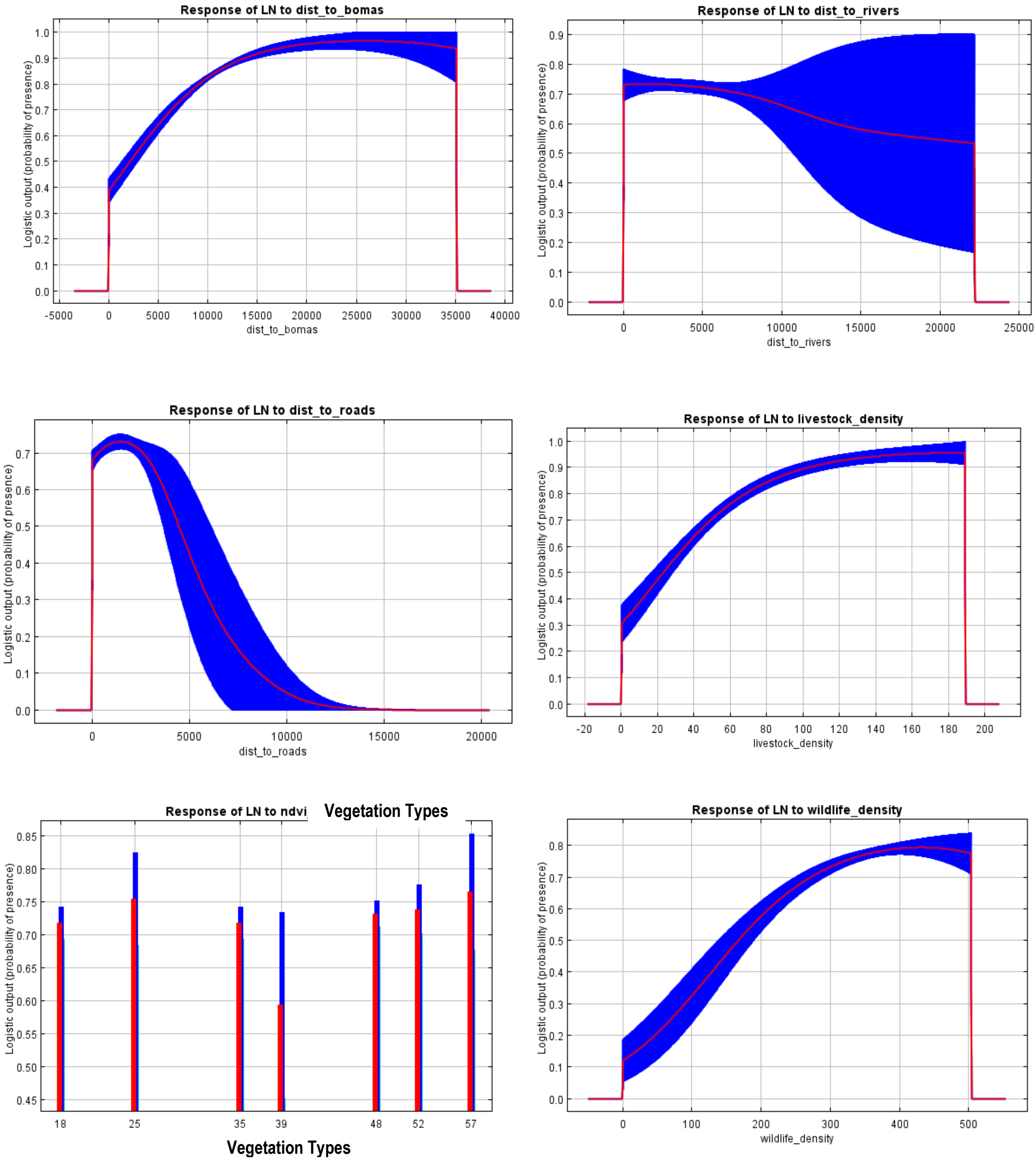
3.2.3. Response Curves

Figure 15 describes the response curves for the six environmental variables, as generated by the MaxEnt model. The probability of lion presence next to bomas is below random (0.4). This may mean that lion presence near bomas is only by chance. This probability however increases with increasing distance. This curve potrays that lions prefer areas located away from bomas. The probability of lion presence next to rivers is better than random (0.7). This probability gradually declines as distance from rivers increases. It seems that lions prefer areas located near rivers as compared to areas that are located far away from rivers. The probability of lion presence next to roads is better than random (0.7). This probability decreases steadily as distance from roads increases. From this curve, it seems that lions prefer areas that are located near roads, as compared to those that are located far from roads.

Where livestock density is 0, the probability of lion presence is below random (0.3). The probability of lion presence increases with increase in livestock density signifying a positive relationship.

All vegetation cover types are strongly connection with lion presence as all of them were predicted well above random. This curve therefore implies that lion presence in these classes is not by chance, as these cover types partly describe lion habitats. Where wildlife density is 0, the probability of lion presence is below random (0.1). The probability of lion presence increases with increase in wildlife density signifying a positive relationship.

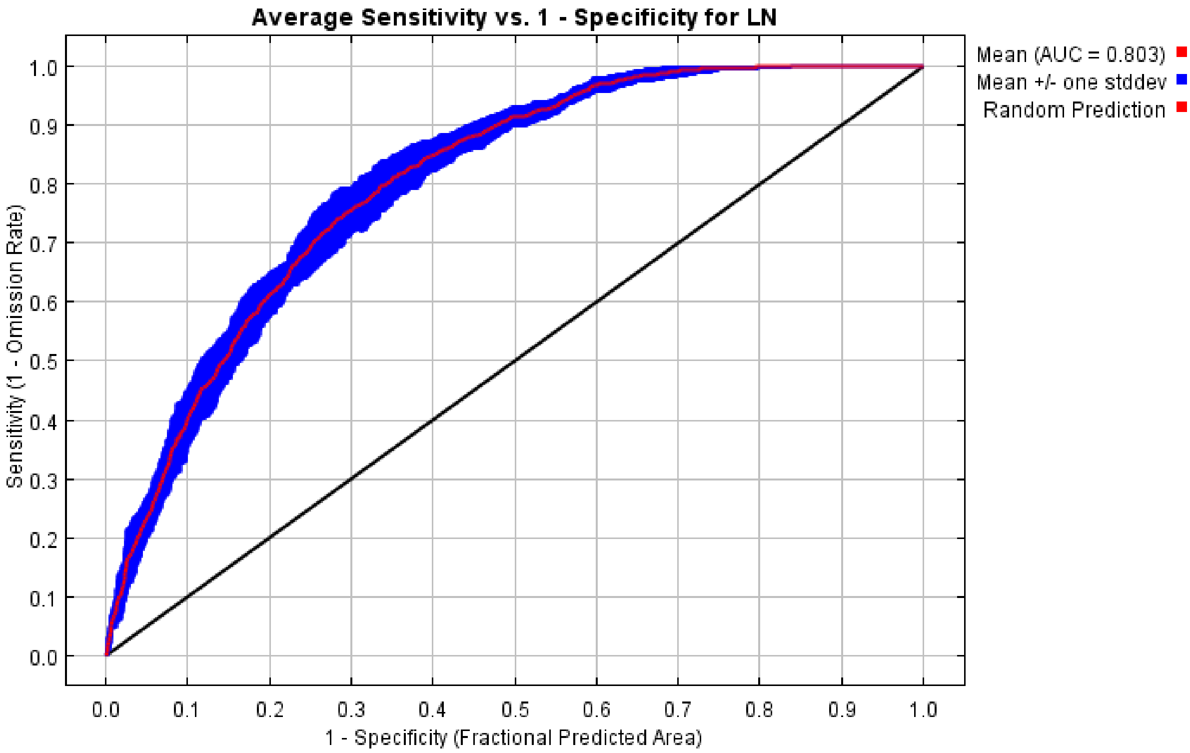
Figure 15: Response Curves illustrating the spatial influence of the six environmental variables on the estimated probabilities of lion presence. The curves indicate how the variables affected the model in different ways**.**



3.2.4. Evaluating Model Performance and Accuracy

Figure 16 shows the area under ROC curve for the MaxEnt model. The AUC curve represents the mean of the 10 model replicate runs. With an AUC value of 0.803, the curve shows that MaxEnt model performed better than random (i.e > 0.5). Analysis of model accuracy yielded TSS value of 0.497, and Kappa value of 0.73, indicating that the accuracy of the model is fair.

Figure 16: ROC Curve of Average Sensitivity vs. Specificity for Lion Species



3.3. Mapping Probabilities of Lion-Livestock Conflict Areas

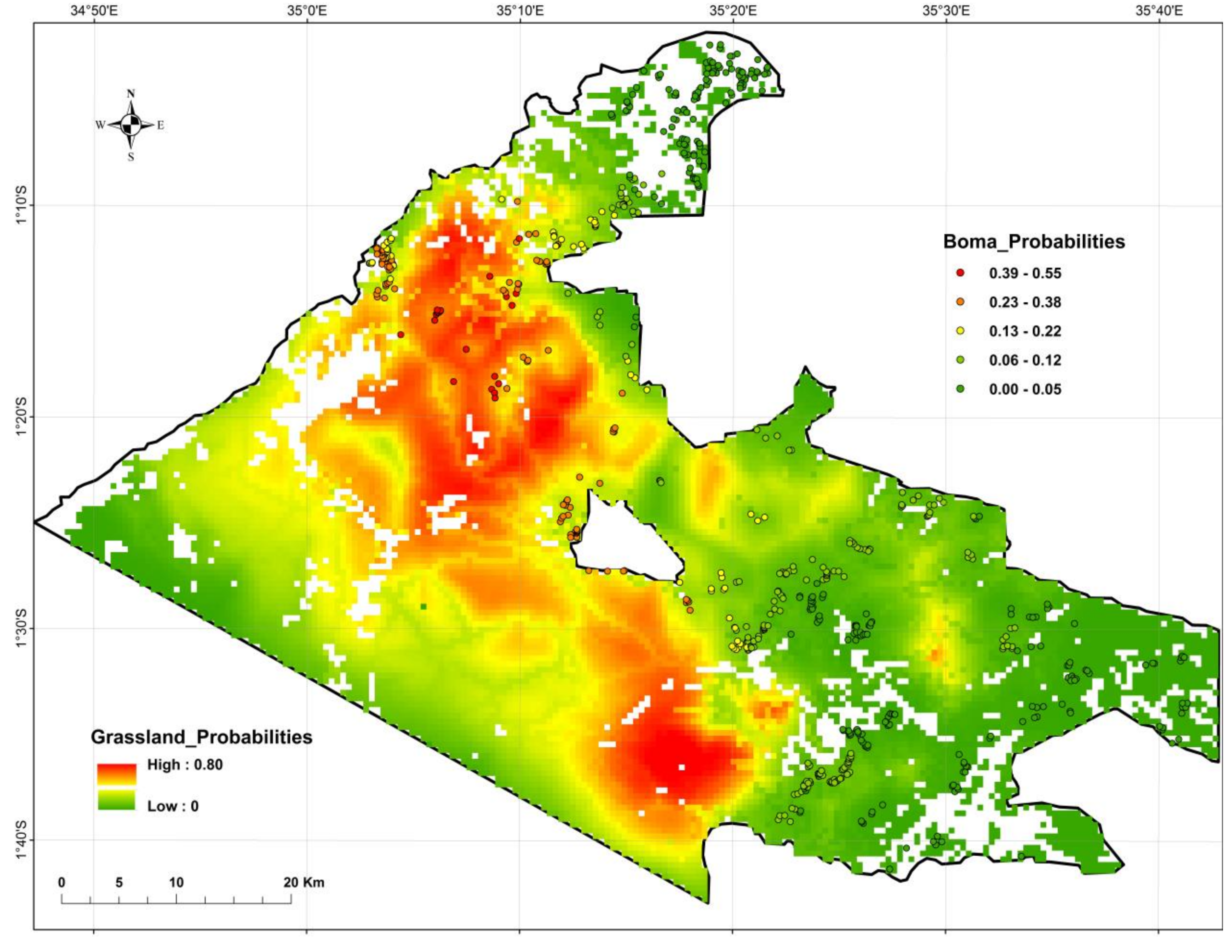
Figure 17 shows the map of lion-livestock conflict probabilities at grasslands and at bomas. Conflict probabilities at grasslands ranged from 0.0 – 0.8. Areas with high conflict probability are characterised by the red and orange areas. Those with moderate conflict probabilities are represented by yellowish areas, while areas with low conflict probability are represented by the greenish areas.

The conflict probabilities at bomas ranged from 0.00 – 0.55. Points displayed in red represent bomas with very high conflict probabilities. Those displayed in orange represent bomas with high conflict probabilities. Bomas in yellow indicate bomas with moderate conflict probabilities. Bomas displayed in light green represent bomas located in areas with low conflict probabilities while bomas displayed in dark green indicate those ones that were located in areas where the conflict probabilities were very low. See Table 9.

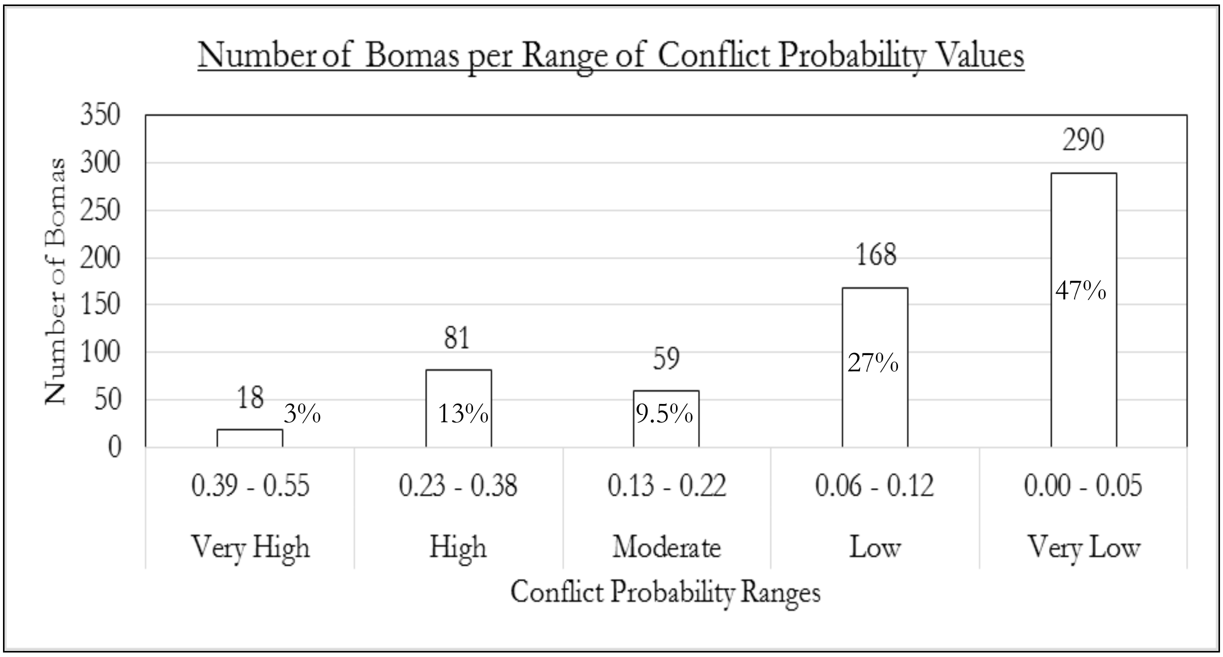
Table 9: Description of conflict probability ranges at bomas

Colour Code	Boma Conflict Probabilities	Label
	0.39 – 0.55	Very High
	0.23 – 0.38	High
	0.13 – 0.22	Moderate
	0.06 – 0.12	Low
	0.00 – 0.05	Very Low

Figure 17: A map of the lion-livestock conflict probabilities at grasslands and at Bomas.



Graph 1: Lion-Livestock conflict probabilities in relation to the number of Bomas in the study area

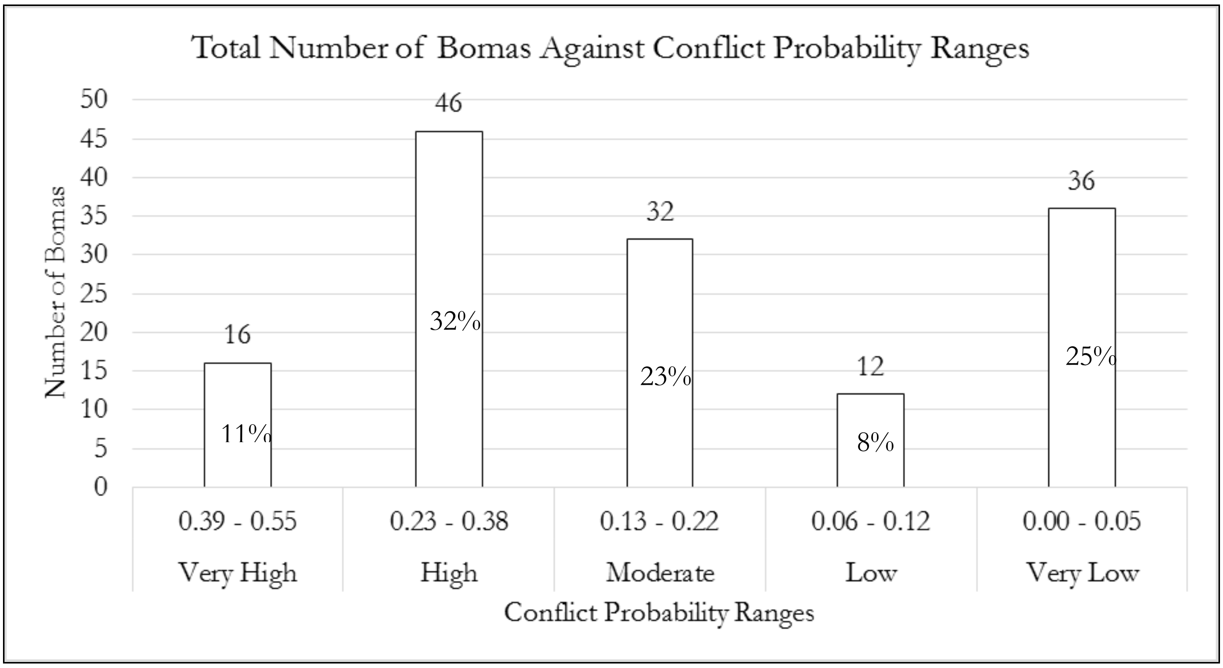


Graph 1 indicates the number of bomas under each range of conflict probability values. In total, there were 616 bomas located within the study area. The results indicated that majority of the bomas i.e 47% (290) are situated in areas where the risk of conflict is very low (0.0-0.05). 27% (168) of the bomas were located in areas where the risk of conflict was low. 9.5% (59) bomas were located where the risk of conflict was moderate, 13% (81) of bomas were located where the risk was high and 3% (18) bomas were located where the risk was very high.

3.4. Validating the Boma Conflict Map

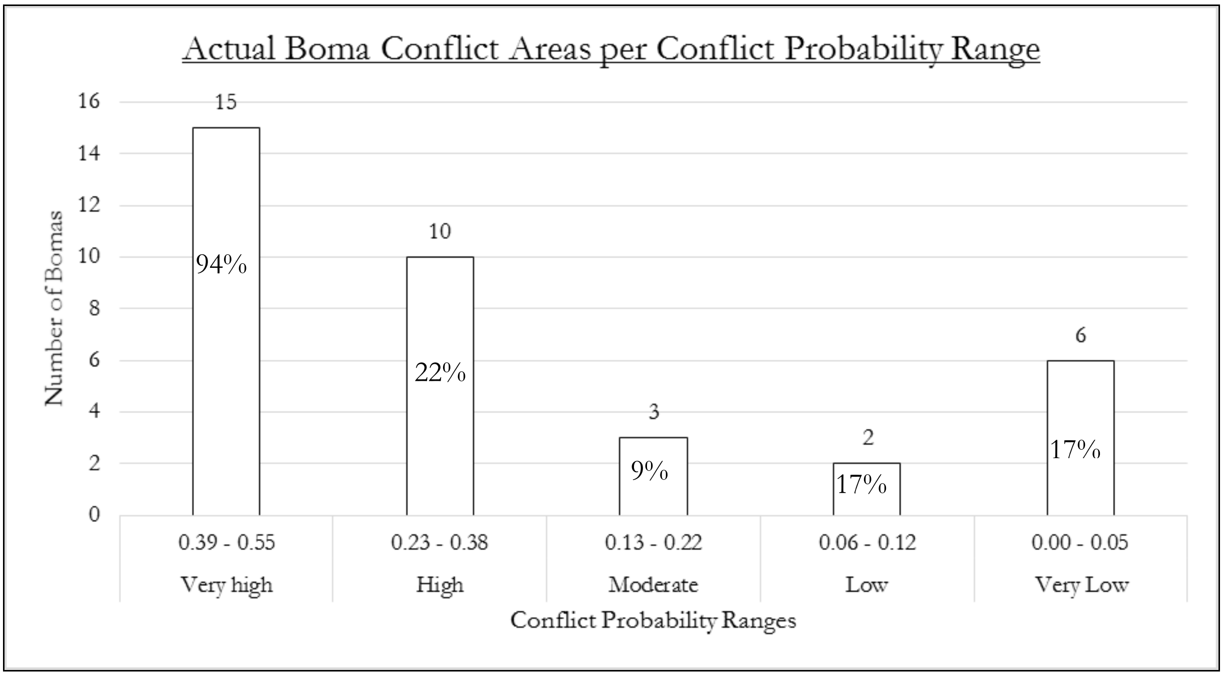
Graph 2 indicates the number of all the bomas located in Mara North conservancy, against their conflict probability ranges. In total there were 142 bomas in this conservancy. 11% (16) of the bomas were located in areas with very high risk of conflict. 32% (46) of bomas were located where the risk of conflict was high. 23% (32) bomas were located in areas where the risk of conflict was moderate. 8% (12) bomas were located where the risk was low, while 25% (36) of bomas were located in areas where the risk of conflict was very low.

Graph 2: Relationship between Total Number of Bomas in Mara North and Boma conflict Probability Ranges



Graph 3 indicates the number of bomas that have experienced conflict in the last two years, per conflict probability range. 94% of bomas located where the risk is very high, experienced conflicts. 22% of bomas located in areas where the risk of conflict is high, experienced conflicts. 9% of bomas in the moderate zone experienced conflicts, and 17% of bomas in the low and very low zones experienced conflicts.

Graph 3: Actual Boma Conflict Areas per Conflict Probability Ranges



4. DISCUSSION

4.1. Mapping Areas Available for Livestock Grazing

The results of the vegetation cover mapping process indicated that five cover types (A1, A2, A3, B and C) represented grassland areas in the study area. These grassland cover types characterized areas suitable for livestock grazing. Type C was easily differentiated as it had the highest % grass cover i.e 70%. Type B could also be differentiated from A1, A2 and A3, as it had significant amount of high shrub layer. It was not easy to distinguish between cover types A1, A2 and A3, based on % grass cover. Their differentiation could lie in their temporal behaviour. In total, grasslands covered a total of 2831.7 sq.km (85.6%) of the study area, making it the dominant vegetation cover type. Type A3 and C had the highest coverage within the study area.

Table 10: A legend providing description on the five grassland vegetation cover types present within the study area.

Average % of Grassland Vegetation Cover Types									
			Ground Cover Layer						
Grassland Cover Type	Tree Layer	High Shrub Layer	Low Shrubs	Herbs	Grass	Litter	Bare	Stony	Sq. Km
A1	0	5	2	0	31	0	67	0	4.4
A2	1	6	1	1	57	0	41	0	137.8
A3	1	8	1	1	37	1	59	2	1145.1
B	2	22	1	2	46	0	51	1	425.5
C	0	1	1	0	70	20	9	0	1118.8

Generally, all grassland cover types experienced moderate to high standard deviations, indicating high grassland heterogeneity in the Mara. Grassland heterogeneity is described by species composition, vertical structure and spatial distribution. Distribution of grassland type C was dominant on the south west part of the study area i.e the Masai Mara National Reserve, next to the Kenya-Tanzania border. In this reserve, activities are limited to tourism and wildlife conservation(Bedelian, 2012) . Research findings by Guo (2004) also showed that conserved grasslands had more grass density at canopy level and were more homogenous .

Grassland heterogeneity was seen to be more in the conservancies as characterised by cover types A1, A2, A3 and B. In these conservancies, land use is restricted to tourism and wildlife conservation. However, anthropogenic activities such as human settlements and livestock grazing are allowed to some extent (Bedelian, 2012). These results are similar to findings by Guo, who attributed spatial heterogeneity of grasslands to management strategies which affect grassland productivity such as increased grazing (Guo, 2004).

4.2. Species Distribution Modelling

The MaxEnt model was used in this study to predict the presence and distribution of lions within the study area using a set of six environmental variables. Our results showed that lions were present in the study area, and that the probabilities of their presence differed in relation to habitat suitability. As expected, high probabilities of lion presence were found in habitats deemed to be suitable for lions. Results from the MaxEnt in-built Jack-knife test revealed that wildlife density was the most important predictor for estimating lion presence probabilities followed by distance to bomas and livestock density. However, the rest of the variables i.e. distance to roads, distance to rivers and vegetation cover types were not as significant. Based on the response curves generated, the results showed that there was a positive relationship between lion presence probabilities and distance to bomas, livestock and wildlife densities. The relationship between lion presence probabilities and distance to rivers and roads was an inverse one. Lion presence probability was more than random in all vegetation cover types. The model performed significantly better than random (0.5), and its accuracy indicated that it was a fair model.

- **Lion Presence Probabilities**

The MaxEnt model predicted lion presence probabilities across the study area, to be high in the red areas. Hence it is these areas which have perfect conditions that characterize lion habitats such as sufficient extents of available area, availability of areas for resting, prey and feeding sites. These suitable habitats enhance thriving wildlife populations (Schaller, 1972). Areas that were predicted to be unsuitable were areas that did not have the above named factors. According to Davidson et al., (2012), factors related to anthropogenic activities such as increased human population, settlements, agricultural activities as well as increased livestock grazing, reduce suitability and quality of habitats and result in declining wildlife populations (in this case, low lion presence probabilities) (Ottichilo, 2000; Waithaka, 2004).

- **Jackknife Test Results**

Wildlife density was selected out to be the most important predictor of lion presence probability by the model. A large part of their time during the day is spent sleeping, lying down, or sitting (Heinsohn, 1997). However, when active (cooler hours of the day and at night), lions engage in hunting (Heinsohn & Packer 1995). Lions are carnivores and a huge part of their diet constitutes wild prey (Hayward & Kerley, 2005).

Due to their opportunistic nature, lions are known to take advantage of prey that is easily accessible and available. With their most preferred prey weight being 350kg (Hayward & Kerley, 2005), livestock are hence easily categorised as lion prey (Patterson, Kasiki, Selempo, & Kays, 2004). Research conducted in Makgadikgadi ecosystem in Botswana found that resident lions did not follow migratory herds, but the reduction in natural prey resulted in diet switch to livestock, which seemed to be abundant and available (Valeix, Hemson, Loveridge, Mills, & Macdonald, 2012).

Livestock attacks by lions can occur in the open grasslands where Maasai graze their cattle during the day or in livestock enclosures (Kissui, 2008). Lions are mainly nocturnal animals (Packer et al., 2011) and hence livestock attacks occurring in enclosures mostly occur at night (Ogada & Woodroffe, 2003). Lions have been known to walk an average of 5.2 km at night (Visser et al., 2009) and hence bomas located within this proximity, and which in addition have poorly maintained enclosures (Okello, Bonham, & Hill, 2014), are most at risk for livestock depredation.

Distance to roads was not an important variable for the prediction of lion presence probability. Lions have been spotted near roads and are also known to prefer areas away from roads where there is thick bush and woodlands for resting, sleeping and lying down (Schaller, 1972). The results by MaxEnt model therefore are false, as they may be influenced by sample bias. Some of the lion presence data used to run MaxEnt model are from Mara Lion Project who mainly collected lion observation data through road drives, and hence most of the observed lions would highly be found next to roads.

The distance to rivers variable was not a significant variable for predicting lion presence. Research by Ogutu & Dublin (2004) indicates that lions obtain water from their prey. Provision of water from rivers would therefore not be the explanation for lion preference for areas near rivers. The research revealed that this preference is linked to the wide array of prey species attracted by the heterogeneous vegetation in these locations. Hence, vegetation cover and distance to rivers cannot be considered as direct predictors of lion presence probability.

- **Response Curves**

The model's response curve for distance to bomas predicted the probability of lion presence next to bomas to be below random (0.4). There is a positive relationship between lion probability of presence with increasing distance from bomas. This indicates that lions prefer areas located away from bomas, though it seems they can also be spotted near bomas. Research done in Laikipia region of Kenya, lions adjusted their behaviour either spatially, and sometimes temporally, to minimize direct contact and risk of conflict with humans. The research showed that lions avoided pastoral lands especially during the daylight hours. When passing through pastoral lands during the day, they did so in a straighter manner and at a faster speed. Lions were observed to be closest to bomas when human activity was lowest i.e between 2300 and 0500 hrs (Oriol-Cotterill, Macdonald, Valeix, Ekwanga, & Frank, 2015). Presence of lions near bomas is by chance and is linked to livestock predation, which mostly occurs at night (Ogada & Woodroffe, 2003).

The response curve for distance to rivers pointed out that the probability of lion presence next to rivers was better than random (0.7), and decreases gradually with increase in distance from rivers. This shows that lions prefer areas that are near rivers as opposed to those located far away. Research conducted by Valeix et al. (2009) to test the relationship between water sources and lion distribution, found that lions significantly selected areas that are located 2km way from water sources. These results are further cemented by Davidson et al. (2013) whose studies on seasonal prey preference of lions found that lions typically make their kills between 1 and 4 km from water holes. The relationship between lion presence and areas near water sources is however an indirect one, as lions obtain water from their prey, according to research results by Ogutu & Dublin (2004). Areas near water sources are characterized by heterogeneous vegetation which attract a wide variety of lion prey.

Results on the influence of roads to the probability of lion presence indicated that lion presence next to roads is better than random (0.7) and it decreased steadily as distance from roads increased. However, as much as lions have been spotted numerous times next to roads (Elliot et al., 2014; Schaller, 1972), it may be argued that most lion data collected is influenced by bias, as most field surveys take place in vehicles along tracks, and hence lions observed are only those found next to roads. These results are therefore considered to be false.

There was a positive relationship between lion presence probability and livestock and wildlife densities. There is increase in lion presence probability with increase in livestock and wildlife. Lions are apex carnivores (Schuette et al., 2013), that rely on medium to large herbivores as source of food. This includes wildlife and domesticated animals, i.e livestock. Lions are highly sedentary animals (Pusey & Packer, 1978), they do not follow patterns of migratory animals. In the absence of wild prey, lions diet switches to livestock (Valeix et al., 2012). Increased wildlife and livestock densities reflects resource abundance.

All the seven vegetation cover types are strongly correlated with lion presence as all of them were predicted well above random. Vegetation structure is one of the key determinants of lion presence. According to Nowell & Jackson (1996) lions are found in open woodlands, thick bush, and grassland complexes. This vegetation description fits very well that which is found in our study area, as illustrated by the legend shown in **Table 8**, where the vegetation cover types constitute Forest, High Shrub, Low Shrub, herbs and grasses. Lions prefer areas with trees and high bushes as they provide ample resting sites and shade against daylight radiant heat, as well as offering protection for cubs (Ogutu & Dublin, 2004). In addition, lions also prefer areas with pronounced grass cover, which provide ample hunting grounds (Ogutu & Dublin, 2004).

- **Model Performance and Accuracy**

The performance and accuracy of the MaxEnt model used in this study was conducted using different methods. The area under the receiver-operator (ROC) curve (AUC) was used to evaluate model performance. This is a threshold independent method and has been rated to be one of the most popular methods for evaluating MaxEnt model performance (Merow et al., 2013). The AUC values range from 0 - 1, with, values =1 representing perfect fit or perfect discrimination, >0.75 represent useful models, while values close to. 0.5 depict that the model is predicting no better than random, and values less than 0.5 represent a worse than random model (Steven, 2009). The performance of the MaxEnt model for lion species generated an AUC value of 0.803, indicating that it was a useful model that can be used for other analysis.

However, other researchers have criticized the use of AUC for evaluating MaxEnt model accuracy as it is only based on single threshold independent measure and the use of other accuracy evaluation methods such as True Skill Statistic (TSS) or Kappa Statistics has been recommended (Allouche, Tsoar, & Kadmon, 2006). In this study, both methods were used to evaluate accuracy of MaxEnt model.

For models using presence –absence data, the Kappa statistic has been the widely used measure. Kappa is a threshold-dependent method that converts predictions to presence – absence and its values range from -1 to +1. It mainly works by examining the extent to which models correctly predict species presence at rates that are better than random. Poor models are represented by kappa values that are less than 0.40, good models have Kappa values which range from 0.40 – 0.75, while excellent models have Kappa values greater than 0.75 (Evangelista et al., 2008). Evaluation of the accuracy of MaxEnt model for lions yielded a Kappa Statistic of 0.733, to indicate that it's a good model. This method however, has been proven to be insufficient for evaluating model accuracy as it is dependent on prevalence i.e, dependence on the training data set at which species have been recorded to be present (Mouton, De Baets, & Goethals, 2010).

The use of TSS was selected as this statistic has all the advantages of Kappa, and does not experience the problem of prevalence. Just like Kappa, TSS is also a threshold dependent statistic and is defined as Sensitivity + Specificity – 1. Its values range from -1 to + 1, with +1 denoting a perfect fit and those less than or equal to zero representing models that are no better than random (Allouche et al., 2006). Assessment of the MaxEnt model for lions using TSS statistic produced a value of 4.97 to indicate a fair model.

4.3. Mapping Probabilities of Lion-Livestock Conflict Areas

The results of mapping the probabilities of lion-livestock conflict areas showed that conflict probabilities at grasslands ranged from 0.0 – 0.8 while those at bomas ranged from 0.00 – 0.55. Red colours indicated areas with very high risk of conflict, orange colours indicates areas with high risk of conflicts, yellow colours indicates areas with moderate risk of conflicts, light green colours represented areas with low risk of conflict while dark green colours represented areas with very low risk of conflicts. Out of 616 bomas, 3% (18) were located in very high risk zones, 13% (81) were located in high conflict risk zones, 9.5% (59) in moderate conflict risk zones, 27% (168) in low risk zones, while 47% (290) were situated in areas where the risk of conflict is very low.

4.4. Validating the Boma Conflict Map

Out of the 616 bomas located in the study area, 142 were found in Mara North conservancy. The relation between these bomas and the conflict probability ranges showed that 11% (16) of the bomas were located in high risk zones, 32% (46) were located in high risk areas, 23% (32) bomas were located in moderate risk areas, 8% (12) were located in low risk areas while, 25% (36) were located in very low risk areas. 94% of bomas located in very high risk zones experienced conflicts. 22% of those located in high risk areas experienced conflicts, 9% of bomas in the moderate zone experienced conflicts, and 17% of bomas in the low and very low zones also experienced conflicts.

The percentage number of bomas that experienced conflicts in the last two years increased with increased conflict probabilities. Bomas in the low and very low conflict zones had substantially higher percentage number of bomas that experienced conflicts and this may have been caused by nomadic lions. Nomadic lions are not confined to any territories. They often follow the migratory patterns of prey, and can walk very long distances. Nomadic lions can live solitary lions or they can form alliances of up to five or eight lions(Pusey & Packer, 1978).

5. CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH

5.1. Conclusions

- The combination of 71 classes, median, SD, and trend was not sufficient to differentiate all vegetation cover types. Some cover types could not be distinguished based on only these four parameters.
- Grassland types situated in more conserved areas i.e Mara Reserve had more percentage grass cover and were more homogenous.
- Grassland types that were situated near and in conservancies were more heterogeneous in terms of spatial distribution and percentage canopy cover.
- Lion presence probability is best explained using presence and densities of wildlife and livestock.
- Bomas located in areas with high lion presence probability have a very high likelihood of experiencing conflicts.

5.2. Research Limitations

Two limitations were encountered when conducting this study;

- Actual lion-livestock conflict data for the entire study area was not available. Hence, validation was only done for Mara North boma conflict map.
- Actual livestock grazing areas within the study area was lacking. Hence, all grasslands were considered to be livestock grazing areas.

5.3. Recommendations

- To minimize livestock depredation by lions, extents of lion habitats should be identified and measures should be put in place to ensure people do not settle in areas where the lion presence probabilities are high.
- In the conservancies where livestock grazing is allowed to some extent, lion movement patterns should be investigated and grazing zones should be defined to avoid direct contact of people, their livestock and lions.
- Lion-proof bomas should be promoted to strengthen and protect livestock depredation by lions at night.

5.4. Future Research

- One of the ways in which data on actual movement and livestock grazing areas has been collected in the Mara is by use of GPS collars (B. Butt, 2010). Further research should be conducted using this kind of data to determine whether the extents of livestock grazing areas would be comparable.
- Data on actual locations of lion-livestock conflicts is collected regularly by Kenya Wildlife Service rangers, and provides a rich database on which future researchers can tap into, to determine whether results of mapping boma and grassland conflict areas would be similar.
- More research should be conducted using hyper-temporal NDVI images to study the health conditions of lion habitat in the Mara region.

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7. APPENDIX

Appendix 1: Releve` Sheet for Field Vegetation Survey

<table>
<tr><td colspan="8">FIELD DATA COLLECTION SHEET</td></tr>
<tr><td>Date:</td><td colspan="3">Sample CODE:</td><td colspan="4">Observers:</td></tr>
<tr><td colspan="4" rowspan="2">Photo No.:</td><td>GPS:
S</td><td colspan="2"></td><td>Altitude:</td></tr>
<tr><td>E</td><td colspan="2"></td><td>Plot size:</td></tr>
<tr><td>Slope</td><td>Steep</td><td>Flat</td><td>Undulating</td><td>Rolling</td><td></td><td>Hilly</td><td>Mountainous</td></tr>
<tr><td colspan="8">A. LAND COVER/USE DATA – (semi-)natural or planted</td></tr>
<tr><td colspan="4">SAMPLE PLOT</td><td colspan="4">POLYGON</td></tr>
<tr><td>Strata</td><td>Height</td><td>Cover %</td><td>Dominant Species (for details p.to.)</td><td colspan="4">General cover/use type (if complex, estimate % cover of each type)</td></tr>
<tr><td rowspan="2">Trees</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>Type</td><td colspan="2">Description</td><td>%Age</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Shrubs</td><td></td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Herbs</td><td></td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Grass</td><td></td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Litter cover</td><td></td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Bare soil</td><td></td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Stones/rocky boulders</td><td></td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Actual Land Cover</td><td colspan="3"></td><td>Actual Land Use</td><td colspan="3"></td></tr>
<tr><td colspan="8">OBSERVATIONS:</td></tr>
</table>

Appendix 2: Field Data Collection Sheet for Lion-Livestock-People Presence

<table>
<tr><th colspan="6">Lion – Livestock – People Presence (Ocular Method)</th></tr>
<tr><td>1. Number of lions</td><td>Male</td><td>Female</td><td>Cubs</td><td>Distance (Approx.)</td><td>N/E/W/S</td></tr>
<tr><td>2. Condition of Lions</td><td colspan="3">Healthy</td><td colspan="2">Unhealthy</td></tr>
<tr><td>3.. Footprints</td><td colspan="2">How Many</td><td colspan="2">Distance (Approx.)</td><td>N/E/W/S</td></tr>
<tr><td>4. Vocalisations e.g Roaring</td><td colspan="3">Distance (Approx.)</td><td colspan="2">N/E/W/S</td></tr>
<tr><td>5. Behaviour of other animals e.g Sudden flight</td><td colspan="2">Which Ones?</td><td>Distance (Approx.)</td><td>N/E/W/S</td><td>How Many?</td></tr>
<tr><td>6. Lion Carcasses</td><td colspan="2">How Many</td><td colspan="2">Distance (Approx.)</td><td>N/E/W/S</td></tr>
<tr><td>7. Lion Droppings</td><td colspan="2">How Many</td><td colspan="2">Distance (Approx.)</td><td>N/E/W/S</td></tr>
<tr><th>Built-up Structures</th><th colspan="2">How Many</th><th colspan="2">Distance (Approx.)</th><th>N/E/W/S</th></tr>
<tr><td>1</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>2</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>3</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>4</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><th>Livestock & People</th><th colspan="2">How Many</th><th colspan="2">Distance (Approx.)</th><th>N/E/W/S</th></tr>
<tr><td>1. Cattle Presence</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>2. Cattle Droppings</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>3. Livestock Pens</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>4. Local People</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><th>Water Points</th><th colspan="2">How Many</th><th>Distance (Approx.)</th><th colspan="2">N/E/W/S</th></tr>
<tr><td>1. River</td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>2. Swamp</td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>3. Wells</td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>4. Boreholes</td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>5. Surface Ponds</td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">REMARKS</td></tr>
</table>

Appendix 3: Some vegetation cover types observed in the field


Site 51


Site 18


Site 21


Site 44


Site 17

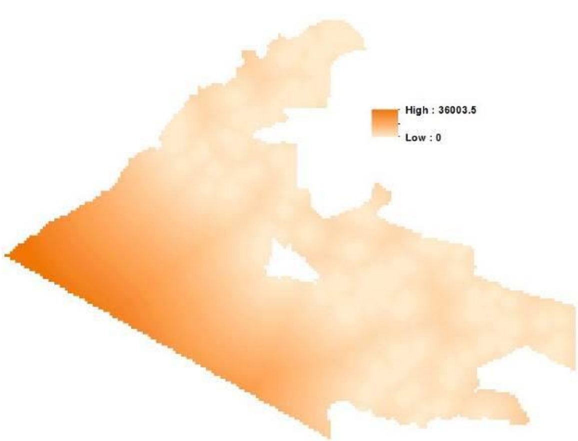

Site 25

Appendix 4: Database used for Legend Construction

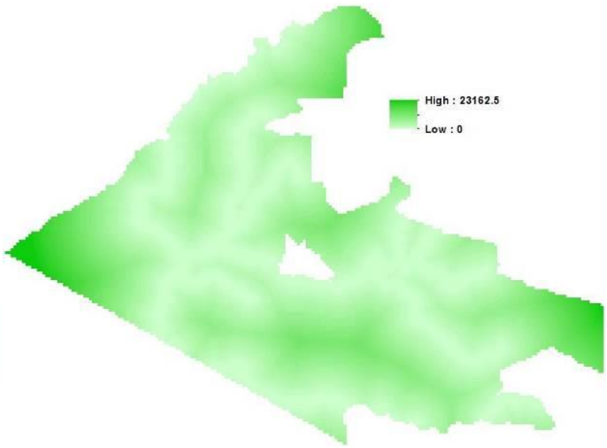
71class	Median	SD	Trend	Tree	high_ shrub	Low_ Shrubs	Herbs	Grass	Litter	Bare	Stony
18	10	5	3	0.80	4.00	1.37	0.00	27.34	0.00	71.29	0.00
18	10	3	4	0.00	0.90	3.31	0.00	30.13	0.00	66.56	0.00
18	10	4	3	0.00	10.80	0.00	0.00	35.84	0.00	64.16	0.00
25	11	2	4	8.00	9.60	0.00	0.00	26.94	0.00	73.06	0.00
25	11	3	4	0.00	25.00	7.61	0.00	27.17	0.00	65.22	0.00
25	11	4	3	0.00	0.00	0.79	0.00	35.64	0.00	63.56	0.00
25	11	3	3	0.00	0.00	0.89	0.00	40.10	0.00	59.01	0.00
25	12	5	4	8.00	10.40	1.65	0.00	47.11	0.00	51.24	0.00
25	12	4	3	0.00	0.00	0.00	15.00	35.00	0.00	50.00	0.00
25	11	4	4	0.00	3.00	0.00	0.00	53.61	0.00	46.39	0.00
25	11	4	4	0.00	3.00	0.00	0.00	58.76	0.00	41.24	0.00
25	11	5	4	0.00	5.00	0.00	0.00	68.42	0.00	31.58	0.00
25	12	4	4	0.50	0.00	0.00	0.00	70.00	0.00	30.00	0.00
25	11	5	3	0.00	17.15	0.00	0.00	70.56	0.00	29.44	0.00
25	12	5	3	1.70	13.00	0.00	0.00	80.82	0.47	18.71	0.00
25	12	3	4	0.00	0.50	0.00	0.00	85.00	0.00	15.00	0.00
25	11	4	3	0.00	0.00	2.17	0.00	97.83	0.00	0.00	0.00
35	14	2	4	0.50	24.75	0.00	0.00	20.69	6.00	69.97	3.33
35	13	3	3	1.00	21.20	3.75	0.00	20.79	0.00	63.26	12.20
35	13	3	4	0.50	5.00	0.00	0.00	31.58	0.00	68.42	0.00
35	13	4	4	1.00	2.00	0.00	8.33	25.00	0.00	66.67	0.00
35	12	3	3	0.00	0.50	0.00	0.00	35.00	0.00	65.00	0.00
35	13	4	3	0.00	0.00	0.45	0.00	40.72	0.00	58.82	0.00
35	13	5	4	1.00	5.00	0.00	0.00	58.82	0.00	41.18	0.00
35	12	4	3	0.00	5.00	0.00	0.00	63.16	0.00	36.84	0.00
39	15	2	4	0.00	50.00	0.00	0.00	20.83	0.00	75.00	4.17
39	14	3	4	0.50	20.00	0.00	6.25	31.25	0.00	62.50	0.00
39	14	3	3	8.25	16.75	1.52	0.00	42.30	0.00	56.19	0.00
39	13	5	3	0.50	2.00	0.00	0.00	55.00	0.00	45.00	0.00
39	15	4	4	0.10	48.60	0.00	4.53	51.42	0.00	44.05	0.00
39	14	4	3	2.00	15.00	4.76	0.00	57.14	0.00	38.10	0.00
39	14	4	4	0.50	0.50	0.00	0.00	64.36	0.00	34.65	0.99
48	12	3	4	0.00	0.00	0.00	0.00	49.00	0.00	51.00	0.00
48	14	6	4	0.00	0.00	3.00	0.00	57.00	35.00	5.00	0.00
48	14	5	4	0.00	0.00	0.50	0.00	59.70	34.83	4.98	0.00
48	15	6	4	0.00	2.00	0.00	0.00	65.31	30.61	4.08	0.00
48	15	5	4	0.00	0.00	0.00	0.00	67.39	28.99	3.62	0.00
48	15	4	4	0.00	0.00	0.00	0.00	67.86	28.57	3.57	0.00
48	15	5	4	0.00	1.00	0.00	0.00	68.35	28.78	2.88	0.00
48	15	4	3	0.50	0.50	0.00	2.13	67.38	28.37	2.13	0.00
48	15	4	3	0.00	0.50	0.00	0.00	70.37	29.63	0.00	0.00
48	16	5	3	0.00	1.00	0.00	0.00	70.37	29.63	0.00	0.00

48	14	5	4	0.00	0.00	5.00	0.00	72.00	3.00	20.00	0.00
48	14	4	4	0.00	0.00	0.00	0.00	73.40	0.60	26.00	0.00
48	15	5	3	0.00	0.00	0.52	0.00	94.24	5.24	0.00	0.00
48	16	5	4	0.00	2.00	0.00	0.00	96.94	0.00	3.06	0.00
52	17	4	4	1.00	80.00	0.00	0.00	0.58	58.48	35.09	5.85
52	15	3	4	13.75	43.75	0.00	0.00	8.46	0.82	89.91	0.82
52	16	2	4	0.00	32.00	0.00	2.86	22.86	0.00	74.29	0.00
52	16	3	4	1.00	29.95	0.00	11.47	75.99	0.00	12.54	0.00
57	17	3	4	1.00	95.00	0.00	0.00	0.62	37.27	49.69	12.42
57	18	2	4	48.30	27.00	19.50	0.00	48.00	7.50	15.00	0.00

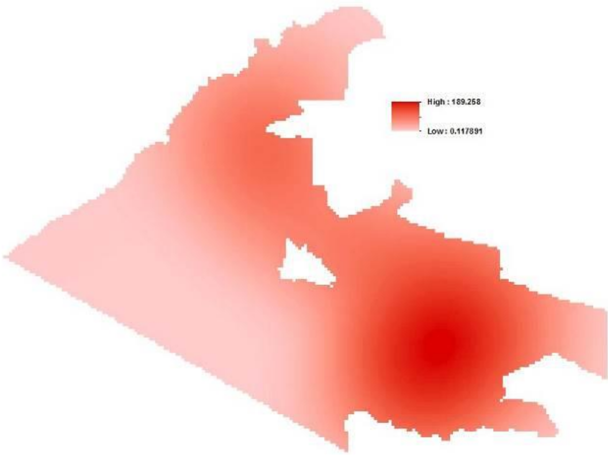
Appendix 5: Environmental Predictors used in MaxEnt Model



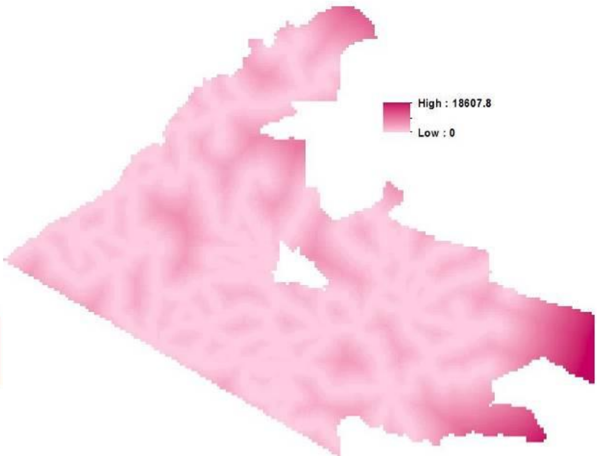
(a) Distance to Bomas



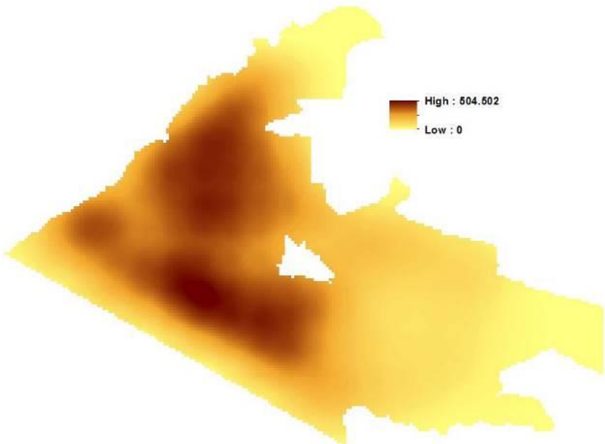
(b) Distance to Rivers



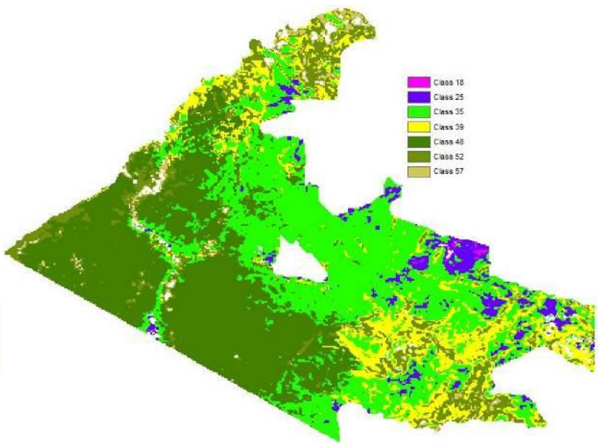
(c) Livestock Density



(d) Distance to Roads



(e) Wildlife Density



(f) Vegetation Cover Types