CHARACTERIZING THE SPATIAL DISTRIBUTIONS OF ELEPHANTS IN MPALA, KENYA

ENOCK ODERA OCHIENG
MARCH, 2015

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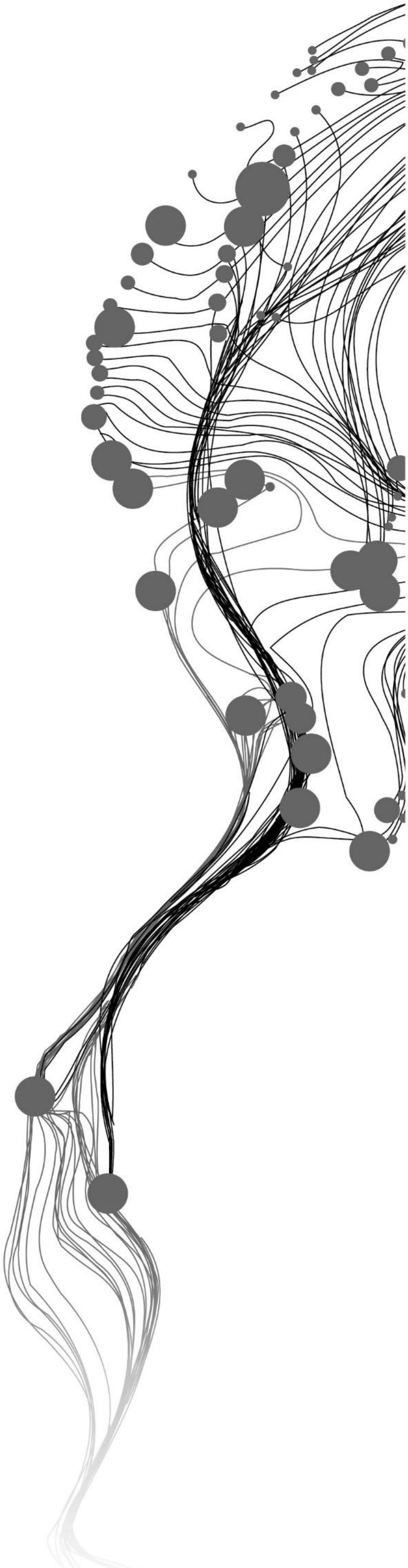

CHARACTERIZING THE SPATIAL DISTRIBUTIONS OF ELEPHANTS IN MPALA, KENYA

ENOCK ODERA OCHIENG
Enschede, The Netherlands, March, 2015

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Natural Resources Management

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Corrections

Abstract

Scientific problem added: and the statement rephrased

Ground observation data method replaced with ground count data

Ecological interpretations replaced with ecological variables

Biophysical and anthropogenic replaced with environmental factors

Statistical reports corrected as advised by Dr. Ignas

Steep slopes changed to high slopes and low lands changed to gentle slopes Laikipia deleted from the keywords

Chapter one

1.1. towards the end of paragraph 1. The word maximum deleted

1.1: Colonize replaced with, were not found

Strategic location at the core of elephant migration corridor "referenced"

Conservation and management decisions explained

1.6: Large/small scales, corrected to larger/smaller spatial extends

Rephrased the specific objective 5

Deleted research questions

Reformulated the hypotheses

Figure of the study area replaced with one of the corrected legend

Chapter two

Rephrased the beginning of the paragraph

Rephrased the beginning of the second paragraph

2.3.3. Added the word GPS which was missing

2.4/2.5: subtitles rephrased

2.6 The legend of the elevation image changed by replacing the low, medium and high legend with the actual elevation values

2.71: Plot sizes changed from 2500m^2 to 50mx50m

2.8: subtitle rephrased

Chapter three

3.1 change in statistical mean and std dev. reports as advised by Dr. Ignas

3.2 change in statistical mean and std dev. reports as advised by Dr. Ignas

3.4: Pie chart deleted

Changed the graphical representation of the results as advised by Dr. Ignas

Chapter four

4.1 First paragraph first line due to..... Changed to "relative to". The following statement has been deleted as well. "Elephants in Mpala were found to have higher ranging mean with higher variation in the wet season. This was contrary to the expectations as well as previous findings"

2nd paragraph, is rephrased

3rd paragraph, this statement is deleted "higher rainfall fed south of Mpala was observed to have high woody cover as opposed to the north which had low rainfall.

Paragraph 3: is rephrased as well.

Paragraph 5 rephrased

4.2 rephrased paragraph 1

4.3 last sentence of paragraph 4 removed

4.5: Subtitle rephrased

4.5: Deleted the last part of paragraph 5

Chapter 5

Rephrased the conclusions, corrected the statistical results' reporting and writing

ABSTRACT

Understanding factors that influence spatial distributions of elephants can provide insight into their population dynamics therefore, assisting in conservation efforts for both elephants and the habitat. Elephant distributions in Mpala are poorly understood since they have not been sufficiently documented. Therefore, this study aimed at describing the spatial distributions of elephants in Mpala. 808 records from 28 elephant families were used for the analyses. The data were collected between January 2011 and December 2013 using ground count method within the demarcated boundaries of Mpala. Family groups for analysis were selected from known female groups with at least 10 re-sightings per season. These were then grouped into the wet and the dry seasons. This study applied GIS and remote sensing techniques to determine distribution factors of elephants and relate them to ecological variables. Elephant populations were described in terms of seasonal distribution range sizes and seasonal probability densities. The range sizes were computed using minimum convex polygon method. Seasonal probability densities were computed using the kernel density estimator. Seasonal distributions were also compared based on elevation gradients after reclassification of a DEM following the Jenks natural breaks method. Woody cover was mapped from Landsat 8 satellite imagery using the maximum likelihood classifier. Finally, environmental factors for elephant distributions were determined using multiple regression analysis. Range sizes varied between $17km^2$ and $85km^2$ in the wet season, while in the dry season ranges sizes were between $27km^2$ to $56km^2$. Even though, wet season average range sizes were larger (mean= $47\pm20.23km^{-2}$) compared to dry season averages (mean= $38\pm10.84km^{-2}$), their differences were not statistically significant ($p>0.05$). The seasonal distribution densities of elephants also showed no statistically significant difference. Wet season (mean= 20.04 ± 10.62 elephants km^{-2}) and the dry season (mean= 17.73 ± 11.45 elephants km^{-2}) ($p>0.05$). On the other hand, elephant density at different elevation gradients changed significantly between the two seasons. In the wet season, elephant densities were significantly different between low medium elevations, and low high elevations, but not between medium high elevations. In the dry season, elephant densities were significantly differently distributed amongst all the elevation ranges ($p<0.05$). A high mapping accuracy for three classes of woody cover was achieved with an overall accuracy of 86.96% and Cohen's kappa of 0.785. Quantification of woody cover showed medium woody cover as the dominant cover, covering 50% of the study area while low and high woody cover covered 11% and 39% respectively of the study area. Multiple regression analysis showed that 5 environmental variables significantly influenced elephant distribution in the wet season ($R^2_{adjusted}$=80%, RMSE=4.2). Based on relative importance to the regression model these environmental variables were; distance from the fenced plots (71%), NDVI mean (11%), NDVI standard deviation (14%), distance from the water dams (4.2%) and slope (0.4%). In the dry season 8 environmental variables were found to significantly influence elephants distribution ($R^2_{adjusted}$ =75%, RMSE=5.4). Based on the relative importance to the regression model, these environmental variables were; distance from the water dams (50%), woody cover (17%), NDVI mean (10%), slope (8%), distance from the human settlements (7%), distance from the roads (3%), distance from the cattle bomas (3%) and NDVI standard deviation (2%). Elephant seasonal distributions showed preference for higher elevations, characterized by high woody cover, and high-clay content soil. Elephants preferred steep slopes in wet season but descended to gentle slopes in dry season. This was because of the available surface water due to rugged terrain and rock outcrops as well as abundance of forage. They moved to the gentle slopes in the dry season, a place with many water dams and where getting food did not require use of a lot of energy since they were flat grounds. Elephant distribution densities in Mpala were influenced by woody cover, water availability, human settlements, cattle bomas as well as the seasonal forage availability.

Keywords: Mpala, Elephant distribution, Elevation gradient, Woody cover, Environmental variables

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1. INTRODUCTION

1.1. Background

Elephants have successfully inhabited tropical, subtropical and temperate zones of the world, and their cousins, the woolly mammoths inhabited sub-arctic and temperate regions. Up to date they can still be found in the arid and semi arid ecosystems of East and Southern Africa, as well as the lush tropical forests in the West and Central Africa. Within these ecological zones, elephants are noted to occupy diverse range of habitats from deserts (Viljoen & Bothma, 1990) to rainforests (White et al., 1993), thus are termed as generalists since they can adapt to a wide range of habitats. A lot of studies have been published on African elephants and this can be attributed to their vast ecological contributions, including opening up of thick forests or bushy landscapes, aiding in survival of either other animals or vegetation species (Pringle, 2008; Blake et al., 2009; Majid et al., 2011). This has made elephants to be described as the keystone species to the environment (Pratt & Gwynne, 1977; Tafangenyasha, 1997). Elephants have also been shown to act as "ecosystem engineers" playing a major role in ecological dynamics and shaping of the savanna ecosystem (Jones et al., 1994). For instance, they are important seed dispersers due to their rapid and long-distance movements. Hence, their conservation is critical to the maintenance of ecosystem's function (Campos-Arceiz & Blake, 2011) as well as detecting early signs of a deteriorating ecosystem. Furthermore, elephants act as source of revenue not only to the government but also to the local community where they are found. They are however, classified as vulnerable species under the International Union for Conservation of Nature (IUCN, 1994). Given the threats they face and their importance, they should be given conservation priorities.

Elephants occupy heterogeneous habitats including arid and semi arid areas, bush lands, pastoral lands, private and small scale agricultural settlements (Thoules, 1996). Previous studies involving elephant distributions have applied environmental factors to determine their spatiotemporal use of landscapes, for instance predicting habitat suitability (Rood et al., 2010), determining distribution factors (Ngene et al., 2009) or even detecting poaching hotspots (Kyale et al., 2011; Maingi et al., 2012). Understanding these ecological parameters for elephant distributions gives insights into the expected distribution patterns in the study area and therefore, aiding in the decision making on management as well as conservation.

Accurate monitoring of elephants across the heterogeneous extended habitat is challenging since data collection is labour demanding and time consuming. Therefore, the advent of geographical information systems (GIS) and remote sensing (RS) has added value to elephant population monitoring. It provides more efficient and cost effective data retrieval methods as well as, processing and storage options. Conventional approaches on elephant data collection methods include those of tradition physical field observations using transects (Moss, 1996), satellite tracking systems, such as radio tracking using very high frequency (VHF) (Hebblewhite & Haydon, 2010) and the geographical position system (GPS) collars (Douglas-Hamilton, 1998) to relate animal distributions to the environmental factors. These data collection methods have been applied by various studies when determining elephant distributions and the spatial relationships with their habitat (Wittemyer, 2001; Thouless, 1995; Ngene et al., 2009).

An important area for elephant conservation in Kenya is Laikipia. Analysis of Laikipia historical data shows that elephants were not found in this district in the northern Kenya until 1940s and 50s (Thoules, 1993), after which their population have increased. Aerial count of Laikipia-Samburu elephants in

November 2008 indicated a population increase of up to 27% from the year 2002 (Litoroh et al., 2010). Thus, Laikipia-Samburu ecosystem has been known as the second important elephant ecosystem with the largest population of free ranging elephants in Kenya after Tsavo ecosystem (Omondi et al., 2002).

Within Laikipia, the area of Mpala can be considered "a special elephant area". By the end of December 2013, 12% of Laikipia-Samburu elephants were recorded in Mpala. Possible reasons for this high elephant populations in Mpala has been attributed to its strategic location at the core of elephant migration corridor (Thoules, 1993), the abundance of resources such as surface water availability through the constructed water dams making water available throughout the year, lack of tourism therefore minimal human disturbance and lastly, lack of perimeter fence therefore allowing free movement of elephants in the study area.

Though Laikipia-Samburu elephant population shows an increasing trend, few scientific studies of this population have been published (Khaemba, 2001; Graham et al., 2009; Thoules, 1993; Thoules, 1996; Thouless, 1995). Of these studies, a few have actually looked at the elephant spatial distributions and seasonal movements. These were conducted at a large spatial extend of the whole of Laikipia. Therefore, a local based study at a smaller spatial extend was necessary for meaningful conservation and management decisions, since it gives the exact environmental factors influencing the spatial distributions and use of the area of interest. Thus, for the past five years, Mpala has been conducting an elephant monitoring project to identify and document individual elephant groups using Mpala (Kinnaird, 2009). The present study consisted part of the Mpala elephant monitoring project. Elephant data were collected through the traditional ground survey method and combined with GIS and satellite data to characterize the spatial distribution of elephants in Mpala. The findings were further analyzed to determine environmental factors that influence elephants to Mpala.

1.2. Factors determining elephant spatial use and distributions

A number of environmental factors have been suggested to influence distribution densities of elephants in a specific area. These include forage availability, water abundance, type of the landscape, precipitation associated variations and human presence. These factors can be classified into two groups; those due to anthropogenic influence. These are factors caused as a result of human impact including, human activities such as human settlements for example; offices, villages, roads and boundary fences (Hoare & Du Toit, 1999; Ngene et al., 2009; Harris et al., 2008) and those of biophysical influence, which are factors that are naturally occurring and have no human influence, including vegetation (Kinahan et al., 2007; Codron et al., 2006), rivers (De Boer et al., 2000; Harris et al., 2008) and terrain (Nellemann et al., 2002; Ngene et al., 2009).

Water and forage availability are major requirements for elephant survival and have been shown to affect their distribution. For instance, Young, (1970) found that elephants in Kruger national park needed water twice in a day during the dry season. This phenomenon has been shown to describe why elephants especially breeding herds stay closer to water sources in dry season, but disperse off during rainy season when water is not a limiting factor (Harris et al., 2008). Clustering of elephants around water holes in dry season was also observed by Chamaille-Jammes et al., (2007) in their study of elephant distribution and interaction with surface water availability in Hwange national park, Zimbabwe. Other studies that have linked elephants distribution to water availability are those by Smith and Kasiki, (2000) in Kruger national park, South Africa and Ngene et al., (2009) in the protected areas of Marsabit national park and reserve in Kenya.

Elephant diet preferences and forage availability has also been shown to influence their distributions. Laws, (1970) in his study of diet preference for elephants in Queen Elizabeth's national park Uganda, noted that grass was the dominant elephant forage, accounting for 53% to 75% while browse and herbs constituted only 6% and 19% of elephant diet respectively. Study of forage preference for Maputo elephants in Mozambique by De Boer et al., (2000) showed that elephant diet constituted of 60% browse and 31% grass, while analysis of elephant dung for dietary preferences using carbon isotopes by Codron et al., (2006), revealed high consumption of grass. Vegetation apart from being used by elephants as forage, it has also been shown to provide shade and shelter during hot weather (Kinahan et al., 2007). Laws, (1970) mentioned that elephants graze for energy while they browse for protein, suggesting the importance of vegetation in determining elephant distributions.

Topography is another ecological and habitat component that has been shown to influence distribution of elephants. Ngene et al., (2009) noted that elephants in Marsabit ecosystem used elevation lower than 500m to those greater than 1600m, while in Samburu, Wall et al., (2006) found elephants to avoid elevation rising above 300m. Elevations can influence elephants distributions directly or indirectly, for instance Ngene et al., (2009) noted that elephants in Marsabit used higher elevations in dry season due to abundance of forage while they avoided the same heights in wet season for being slippery and could cause injury. Vector ruggedness measure (VRM), is a measure of topography defined as uneven, rocky and steep landscape (Sappington et al., 2007). It is used to evaluate relatively flat grounds where slope cannot be an effective measure. Thus, it is an effective measure of terrain roughness, effectively capturing variability in slope and aspect into one single measure (Nellemann et al., 2002). Its use was adopted from the method first proposed by Hobson, (1972), and its application in wildlife distribution studies include that of Sappington et al., (2007), to study bighorn sheep in Mojave desert. Their findings showed terrain roughness having a major role in the distribution of the sheep. De Knegt et al., (2011) coupled elevation with slope to describe elephant habitat in Kruger national park.

In free ranging areas, human factors such as human settlements activities have been noted to influence elephant distributions (Harris et al., 2008; Hoare & Du Toit, 1999). For instance, elephants in areas where their distribution ranges overlap with that of humans have been noted to develop survival techniques to coexist with the humans, for instance, by altering their behaviour, e.g. visiting water points at night instead of daytime when humans are active and using the same water points. They have also been shown to move faster and spend less time in highly fragmented landscape (Graham et al., 2009; Gara, 2014). These helping them minimize contact with the humans. Sitati et al., (2003), Hoare, (1999), Parker and Osborn, (2001) all noted that under circumstances of an overlapping distribution ranges between the elephants and humans, there was an increased conflict reports. This is ascribed to the fact that conflict incidences were related to the spatial factors such as human encroachment, land conversions land fragmentation among others, resulting into competition for resources between the elephants and the humans. Elephant in Marsabit ecosystem in Kenya were found to cluster near human settlements in dry season because of shared water resources with humans in this ecosystem (Ngene et al., 2009).

GIS and remote sensing has also been applied to understand elephant distributions for instance, development of hyper-temporal remote sensing data such as vegetation indices, digital representation of earth surface through digital elevation model (DEM). They have given ecologist and wildlife managers an opportunity to link elephant distribution data with the remote sensing data therefore, improving in management as well as decision making. Vegetation indices such as NDVI or EVI, are always used as surrogates for forage availability and productivity (Pettorelli et al., 2005). They have also been shown to perform well as indices of above ground biomass in drier savanna areas where they are closely related to rainfall availability (Coe et al., 1976). Vegetation indices values correlates to above ground productivity and higher values are related to higher vegetation vigour translating to dense vegetation cover. Primary productivity measured by the vegetation indices have also been shown to influence elephant spatial use of an area. For instance elephant density increases with an increase in productivity of specific areas.

Seasonal variability as dictated by rainfall and forage availability affects ranging patterns of elephants eventually determining their distributions (Viljoen & Bothma, 1990).

1.3. Elephant distribution ranges

Description for distribution range here is according to Kernohan and Gitzen, (2001) as the extent of an area with defined probabilities of animal occurrence over specified period of time. Measures of distribution range of elephants can aid in understanding their ecosystem requirements in relation to various environmental factors. Estimation techniques of wildlife range size as discussed by Dixon and Chapman, (1980) can be separated into two. That is, either as statistical distribution loci or as non statistical method, both involving drawing polygons around the outer fixes and overlaying with the grid cells and then calculating the area under the polygons, to represent the range size. It is the simplest and commonly applied method, also called minimum convex polygon (MCP). MCP describes animal use of two dimensional space (Burt, 1943; Anderson, 1982; Kie et al., 1996). The advantages of its application in range size determination includes, easy computation as well as for comparison purposes since it is the widely published method (Burgman & Fox, 2003). Its application in the field of ecology include that by IUCN, (1994) in classification of animals species as critically endangered.

This agreed upon approach for measuring animal range sizes based on computation of area under the polygon has however, been criticised because of its inability to show intensity of animal spatial use of an area (Harris et al., 1990). This therefore, led to the emergence of utilization distribution (UD) techniques. Utilization distribution is a method for describing probability frequency of location data over a period of time and kernel density estimate (KDE) is the method commonly used (Kernohan & Gitzen, 2001).

Previous studies that have applied MCP method in determining elephant range sizes include those of (Thoules, 1996; Alfred et al., 2012; Leggett, 2006). They all found variation in elephant ranges sizes, for instance the widest variation in elephant range size ever recorded from a single population as well as the largest elephant range size ever recorded.

1.4. Kernel density estimation

Species range can operationally be defined as an area where probability of finding individual animal species is greater than some defined values or an area containing subjective proportion of the total species population (Fortin et al., 2005). Since species tenancy varies across the geographical range. Characterization of their spatial abundance can be of valuable insight to their response on ecosystem changes as well as variability of the habitat.

Point data occur in specific geographical locations with time scale. Therefore, spatial data analysis technique can be applied to describe their pattern in space, and relate it to the ecological features on the ground to find out the suitable ecological explanations on the observed relationship with the ecosystem. Several methods have been invented to estimate probability densities, but the commonly used is the kernel density estimation (KDE). This is because of its statistical attractive properties such as graphical representations as well as probability density functions for analysis. Thus, it has been referred to as the true probability density function (Fortin et al., 2005).

Kernel is a moving three dimensional function used to weigh points in accordance with their distances from where the estimation is being done. It functions by giving heavier weights to nearby events than those far off (Gatrell et al., 1996), resulting into smooth estimation of variability in concentration. This has made it become a renowned way of visualizing point pattern probabilities depicted by the species in question hence, its application in determining occurrences of hotspots. The degree of smoothness in kernel density estimate is determined by the bandwidth size used. Bandwidth is the length of search radius within which the kernel exerts its influence. For reference purposes, appropriate bandwidth selection for kernel density should have meaning to the context of the study. For instance, kernel estimation for distribution of a given species should be estimated using bandwidth relative to its home range.

Its estimation have been found to perform better compared to other methods in terms of accuracy and precision (Worton, 1995). However, it has been criticized on its inability to counter edge effects. Though, Gatrell et al., (1996) recommends two possible solutions to this problem. One would be to leave suitable buffer around the study area. The other would be to normalize the kernel function by assigning more weight to the points closer to the boundaries. Previous studies that have applied kernel density in modelling wildlife hotspots include mortality hotspots of wildlife along Australian road (Ramp et al., 2005), detection of elephants poaching distribution hotspots in national parks of Kenya (Maingi et al., 2012; Kyale et al., 2011).

1.5. Land cover mapping

Remote sensing has been described as a vital information source for land cover mapping giving reliable land cover information for necessary decision making and policy formulation, but these are often missing or insufficient. (Wyatt, 2000; Han et al., 2004). Landsat images have been successfully used to map land covers especially, studies involving natural resources (Cherrill et al., 1994; McCarthy et al., 2005; Muller et al., 1999). Generating a map from satellite imagery involves digital processing of multispectral images when relying on the spectral reflectance of each pixel in the image. Spectral characteristics exhibited by various land covers present in the study area forms distinct spectral signature that can discriminate one feature from the others (Lillesand et al., 2008). By applying one of the several classification methods one can derive either land cover or land use images for analysis.

Two of the commonly used image classification techniques include, supervised or unsupervised image classification (Jensen, 2005). Supervised classification requires before hand knowledge of the area of study. Hence, it combines fieldwork, aerial photograph interpretations, map analysis and personal experience to spectrally define and separate classes (Lillesand et al., 2008). Unsupervised classification on the other hand uses computer programmed settings to group pixels with similar spectral characteristics into unique clusters according to the set statistical method. Thus, it is handy when one is working in an area they are not familiar with.

After classification, it is important to validate the image produced using reference data (Congalton & Green, 2009). The overall accuracy is the commonly applied validation measure to determine the accuracy of the classified image however, it is never convincing. Therefore, Cohen's kappa statistics is always accompanied with the overall accuracy. It is defined as a measure of agreement between the classification map and the reference data (Cohen, 1960). It has been noted as one of the suitable derived confusion matrices because, it uses maximum information provided by the confusion matrix to determine the accuracy (Fielding & Bell, 1997). Some of the previous studies that have either incorporated classified image with other spatial data to address spatial concerns of elephant problems include (Rood et al., 2010) or produced classified image while studying elephant habitat (Harris et al., 2008).

1.6. Problem statement

Elephants have been regarded as one of the key drivers in biodiversity change. However, most of the studies linking their distribution to biophysical and anthropogenic factors are largely derived from southern Africa. A few for example, (Ngene et al., 2009; Thouless, 1993; Douglas-Hamilton, 1972; Thoules, 1996; Thouless, 1995) have actually focused in East Africa northern Kenya. Surprisingly, even within the studies carried out in relatively comparable southern Africa regions, there are variations in conclusions about the factors for elephant distributions. For instance Codron et al., (2006) concluded that Kruger national park elephants preferred grazing to browsing, while De Boer et al., (2000) concluded that Maputo elephants preferred browsing to grazing. This controversy in conclusions indicates that characterising environmental factors for elephant distribution need to be area specific.

While elephant population have been noted to decline over much of their former ranges (CITES, 2013), this is not true for Laikipia-Samburu region and Mpala as well. Elephant population in fact is increasing (Litoroh et al., 2010) and their spatial distribution in these areas has not been sufficiently studied. Previous studies on elephants in this diverse area have included a range of topics including, human elephants interactions (Graham et al., 2009), animal census (Litoroh et al., 2010), home ranges and social organization (Thouless, 1996), spatial point pattern analysis (Khaemba, 2001) and migration (Thouless, 1995). All these studies were conducted at a large spatial extend of Laikipia region and therefore cannot be reliably used to interpret and understand smaller spatial extend interactions for instance Mpala ecosystem. Marshal et al., (2011) in their study of pattern of habitat use by elephants concluded that aspects regarding nature and its mechanisms for a particular ecological process are strongly dependent upon the scale at which they are investigated. Therefore this study describes the elephant distribution mainly at a smaller spatial extend to understand factors for elephant spatial distribution and use of Mpala ecosystem.

1.7. Research objectives

The main objective of this study is to characterize the spatial distributions of elephants in Mpala. The specific objectives include:

- To estimate and compare seasonal distribution range sizes of elephants in Mpala.
- To estimate and compare seasonal distribution densities of elephants in Mpala.
- To compare seasonal distribution densities of elephants based on elevation gradient of Mpala.
- To map and quantify woody cover in Mpala.
- To determine environmental factors influencing seasonal distributions of elephants in Mpala.

1.8. Research hypotheses

- Seasonal range sizes of elephants in Mpala are influenced by availability of water and forage resources.
- Utilization distribution densities of elephants in Mpala are similar across all seasons.
- Seasonal densities of elephants in Mpala do not vary amongst the elevations

2. MATERIALS AND METHODS

2.1. Study area

Mpala is located to the north of the equator, northwest of Mount Kenya on Laikipia plateau (Figure 1) (36°53'52"E, 0°17'32"N). It covers approximately 200km² of semi-arid savanna (MRC, 2009). Climate is described as having north-south rainfall gradient, with weak tri-modal annual pattern. Rainfall peaks in April-May, August and October and a consistent dry season in the months of January to March (Goheen et al., 2013; Pringle, 2008; Augustine, 2003; Augustine & Mcnaughton, 2004).

The geology of Mpala is predominantly friable sandy loams derived from metamorphic basement rocks. A region of high clay content black cotton soil developed from volcanic rocks occurs to the southwest (Ahn & Geiger, 1987). Dominant woody species in this high clay region is *Acacia drepanolobium* (whistling thorn). It is characterised as small tree of up to 6m tall. Individual trees have swollen and hollow spines inhabited by symbiotic ants that have been noted to defend it against herbivores (Palmer et al., 2010). Altitude ranges between 1400m-1900m above sea level. Topography consists of gently rolling hills and occasionally granitic inselbergs. It is bounded by two permanent rivers, Ewaso Nyiro to the East and Ewaso Narok to the north (MRC, 2009). Apart from the permanent rivers, Mpala has twenty water dams constructed mainly for the ranch cattle but also shared with the diversity of wildlife found here.

Vegetation in the study area is characterised as open Acacia thicket, underlained by a discontinuous herbaceous layer. Woody vegetation is dominated by acacia tree species primarily *Acacia brevispica*, and *Acacia etbaica*, but also *Acacia mellifera*, *Acacia gerrardii* and *Acacia nilotica*. Other shrubs like species include *Croton dichogamus*, Grewia species and *Rhus vulgaris*. Two vegetation invasive species in Mpala are *Euphorbia nyikae* common in the north and *Opuntia ostrica* common in the south. Wildlife here includes impalas, common zebras, scrub hares, waterbucks, cape buffaloes, elands, guenther's dik-dik, rodents and elephants. Predators include spotted hyena, lion, leopard and wild dogs.

Mpala practises cattle ranching using the traditional Maasai herding method (Augustine, 2003). It has no perimeter fence and therefore wildlife movement in Mpala is neither limited nor restricted. There are daily patrols by the ranch rangers both on foot and on cars. Security camps are strategically located within the study area. Mpala hosts an active research centre with various long term study plots which are fenced using electric fences (KLEE, 2012; UHURU, 2014).

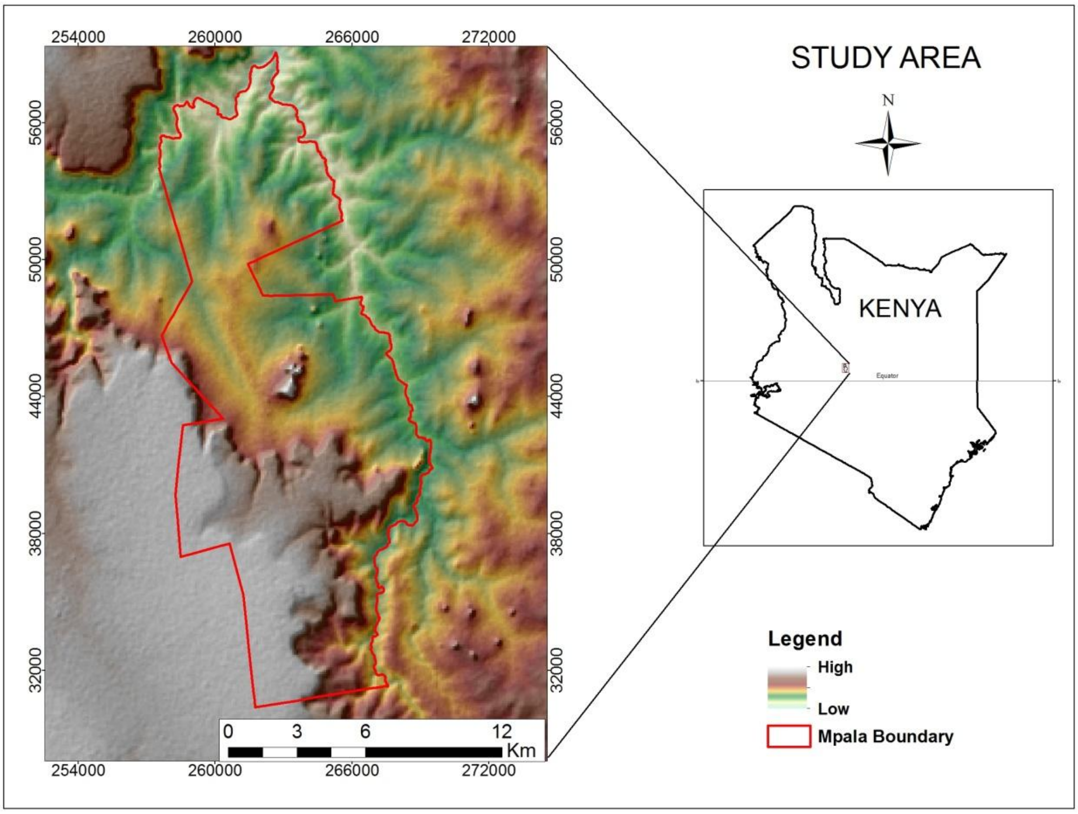

Figure 1: Location of the study area in Kenya and a hill shade map showing the topographic characters of Mpala.

2.2. Elephant observation data

This study used elephant data obtained from Mpala elephant monitoring project. The data were from January 2011 and June 2013. Most of these data were collected by the author. A section of the dataset not collected by the author included records from the months of August to December 2013, but was used in the analyses as well, since the method of collection was the same. All the elephant records were collected within the demarcated boundaries of Mpala using a 4x4 vehicle along existing roads and off roads where navigation was possible (Figure 2). Average numbers of observation days per month were 18. An Individual elephant was recorded once in that particular day it was met. All the data were collected using a hand-held global positioning system unit (GPS) Garmin 60 model with a spatial error of 5m. Datum and projection of the data was ARC 1960 and UTM respectively, zone 37N. Unit of measurements were in meters.

In the field, when an elephant was sighted, an attempt was made to approach and observe it as close as 20m. This was necessary for accurate identification as well as reliability of the data taken such as total count as well as accurately identifying the individual identity marks such as ear notches. Records collected included; date, time and the GPS location. Identity of conspecifics such as group type (bull, cow, mixed, lone bull/calf or female), group size and group activity were also recorded. Individual associations and behavioural interactions were also observed and recorded. Those individual elephants that were observed within 500 meters of each other were defined as belonging to one group (Wittemyer et al., 2005).

Figure 2: Ground observation data collection method.
Courtesy of Mpala elephant project.

All the elephants sighted within the study area were classified into various groups of family units, consisting of related breeding females and their offspring (Figure 3). Individuals in the family group were also identified using sex, age and features unique to them, such as ear patterns (nicks and tears), tusk size and shape as well as other permanent scars or injuries (Douglas-Hamilton, 1972; Moss, 1996). Digital photographs and drawings of these features were also taken and used to develop the identification catalogue (Figure 4). No individual elephant was allocated to more than one group. Family units were organized and coded in alphabetical order of discovery from AA to AZ, followed by BA to BZ and so on. By December 2013, 86 family units, 130 bulls and a total of 890 individual elephants had been recorded in Mpala.

For this study a total of 808 elephant location data were selected from the Mpala dataset and used in the analyses. To select this part of the data, the available elephant dataset was first defined based on female elephants with matriarchal society of known individuals. This was necessary because bull elephants are known to be transient and responds to social factors other than ecological factors (Thouless, 1993). A criterion of at least 10 sightings per season was used to select only those family groups with the most sightings. This criterion was applied due to the low temporal resolution of the individual family sightings data. A total of 28 family groups met the criteria. Some family groups appeared in both seasons while others appeared once. Since data were defined seasonally, reappearing of family in both seasons was assumed to have no implications on the further analysis. The selected elephant data were then classified into the wet and the dry seasons according to climate description by Augustine and Mcnaughton, (2004) (Table 1).

Table 1: Summarized seasonal elephant datasets available for this study based on elephant families

Point shapefile	Number of records
Wet season	450
Dry season	358

Figure 3: Typical cow calf family unit in Mpala.
Courtesy of Mpala elephant project.

Figure 4: Digital photograph of female elephant showing ear notches.
Courtesy of Mpala elephant project.

2.3. GIS and remote sensing data

2.3.1. MODIS NDVI

Three years (2011-2013) time series of 16 day composite, 250 meter resolution MODIS Normalized Difference Vegetation Index (NDVI) Terra sensor data (MOD13Q), were downloaded from Land Processes Distributed Active archive Centre (LP-DAAC), via Reverb Echo website (NASA, 2014). NDVI is an index of vegetation greenness and is based on the following equation;

$$\mathrm{NDVI} = (\mathrm{nir} - \mathrm{red})/(\mathrm{nir} + \mathrm{red}) \quad (1)$$

Where red and nir are the surface reflectance values of the first and second spectral bands of MODIS.

Each year consisted of 23 composite dimensions. One tile (H21V08) of the MODIS data was required for the study area. From each composite dimension, NDVI information was extracted. NDVI images were then stacked into two mega files of the wet season and the dry season months according to (Augustine & Mcnaughton, 2004). Each mega image was then converted from sinusoidal to Universal Transverse Mercator projection zone 37N. The images were then clipped through subset to the area of study boundary. The above processes were conducted in Erdas Imagine 2014. To reduce potential noise of clouds and outliers, but keeping data consistency, the images were de-clouded, de-hazed and outliers removed by using modified version of adaptive Savitzky Golay filter (ASAVGOL) (Beltran-Abaunza, 2009), in ENVI-IDL "NRS-Timeseries". Seasonal mean and standard deviation of the cleaned data were then computed in ENVI IDL for use in the analysis. These data were necessary for this study to simulate forage availability as well as forage variability (Pettorelli et al., 2005).

2.3.2. Landsat 8 satellite imagery

Landsat 8 satellite image of 30m spatial resolution of 1st October 2014, was downloaded from the United States Geological Survey (USGS, 2014). The image was preferred because of three reasons first, it was the nearest date to the fieldwork dates therefore, minimal phenological variation with the collected reference data. Secondly, because the image was acquired at the beginning of wet season and therefore it was easy to spectrally separate cover classes, and thirdly because this image had no clouds cover on the area of study. Spectral bands (1-7) were then layer stacked using Erdas Imagine 2014. Landsat 8 satellite image data was then converted from WGS 1984 to ARC 1960 Universal Transverse Mercator projection zone 37N. The image was then clipped through subset to the area of study boundary in Erdas Imagine. Landsat 8 satellite image was used to classify woody cover based on the training reference data collected during fieldwork. This information was necessary as one of the environmental factors in modelling factors for elephant distribution. But it was missing from GIS office in Mpala.

2.3.3. GIS data

Table 2 is a summary of GIS data layers collected during fieldwork their formats and sources. Some of these data were provided by Mpala GIS office, but some were either collected or updated during fieldwork. For both new and updated datasets, locations were recorded using handheld IPAQ 200 GPS series with a spatial error of 3 m. Coordinates for new datasets were collected by applying procedure described by Ngene et al, (2009). That is coordinates were taken from the centre and the peripheries, since these were features with geometrical shapes. The datasets were then imported into ArcMap 10.2.2 to create point shapefiles with their respective attributes.

Table 2: GIS data collected during fieldwork their formats and sources.

Data	Format	Source
Mpala boundary	Polyline	Mpala GIS office
Cattle bomas	Point	Mpala GIS office
Fenced plots	Point	Fieldwork
Security bases	Point	Fieldwork
Ranch and MRC offices	Point	Fieldwork
Ranch and MRC villages	Point	Fieldwork
Campsites	Point	Fieldwork
Roads	Polyline	Mpala GIS office
Rivers	Polyline	Mpala GIS office
Water dams	Point	Mpala GIS Office/Updated
Digital elevation model	Raster	ASTER DEM 30m

2.4. Estimating wet and dry seasonal elephant distribution range sizes using minimum convex polygon

Elephant distribution range here was defined as a coarse representation of the total area extent within which each elephant family was spatially located. From the available seasonal datasets, 8 random elephant family groups were selected from each season using Microsoft office excel 2007 random function. These family group location data were then used to compute individual family groups seasonal range size. Minimum convex polygon (MCP) method was applied to determine family ranges sizes using all the location data from each family group. MCP range size estimations were conducted by applying convex hull algorithm in ArcMap 10.2.2. This gave the 100% MCP. Area for each computed seasonal MCP was calculated to represent range size of the respective elephants group in that particular season. These were assumed as the general seasonal range sizes of elephant families using Mpala.

Independent samples t-test was then used to determine whether there was statistically significant difference in the computed seasonal range sizes. This method was used because both seasonal range sizes data met all the assumptions for using this test. Including; lack of outliers which was assessed using boxplots, normal distribution at significance level of $p>0.05$ assessed using Shapiro-Wilk and homogeneity of variances assessed using Levene's test at a significance level of $p>0.05$. The interpretations of the results were based on range size averages, their standard deviations and pooled variances. Analysis was done using R (R Core Team, 2014).

2.5. Estimating wet and dry seasonal elephant distribution patterns using kernel density estimator

Measures of spatial distribution densities were based on seasonal point pattern analysis of utilization distribution and spatial intensity of visits per grid cell. Spatial utilization and distribution intensity were computed using kernel density algorithm in ArcMap 10.2.2. All the available elephant seasonal location data were used during kernel density estimation analysis. This analysis was applied to determine the probability distribution density surfaces for elephants in each season. Kernel density requires that searching radius be specified. It is always recommended to use a searching radius relative to the distribution range of the elephants. However, for this study, half the averaged range size (3km) was used when computing density surfaces for both seasons. This was observed to ensure better visualization of the hotspots because of the small size of the study area. A 10 kilometre buffer of Mpala boundary was also generated and used during kernel density estimation, this buffer was considered sufficient to reduce edge effect. Spatial cell size output was set to 250m. Core utilization areas for elephants in Mpala were determined at 50%, 70% and 95% intervals of the elephant location data. These were plotted on a bar graph for visualization of the core utilization sizes differences between the wet and the dry seasons.

To compare seasonal distributions densities, distribution surfaces data were overlaid on ArcMap 10.2.2 and 50 random surface values extracted. This process was done by applying spatial analyst extraction tool in ArcMap 10.2.2. The extracted probability surface random values were then compared using Independent sample t-test. This method was used because both the wet season and the dry season data met all the assumptions including; lack of outliers which was assessed using boxplots. Normal distribution was tested using Shapiro-Wilk test at significance level of $p>0.05$ and homogeneity of variances tested using Levene's test at significance level $p>0.05$. The interpretations of the results were based on the averages of the seasonal data, standard deviations and the pooled variances. Analysis was done using R (R Core Team, 2014).

2.6. Determining the relationship between seasonal elephant distribution densities and elevation ranges

To determine elevation gradients of the study area, a Digital Elevation Model (DEM) 30m of Mpala was reclassified by applying Jenks natural breaks classification method in ArcMap 10.2.2. This method was chosen due to the small range of elevations in Mpala therefore, there was a need for a method that could make the distinct elevation classes as different as possible while making them as similar as possible. Thus, the application of Jenks was deemed justifiable for this process. Advantage for its use is that it identifies real classes. The DEM image was reclassified into three classes of elevations. These were low elevation (1484-1659m), medium elevation (1659-1737m) and high elevation (1737-1872m) (Figure 5). Reclassified DEM image was then overlaid with both the wet and the dry season's probability density surfaces. Then 100 random values of the density surfaces extracted from under each elevation. The points were randomly distributed among the elevations as follows; low elevation ($n = 32$), medium elevation ($n = 34$) and high elevation ($n = 34$).

Elephant distribution densities among the elevations were then compared using non parametric Kruskal-Wallis test. This test was used because at least one of the elevation data did not follow a normal distribution (Shapiro Wilk test, $p < 0.05$). In case of significant difference in elevation distribution densities in either season's data, a pairwise comparison between the elevations of that season was conducted using Wilcoxon rank sum test. A bar plot of the distribution density mean amongst the elevations were also produced to aid in visual interpretation of the results between the two seasons.

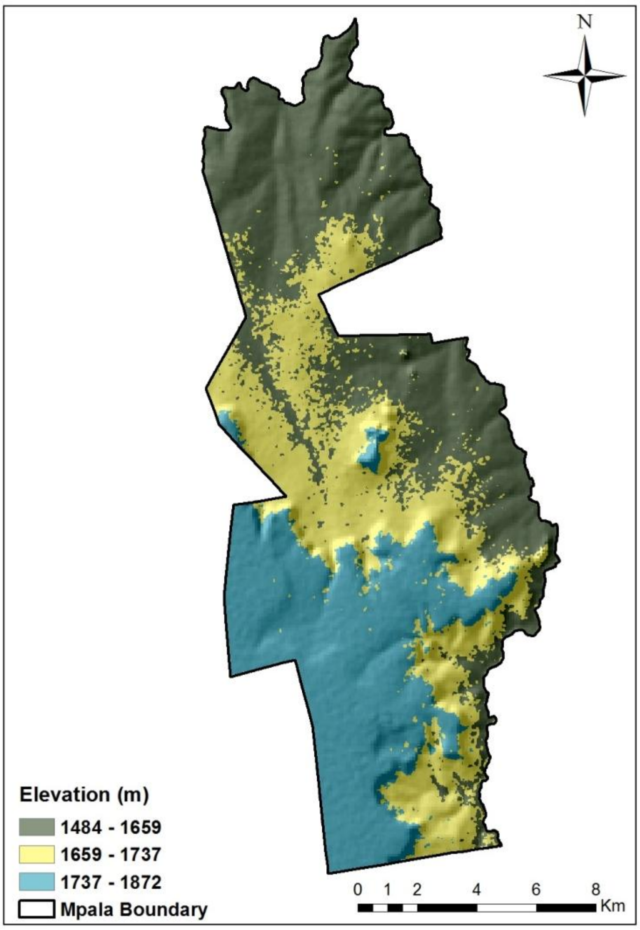

Figure 5: Reclassified DEM 30m showing elevation gradients in Mpala

2.7. Maping woody cover from satellite image

Woody vegetation was defined according to Food and Agriculture Organization of the United Nations (FAO) as the plants that use wood as part of their structural support FAO, (2000). While in the field shrub and herb plants with developed woody stems of at least 2 meters were also classified as woody vegetations and were included during estimations of the plot tree cover. Landsat 8 satellite image was used to classify woody cover of Mpala into three woody classes. These classes included; high, medium and low woody covers. To validate the accuracy of the image produced, fieldwork was carried out between 10th and 25th September 2014 to collect reference data.

2.7.1. Ground truth data collection

Application of Google earth image coupled with stratified random sampling were used to determine reference data locations prior to actual fieldwork dates. Google earth image was visually interpreted to define the pre-determined cover classes forming strata. Interpretation of the image relied mostly on the ocular interpretation of the tree canopy covers on the Google earth image. The defined strata were then assigned random point locations proportional to the size. Selection of sample points based on random strata was applied to limit bias when choosing sample locations.

In the field, each location point was given a allowance of maximum of 50m from the original point if it was impossible to reach. After which then it was considered null. Plot sizes of 50mx50m were staked out around each pre-determined sample centre point and the percentage tree cover then visually estimated on each plot including woody herbs and shrubs. The estimated percentage tree covers were then used to assign each plot as either having high, medium or low woody cover. This was based to criteria found in (Table 3). Percentage cover estimate ranges used for each class were determined based on interpretation of the Google earth images and expert knowledge on spatial woody cover of the study area, with reference to plot sizes used. A total of 115 reference data were collected from the fieldwork and classified into the three predetermined woody classes (Table 3). The instruments used during fieldwork were; IPAQ 200 series GPS unit with spatial error of 3m, 50m tape measure and a digital camera. Figure 6 are photographs taken while in the field showing examples of woody cover and how they were assigned into their respective cover classes.

Table 3: Ground truth data collection scheme.

Cover estimates	Cover class	Ground data collected
More than 50%	High woody cover	48
Between 15-50%	Medium woody cover	48
Less than 15%	Low woody cover	19

2.7.2. Image classification and accuracy assessment

Landsat 8 satellite image was used to classify spatial woody cover of Mpala into pre-determined cover classes according to Table 3. Supervised classification method was used by applying maximum likelihood classification algorithm (MLC) during classification in Erdas Imagine 2014. MLC was used because of its well known advantages over other classification techniques including; logical interpretations, feasible assimilations and simple realizations. To evaluate the accuracy of the map, the reference data were divided into two parts, that is training data and testing data. 60% of the data were used for training the image during classification, while the remaining 40% of the data were used for testing the accuracy of the image produced. Testing of the data was based on confusion matrix method using accuracy assessment in Erdas Imagine 2014.

Overall accuracy of the map was assessed based on user and producer accuracy indices. Higher user accuracy index suggested that the pixels were correctly classified while higher producer accuracy index suggested that the cover type was correctly estimated (Bakx et al., 2012). The classified woody cover image was validated by using Cohen's kappa. To quantify area for each woody cover class, the classified image was imported was imported into ArcMap 10.2.2. Using spatial analyst raster calculator, area for each woody cover class was computed in square per kilometre then converted to percentage cover of the study area. Lastly the image was converted to shapefile for better visualization of the spatial woody cover distributions in the study area.

(a)

(b)

(c)

Figure 6: Photographs taken during fieldwork showing percentage woody cover
(a) High woody cover, (b) Medium woody cover and (c) Low woody cover

2.8. Relating elephants distributions to the environmental factors using multiple regression analysis

2.8.1. Preparation of the environmental variables

To determine biophysical and anthropogenic factors influencing seasonal distributions of elephants, multiple regression analysis for the wet season and the dry season were conducted. The same variables were used in both regression models (Table 4). Variables used for this study were selected based on their potential influence on elephant distribution and their frequent inclusion in modelling elephant distribution from the previous studies (De Boer et al., 2000; Ngene et al., 2009; Kinahan et al., 2007; Rood et al., 2010). Preparation of the variables included creating distance surfaces of all the GIS datasets in ArcMap 10.2.2, by applying euclidean distance algorithm at a spatial resolution of 250m, same resolution as the kernel estimates of the probability distribution densities.

Cattle bomas were combined with the cattle dips. Human settlements included campsites, offices, villages and all the security bases. Slope gradient and vector ruggedness measure (VRM) were generated from Digital Elevation Model (DEM). Seasonal mean NDVI and standard deviation were also incorporated in the model as proxy for forage. NDVI mean was used as surrogate for forage productivity while NDVI standard deviation was used as forage variability. Woody cover layer was derived from the previously classified woody cover image. Image accuracy was 87%, this accuracy was above the recommend 85% for an operational accuracy (Anderson et al., 1976). Therefore it was deemed suitable it as one of the environmental factors. Before including the image, first it was pre-processed in ArcMap 10.2.2 through pixel aggregation based on mean values with a moving window size of 8*8 which corresponds to ground size of 240m*240m values, then resampled to 250m. Finally all the values from all the environmental variables were extracted using elephant location points. These were then imported into R statistics (R Core Team, 2014) for a backward stepwise regression analysis based on elimination method. Only statistically significant variables ($p<0.05$) were left for further analysis and interpretations of the results.

Table 4: Summary of the environmental variables used for multiple regression analysis.

Category	Independent variables	Description
Anthropogenic factors	Distance to fenced plots (dist. plots)	Euclidean distance to fenced plots
	Distance to settlements (dist. settlements)	Euclidean distance to human settlements
	Distance to roads (dist. roads)	Euclidean distance to roads
	Distance to cattle bomas (dist. bomas)	Euclidean distance to cattle bomas
Biophysical factors	Distance to rivers (dist. rivers)	Euclidean distance to rivers
	Woody cover	Classified woody cover
	Vector ruggedness measure (vrm)	Standard deviation of elevation
	NDVI Standard deviation (ndvisd)	Standard deviation normalized vegetation index
	NDVI Mean (ndvimean)	Mean normalized vegetation index
	Distance to water dams (dist. dams)	Euclidean distance to nearest water dam
	Slope	Rate of change in altitude

2.8.2. Testing model assumptions

Prior to running the regression analysis model, existences of collinearity among the predictor variables were tested using variance inflation factor (VIF). Multi-collinearity test was necessary since its existence can lead to inflation of standard deviations of the regression coefficients giving smaller t-values resulting in type II error. VIF rule of no variables having values greater than 10 was applied (O'brien, 2007). Correlations among partial regression scatterplots were also produced to examine linear relationship between each independent variable and the dependent variable. To determine correlation among the independent variables, Pearson correlation was applied. A rule of thumb of none of the independent variables should have a correlation greater than 0.7 was applied. The rest of the assumptions were tested and evaluated after running the regression models. This was because they could only be evaluated by inspection of the residuals. Test for autocorrelation of the residuals was conducted using Durbin-Watson statistics. Durbin-Watson rule of thumb of d=2 was applied to indicate that the assumption of no autocorrelation was met. Scatterplot of studentized residuals against predicted values with superimposed horizontal line was computed and used to examine for homoscedasticity, this assumption was tested by visually interpreting the spread of the residuals. Constant residual spread meant that the assumption of homoscedasticity of the residuals was met.

To detect outliers, influential points and normality of the residuals, regression diagnostics plots were produced and examined. A value of ±3 was used as the cut off point for determining outliers in residuals (Field, 2012). For leverage, values less than 0.2 were assumed to be safe and for Cook's distance values less than one (1) were accepted (Cook & Weisberg, 1982). To test for of normality, normal Q-Q plot of the studentized residuals were visually interpreted for approximation of the normality assumption and Shapiro Wilk test was used to test the significance of the normality of the residuals ($p>0.05$). Interpretations of the results were based on the adjusted R^2, regression coefficients, F-statistics and relative importance of the variables. Analyses of both seasonal multiple regression models were done in R (R Core Team, 2014).

2.8.3. Model Validation

Validations for the wet and the dry seasons multiple regression models were done using a 10K-fold-cross validation method. Data were randomly partitioned into equal subsamples. Single subsample was retained as a validation data for testing the model and the remaining 9 subsamples used as training data. It is repeated until all the subsamples are used once as validation data. All the folds mean square errors were then averaged and the obtained square root was compared to the residuals standard error of the model (Gara, 2014). Lower root mean square error meant better fit. One advantage of this type of validation process is that all observations are used for both training and validation. Analyses were done using R statistic package Data Analysis and Graphics Data functions (DAAG) (Maindonald & Braun, 2014).

3. RESULTS

3.1. Seasonal range sizes of elephants in Mpala

Distribution range sizes of elephants using Mpala for the three years indicated variation in range sizes. In the wet season range sizes varied from $17km^{-2}$ to $85km^{-2}$ while in the dry season range sizes varied from $27km^{-2}$ to $56km^{-2}$ (Table 5). The finding revealed that for the elephant groups that had data in the wet and the dry seasons, they showed tendency of maintaining their range locations but with a seasonal size variation. Most of the elephant distribution ranges were located in central Mpala. Overlapping of the distribution ranges was also evident from the computed results in the two seasons. Elephant range sizes were observed to concentrate next to the water dams in both seasons (Figure 8).

Independent sample t-test showed that there was no statistically significant difference in seasonal range sizes $t(14)= 1.156$ $p= 0.267$. However, wet season had higher mean and higher variations ($47 \pm 20.23km^{-2}$) compared to dry season having lower mean and lower variations ($38 \pm 10.84km^{-2}$) (Figure 7).

Table 5: Summarized findings of elephant range sizes in Mpala and family group sightings.

Season	Family	MCP area km^2	Total sightings
Wet season	BC	17	27
	AP	37	37
	AL	62	27
	AJ	55	40
	AF	85	28
	AH	45	13
	DK	45	12
	BU	36	15
Dry season	CK	28	30
	AP	27	28
	AJ	53	46
	AI	40	23
	AD	30	28
	BU	56	10
	CV	38	12
	BT	34	13

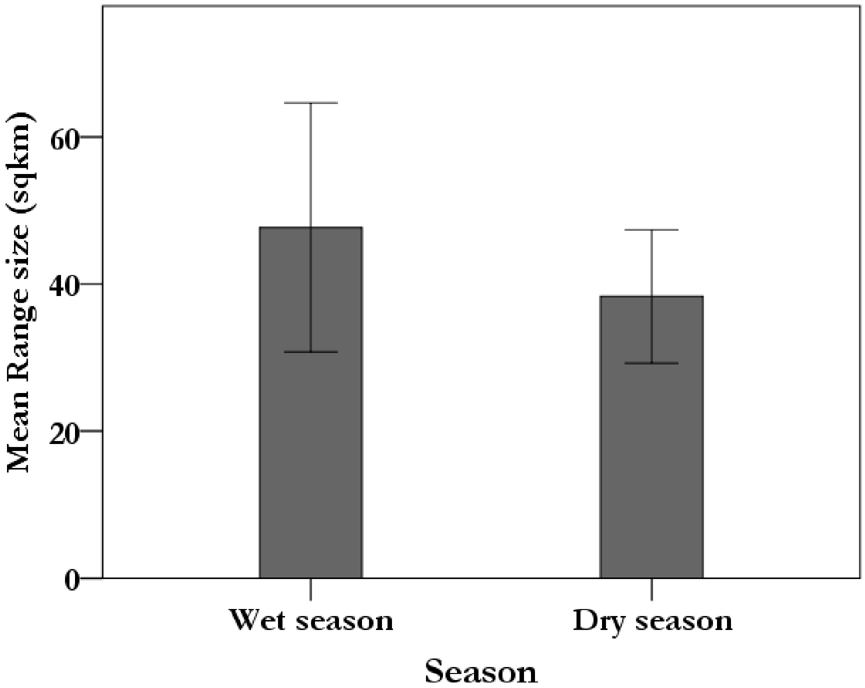

Figure 7: Mean elephant range sizes in wet and dry seasons in Mpala (n=16)

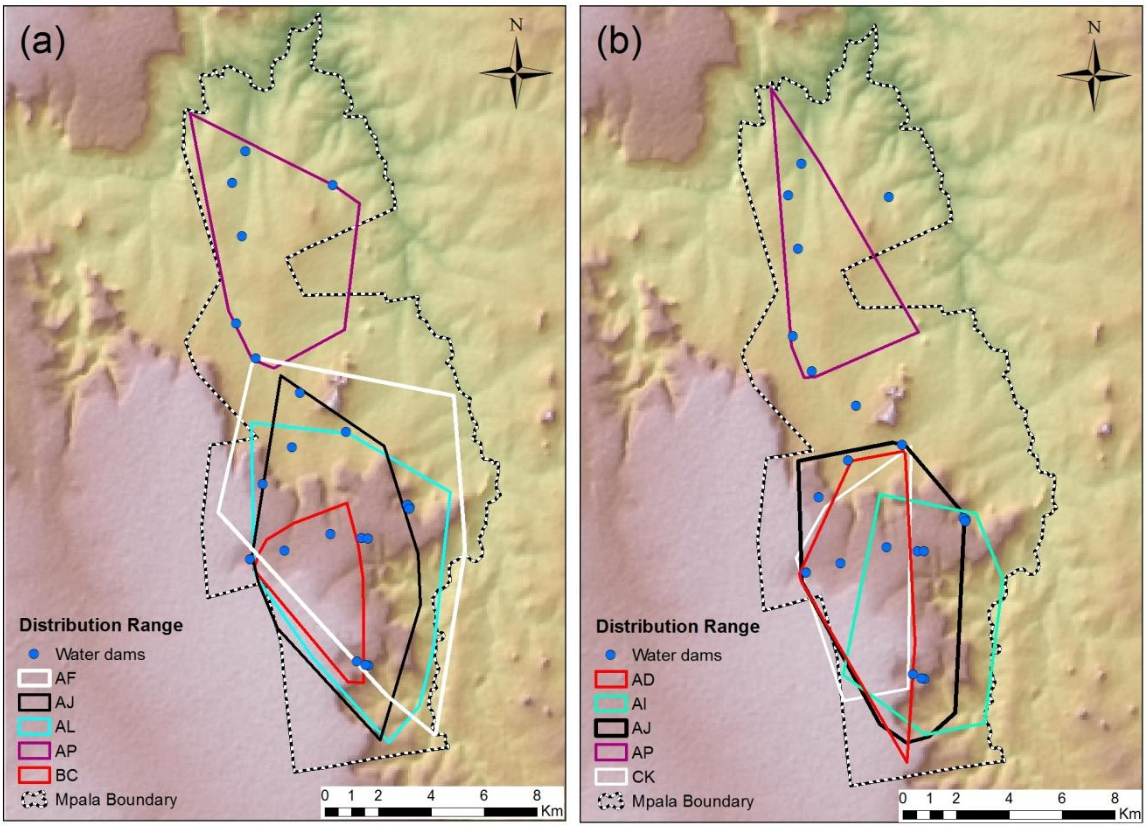

Figure 8: Subsets of seasonal MCP computed range sizes of elephants in Mpala.
(a) Wet season (b) Dry season.

3.2. Seasonal distribution densities and core utilizations

Seasonal kernel density surfaces showed hotspots of elephant spatial use spread almost covering the whole landscape of Mpala. Core utilizations were defined using 50%, 70% and 95% isopleths for the two seasons. Results revealed that wet season had larger isopleths compared to the dry season isopleths (Figure 9). In wet season, 50% isopleths revealed two core use areas (Figure 11a), but 3 core use areas in the dry season (Figure 11b). Observation of 70% isopleths, between the two seasons, were in same location that is, from the south to the central Mpala. Dry season isopleths had south west skewness as where elevation was found to be higher compared to wet season same isopleths. 95% elephant core utilization of Mpala extended from the southern Mpala to the northern Mpala with a break in the wet season while the dry season 95% was continuous to the north. Visualization of the core utilizations distribution revealed that they were concentrated around the water dams in the two seasons.

Independent sample t-test revealed no statistically significant difference in the distribution densities between the wet season and the dry season $t(98) = 1.045$ $p = 0.299$. Elephants had higher average densities in the wet season with lower variations (20.04 ± 10.62 elephants km^{-2}) as compared to the dry season with low average densities, but higher variations (17.73 ± 11.45 elephants km^{-2}) (Figure 10).

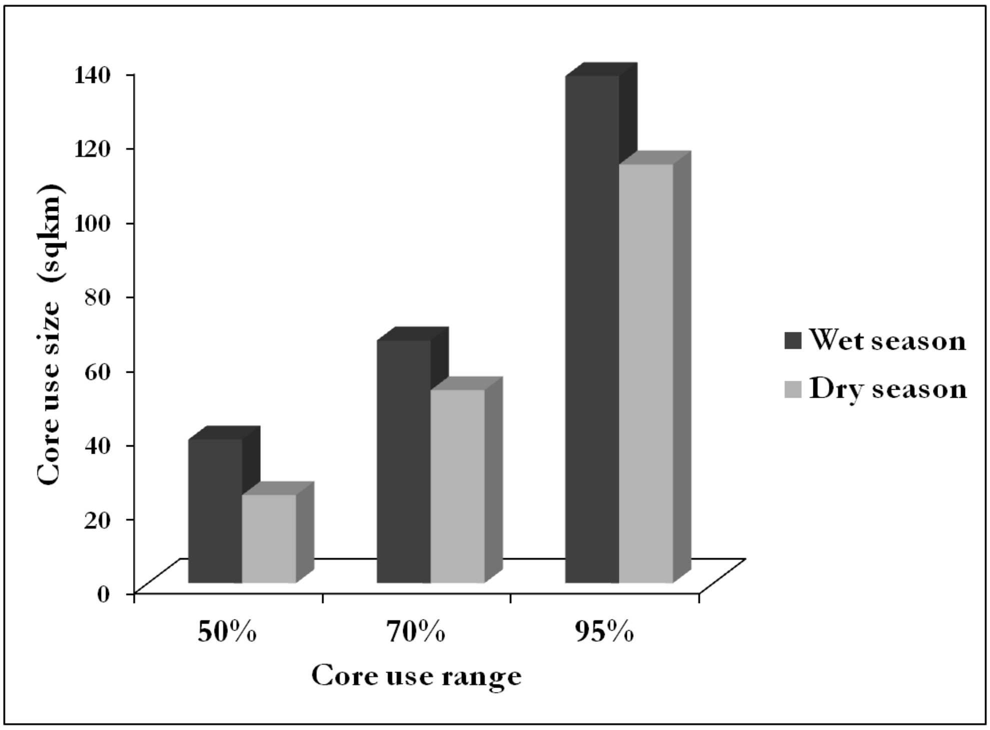

Figure 9: Comparing seasonal elephant core use isopleths sizes in Mpala

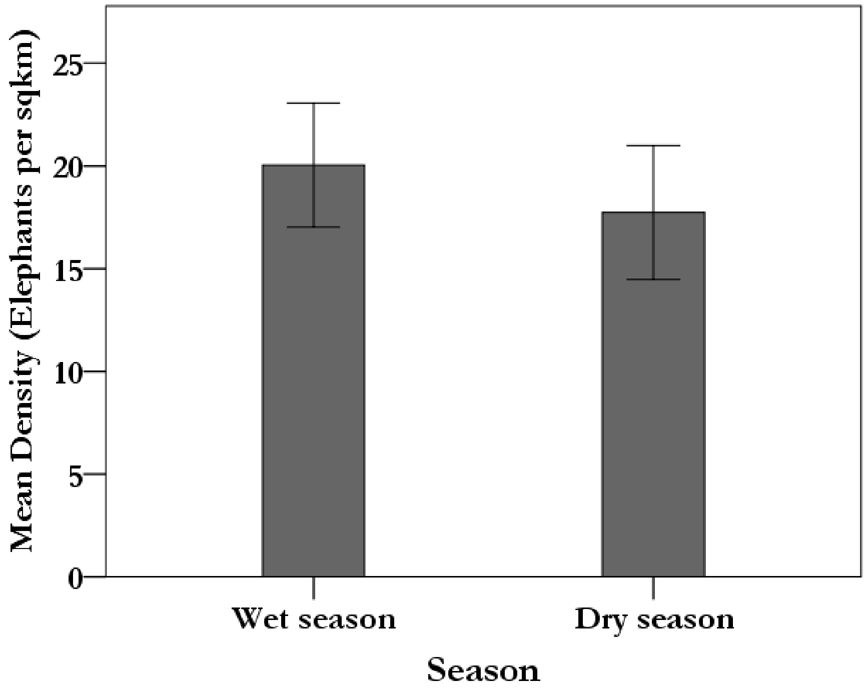

Figure 10: Mean distribution densities of elephants in Mpala in wet and dry season (n=50)

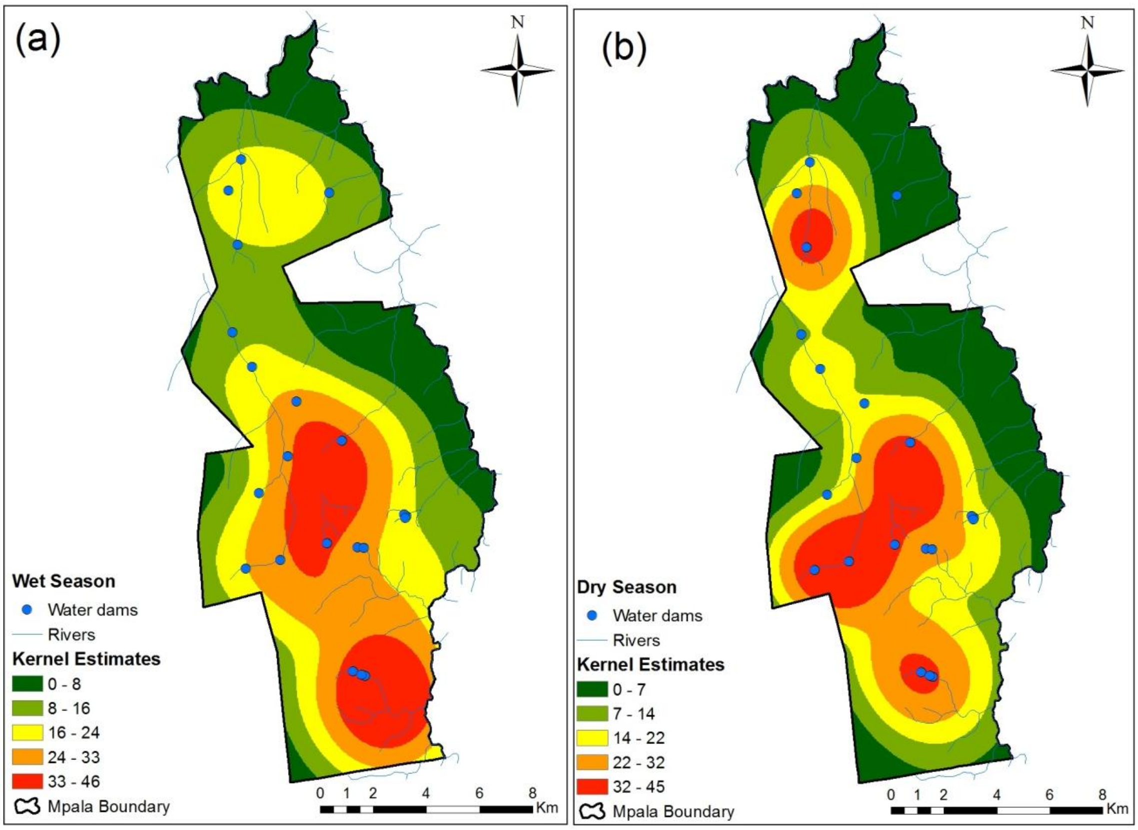

Figure 11: Kernel density estimations of utilization distributions of elephants in Mpala
(a) Wet season (b) Dry season

3.3. Elevation as a determinant of elephants distributions

The bar graph plots showed that elephants in Mpala preferred higher elevations in both seasons while the lower elevations were less preferred. They showed higher and lower mean respectively interpreted as high densities vs. low densities. Wet season generally had higher seasonal distribution density means throughout the study period (Figure 12). This suggested more elephants were found in Mpala in the wet season compared to the dry season. This is contrary to previous findings of more elephants in Mpala when dry season.

There was statistically significant difference in elephant distribution densities among the elevation classes in both the wet season and the dry season. Wet season Kruskal Wallis chi-squared= 34 .92, df= 2, p= 0.00. Dry season Kruskal Wallis chi-squared= 31.46, df= 2, p= 0.00. Subsequently, pairwise comparisons were computed using Wilcoxon rank sum test. Wet season distribution densities revealed statistically significant differences between low and medium elevations, low and high elevations but not between medium and high elevations. Unsurprisingly in the dry season there was statistically significant difference among all elevation classes (Table 6).

Table 6: Pairwise comparison of the elephant densities between elevation gradients in Mpala.

Season	Pairwise	W	P value
Wet season	Low - Medium	224	0.00
	Low - High	1026	0.00
	Medium - High	724	0.07
Dry season	Low - Medium	241	0.00
	Low - High	930	0.00
	Medium - High	818	0.00

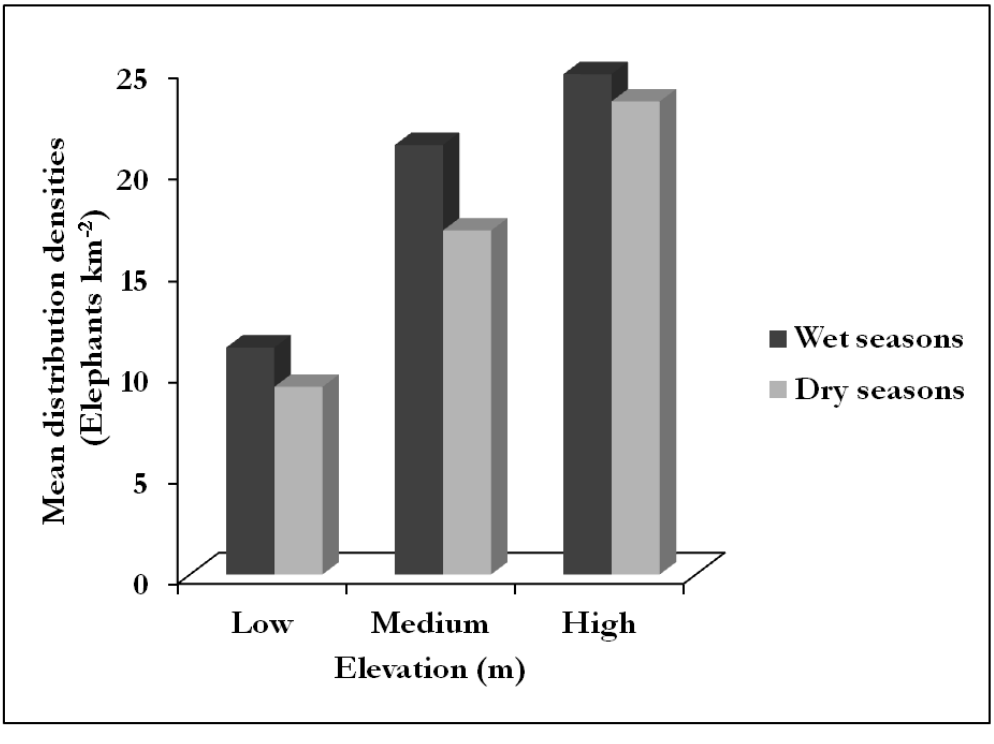

Figure 12: Comparing seasonal distribution densities of elephants amongst elevation gradients of Mpala

3.4. Spatial distribution of woody cover in Mpala

Figure 14 displays woody cover classified image results. Through visual interpretation, high woody cover was dominant to the south of Mpala as well as along the permanent rivers. From fieldwork investigation, this class was characterised by thick bushlands, thick shrublands with dense canopy cover. Medium woody cover classes were characterised by relatively thick bushlands and shrublands. The classified image revealed that Mpala was dominated by medium woody cover, spreading from the south to the north, with patches of either high woody or low woody covers. Low woody cover classes were characterized by open canopy covers. They were dominated by either grass or bare grounds. During fieldwork, plots that were found dominated by either of the two invasive species *Opuntia stricta* or *Euphorbia nyikae* (Figure 13), were classified under low woody class.

(a) (b)

Figure 13: Vegetation invasive species found in Mpala (a) *Opuntia stricta* (b) *Euphorbia nyikae*
Courtesy of Xiyao Li

The overall classification accuracy was 86.96% and Cohen's kappa was 0.785 (Table 7). User accuracy showed high woody cover to have the best pixel estimation (88%), followed by medium woody cover 87% and the low woody had the least pixel estimation (83%). Producer accuracy revealed that, medium woody cover was the best estimated cover (95%) while high woody was the second (83%) and the least was low woody cover class with (71%). Quantification of spatial woody cover showed medium woody as the as the dominant cover class. It covered (50%) of the study area. The second dominant woody cover was high woody with (39%) of the study area while low woody covered of (11%) of the total area of Mpala.

Table 7: Contingency matrix for the classified woody cover image of Mpala.

Class Name	Reference Totals	Classified Totals	Number Correct	Producer Accuracy	User Accuracy
Low	7	6	6	71.43%	83.33%
Medium	21	23	20	95.24%	86.96%
High	18	17	15	83.33%	88.24%
Total	46	46	40		
Accuracy	86.96%				
Kappa	0.785				

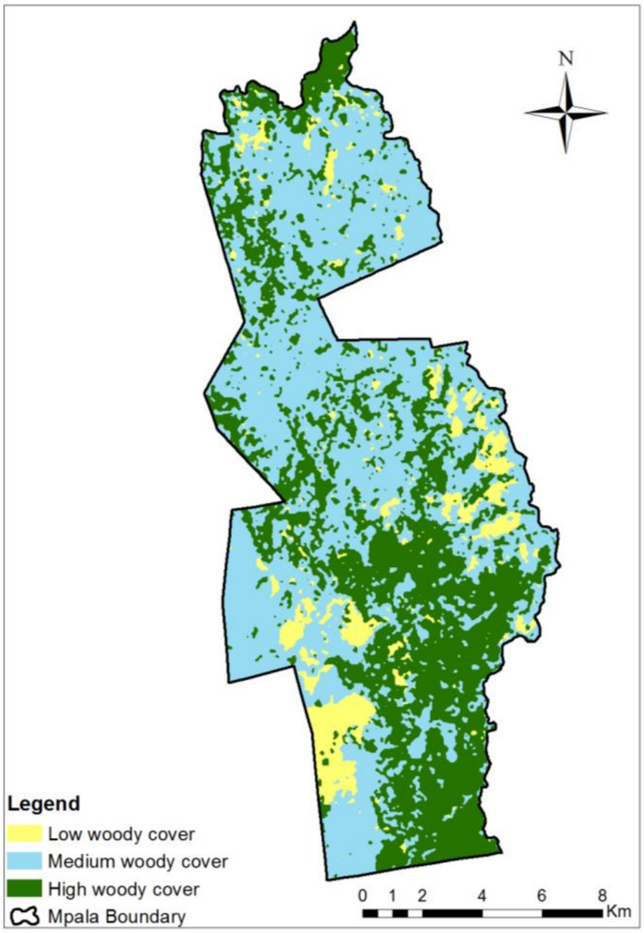

Figure 14: Spatial distributions of woody cover classes in Mpala

3.5. Environmetal factors influencing seasonal distribution of elephants

Assessment of significant variables influencing seasonal distribution of elephants in Mpala using multiple regression analysis revealed interactions of both anthropogenic and biophysical factors (Table 8 Table 9). Wet season model revealed five parameters with an adjusted R^2 value of 0.80 (RMSE= 23%). The Dry season model showed 8 parameters including those observed in wet season with an exemption of the distance to the fenced plots. Additional parameters for dry season model included; distance to cattle bomas distance to the road both showing (positive correlation). Two variables that produced unexpected results are, the distance to human settlements (negative correlation) and woody cover (negative correlation). The dry season model had an adjusted R^2 value of 0.75 (RMSE= 19%). All the regression models were significant with significant variables ($p<0.05$).

Table 8: Summarized results of the wet season multiple regression analysis.

Variables	Unstandardized coefficients	P values	Standardized coefficients	F statistics	Adjusted R^2
Intercept	-12.723	0.00		$F_{(5,245)}$= 202.1	0.801
Slope	0.468	0.01	0.079	p= 0.00	
Dist. Fenced plots	-0.005	0.00	-0.83	RMSE = 4.2	
Dist. Water dams	-0.003	0.00	-0.297		
NDVI Mean	95.463	0.00	0.388		
NDVI Std. Dev	-321.058	0.00	-0.382		

Model Wet season: (Elephant distribution= -12.723 + 0.468*slope - 0.005*fenced plots - 0.003*water dams + 95.463*NDVImean - 321.058*NDVI standard deviation).

Table 9: Summarized results of the dry season multiple regression model analysis.

Variables	Unstandardized coefficients	P values	Standardized coefficients	F statistics	Adjusted R^2
Intercept	29.2	0.00		$F_{(8,220)}$= 85.98	0.749
Slope	-1.078	0.00	-0.148	p= 0.00	
Dist. Bomas	0.003	0.00	0.163	RMSE = 5.4	
Dist. Roads	0.005	0.02	0.082		
Dist. Settlement	-0.003	0.00	-0.391		
Dist. Water dams	-0.01	0.00	-0.77		
NDVI Mean	61.21	0.00	0.216		
NDVI Std. Dev	-152.42	0.00	-0.134		
Woody	-7.9	0.00	-0.308		

Model Dry season: (Elephant distribution= 29.2 -1.078*slope + 0.003*distance to cattle bomas + 0.005*distance to roads - 0.003*human settlements - 0.01*water dams + 61.21*NDVImean - 152.42*NDVI standard deviation - 7.9*woody).

Relative importance of each contributing variables were then computed to assess how each variable performed individually to the model using R statistics' relaimpo package (Grömping, 2006). Fenced plots contributed the most in the wet season model with 71%, as opposed to the slope contributing 0.4% in the same season. While in dry season water dams contributed the most 50% and NDVI standard deviation contributed the least 2%. Relative importance Table 10 and Table 11 gives summaries of these findings.

Table 10: List of the relative important variables from the wet season regression analysis model.

Variable	Percentage contribution
Slope	0.4
Fenced plots	71.4
Water dams	4.2
NDVI Mean	13.5
NDVI std. Deviation	10.5

Table 11: List of the relative important variables from the dry season regression analysis model.

Variable	Percentage contribution
Slope	8.4
Cattle bomas	3.1
Roads	2.8
Human settlements	7.1
Water dams	50.2
NDVI Mean	10
NDVI std. Deviation	2
Woody cover	17

4. DISCUSSION

4.1. Seasonal range size differences of elephants in Mpala

The observed range sizes (17-85km^{-2}) were within the expectations relative to the size of the study area. However, the new insight for this finding was the ranging patterns observed between the wet season and the dry season. In theory elephants should range further during the dry season since their habitat use is dependent on the productivity (Harestad & Bunnel, 1979). In Mpala this seems not to be the case, suggesting that there are more reasons for this distribution other than the water availability, for instance, landscape heterogeneity (Murwira & Skidmore, 2005). Heterogeneity in this study is defined as the complexity and variability of the spatial patterns of the elephant resources including water, forage and shelter. Elephants are known to prefer areas with high and diverse forage. These resources seem abundant in Mpala especially in the wet season.

The range sizes were observed to concentrate near water dams. This finding shows that seasonal range locations of elephants in Mpala are determined by the availability of water regardless of the spatial distribution of other resources. Location of elephant range next to water dams suggests that elephants often seek to use vegetation near water dams, therefore, avoiding places not associated with suitable resources. This is attributed to the fact that not all available water sources have palatable forage. This finding is the same as that by David, (2010) who also found that elephants in Mpala concentrated their foraging activities close to water dams.

Rainfall variability in Mpala also explains the variation in range sizes. For instance, variation in productivity measured by woody cover seemed to influence the spatial use of Mpala by the elephants, since they were found to be mostly located to the higher productive southern Mpala as opposed to the north of Mpala. This finding is supported by the previous findings of elephants to limit their range locations within certain type of landscapes such as wetlands and riverine habitats due to abundance of quality resources (Kinahan et al., 2007; Ntumi et al., 2005). This finding also suggests that elephants in Mpala reduces their ranging size especially in the dry season to conserve energy since moving larger distances means more energy requirements considering that during the dry season there is scarcity of both food and water resources.

Considerable computed range locations overlaps were mostly observed in the area with close proximity to the water dams. This was expected, considering the size of the study area in relation to the population of elephants. This overlap signifies high competition for the resources, in this case water and forage. This type of distribution has been noted to negatively affect the ecosystem. Thrash, (1998) in his study observed trampling and over grazing of wildlife around water points to have an effect around the water points up to approximately 200m from these water points.

Re-sighting of the same family groups in both seasons suggested that elephants are developing residency, since elephant groups were observed to spend more time in Mpala than the expected time of only dry season. Thouless, (1995) in his study of migration of elephants in the northern Kenya, described elephants found in southern Laikipia ranches as long distant migrant and as such, they are only expected on Mpala in the dry season but not in the wet season.

4.2. Elephant population distributions and core utilization in Mpala

The utilization distributions in this study are areas that were intensely used by the observed elephant groups. Elephants showed non random as well as clustered utilization distributions, suggesting that point resources such as water were the main influence of their distributions, since all the isopleths were located around water dams. This suggests that water is the key requirements of elephant distributions in Mpala rather than food. This point resource influence as a result of small utilization distribution sizes has been noted to benefit the ecosystem, since under small size utilization distributions; there is minimal extraction of resources.

Elephant distributions between the two seasons was not significantly different ($p>0.05$). This is consistent with the initial hypothesis of the study of the same distribution of elephants in Mpala. Seasonal variation differences was however, attributed the size of the study area relative to the number of elephant population. The small size of the study area suggests that elephants were seasonally returning to the same ranging areas. For instance, aggregation of elephant subgroups in wet season as opposed to segregation during the dry season. This therefore, explains the high clustering in wet season resulting to low variation as opposed to dry season when the families segregate to reduce competition for the scarce resources leading to high distribution variations. This finding is similar to that by Harris et al, (2008) where they found elephants of southern Africa distributed more near water sources with palatable vegetation while avoiding dried up water holes or those associated with poor forage.

Observation of elephant distribution densities concentrating around water dams could be used as well to explain the social hierarchy formation of elephants found in Mpala. This is because dominant elephant herds have been observed to spend more time near water sources while moving short distances from these places (Wittemyer et al., 2007). This observation is supported by the fact that elephant data used in this study were from some elephant groups with the highest re-sighting frequencies. This again supports the previous finding of developing residency of elephants in Mpala.

4.3. Elephants distribution densities in relation to the elevation gradients in Mpala

Mpala elephants were found to use elevation ranges between 1484m-1872m in both seasons. This was different from the observation made in the neighbouring region of Samburu by Wall et al., (2006), where elephants were noted to avoid elevations of 300m. This finding is supported by the fact that higher elevations in Mpala are characterized as lowlands having higher woody covers as well as sufficient water to support elephants' food and water requirements. The high woody cover also acts as shade and shelter during high temperatures, since the high woody cover classes were characterized by high canopy covers. Availability of high-clay content "black cotton soil" is another reason for this distribution. Therefore, elephants preferred these elevations to obtain mineral supplements. This finding is similar to the finding in Marsabit where Ngene et al., (2009) found that elephants utilizations of higher elevations was influenced by the vegetations as well as mineral availability.

In wet season, statistical analysis revealed no significant difference in distribution densities between medium elevations and high elevations ($p>0.05$). This was unexpected result since medium elevation is located on higher grounds. The finding in Mpala of elephant preference for higher elevations is attributed to the type of soil found on these high elevations. It is described as well drained sandy clay soil, therefore, does not limit elephant movements on these high elevations even during wet season. This result was contrary to the previous finding by Ngene et al., (2009) of elephants avoiding high elevations in wet season.

Statistically significant difference among elevation gradients during dry season ($p<0.005$) was not surprising. This finding can be attributed to the fact that during dry season elephant families are known to segregate into smaller family herds from the big matriarchal herds. These segregated family herds then distribute randomly amongst different elevations based on the food and water availability. These are termed as dry season foraging ranges. This finding also suggests that elephants in Mpala have established dry season foraging areas. Location of water dams in Mpala also seems to play a role in explaining this non equal distribution in the dry season since they are spatially unevenly spread in the area of study.

Elevation gradients in Mpala also had distinct characteristics segregating them. For instance, higher elevations located to the south of Mpala, were characterised generally as lowlands, having higher rainfalls and high-clay content soil type. From the classified satellite image they were dominated by high woody cover. Medium elevations located to the central Mpala, were characterized as well drained clay sandy soil, rugged terrain with rocky outcrops, high number of water dams, rainfall described as moderate. While lower elevations are located to the north of Mpala and characterised as having low rainfalls, dominated by low woody cover and few numbers of water dams. They are found on lowlands. These findings generally can explain the heterogeneity of Mpala landscape therefore, aiding in explaining the differences in elephant distribution densities amongst the elevations.

4.4. Spatial distribution of the woody cover in Mpala

High woody cover was found dominant to the south Mpala and decreased as one moved to the north. This can be attributed to the fact that south of Mpala records much higher rainfall as compared to the north of Mpala (Goheen et al., 2013). Another factor could be due to human settlements which are all located to the south. This can be seen as a factor keeping away wildlife from using this part of the study area hence more woody cover due to minimal use by the wildlife. In addition these human settlements were found to have electric perimeter fence. These were observed to keep away wildlife from the south of Mpala hence, high woody cover. South of Mpala being a plateau and having higher elevation also explains the fact that there is high groundwater table therefore, sustaining woody cover here.

These findings were consistent with the previous findings by Augustine, (2003) that herbaceous biomass in Mpala declines with the decline in rainfall. This finding was the same for this study. Wahungu et al., (2011) mentioned that tree damages increases with an increase in elephant densities. Surprisingly, this was not the case in Mpala even though; there were high elephant populations relative to the size. This can be attributed to lack of perimeter fence, therefore no restrictions on wildlife movements.

The other reason could be the fact that elephants may intensely use Mpala in dry season but not in wet season, allowing the regeneration of vegetation in the wet season. This explanation is supported by the finding of David, (2010) that Mpala is a dry season refuge for Laikipia elephants, where he observed elephant population to increase in dry season but reduce drastically in wet season. Another explanation can be that the dominant discontinuous herbaceous layers of Mpala may have developed herbivores tolerance traits and resistance mechanism such as high mass compensatory growth abilities, extensive tree branching abilities, rapid shoot rates and short spacing or large prickle size (Fornara & Toit, 2007).

Lastly the distribution density of elephants in Mpala was found to be influenced by point resource rather than dispersed resource such as forage. One advantage of this kind of influence in distribution is that there is low intensity of extraction of the resources as opposed to the high intensity resources extraction when the distribution is determined by the dispersed resources. This therefore explains the finding of dominant medium woody cover regardless of the high elephant populations.

4.5. Relating elephant distributions to environmental factors in Mpala

Environmental variables influencing distribution of elephants increased from five in wet season to eight in dry season, this is because of abundance and readily available resources in the wet season therefore elephants limit their spatial use to certain areas, while in the dry season the quality and quantity of these resources are often scarce and limited. For instance, some water dams may dry up or forage shedding leaves, leading to elephants using more resources within their habitat to meet their forage requirements.

In the wet and the dry seasons, densities of elephants were found to decrease with an increase in distance from the water dams. This was attributed to the fact that, in this study water had a significant role in describing elephant distributions as well as the spatial use of Mpala landscape. Food and water have been noted as the key requirements of elephant distribution. An adult elephant drinks up to 200 litres of water daily. Water is also used by elephants to spray on their body. This helps cool their body temperature. The tendency of elephants to limit their movement to areas of viable water sources helps explain this finding. For instance, range sizes were found located around water dams and the core utilizations areas described as point influence rather than a dispersed resource influence. This finding was comparable to the finding by de Beer et al., (2006), when studying Namib desert elephants. They found elephants to increase with an increasing water point densities.

In the wet season, elephant densities were found to increase with an increase in slope, but decreased with an increase in slope in the dry season. Sloppy landscapes are located in the central of Mpala. These slopes are characterised as rugged terrain with rocky out crops, composed of high woody cover and have well drained sandy clay soils. Previous study has shown that elephants are well capable of moving through steep slopes using *zig zag* routes (Ngene et al., 2009). Application of this movement method was deemed possible in Mpala even during wet season because of the type of soil which is not slippery to restrain elephant movements up the slope. Surface water formed as a result of terrain ruggedness and rock out crops plus food abundance due to high woody cover were therefore deemed as an explanation for this positive correlation in wet season as opposed to dry season when the available surface waters dries up forcing elephants to move to the lower grounds where water is available. In the dry season, food quality and quantity reduces forcing elephants to descend to the lower slopes where water dams and forage are plenty and readily available. This suggests that elephants uses steep slopes in wet season due to food and water abundance, but the lower slopes act as reserves for dry season when conditions worsens and little energy is necessary to acquire the available food.

Elephants are known to avoid places of high human density or places with high human activities. In this study, human settlements and elephant density distribution in the dry season were negatively correlated, that is elephant density decreased as the distant to human settlement increased. This can be explained by the fact that Mpala is located in a dry ecosystem, and elephants associate the presence of human settlements to resources availability, for instance water. Mpala has artificial water tanks for domestics use. These were observed to be frequented by elephants mostly in the dry season (Figure 15). This finding was comparable to the finding by Ngene et al, (2009) who also reported that elephants in Marsabit clustered near human settlement due to availability of water.

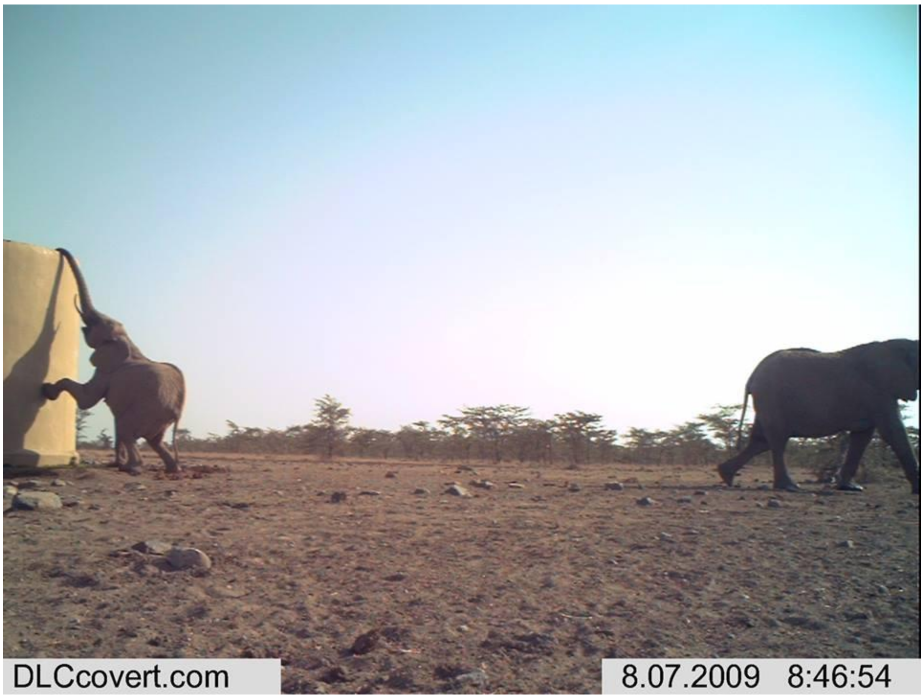

Figure 15: Camera trap image of an elephant trying to get water from the water tank
Courtesy of Mpala camera trap Tim O'brien

Elephant densities increased with an increase on distance from the roads. This can be explained by the fact that elephants tend to avoid roads to minimize their contact with the humans. It is important to note that Mpala roads are not for public use, but are frequently used by the researchers' cars as well as security patrol cars. Mpala do not practise tourism, and therefore elephants here are not habituated to cars. This suggests that they avoid the roads due to the presence of cars therefore, minimizing their contact with the presence of humans in the study area. This was evident during data collection period when most of the sightings were done when on off road the observed elephant groups were scared of the car approaching them. Similar findings are those by Blom et al., (2005) and Barnes et al., (1991) in Gabon and Central African Republic. They found elephants to avoid areas next to the roads since they were used regularly by the poachers. This explanation however does not apply to Mpala directly, but it can generally be used to describe the elephant populations in Laikipia-Samburu. Elephants in Mpala are a subpopulation of the Laikipia Samburu population. They have been described as long distant migrants (Thouless, 1995; Thoules, 1993) and therefore, might be encountering human hostility during their migration to Mpala. This is supported by the fact that, during data collection period, several elephant carcasses were recorded as well as some treated from gunshots and spear wounds.

NDVI mean values were found to have positive correlation with the elephant distributions in both seasons. High elephant densities were observed in areas with high NDVI values. This was an indication that the availability of biomass was attracting more elephants in the area. Previous studies have shown that there is a relationship between rainfall and forage productivity for a particular area (Coe et al., 1976). Forage productivity measured by NDVI does influence elephant spatial use. The large negative correlation between NDVI standard deviation and elephant densities shows that there is large forage variability. For instance, acacia shrubs and herbs found here shedding their leaves. This however seems not to affect the populations of the elephants here because of the availability of other resources, such as woody cover. Elephants have been noted to use tree bark during dry season when there is lack of either grass or browse (Ihwagi et al., 2010; David, 2010)

Elephants were found to avoid high woody cover areas. This was a surprising result given that elephants in the study area were found to show preference for high elevations. The higher elevations were characterised as having high woody cover. Therefore, this finding could be seen as a bias result due to elephant data collection method used. The physical ground observation using the car did not allow the accessibility of certain terrains as well as certain woody cover percentages especially high woody cover areas. For instance, data were collected on accessible roads as well as only places where off road was possible. Finding of this study of elephants avoiding roads also explains the biasness of this finding.

Elephant densities increased as the distance to the cattle bomas increased. This is attributed to the fact that the abandoned bomas do not have palatable forage in the dry season. The abandoned cattle bomas are characterized as glades; these are treeless landscape patches that occur after abandoning cattle bomas. They are usually fertile and result in lush fresh and palatable grass. As such, they have been noted to either attract or repel animals (Veblen, 2012; Young et al., 1995). For instance they attract wildlife in wet season resulting in their overuse by the wildlife therefore, becoming non-productive and unavailable in the dry season. The fact that they lack trees results in their minimal use by the elephants. This is supported by finding of Ihwagi et al., (2010) that elephants use alternative sources of forage especially in the dry season such as tree bark. Lack of shelter or shade to protect elephants from the high temperatures in the dry season, is another reason why elephants were found to avoid cattle bomas.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Main findings

The main objective of this study was to characterize the spatial distribution of elephants in Mpala. The findings showed that GIS and remote sensing can be used to give insight to the important anthropogenic and biophysical factors influencing seasonal distributions of elephants in Mpala ecosystem, while interpreting the observed spatial distribution patterns for sound ecological implications for a comprehensive management as well as decision making.

1. **What are the seasonal distribution ranges of elephants in Mpala?**

Seasonal range sizes of elephants in Mpala differed in sizes. There were overlaps of range locations and the overlaps mostly occurred near water points. Individual family range locations remained within the same locations but had seasonal range size variation. Most of the ranges were located in central Mpala but were skewed towards the south west Mpala. Seasonal range sizes were not significantly different, $t(14) = 1.156$ $p = 0.267$. Wet season (mean= $47 \pm 20.23km^{-2}$) while dry season (mean= $38 \pm 10.84km^{-2}$). This study concluded that elephant range sizes in wet season are influenced by both water and forage availability. While in the dry season, the range sizes are influence majorly by availability of water.

2. **What are the seasonal probability densities of elephants in Mpala?**

The core use areas were concentrated next to the water dams and varied seasonally. In wet seasons, elephants revealed larger utilization distribution areas as opposed to the dry season. The utilization distributions were skewed towards the southwest Mpala which has higher elevations. Northern Mpala acts as food reserve for dry season. Seasonal distribution densities were not significantly different $t(98)= 1.045$ $p= 0.299$. The wet season (mean= 20.04 ± 10.62 elephants km^{-2}) while the dry season (mean= 17.73 ± 11.45 elephants km^{-2}). The seasonal utilization distribution was influenced by water availability.

3. **How does elephant distribution vary seasonally across and within different elevation types in Mpala?**

Elephants were found distributed in all the elevation gradients of Mpala. In this study, seasonal elephants distributions demonstrated that, in the wet season, they preferred medium to higher elevations ($p>0.05$) as opposed to the dry season when they were unevenly distributed across the elevations ($p<0.05$). In the wet season, elephants had higher distribution densities as opposed to the dry season. This distribution pattern was influenced by the availability of food, water as well as mineral supplement. Analysis of elephant elevation preferences revealed three findings. Firstly, elephants still migrate into Mpala, but in the wet season as opposed to earlier findings of elephant population being of long distant dry season migrants only. Secondly, there was dry season segregation of the family groups to minimize competition for the resources. Lastly, Mpala has established resident family groups as opposed to earlier findings of the elephant populations composed of migrant groups only.

4. **What is the spatial pattern of the woody cover in Mpala?**

Classification of the Landsat 8 satellite image gave a reliable spatial woody coverage of the study area. Accuracy was 87% and kappa of 0.79. Spatial distribution of the woody cover had the same gradient as the rainfall gradient of the study area. High woody cover dominated the southern part of Mpala and along the permanent rivers. It was found to be influenced mainly by high groundwater table as well as human settlement in this region of the study area. Medium woody class was the dominant cover class spreading from the south to the north Mpala. It had patches of high and low woody covers. It covered half the study area. Low woody cover class had the least spatial coverage. It was characterised by open woody canopy cover and dominated by either grass or bare ground.

5. **What environmental factors significantly influence seasonal distribution of elephants in Mpala?**

Multiple regressions model for wet season revealed 5 environmental variables to influence elephant distribution densities. These variables included; slope (positive correlation), distance to fenced plots (negative correlation), distance to water dams (negative correlation), NDVI mean (positive correlation) and NDVI standard deviation (negative correlation). Model produced was good enough for future simulations. These outcomes demonstrated that elephant distributions in wet season are influenced primarily by forage abundance, water availability and the nature of the landscape.

Results for the dry season regression model demonstrated that 8 variables were significantly influencing elephant distribution densities. These variables included; slope (negative correlation), distance to cattle bomas (positive correlation), distance to roads (positive correlation), distance to human settlements (negative correlation), distance to water dams (negative correlation), NDVI mean (positive correlation), NDVI standard deviation (negative correlation) and woody cover (negative correlation). Model produced was good enough for consequent simulations. These findings implied that elephant distributions in the dry season were being influenced by forage abundance, water availability, high woody cover as well as the security in the area of study.

5.2. Recommedations for management and future studies

The spatial distribution density and clustering of elephants in central Mpala was found to be as a result of the high densities of water dams in this area. This can lead to habitat degradation, due to over utilization of resources here. I therefore, recommend to Mpala management to spatially spread the water dams across Mpala targeting the north and the south of Mpala.

Preference of high woody areas and avoidance of open landscapes such as roads could imply increased poaching incidences. This is because elephants in Mpala are characterised as long distant migrants, and may be experiencing human hostility through poaching or conflicts, I recommend for the future analysis to include analysis of reaction indices. This was part of data collected in the field with the aim of reporting the poaching incidences. This could be useful to test whether the observation made for poaching in this study is true. For management I would recommend an increased security patrol routines, as well as to the Kenya wildlife service (KWS) staff to ensure security of elephants along the migration corridors.

Mpala has proved as an important refuge not only for Laikipia-Samburu elephant population but also for array of wildlife species found here. Therefore, to the government and wildlife authorities, I would recommend the establishment of more conservancies like Mpala in unprotected areas to ensure survival of wildlife in these areas.

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