Elephant Foraging Behaviour: Application of Levy Flights in Geo-information Science and Remote Sensing

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by

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Abstract

The foraging behaviour of the African elephant (*Loxodonta africana*) along its movement path has been studied minimally due to lack of detailed movement data. However with advancement in Geographic information systems and remote sensing, data is available for understanding movement and resource use. Different methods have been used to understand animal movement, but random walks are among common models used to study animal forage search behaviour along their movement path. A recent and controversial type of random walk model is the Levy flights. Some researchers have disputed its existence in biological organisms, while others have faulted prior methods used in estimating it. Consequently, a more accurate method, Maximum Likelihood Estimation (MLE) has been proposed.

This research strives to understand foraging behaviour of elephant population in Marsabit Protected area (Kenya) during the dry period. First, the research uses MLE method to determine whether elephants use Levy flights when searching for resources. Secondly it determines whether the foraging behaviour is influenced by forage density (vegetation), gender and time of feeding.

Elephant movement data recorded for about 3years at one-hour time intervals was used for determining Levy flights. ASTER image was used to derive suitable foraging areas through Maximum Likelihood Classification and forage densities were estimated through Spectral Mixture Analysis using the Linear Mixture Model. For data organization and statistical analysis, Microsoft Excel and SPSS softwares were used.

The research established that elephants use Levy flights in their search for resources in the Levy index range $1.2<\mu\leq1.3$. Levy index had a positive relationship with the forage density, while males and females had different foraging behaviour. For the three elephant feeding peaks, the Levy indices were different.

It was possible to understand the foraging behaviour of Marsabit Protected Area elephants during the dry season. However, there is need for further research to understand the elephant behaviour during the wet season. The map generated in the research for the suitable elephant foraging areas would be useful in management. An improvement in the determination of forage density would also be handy for improvement of the findings.

Key words: Elephant, Foraging Behaviour, Forage, Levy Flights, Maximum Likelihood Estimation, Maximum Likelihood Classification, Spectral Mixture Analysis, Linear Mixture Model

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Dedicated to my son ROY
'Sweet boy for you I will for a better tomorrow.'

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List of Abbreviations

ANOVA- Analysis of Variance

ASTER- Advanced Space-borne Thermal Emission and Reflection Radiometer

ECW- Enhanced Compression Wavelet

EVI- Enhanced Vegetation Index

GeoTIFF- Geo-Tagged Image File Format

GIS- Geographic Information Systems

HDF- Hierarchical Data Format

HSD- Honestly Significant Differences

IUCN- International Union for Conservation of Nature

KWS- Kenya Wildlife Service

LF- Levy Flights

LMM- Linear Mixture Model

MLC- Maximum Likelihood Classification

MLE –Maximum Likelihood Estimation

MODIS- Moderate Resolution Imaging Spectroradiometer

MPA- Marsabit Protected Area

MRT- MODIS Re-projection Tool

NDVI- Normalized Difference Vegetation Index

NIR- Near Infra-Red

RMSE- Root Mean Square Error
ROI-Region of Interest

RS- Remote Sensing

SMA- Spectral Mixture Analysis

SWIR- Short Wave Infra-Red

USGS- United States Geological Survey

UTM - Universal Traverse Mercator

VNIR- Visible and Near Infrared

WGS- World Geodetic System

1. Introduction

1.1. Background Information

1.1.1. The African Elephant in General

The African elephant (*Loxodonta africana*) is classified as critically endangered (IUCN, 2007). It is found in selected localities within Central, Eastern, Southern and Western Africa. Its habitat varies widely ranging from 'dense forest, open and closed savanna, grassland and, at considerably lower densities, in the arid deserts...' (IUCN, 2007).

African elephants move in search of resources (forage, minerals, water, and mates). Although all resources are important for their survival, foraging seems to take the priority. In fact it is estimated that about 75% of its time is dedicated to foraging (Wyatt and Eltringham, 1974; Ruggiero, 1992). Foraging is a continuous activity, with peaks in the early morning, afternoon and around midnight (Wyatt and Eltringham, 1974). Elephants consume large amounts of food averaged at about 5% their body mass, i.e. up to 300kg/day (Kingdon, 1997; Brüssow, 2007). This is as a result of its poor digestive system, unlike the ruminants (Wyatt and Eltringham, 1974), and its large body mass.

Elephant feeding behaviour is dependent on food availability (Balfour, D. *et al.* 2007) and sex (Stokke, 1999; Shannon, *et al.* 2006; Kinahan *et al.,* 2007). They alternate browsing in the dry season with grazing during the wet season (Wyatt and Eltringham, 1974; Barnes, 1982; Ruggiero, 1992). Elephants in family units feed more selectively as they look for patches of high density palatable species unlike the bachelor herds that are not discriminative of forage patches (Stokke, 1999; Shannon, *et al*. 2006). Their diet comprises of many plant species, with reports of up to 95 species (De Boer, *et al.* 2000).

Movement and forage search is a family affair in most cases. Naturally, elephants are gregarious animals (Poole, 1996). The main family unit comprises of the mother and her offspring, usually 10-20 individuals or more (Kingdon, 1997; Balfour *et al*., 2007). However bulls do not remain in the family unit for long, as they are chased out at 14 years (Poole, 1996). They may join in other small bachelor groups led by an older bull (Kangwana, 1996). They are only allowed in the family units during the mating season.

Information on the ecology of African elephant results from intense studies done in the past. They range from simple daily activities to complex ecological aspects (Guy, 1976; Western and Lindsay, 1984; Koch. *et al.,* 1995; Dublin, 1996; Stokke, 1999; Douglas-Hamilton, *et al.* 2005; Shannon, *et al*., 2006). However, its movement behaviour when foraging in heterogeneous landscapes has been minimally studied.

A recent development in animal movement when searching for patchy resources has been the use of random walk models. Particularly Levy flights have been concluded by several authors as the optimal forage search strategy (Viswanathan *et al.,* 1996; Viswanathan *et al.,* 2000). As a recent and evolving approach in biological encounters, there have been criticisms and new developments. For instance Benhamou, (2008) disputes presence of Levy flights in biological organisms, while other authors

(Edwards *et al,.* 2007; Sims *et al.,* 2007; Edwards, 2008) have corrected prior methods used in determining Levy flights and proposed more 'accurate' and reliable methods.

The minimal studies on elephant movement behaviour when foraging in heterogeneous landscapes coupled with criticisms and proposed methods in Levy flights necessitate further investigations if any comprehensive conclusions are to be derived. Through advancement in Geographic Information Systems (GIS) and Remote Sensing (RS) technology, elephant movement data and resource characteristics in Marsabit Protected Area are available. This research therefore focuses on understanding elephant movement behaviour when foraging using the Levy flights model

1.1.2. The African Elephant in Marsabit Protected Area

The Marsabit Protected Area elephant population is estimated to be about 150 individuals (Blanc *et al.,* 2007). It inhabits both the protected area and the surroundings. Hence, the study area will hereby be referred to as MPA. Based on information gained from fieldwork and assessment of movement data a few conclusions on the MPA elephant population can be made.

Some elephant groups are residents in the protected area during the wet and dry season while other groups are migratory moving to areas as far as 150km from the protected area during the wet season.

Their feeding behaviour varies with the season and available food. In the wet season, they feed on grass and shrubs, whereas in the dry season they feed on dry/green shrubs and a few green trees in the area (see Figure 1-1, debarked dry shrubs).

Although the forest area comprises of evergreen trees, elephants do not feed on them, but a few dry and semi-dry shrubs inside the forest. The forest area is the major water reserve during the dry season and a source of shade during hot hours of the day.

Figure 1-1: Encircled in red are dry shrubs that have been fed on by elephants

MPA elephant alternate feeding areas that are hereby described using two terms: uplands and lowlands. The uplands consist of the Mt. Marsabit Forest and the surrounding hills, while the lowlands are the surrounding flat areas. Some elephant groups move to lowlands during the day while in the evening they move to the uplands. The other group reverses this pattern.

1.2. Problem Statement and Justification

The foraging behaviour of African elephants along their movement paths has been minimally studied. This is important for improving the understanding of elephant ecology. To understand an animal's ecology, one should focus on utilization of resources within its home ranges (Whyte,. 1996). Although many definitions are used for the term 'Ecology', it is hereby defined as "*The scientific study of the processes influencing the distribution and abundance of organisms, the interactions among organisms, and the interactions between organisms and the transformation and flux of energy and matter*" (Cary Institute of Ecosystem Studies)

It is also important to perform studies on elephant ecology for populations in different habitats. Elephants inhabit a wide range of ecosystems hence findings in one habitat might differ with other areas. Therefore there is need to strike a balance in the studies as some populations have received more attention than others. MPA elephant population has been minimally studied. In comparison with other elephant populations in Kenya and other home ranges in Africa, MPA wildlife has been marginalized a great deal. Perhaps it has been due to its remote location in contrast with other populations elsewhere.

Forage is an important resource for elephant survival. This is clear from the time spent in a day searching for forage. Elephants move from one vegetation patch to another searching for forage (Ngene, *et al* in press; Wyatt and Eltringham, 1974). Therefore, it is imperative to understand elephant foraging behaviour along their movement path.

Today it is possible to get animal location, movement and resource characteristics thanks to GIS and RS. In MPA elephants have been equipped with Iridium satellite-link GPS collars, which provide point data as well as movement tracks. Moreover, the satellite imagery provides useful data for analysis of resource characteristics.

MPA has scattered vegetation (except for the closed forest canopy) almost all year round. This is due to its arid and semi-arid characteristics (Adano, 2002). In such scattered food densities it is assumed that organisms should move in an efficient way to maximize finding it (Sims *et al.,* 2007). Hence MPA elephants must decide where, what, how long, and the intake rate of the available food (Brüssow, 2007). When figuring out the where, an animal must be involved in a search strategy. Bartumeus *et al* (2005) suggest that when an animal has no clue on where to find forage, a random walk may help in finding it.

Animal foraging behaviour along their movement path is not a new concept in science. This field has taken many forms from simple to complex. A recent development is the use of Random Walk Models, which are highly simplified animal movement behaviour. They assume that animal movement comprises of move lengths separated by successive turning angles (Bartumeus *et al.* 2005). These authors continue to elaborate that the turn angles and move lengths are parameters used to describe the type of distribution in statistics, which is used to infer the type of random walk. From a literature review done in this research the most commonly used types of random walk models are *Levy Flights* and *Correlated Random Walk.*

Levy Flights (LF) Model

LF model, also referred to as Levy Walk Model, is said to be more efficient in search for forage in heterogeneous landscapes (Viswanathan *et al.,* 2000; Viswanathan *et al.,* 2001; Bartumeus *et al.,* 2002; Raposo *et al.,* 2003). Compared with other random walk models, LF is considered ideal in encountering new patches (Viswanathan *et al.,* 2000; Bartumeus *et al.,* 2002; Viswanathan. *et al.,* 2002). A further emphasis on LF is presented in a review article (Viswanathan *et al.,* 2008) that many organisms perform LF in their search.

LF is a class of fractal and scale invariant random walks whereby the direction of successive walks is uncorrelated. It is characterized by a uniform distribution for the turning angles, but a power-law distribution of the move lengths, x, referred to as flights. Edwards (2008) emphasizes that 'Levy flight [...] is only concerned with the tail of pdf [probability density function] (i.e. the long movements); the distribution of short movements is not relevant'

The power-law tail probability density function is given as:

$f(x) \sim x^{-\mu}$, i.e. $f(x)$ goes like $x^{-\mu}$, ***(1)***
(Edwards, 2008)

The exponent μ of the power-law is named the Levy index ($1<\mu\leq3$), which controls the range of correlations in the movement. When $\mu \approx 1$, the path is characterized by many long flights; while with $\mu\approx2$ the path shows a fractal alteration of short and long steps; and $\mu\approx3$ equals Brownian motion (Figure 1-2 an LF example at different μ).

Calculations and further elaboration on Levy Indices is in § 4.2.1

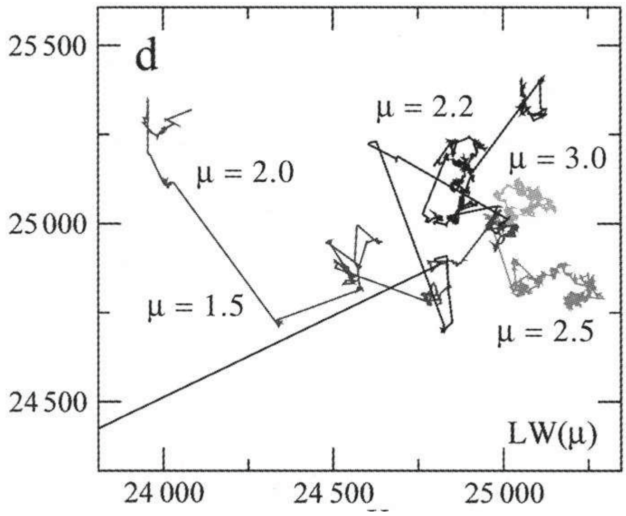


Figure 1-2: Levy Flights at different μ (Bartumeus, *et al.,* 2005).

As mentioned earlier LF is a recent development in science. Although they have been widely used to understand animal forage search strategy along their movement paths, recent developments show that the conclusions made on LF may have risen due to application of poor analysis methods (Edwards, 2008). Consequently, there are suggestions of improved methods to minimize errors in the analysis (Sims *et al.,* 2007; Edwards, 2008). Other authors argue that LF is a rare occurrence in animal movement (Benhamou, 2008), but no further confirmations have been made.

For the aforementioned reasons and calls from researchers to conduct studies that would further affirm that organisms perform LF although there is a general agreement that they do (Viswanathan *et al.,* 2002; Viswanathan *et al.,* 2008), it was thus important to understand MPA elephant movement when searching for forage using the LF model.

To understand an animal's behaviour along its movement path, its activity is recorded in time and space (Marell *et al.,* 2002; De Knegt *et al.,* 2007). This is easy when dealing with animals that require small space to satisfy their daily needs or in small-scale field experiments. However, for wildlife in their natural habitats, this requires observations for long periods, maybe for years. Hence, with available elephant movement data taken over a long period in their natural habitat, this research applies an innovative approach that uses GIS and RS techniques, to study a mega herbivore at large spatio-temporal scale.

Therefore, the objective of this research was to determine elephant forage search behaviour along their movement paths. Using the proposed method of verifying LF, first the research determines whether elephants are really doing LF, and second whether this LF is influenced by: resource densities (in this case vegetation), feeding time of the day (morning, noon and midnight feeding peaks), and gender.

1.3. Research Objectives, Questions and Hypothesis

1.3.1. Research Objective

The main objective in this research is to understand how elephants search for forage along their movement path in Marsabit Protected Area using the Levy Flights Model

1.3.1.1. Sub-objectives

1. **To use the maximum likelihood estimation method to determine whether elephants apply Levy Flights when moving in search for resources.**

   Expected outputs
   - Ranges of the exponent (μ) for the power-law distribution of the elephant movement lengths

2. **To determine whether there exists variations in elephant movement path when foraging at varying vegetation densities, at different feeding peaks and between genders using the Levy Flights Model.**

   Expected output
   - Map showing forage suitable areas in Marsabit Protected Area, during the dry season.
   - Map showing percentage covers of available forage
   - Statistical results of the Levy Flights Model for different cover percentages, different feeding peaks and between genders.

1.3.2. Research Questions and Hypothesis

Sub-Objective 1:

❖ *Do MPA elephant movement lengths follow a power-law distribution?*

- H_0: The exponent (μ) for the power-law distribution of the elephant movement lengths fall outside the ranges $1<\mu\leq 3$
- The exponent (μ) for the power-law distribution of the elephant movement lengths is within the ranges $1<\mu\leq 3$

Sub-Objective 2:

i) *What areas in Marsabit Protected Area are suitable for elephant foraging during the dry season?*

i) *What are the cover percentages of available forage materials for elephants in MPA?*

ii) *How does the elephant movement path when foraging respond to varying vegetation densities?*

- H_0: There is no relation between the Levy index (μ) for elephant movement path and vegetation densities i.e. $\beta=0$
- H_a: There is a positive relation between Levy index (μ) for elephant movement path with vegetation densities i.e. $\beta > 0$

iii) *Are there variations between elephant genders along their movement path when foraging?*

- H_0: The Levy index (μ) for male and female movement paths when foraging is the same i.e. Male μ= Female μ
- H_a: The Levy index (μ) for male and female movement paths when foraging is different i.e. Male $\mu \neq$ Female μ

iv) *Are there variations in elephant movement during foraging at different times of the day?*

- H_0: The Levy index (μ) for elephant movement path during foraging at different times of the day is the same i.e. morning μ = afternoon μ = night μ
- H_a: The Levy index (μ) for elephant movement path during foraging at different times of the day varies i.e. morning $\mu \neq$ afternoon $\mu \neq$ night μ

2. Research Materials and Fieldwork

2.1. Introduction

The advancement in GIS and RS has been a significant breakthrough in understanding wildlife ecology. It has provided avenues for studying habitat use that would have been difficult if otherwise not impossible to do (Douglas-Hamilton. *et al*., 2005; Murwira. and Skidmore, 2005; Galanti *et al*. 2006; Wall *et al*., 2006; Dolmia *et al.,* 2007). This has been due to availability of movement data and resource characteristics thanks to GIS and RS.

Different approaches that exploit the opportunities created by advancement in GIS and RS have been used to understand wildlife ecology (Nagendra, 2001; Osborne *et al.*, 2001; Mueller *et al*., 2008; Patterson *et al.*, 2008), among others. This paper too exploits this advancement to understand elephant foraging behaviour in varying vegetation densities. First using elephant movement data, the behaviour of elephant when searching for forage is determined using LF Model. Secondly, areas of available forage for elephant are determined using Maximum Likelihood Classification and digitization after which Spectral Mixture Analysis is used to determine the vegetation densities. Finally, using the results of LF Model and vegetation densities, a statistical analysis is performed to determine: variations or similarities of foraging at different vegetation densities, between gender and at different feeding hours.

2.2. Study Area

The study was conducted in Marsabit Protected Area and its immediate surroundings, hereby referred to as MPA. It is located in Northern part of Kenya, Eastern Province, and lies around latitude 2^0 20' and longitude 37^0 20'. MPA comprises of a National Park and Reserve, covering an area 360km^2 and 1,132km^2 respectively. This area is under the joint management of Kenya Wildlife Service (KWS) and the Kenya Forest Service (Adano, 2002).

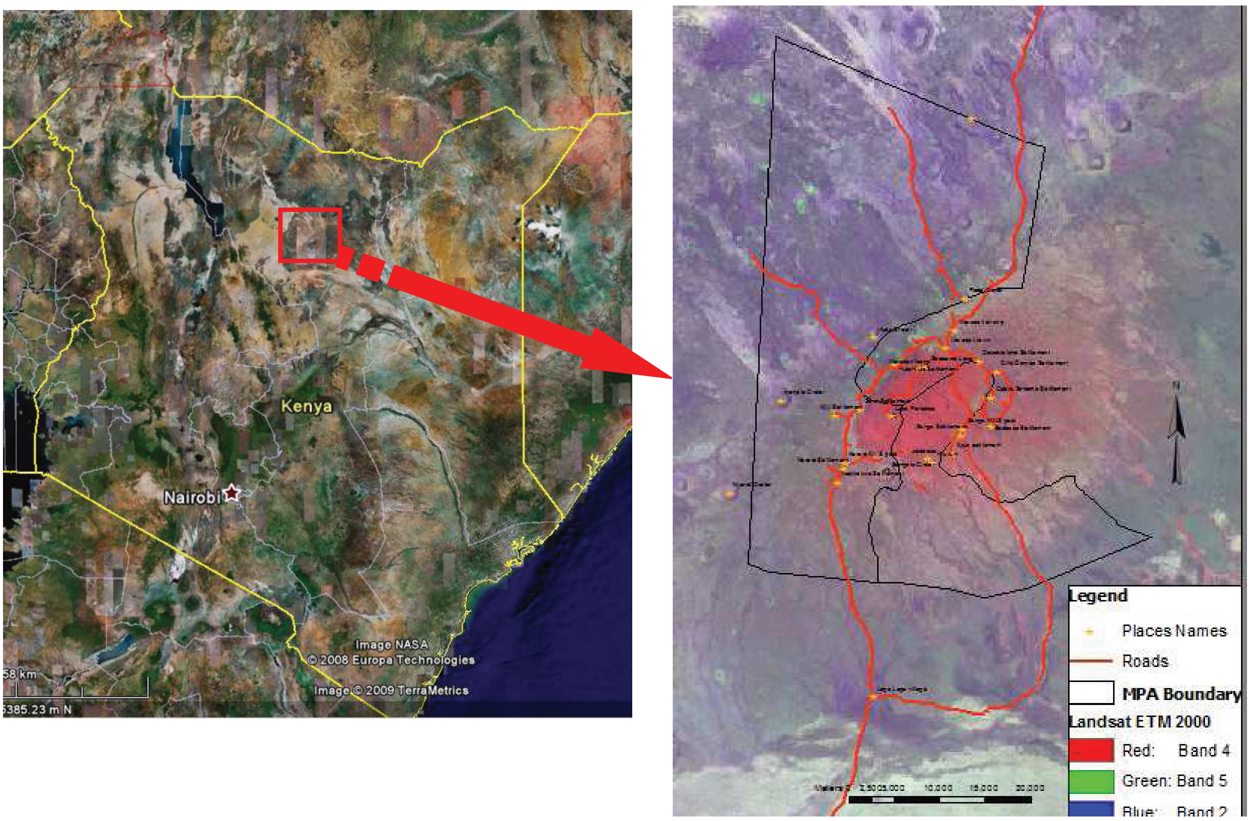


Figure 2-1: Map of the study area

The area is characterized by four main seasons namely: warm dry (December to mid-March), long rains (mid-March to mid-May), cold dry (mid-May to early October) and short rains (October to December) (Herlocker *et al.,* 1995). Rainfall peaks are experienced in April and November (Gachanja, M. et al. 2001). The annual rainfall varies between 50 mm to 250 mm (on the lowlands) and 800 mm to 1000 mm (in the mountain forest; Loltome, 2005). The area experiences morning fog and mist that moisten the mountain area in the dry season (Dabasso, 2006)

MPA has a diverse composition of flora and fauna. It is an important home for the northern Kenya elephant population and other mammal species such as greater kudu, buffalo, oryx, genet cat, klipspringer, caracal, leopards, common duiker, grant gazelle, bushbuck, Grevy's zebra, lion, monkeys; and over 66 bird species (Gachanja *et al.,* 2001; Adano, 2002). Vegetation varies widely in the area, but the three main types are forest, shrubland and grassland (Gachanja *et al.*, 2001; Adano, 2002)

MPA has different land cover types at varying proportions. The broad categories include: vegetation, water, bare ground and settlements. These classes can be further divided into subclasses, for instance bare ground to consist of bare soils, sands and rock; vegetation into dry shrubs, green vegetation and grass classes.

The vegetation cover is varied based on its location and season. On Mt. Marsabit, vegetation comprise of a dense evergreen forest, called Mt. Marsabit Forest while the surrounding areas have scattered vegetation. During the wet season, area outside the forest has green vegetation almost everywhere while in the dry season, only patches of green remain.

The major 'open' water points are Lake Paradise and Sokorte Dika (*commonly referred to as Lake Lodge*). The two lakes are seasonal but mainly dry up during extreme dry conditions. At the time of fieldwork, they were dry. In addition, there are permanent water wells in the very deep parts of the forest, while some in the accessible forest areas have been tapped for water supply to man and wildlife.

MPA is characterized by a rugged terrain. Inside the Marsabit National Park lies a high mountain at 1680m that is covered by Mt. Marsabit Forest. The rest of MPA consists of hills, craters, seasonal river valleys and flat terrain.

Traditionally, Marsabit local communities were pastoral nomads. The lowlands were used as livestock feeding grounds during wet season while uplands were reserves for dry season. However with the change in lifestyle and the gazettment of MPA, sedentary lifestyles have been more apparent (Dabasso, B. H. 2006). Settlement areas are characterised by permanent and semi- permanent shelters roofed with thatch material and iron sheets.

Figure 2-2: A herd of goats grazing in the reserve

The people's source of livelihood is livestock keeping with large stocks of shoats and cattle (about 100 of each type per household; *pers comm.* Karare Chief)

In arid and semi-arid lands like Marsabit, resource scarcity is a major problem (Mati, *et al.* 2005). This has brought about cutthroat competition for resources between man and wildlife. Competition is more pronounced during the dry season. Interviews with the local communities and the MPA management indicated that although there is competition for other resources, water takes the lead especially during the dry season. This has been interfering with wildlife activities, given that the local communities have access to resources in most of the protected area. Further reports showed that livestock are at watering points between 06.00-19.00hrs. This leaves no room for wildlife to access water during the day. Hence, if their normal activity includes watering during the day, it is highly interrupted.

Other commodities extracted from the forest area include fuel-wood, construction poles and medicine (Gachanja *et al.,* 2001; Adano, 2002)

2.3. Research Data

Data used in this research was acquired at different dates as summarized in Table 2-1

Table 2-1: Summary of the study data and the dates acquired.

Data Type	Date Taken
ASTER image	3rd March 2004
Movement data	January to March 2006 and 2008
Ground truth data	September/October 2008

Finding data for specific periods of interest is a major challenge in research. This has been due to limitations such as availability (Knight *et al.* 2006), financial constraints and suitability. Therefore, available materials must be utilized to the maximum. In this research to be able to do Spectral Mixture Analysis (see §3.4), a multispectral image is required, due to the many numbers of cover types present at the study scene. This makes an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image ideal, but due to cloud cover problems that are persistent in the equatorial forests (Laporte *et al.* 1995) the best quality available scene for MPA is of 3rd March 2004, the reason why it is used in this research.

2.3.1. Testing the Reliability of the Research Datasets

It is important to note that the data available was adequate for derivation of variables of interest in this research. In the case of vegetation density, the assumption is that the amount of vegetation cover present at the time the ASTER image was taken in March 2004 has a high correlation with forage available for elephants between January and March 2006 and 2008. This assumption also holds for the ground truth data collected in September/October 2008. Usually, in Marsabit, the beginning of March when the image was taken is a dry period and so was the time the ground truth data was collected. Hence, minimal variations would be expected especially for shrubs and trees which are of interest as elephant forage. Furthermore, deep rooted plants such as shrubs and trees are able to survive dry conditions for longer (Davis and Mooney, 1985), and hence would be standing during both periods.

In addition to the assumptions made above there was need to test the reliability of these datasets. This was done by comparing weather data and Enhanced Vegetation Index (EVI) for the periods of interest. Average precipitation and maximum temperatures were compared between the years, but their spatial distribution was not taken into account as the available weather data were recorded at one station. EVI was used to test whether there was a correlation in the spatial distribution of plant patterns at the time the ASTER image was taken and the time of ground truth data collection.

2.3.1.1. Weather Pattern for 2004, 2006 and 2008

Plant growth is determined by many factors, but the most important are: water, temperature and soluble salts (Evenari, *et al.,* 1986). Evenari, *et al.* further expound that precipitation determines the amount of water that is available, while Nicholson *et al* (1990), mentions that in general vegetation responds directly to seasonal variations of precipitation. Nevertheless, it is important to mention that the amount of available water from precipitation is dependent on other factors such as soil type and topography. These are complex relationships that are beyond this research, compounded by lack of data for comparisons hence this research assumes that they have no effect in this case. Temperature on the other hand has an impact on transpiration rate, nutrient uptake, distribution of plant communities among others all of which have an influence on plant growth. Therefore precipitation and maximum temperature are used here as important factors that determine plant phenology that is detectable from RS.

Weather data for the dates of research data were compared. The data was collected from Kenya Meteorological Department for January to October 2004, 2006 and 2008. The monthly mean precipitation and maximum temperature for different years was calculated. The aim was to check the annual overall pattern as well as test for variations or similarities for the dates of interest.

Precipitation pattern for 2004, 2006 and 2008

The overall weather pattern is the same for the three years. Peak rainfall for the analyzed months is observed in April. Dry months are between January and March as well as June to September (see Figure 2-3). This gives a good base for the assumption that vegetation cover at the time of Aster image (3March 2004) is highly correlated with what was observed during ground truthing data collection in September October 2008. This also applies for the dates of movement data

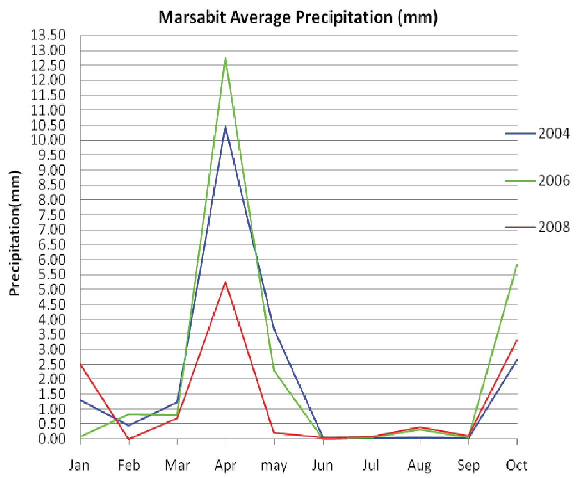


Figure 2-3: Monthly average precipitation for years 2004, 2006 and 2008

Maximum temperature pattern for 2004, 2006 and 2008

The temperatures also portray a similar pattern for the three years.

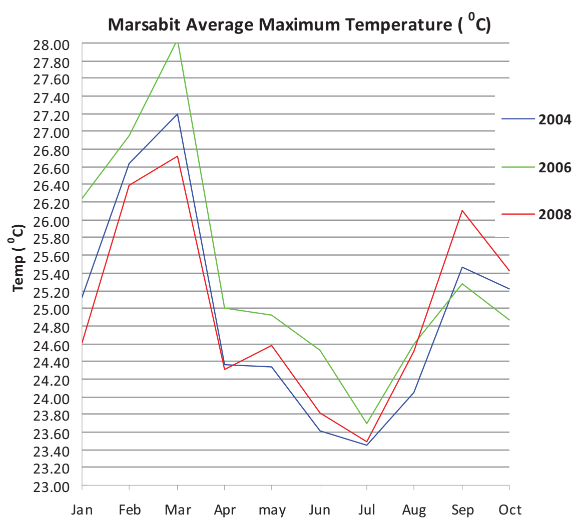


Figure 2-4: Monthly average maximum temperature for years 2004, 2006 and 2008

2.3.1.2. Enhanced Vegetation Index (EVI) for 2004, 2006 and 2008

Vegetation indices are good indicators of vegetation conditions. The most commonly used vegetation indices are the Normalized Difference Vegetation Index (NDVI) and EVI. They are used to measure the amount of biomass, primary production, changes in plant cover and land cover conversion (USGS Land Processes Distributed Active Archive Center; Evrendilek and Gulbeyaz, 2008). EVI is an improved version of NDVI. It is formulated to counter the saturation effects caused by dense canopy as well as to remove atmospheric effects (USGS Land Processes Distributed Active Archive Center; Huete *et al.,* 2002).
EVI is derived from the equation given by (Huete *et al.,* 2002):

$$EVI = G\frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} - C_1 \times \rho_{red} - C_2 \times \rho_{blue} + L} \quad \textbf{(2)}$$

Where:
$G= 2.5$ is the Gain Factor
ρ -Atmospherically corrected surface reflectance
NIR- Near Infrared band
Red - Red band
Blue- Blue band
$C_1 =6$ and $C_2 = 7.5$ are the coefficients of the aerosol resistance term
$L= 1$ is canopy background adjustment that addresses nonlinear, differential NIR and red radiant transfer through a canopy

EVI is used here to check whether the conditions experienced at the time the image was taken were relatively similar to the collection of ground truth data.

Moderate Resolution Imaging Spectroradiometer (MODIS) EVI 16-day composite data at 250m resolution, was downloaded in the Sinusoidal Projection, with MPA covered in the tiles h21v08. The data presented in Hierarchical Data Format (HDF) was geo-referenced to UTM WGS-84 zone 37 using the MODIS Re-projection Tool (MRT) and converted to Geo-Tagged Image File Format (GeoTIFF).

EVI values range between 0 (no vegetation) and 1 (presence of photosynthetic active vegetation). However, the data was presented in the range -32768 to 32767, the maximum range of values for the data type (16-bit integer). Therefore, there was need to convert to values to EVI ranges 0 and 1. In the Raster calculator using the formula:

OUTPUT image = SetNull([EVI.tif] < 0, [EVI.tif] / 10000.0) ***(3)***

To test for similarities between the time of ground truth data collection and ASTER 3rd March image, MODIS EVI for 5th March 2004 was compared with mean MODIS EVI of September 2008. 100 randomly generated points were used to extract the EVI values. A linear regression was run and scatter plot generated. The results show that the correlation was significant with Adjusted R^2 =0.5; β = 708; SEβ= .063; F=98.7; d.f= 99; P= .000 < P= .05 (refer to appendix 1 for scatter plots)

2.3.2. Elephant Movement Data

MPA elephant movement data was derived from eight elephants (four cows and four bulls) equipped with Iridium satellite-link GPS collars. The movement data is downloaded and sent to an email address. It comprises of movement tracks, movement speeds and distribution points, recorded on hourly intervals. The assumption of the selection criteria in this research is that each collared animal represents a family unit or a bachelor herd. This is in line with sampling designs proposed in literature, where an individual is identified and its resource use recorded to represent the population (Manly *et al.,* 1993)

The data was received in geodatabase feature classes and accompanying information on characteristics of the collared animal. It included data from December 2005 to July 2008 as summarized in Table 2-2. There were gaps in the data due to different collaring periods and malfunctioning of the collars. Therefore, the data was selected based on the research objective.

Table 2-2: Available Movement Data

Animal Name	Gender	Dates			
		2005	2006	2007	2008
1.Hermes	M			25th April to 31st Dec	1st Jan to 28th July
2.Felista	F	4th Dec to 31st Dec	1st Jan to 28th Aug		
3.Jaldessa	M	6th Dec to 31st Dec	1st Jan to 15th Aug		
4.Kamau	F		8th July to 31st Dec	1st Jan to 31st Dec	1st Jan to 27th April
5.Karare	M	8th Dec to 31st Dec	1st Jan to 17th Oct	30th April to 31st Dec	1st Jan to 23rd Jan
6.Paradise	F	6th Dec to 31st Dec	1st Jan to 17th Oct		
7.Rita	F		9th July to 31st Dec	1st Jan to 31st Dec	1st Jan to 27th July
8.Sora	M			30th April to 31st Dec	1st Jan to 28th July

The feature classes were in the UTM Arc1960 Zone 37 coordinate system, with move lengths recorded in meters. They were re-projected to UTM WGS-84 zone 37 to correspond with the working data sets.

2.4. Fieldwork

This was an important step for collection of ground truth data and validation of elephant daily activities.

2.4.1. Ground truth Data for Image Classification

Data was collected for training samples and accuracy assessment for Maximum Likelihood Classification and Spectral Mixture Analysis (see Chapter 3).

Prior to fieldwork, a stratified random sampling scheme was prepared with the aim of avoiding bias in the sample as well as to increase the precision (Kumar, 2005). First, 250 points were randomly generated using ArcGIS and then stratified based on image interpretation. The image was displayed with bands 3, 4, 1 in the Red, Green and Blue. Interpretation of the ASTER image of 3rd March 2004 was done by identifying colour and texture of cover components. 200points of the randomly generated points were selected based on the image interpretation. Finally, the image was compressed into Enhanced Compression Wavelet (ECW) format and loaded together with the 200 sample points into an iPAQ 2700.

During fieldwork, it was not possible to collect the intended 200points in the exact locations due to limited accessibility (lack of roads, poor terrain, and vegetation thickness) and security related issues. However, with the guidance of KWS management, 126 sample points were collected. Care was taken to ensure full representation of the various cover types. The map in Figure 2-5 shows the roads followed and collected sample points.

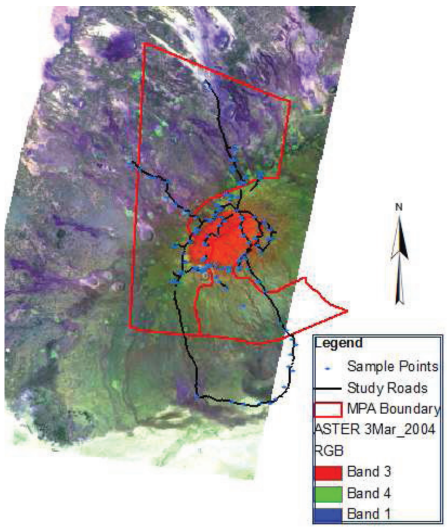


Figure 2-5: Study routes and data collection points in MPA

One form was used for collection of samples for both Spectral Mixture Analysis (endmember training) and Maximum Likelihood Classification (training and accuracy assessment). The points were recorded in both the iPAQ2700 and data collection forms. The forms were more detailed and the following information was recorded: X, Y coordinates of the point, land cover types, vegetation characteristics (species composition, height estimates, percentage cover estimates), and comments (included observations and information from KWS officers and the local communities)-see appendix 2. Plots of 30x30m were established for selected areas to estimate the cover percentages that were to be used in the Spectral Mixture Analysis.

2.4.2. Observations and Interviews to Validate Elephant Feeding Peaks

Elephant's daily activity has been studied for a long time. Conclusions are that they have three feeding peaks within the 24-hour cycle (morning, afternoon and midnight). Although daily activity of the same species tends to be similar in many ways, variations may occur due to environmental variations within their habitats. This necessitated field observations and interviews to wildlife managers and neighbouring communities in MPA, to validate elephant feeding peaks.

2.4.2.1. Field Observations

The initial plan for field observations was to follow all the collared elephants during the well lit hours of the day i.e. from 06.00 to 18.00hrs. However the observations were only possible for a few animals (collared and non collared) at different times of the day between 06.00hrs and 14.00hrs. It was difficult to follow an individual animal continuously, because after a while they would disappear into thick and thorny vegetation difficullt to penetrate.

The search for elephants started as early as 05.00hrs. To detect the location from radio transmitters in the elephant collars a radio receiver was used. Guided by a beep from the receiver the elephants were searched and followed where possible. A pair of binoculars aided in observations from a distance to avoid inteference. Finally a stop watch was used to mark time for activity recording at 30minutes intervals. Additional information recorded was on the GPS location, group composition and vegetation characteristics (see appendix 3)

Whenever non-collared elephants were encountered, their activity together with other information was recorded. A total of 8 observations for different animals were made. Signals from collared animals were detected but no observations made (See a summary in Figure 2-6)

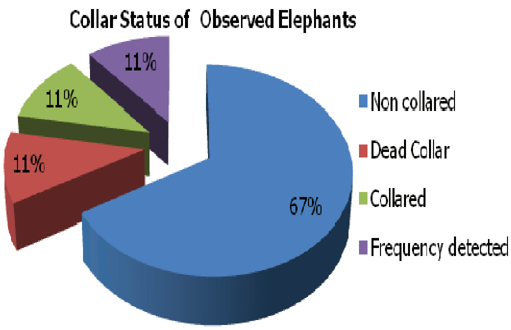


Figure 2-6: Collar status of observed elephants

From the observations made from 06.00-08.00hrs, elephants were returning to either the lowlands or the uplands. This was accompanied by quick browsing along their path.

The few observations made after 08.00hrs cannot be used to determine conclusively, activities later in the day. It is also worth to note that elephants were seen feeding on green grass on two different occasions inside the dried up Lake Paradise. However, grazing will not be treated as a foraging activity in this research because there is hardly any grass in the area during the dry season.

Figure 2-7: Two cows and three young ones crossing the road from lowlands to the uplands

2.4.2.2. Field Interviews

Data was collected through a structured interview that sought to identify elephant daily activity patterns and feeding areas. The interviews were guided by an *interview schedule* (see Appendix 4); described by Kumar (2005) as a set of questions, open or close ended, used by an an interviewer to seek information from the respondents. The interviewer asks the questions, explains them if necessary, and records the replies.

The interviews were conducted in the local villages surrounding MPA as well as with herders in the field. The interviewer interpreted the questions in Kiswahili to interviewee(s) and enganged them inform of a discussion and picked the relevant answers to the questions. Sometimes more than two respondents complemented each other in answering the questions. They are hereby treated as individual interviews. A total of 61 interview schedules were filled.

To understand the elephant feeding peaks respondents were asked what elephants are doing at certain times of the day. Time brackets were given: Early Morning (05.00-08.00hrs), Mid Morning (09.00-11.00hrs), Afternoon (12.00-14.00hrs), Late Afternoon (15.00- 17.00hrs), Evening (18.00-20.00hrs), and Night (21.00hrs onwards).

Out of the 61 respondents, 42.6% gave time specific responses as guided by the time brackets while the rest (57.4%) gave general answers. In the analysis, elephant activity indicated as feeding only was treated as a feeding peak.

Due to the general and varied nature of responses in the non-specific time responses there was need to come up with comprehensive categories for the time of the day mentioned and the elephant activity. Time brackets were grouped as:

i) Morning
ii) Daytime
iii) Hot sun/Afternoon hours
iv) Cool afternoon
v) Evening/sunset
vi) Night
vii) No time attached (general statements given)

While elephant daily activities were categorized into four classes namely:

i) Feeding
ii) Feeding and other
iii) Others (drinking, resting, moving)
iv) Not sure

For the purposes of mapping, the respondents were asked where and what elephants were feeding on during the wet and dry seasons. The wording of the answers varied while in real sense they were referring to the same areas.

3. Derivation of Elephant Forage Components

3.1. Overview

This chapter discusses an intermediate step for the achievement of the study objectives. Suitable elephant foraging areas are identified using Maximum Likelihood Classification, and digitization while forage density (vegetation) determined through Spectral Mixture Analysis of an ASTER image of 3rd March 2004. The process involved application of various softwares back and forth i.e. Erdas Imagine 9.2, ArcGIS 9.3 and ENVI 4.4. A summary of the process is presented in a flow chart in Figure 3-1

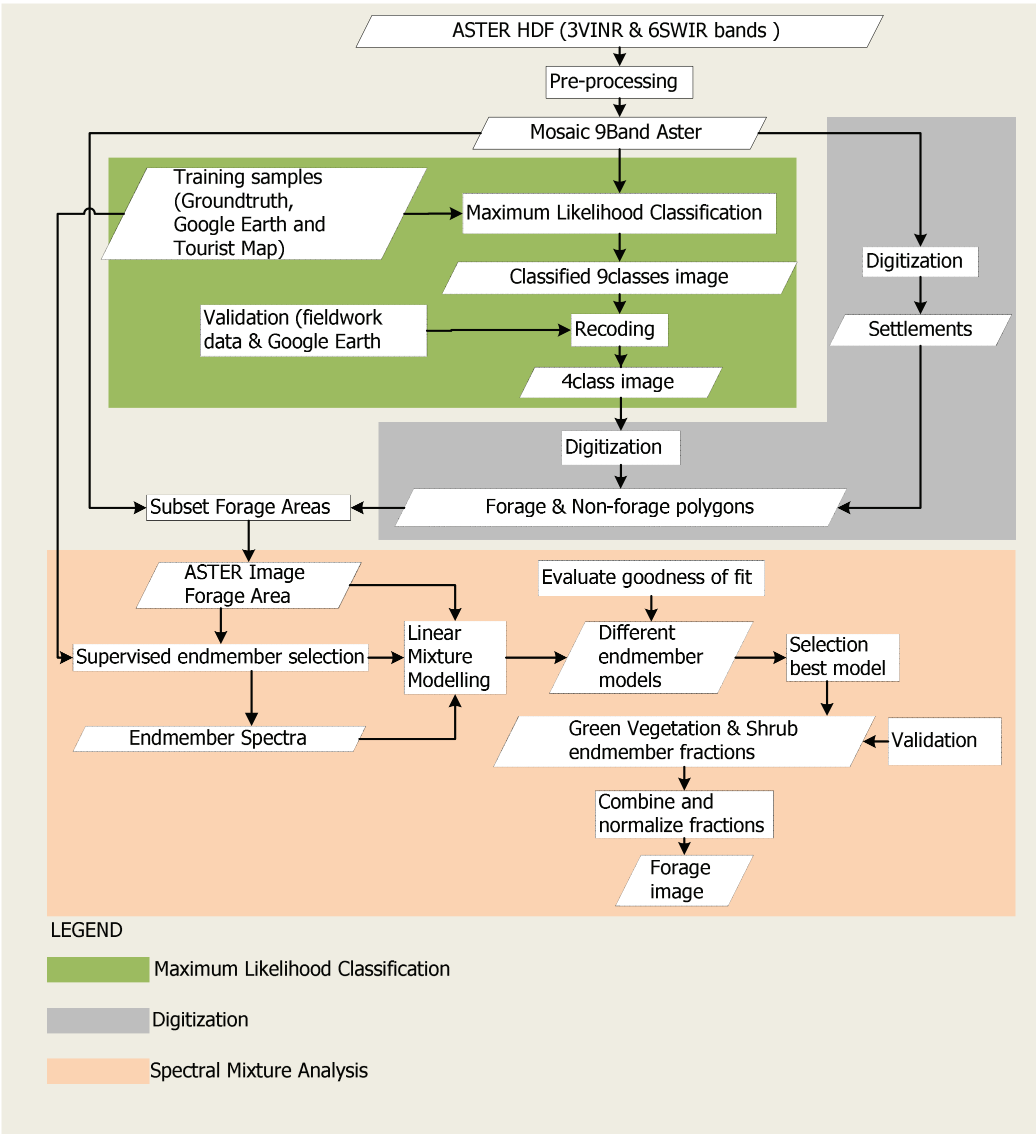


Figure 3-1: Diagrammatic presentation of steps to derive elephant forage cover and density

3.2. Pre-processing

MPA is covered by two ASTER scenes. They were received in 9 bands i.e. 3 Visible and Near Infra-Red (VNIR) and 6 Short Wave Infra-Red (SWIR), Level 1B (with radiometric and geometric corrections) in HDF format. The bands were imported from HDF to Erdas Imagine files.

Geo-referencing was done for the VNIR and SWIR to the UTM WGS-84 Zone 37 coordinate system. The polynomial model and nearest neighbor re-sampling methods were applied using the geo-location information supplied with the ASTER image. The nine bands were layer stacked and SWIR resampled to 15x15m pixel size to match the spatial extent and resolution of VNIR bands. Finally, the two ASTER scenes were mosaicked for a full coverage of the study area.

Atmospheric correction was not done in this study for two reasons: one the Maximum Likelihood Classification and Spectral Mixture Analysis use an ASTER image from one period that was not highly contaminated by atmospheric effects and secondly for Spectral Mixture Analysis, the endmember spectra are derived from the image. This follows the argument put forth in literature that the level of atmospheric correction applied is determined by the objective of the study (Tso and Mather, 2001). They further elaborate ‘in general land cover identification processes based on single date images do not require atmospheric correction if it can be assumed that all pixels in the image are equally affected by atmospheric processes, as the pixels are being compared with other pixels within the image’.

Although Marsabit is characterized by a rugged terrain topographic correction was not carried out because the slope angle is small hence it is assumed that the terrain has no major illumination effects.

3.3. Mapping Suitable Elephant Forage Areas in MPA

3.3.1. Maximum Likelihood Classification (MLC)

The diet of elephants consists of many plant species (Poole, 1996; De Boer *et al.,* 2000). This is also dependant on their environment and season, as they mainly browse on trees and shrubs during the dry season whereas in the wet season browsing is alternated with grazing (Western and Lindsay, 1984; Ruggiero, 1992; Dublin, 1996; Shannon *et al.,* 2006)

MPA is characterized by arid and semi arid conditions with different land cover and land use types. Cover type of interest is vegetation as it is the elephant forage. Therefore, it was important to discriminate non-forage areas.

MPA comprises of varying vegetation types with different phenotypic characteristics. Different methods have been used to categorize vegetation types. These may include physical characteristics (physiognomy), species composition, density, climatic zone they belong to (Pratt and Gwynne, 1977; Van Der Maarel, 2004). However, for the purposes of this research and the limiting power of classification methods used here to discriminate between vegetation classes, four main vegetation classes are coined.

They include:

- ❖ Dry grass
- ❖ Dry Shrubs (includes dry and semidry woody plants e.g. see Figure 3-2)
- ❖ Green vegetation forest area (evergreen)
- ❖ Green vegetation outside forest

Figure 3-2: Example of vegetation type referred to as dry shrubs

Supervised MLC was used to differentiate the cover types. In supervised classification the analyst selects pixels that represent patterns, or a certain land cover they recognize. It is based on prior knowledge of the features from ground truthing, aerial photos, and maps (Mather, 2004)

MLC of the ASTER image was done in Erdas Imagine 9.3. Training samples were collected from field ground truth, Marsabit tourist map dated 1979 and Google Earth. 9 cover types were classified.

- ❖ Green vegetation (inside and outside forest area)
- ❖ Water
- ❖ Dry/semi-dry vegetation (included grass, trees and shrubs)
- ❖ Dam
- ❖ Sand
- ❖ Rocks/gravel

- ❖ Vegetated hills
- ❖ Mixed dry vegetation and sand
- ❖ Mixed rock/gravel and sand

Although houses were part of the cover types, it was very difficult to discriminate with MLC. MPA settlement area comprises of a very heterogeneous landscape. There are patches of vegetation (green and dry), houses roofed with thatch, iron sheet and earth material. For instance when the roofs were identified and several runs of MLC done, the small spots identified as houses influenced classification of known rocky non- settlement areas as houses. Further assessment of the signature in the image feature space proved impossible to separate the shiny iron sheet and white roofs from the rock/gravel and sand classes. Therefore, it was avoided at this stage.

3.3.1.1. Recoding of the MLC result

The MLC resulting 9classes were re-coded into 4classes as summarized in Table 3-1

Table 3-1: Recoded classification categories

Class	Description
Bare	Sand, rocks/gravel, green vegetation, mixed dry vegetation & sand, mixed sand and rock/gravel
Green vegetation	Forest evergreen and green vegetation outside
Water	Water
Dry/semidry vegetation	Dry and semidry grass, shrubs and trees, vegetated hills

3.3.1.2. Validation of MLC Results

There is need to determine the degree of error in classification output (Mather 2004). The most commonly used method is the *confusion matrix* (Foody, 2002). Therefore, the recoded result of MLC classification was validated using ground truth data in a confusion matrix. Note that due to the small number of sample points, the training sample data is the same one used for accuracy assessment. 97points of were used. The overall accuracy, cover class accuracy and kappa statistic were determined.

Kappa (K^) Statistics

The Kappa also called KHAT statistic (Smits *et al.,* 1999) is used to summarize the information provided by a contingency matrix. It is a good measure of accuracy assessment as it compensates for by chance agreement which may arise in the correctly classified case percentages (Foody, 2002). It is calculated using the equation:

$$K= \frac{N\sum_{i=2}^{r} x_{ii} - \sum_{i=1}^{r} x_{i+} x_{+1}}{N^2 - \sum_{i=1}^{r} x_{i+} x_{+1}} \qquad (4)$$

Where:

x_{ii} is the diagonal entries; x_{i+} sum of row *i;* and x_{+1} sum of column of confusion matrix

N number of elements in the confusion matrix

A value of 0 indicate no agreement while, perfect agreement is at 1.0. A Kappa statistic at 0.75 is accepted, as 'very good to excellent' output by the classifier, while below 0.4 is considered very poor (Mather, 2004).The resulting 4class image was used in ArcGIS for discrimination of non-forage areas.

3.3.2. Separation of Forage and Non-forage Areas

After the classification of the cover types, it was necessary to discriminate elephant non-forage areas in MPA. First, there was need to device a way of identifying the settlement areas that were not classified with MLC. This was challenging not only for lack of MLC power to discriminate settlement areas, but also lack of a detailed map with boundaries of the settlement area. Nonetheless, with some prior knowledge of MPA, unique pattern portrayed on the ASTER image and some reference to high resolution Google Earth images, it was possible to digitize the settlement area in the ASTER image. It should be noted that this digitization without detailed boundary extent maps, may have led to under or overestimation of settlement boundaries, but with negligible effects to be expected for this research.

Additional information was essential for meaningful elimination of non-forage areas. This was gathered from fieldwork observations and interviews. First, the Mt. Marsabit Forest vegetation (covered in the green vegetation class) was not browsed by elephants except in a few shrub patches inside the forest. Second, the settlement area has small patches of green trees, fences and shrubs that elephants forage on. Thirdly, elephants avoided very rocky and sandy ground found in the north of the protected area and south outside the protected area.

Digitization of the available forage areas was done with careful consideration of the aforementioned information and classification results. Although the forest and settlement areas contained small patches of forage material, the whole area was eliminated to avoid small fragments that would bring confusion in the analysis. The bottom of Bongole crater containing water was also discriminated. The final polygon of the Forage area was produced (see Figure 3-3)

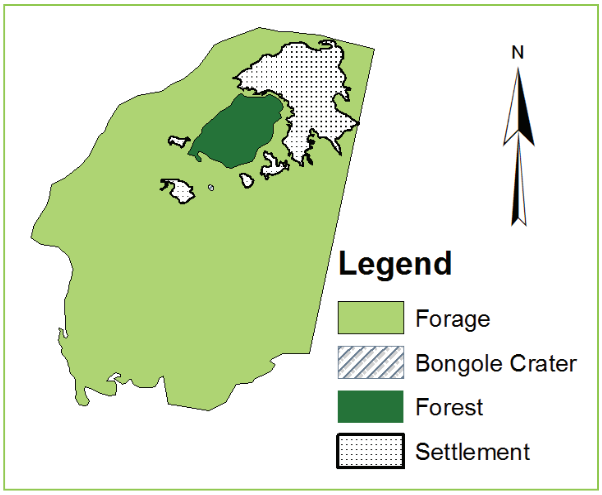


Figure 3-3: Polygons of areas identified as elephant forage and non-forage

Using the polygons, the ASTER image 3rd march 2004 was subset to reflect the forage areas for Spectral Mixture Analysis

3.4. Estimating Forage Densities through Spectral Mixture Analysis (SMA)

3.4.1. The Linear Mixture Model

Vegetation cover class was identified with MLC as the available forage areas. However, due to the heterogeneous nature of MPA, often the case in arid and semi-arid lands, pixels of vegetation mix with the bright earth materials (Shupe and Marsh, 2004). MLC can only detect classes but not the quantitative cover. This is a major problem in intermediate resolution images (Theseira *et al.,* 2003) such as the ASTER used in this analysis. Nonetheless, reliable methods have been developed to solve mixed pixel problem e.g. Spectral Angle Mapping, Linear Mixture Modelling (Mather, 2004; Liu and Wu, 2005)

The most commonly used method to tackle the problem of mixed pixel is SMA (Lu *et al.,* 2003; Tateishi *et al.* 2004; Wang and Uchida, 2008). It is also referred to as Linear Mixing Models, Linear Spectral Mixture Analysis, Mixture Modelling, Linear Spectral unmixing, or Spectral Unmixing (Defries *et al.,* 2000; Heinz and Chang, 2001; De Asis *et al.,* 2008). SMA provides 'relative proportions of ground cover components within a mixed pixel' (Tso and Mather, 2001). Many studies have seen the application of SMA for instance, it has been applied in:

- Vegetation and land cover mapping (Verhoeye and De Wulf, 2002; Lu *et al.* 2003; Tateishi *et al.* 2004; Uenishi *et al.* 2005; Ferreira *et al.,* 2007)
- Mapping urban composition (Wu, 2004; Song, 2005; Powell *et al.* 2007)
- Mapping burnt areas and assessing effects of fire on vegetation(Quintano *et al.,* 2005; Smith *et al.,* 2007)
- Crop mapping (Verbeiren *et al.,* in press; Peddle and Smith, 2005; Wang and Uchida, 2008)
- Terrain evaluation(Casals-Carrasco *et al.,* 2000)
- Soil erosison studies (De Asis *et al.,* 2008)

SMA often uses the Linear Mixture Model (LMM), which makes two assumptions. First, pixels are a product of linear mixing i.e. no multiple scattering takes place whereby pixels are a product of photon interaction with just one cover type (Robinson *et al.,* 2000; Tso and Mather, 2001). Secondly, one can identify the mixture components (Wang and Uchida, 2008). However, there are arguments that, the assumption of linear mixing does not hold in some environments and results to errors in the model (Ray, and Murray, 1996). This research follows most researchers who assume nonlinear mixing is negligible.

The LMM mathematical expression is $R_i = \sum_{j=1}^{m} f_j a_{ij} + \xi_i$ ***(5)***

Where:

R_i is the reflectance of given pixel in the *i*th of m spectral bands;

f_j Proportions of endmembers *j* in a pixel (*n* number of mixture components);

a_{ij} Is the spectral reflectance of endmember *j* within the pixel in band *i*;

ξ_i Is the difference between the observed pixel reflectance r_i and reflectance for the pixel computed in the model.

LMM can be applied with a constraint or unconstrained (Gong and Zhang, 1999; Heinz and Chang, 2001). In constrained models, the following conditions are applied:

- Fractions of endmembers be non-negative ($f_i \geq 0$); ***(6)***
- The combination of endmembers sum to unity ($\sum_{j=1}^{n} f_j = 1$) ***(7)***

The constraints ensure that LMM has logical results with the assumed linear mixing of components (Mather, 2004). On the other hand LMM can be applied without considering the constraints but this may result to illogical values of the endmember fractions outside the range 0 and 1 referred to as undershoots (negative values) and overshoots (values greater than 1).

For best performance of LMM, certain conditions must be satisfied (Theseira *et al.,* 2002; Lu and Weng, 2004; Tateishi *et al.,* 2004; Uenishi *et al.,* 2005). They include:

i) Endmembers should be independent, and accounted for in the mixed pixels
ii) The maximum number of separable end members should be less than or equal to the number of bands (Tso and Mather, 2001)
iii) Only a few endmembers should be input into the model. Too few will lead to division of missing endmembers into proportions of the modelled end-members. This results into negative values in the model. On the other hand, too many endmembers results into the model getting more sensitive to instrumental noise, atmospheric interference and natural variability in spectra (Sabol *et al*., 1992). Three to four is assumed as the typical number to be used.
iv) Spectral bands should not be highly correlated otherwise this may be problematic in the analysis (Tso and Mather, 2001)

To test the goodness of fit for the model two methods are applicable according to Mather (2004).

i) Root Mean Square Error (RMSE) it gets the square root for sum of the squares of all residuals in a given pixel.

RMSE is computed as = $\sqrt{\frac{1}{M}\sum_{j=1}^{M}\xi_i^2}$ ***(8)***

Where: ξ_i is the residual value in each spectral band (difference for observed pixel value and computed LMM value)

The larger the RMSE the worse the fit of the LMM (Lu *et al.,* 2003; Mather, 2004; Wang and Uchida, 2008)

ii) Range of LMM endmember output fractions. The ranges should be between 0 and 1. Both the overshoots and undershoots should comprise a small percentage i.e. <5% according to Mather (2004)

3.4.2. Application of LMM on the Forage Areas Image

LMM was run using ENVI 4.4 software.

3.4.2.1. Selection of Endmembers

Many approaches have been applied in the identification of endmembers. Some of these include selection from a spectral library in softwares such as ERDAS IMAGINE, ENVI; field/laboratory reflectance measurements and derivation from purest pixels in the image (Lu *et al.* 2003; Souza *et al.,* 2005; Wang and Uchida, 2008).

Endmember selection from the image is done using various methods. Examples include: Pixel Purity Index which is calculated by transforming image pixels and projecting them onto random unit vectors (Dennison and Roberts 2003); and Principal Component Analysis transformed data (Theseira *et al.* 2003)

In this study supervised selection of endmembers was done based on training samples collected during fieldwork. This method has been applied in other researches (Elmore *et al.,* 2000; Shoshany and Svoray, 2002). It is advantageous in that the endmembers correspond with the atmospheric conditions of the image scene (Wang and Uchida, 2008), can be obtained easily and spectrum was of the same scale as the image data of interest (Lu *et al.* 2003).

The heterogeneous nature of MPA and the scattered vegetation often the case in arid and semi-arid environments (Elmore *et al.,* 2000) made it difficult to find 'pure' pixels for the various land cover types. Therefore, pixels comprising less than 100% land cover type were considered as the 'pure' endmembers. A summary of the covers considered for endmember selection in this analysis as recorded during fieldwork is shown in Table 3-2

Table 3-2: Cover type percentages as used for endmember selection

Endmember	*Percentage Cover*
Green Vegetation	95%
Dry Shrubs	75-80%
Dry Grass	95%
Bare Soil	90%
Rock/ Gravel	95%
Sand	95%

The endmembers were selected using ENVI 4.4 Region of Interest (ROI) tool and then plotted on an ROI statistics plot to check their independence (see Figure 3-4)

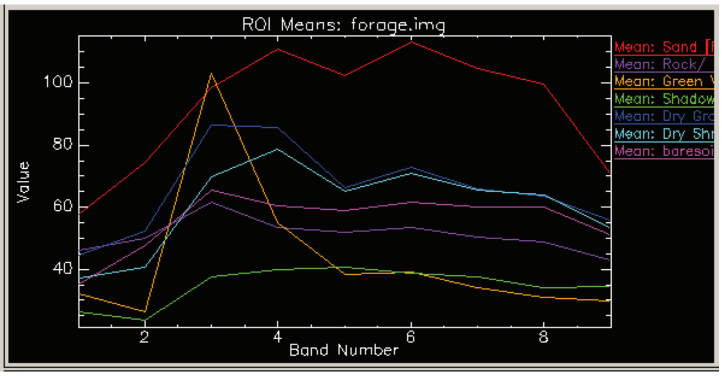


Figure 3-4: Plot for cover type means from ROI statistics

Cover type statistical separability was computed using the ROI separability option. It computes the Jeffries-Matusita and Transformed Divergence separability measures, which range between 0 and 2. Values greater than 1.9 indicate good separability, while values less than indicate same cover component. The statistics were high between 1.999 and 2.0 indicating a good cover type statistical seperability (ENVI 4.4 help). The statistics are shown in Appendix 5

3.4.2.2. Implementing the LMM

Different endmember models were run with the summation constraint (equation 7). However non-negative constraint (equation 6) was not done. Summation constraint is the easiest to implement (Heinz and Chang, 2001) and in fact it was an available option in ENVI 4.4 LMM.

Assessment for Goodness of Fit

To test for goodness of fit for LMM output *RMSE* was used. Different 'endmember models' were tested for the best fit. The model with least RMSE, maximum endmember numbers and portraying least noise was selected (See appendix 6 for the tested endmember models).

The LMM resulting fraction covers of interest 'green vegetation' and 'shrubs' were combined using ENVI4.4 band math addition option as shown in Figure 3-5.

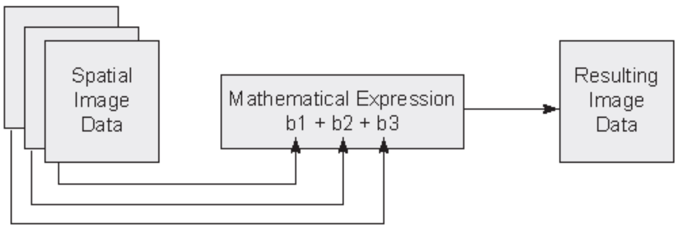


Figure 3-5: Band math processes addition of three bands (ENVI 4.4 Help)

Note carefully that although the cover percentages used as pure endmembers were less than 100% (see Table 3-2), it would have been illogical to convert resulting LMM fractions to suit the field fractions due to the problem of overshoots and undershoots. Therefore, the fractions were added as they were using equation 9 and the resulting images normalized to 0-100% with equation 10. Furthermore, this research was only interested in relative forage cover amounts, thus it was assumed that the relative forage covers were between 0 and 100%.

The shrub and green vegetation image fractions were combined as follows:

b1+ b2= b0 ***(9)***

The equation translates to Green Vegetation Fraction + Dry Shrub Fraction **= Forage Image**

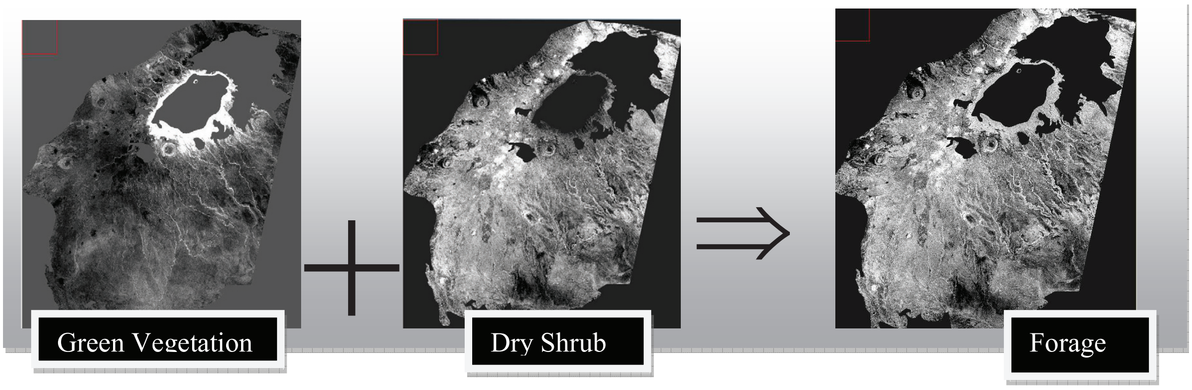


Figure 3-6: Images Fractions added in ENVI 4.4 band Math for production of Forage Fractions

After adding the green vegetation and dry shrub fractions, the forage image consisted of undershoots and overshoots. These were eliminated by setting a band math condition (equation 10) thereby limiting the range of output values to 0 and 1:

0>b1<1 ***(10)***

3.4.3. Comparison of SMA Results with MODIS EVI

To test how SMA results compares with other vegetation indicators, MODIS EVI was compared with LMM green vegetation fraction. MODIS EVI band of 5th March 2004 was downloaded and processed through the procedure described in § 2.3.1.2. The date is close to the date the ASTER image used in the analysis was taken. 200 random points were generated in ArcGIS 9.3 within the extent of the forage area. Then the values from the green vegetation fraction image from LMM and MODIS EVI were extracted and compared in a linear regression analysis

4. Elephant Foraging Behaviour Using LF Model

4.1. Overview

In this section, the product of vegetation classification (chapter 3) is used to understand elephant foraging behaviour. First LF in elephant movement is tested using the recently proposed Maximum Likelihood Estimation method (Edwards, 2008). Second elephant feeding behaviour at different vegetation densities is analyzed by calculating Levy indices from lowest to the highest density from the SMA results. Third, the Levy index is calculated for the different feeding peaks (Morning, afternoon and night feeding). Finally, analysis done to test whether foraging behaviour is dependent on gender (see a summary flowchart in Figure 4-1). All the analyses were done in ArcGIS 9.3, Microsoft Excel 2007 and SPSS 15.0.

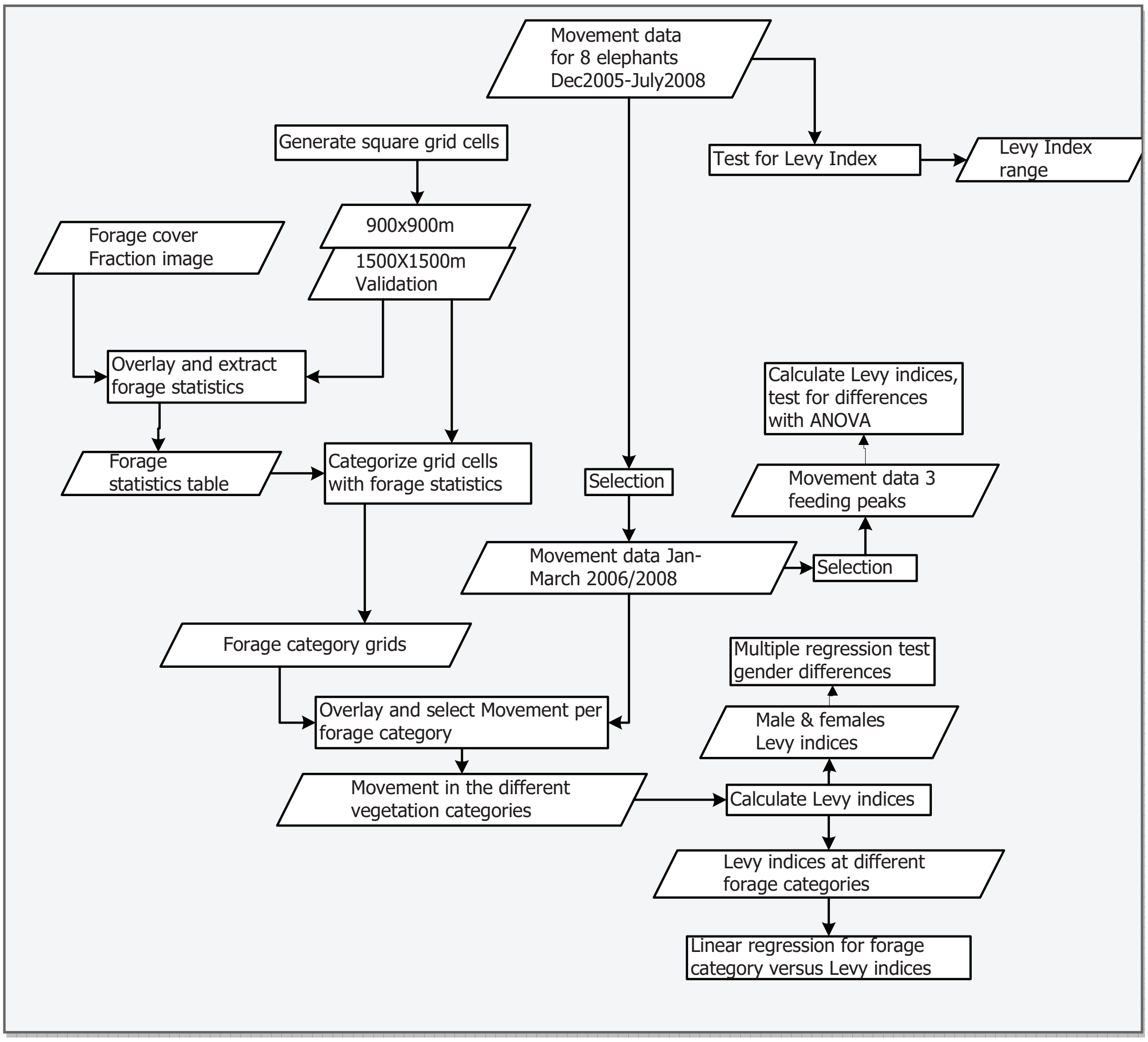


Figure 4-1: **Diagrammatic presentation of procedure followed in LF Modelling**

4.2. Determining LF in Elephant Movements.

4.2.1. Methods for Estimating Levy Indices

Different methods have been used to estimate LF in animal movements. According to Sims *et al* (2007) LF is dependent on accurate determination of Levy exponent (μ) which is in the range $1<\mu<3$. The methods include:

i) Log transform method where the data is binned and frequency are plotted in a histogram on a log-log scale (Viswanathan *et al.* 1999; Marell *et al.,* 2002; De Knegt *et al.*, 2007; Sims *et al.,* 2007)
ii) Log binning with normalization (Bartumeus *et al.,* 2003)
iii) Calculating the cumulative frequency distribution function
iv) Rank frequency

LF modelling in biological encounters is a recent field in science and a lot of work is underway. The aforementioned methods have been faulted and termed erroneous in determining LF in animal movements (Edwards *et al.,* 2007; Edwards, 2008). This was concluded after these authors reanalyzed published data in previous studies as well as simulating randomly generated data for generation of LF. Consequently they proposed a more reliable and accurate method, referred in their publication as Maximum Likelihood Estimation (MLE). This is the method applied in this research.

The mathematical expression of MLE involves determination of the likelihood function from the log-likelihood function for the power-law tail equation:

$$\log[L(\mu / \text{data x})] = n\log(\mu-1) + n(\mu-1)\log a - \mu\sum_{j=1}^{n}\log x_j \quad \textbf{\textit{(11)}}$$

Where:

x is known movement data,

a is the shortest measured move length (which is 5m in the elephant movement data),

$\log[L(\mu / \text{data x})]$ is the likelihood of a particular value of unknown μ given the known movement data x, and log is the natural logarithm

Hence, MLE for μ (denoted as $\hat{\mu}$) is given in the equation:

$$\hat{\mu} = \mathbf{1} - \frac{n}{n\log a - \sum_{j=1}^{n}\log x_j} \quad \textbf{\textit{(12)}}$$

4.2.2. Calculating Levy Indices in Elephant Movement Data

To determine whether MPA elephant movement pattern when searching for resources follows a power-law distribution, all the available movement data from 2005 to 2008 (see Table 2-2) is used for calculation of the μ. The choice for all the available data is that it offers an opportunity to work with a large sample size, which increases the accuracy in data analysis (Sims *et al.,* 2007; Edwards, 2008; Moore *et al.,* 2009). Care was taken to eliminate move lengths associated with migration (see Figure 4-2), which Bartumeus *et al* (2005) argues that when a move is not driven by a search but 'strong internal navigation mechanisms (i.e. migrations) or environmental constraints' it should not treated as forage search.

The migration paths were manually selected in ArcGIS because they formed long straight-like paths.

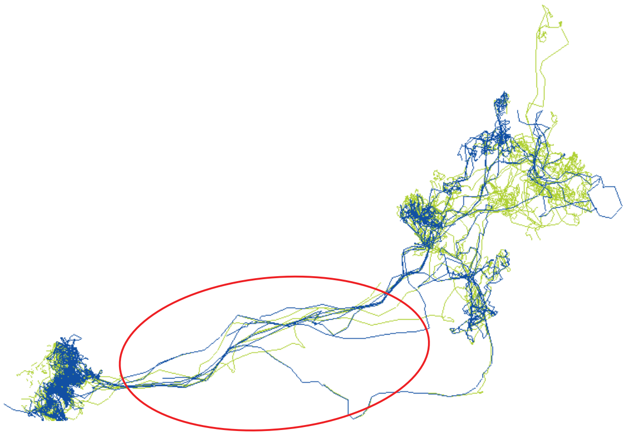


Figure 4-2: Example of elephant migratory tracks omitted in LF estimation (encircled)

The selection of the elephant flights was done using ArcGIS 9.3 and then exported to Microsoft Excel. In other instances, SPSS was used for graphical presentations. Using the flights, μ was calculated using *equation 12*. It is noteworthy that the *minimum flight* recorded in the elephant movement data of study was *5m*. Thus, whenever *equation 12* was applied in this paper to calculate μ the minimum flight was 5m.

4.3. Determining the Influence of Forage Density on Elephant Foraging Behaviour.

4.3.1. Elephant Movement Data for the Analysis

Sound science requires a serious forethought on the choice of study parameters. This is important in this research due to different dates of study materials. The ASTER image used to derive forage parameters is for a single-date. On the other hand available complete movement datasets covered different dates. Therefore, selection of movement data had to be given careful consideration. It had to be within dates that correspond with relatively similar vegetation conditions as the dates the ASTER image of study was taken.

In MPA January through March are dry periods. During this period, the vegetation conditions are more or less the same. Therefore, the elephant movement data was selected for January to March 2006 and 2008 as shown in Table 4-1 with the assumption that the vegetation conditions analyzed in the ASTER image of 3rd March 2004 are representative of field conditions at the movement data period.

Table 4-1: Movement data in analysis of vegetation influence on elephant foraging behaviour.

Animal Name	Gender	Data Months	Data Year
Felista	Female	January to March	2006
Hermes	Male	January to March	2008
Jaldesa	Male	January to March	2006
Kamau	Female	January to March	2008
Karare	Male	January to March	2006
Paradise	Female	January to March	2006
Rita	Female	January to March	2008
Sora	Male	January to March	2008

It is noteworthy that an assessment of the selected movement data showed a few disjoint tracks due to collar failure during certain hours of the day. However, these were not removed from the data with the assumption that their effects on the analysis would be negligible.

4.3.2. Forage Cover Percentages

The output 'Forage Image' was in ENVI 4.4 High Dynamic Range (HDR) format. It was exported into TIFF format for analysis in ArcGIS 9.3. Square grid cells of 900m were generated within the extent of forage area. The choice for size of the grid cells was with the reasoning that for elephants, an area of about 1km is logical when searching for forage, and to avoid cutting the image pixels that are in 15mx15m, a multiple of this value close to 1km was taken. Then movement data was overlaid on the grid cells. 412 grid cells consisting of the movement data were selected. Movement data falling outside the forage area was eliminated.

Using the ArcGIS 9.3 Spatial Analyst Tool, the minimum, maximum, mean and standard deviation statistics of 3600 15x15m cells of the forage fraction image were aggregated to the grid cells with the movement data.

To have statistically testable sample sizes for the movement data in each of the grid cells, the forage cover means were categorized in groups of 10 as shown in Table 4-2. It is noteworthy that in the selected grid cells the mean cover abundance was between 44% and 100%, hence covering codes 5 to 10, also as shown by the standard deviations. The counts for each of the cover category are shown in Appendix 8

Table 4-2: Forage cover categories

Forage Mean Cover Category	Standard Deviations	Cover Code
0-10		1
11-20		2
21-30		3
31-40		4
41-50	26	5
51-60	29	6
61-70	28	7
71-80	25	8
81-90	20	9
91-100	12	10

4.3.3. Calculation of μ for Elephant Flights in Varying Forage Cover Percentages

Flights for the eight elephant were overlaid on the grid cells with known mean forage cover percentages, then selected for each of the cover code using the select by location command 'have their centroid in' in ArcGIS. The count for all the move lengths in the various forage cover categories are summarized in a bar graph in Appendix 9.

A linear regression was done for forage cover categories versus μ.

4.4. Determining the Influence of Gender on Elephant Foraging Behaviour.

In this section, movement data for four cows and eight bulls is analyzed. The distribution of the data is summarized in Figure 4-3.

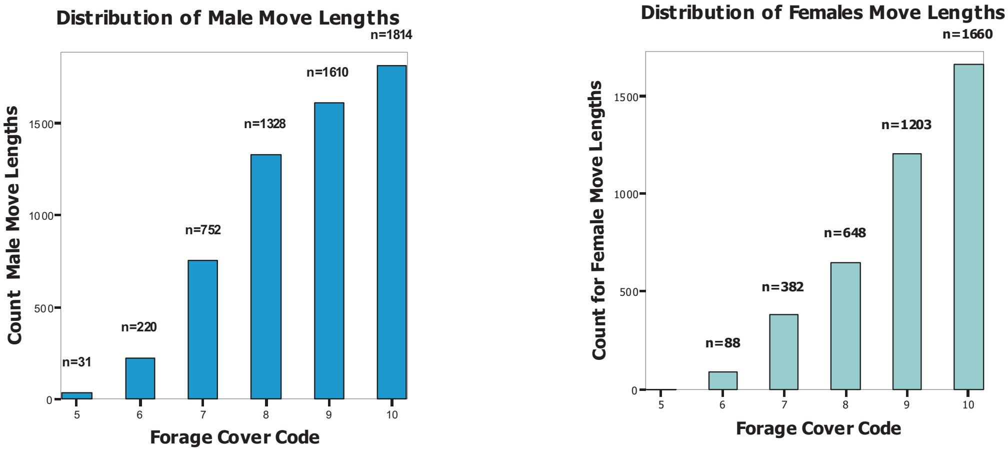


Figure 4-3: Distribution of male and female move lengths in varying vegetation densities

4.4.1. Calculation of μ for Males and Females in Varying Forage Cover Densities

Using the grid cells as described in § 4.3.2, the elephant flights for both males and females was selected. Using the *equation 12,* μ was calculated for both male and female at varying vegetation densities. It should be noted that for forage cover code 5, it was ignored in this analysis because there was only one move length for females. Hence, the mean μ for the males and females was calculated from cover code 6 to 10.

To test whether the μs for males and females were significantly different, a Multiple Regression was done. Forage Cover, Gender and Interaction Term (Gender x Forage cover) were entered as the predictor variables while μ was the dependent variable. The Interaction Term (Gender x Forage Cover) was added to the predictors to test whether selection of foraging areas was influenced by gender.

The Multiple Regression Model is adapted from (Field, 2005). Basic equation:

$\text{Outcome}_i = (\text{Model}_i) + \text{error}_i$ ***(13)***

Addition of variables in the model reads as: $Y_i = (b_0 + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n) + \varepsilon_i$ ***(14)***

Where Y is the outcome variable; b_1 coefficient of the first predictor (X_1); b_2 coefficient of the second predictor (X_2); b_n coefficient of the nth predictor (X_n); and ε_i is the difference between the observed Y value for the ith participant.

The model was run using the ‘Backward Regression Method’ in SPSS. As explained by Field, (2005), backward method follows a stepwise removal criterion, whereby all the predictors are put into the model and their significance weighed. If not significant the predictor is eliminated and the model runs again, until all the predictors with significance contribution are left in the model.

4.4.2. Validation of Grid Cell Size

To test whether the size of grid cells would have an effect on the μ for different forage cover densities, larger square grid cells of 1500m were used. The data was analyzed following the steps described in **§ 4.3.2 to 4.4.1**. However, it should be noted that the least forage cover for these grid cells was from cover code 6 unlike for the 900mx900m grid cells, which was cover code 5.

4.5. Determining the Influence of Time on Elephant Foraging Behaviour.

This analysis was done for three elephant feeding peaks i.e. Morning, Afternoon and Midnight. The January to March 2006 and 2008 movement data for the eight elephants was used to select the feeding peaks. The movement data contains information on the time of recording and therefore it was possible to select move lengths for the various feeding peaks.

According to field interviews, observations and literature, elephant feeding peaks were identified as:

- Morning- 9.00-11.00hrs
- Afternoon-15.00 to 17.00hrs
- Midnight- 22.00 to 00.00hrs

Therefore, movement data was selected for the three periods. Flights that fell outside the forage area were discriminated.

A total of **3943** flights were available for the three feeding peaks. A summary of their distribution is presented in Figure 4-4

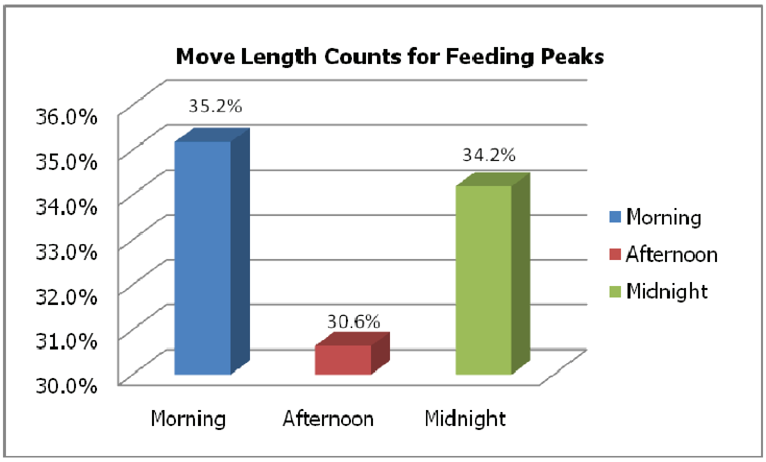


Figure 4-4: Elephant Flights for Morning, Afternoon and Evening Feeding Peaks

For each of the feeding peaks six categories comprising of 200flights selected at random were formed. Then μ for each category was calculated using *equation 12*. This was necessary to test whether there were variations in averages within and between the feeding peaks. An ANOVA (Analysis of Variance) test was done to check for significant differences (Field, 2005).

Tukey's HSD (Honestly Significant Differences) post-hoc test was done after the ANOVA test to determine which group of mean μs for the three feeding peaks differed from each other.

5. Results

5.1. Validation of Elephant Feeding Sites and Periods

5.1.1. Observations

The observations made during fieldwork were few in number and only possible for morning hours i.e. 06.00-08.00hrs, before the elephants disappeared into thick vegetation. From the observations, it was apparent that elephants are exchanging feeding areas in the morning and evening. There are two groups that alternate the feeding areas whereby in early morning 06.00-08.00hrs, one group is heading to the uplands from the night feeding in the lowlands while the other group moves in opposite direction. In the evening, this feeding movement pattern is alternated.

5.1.2. Interviews

After analyzing the interviews from all respondents (N=61), a few conclusions can be drawn. 42.6% of the 61 respondents gave activity pattern specific to the time bracket in question. Answers given as feeding only were counted as the feeding peaks.

96.2% of the 42.6% responses indicated 09.00-11.00hrs as the morning feeding peak. Figure 5-1 summarizes the responses.

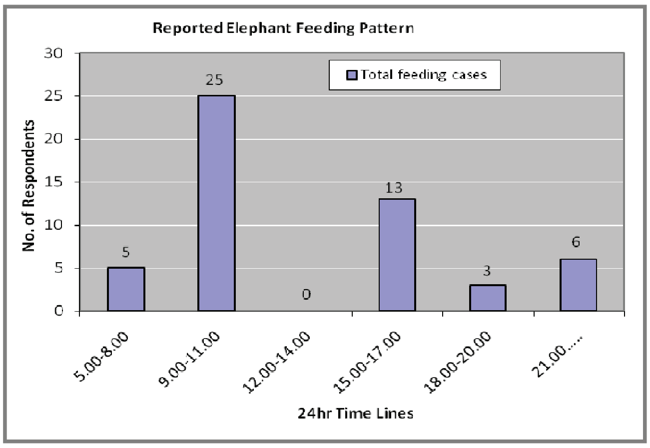


Figure 5-1: Number of respondents indicating feeding only activity

'Non-specific time' (generalized periods) responses were also treated as the time specific responses. Answers given as feeding only were treated as the feeding peaks. However, it was difficult to identify the morning feeding peak as the morning period the respondents were referring could be any time between 7.00-12.00hrs, but there is an agreement that elephants are feeding in the morning. Therefore, the morning feeding peak was identified using the time specific responses backed by field observations as the 09.00-11.00hrs time bracket.

For the afternoon feeding 50% (n=26) of the time specific respondents indicated that the feeding is between 15.00-17.00hrs. This is in agreement with non-specific time responses where 72.7% (n=22) indicating time as cool afternoon gave elephant activity as feeding (see Figure 5-2). Prior knowledge is that many people in Marsabit and Kenya in general refer to the time 15.00-17.00hrs as cool afternoon. This period was therefore taken as the afternoon feeding peak.

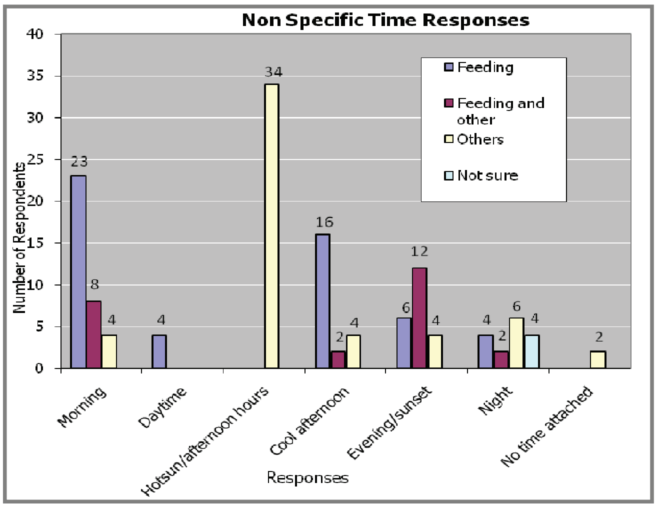


Figure 5-2: Non-specific time responses on elephant daily activity

The night feeding peak was not properly understood. This was clear in almost all the answers respondents gave except a mention of raids on crops and fences that mostly started from 22.00hrs.

Feeding areas for the dry and wet season vary. 88.9% of all the respondents agreed that, elephants alternate feeding in the lowlands and uplands i.e. the immediate surroundings of Mt. Marsabit Forest. 4.9% indicated that elephants are only feeding in the uplands, which include the Marsabit Forest area, while the remaining 6.6% said that some elephants are permanently feeding in the uplands while others feed in the lowlands. See a summary in Figure 5-3

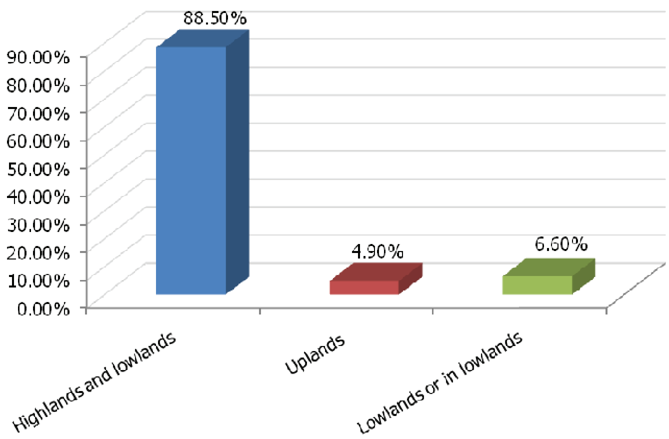


Figure 5-3: Elephant feeding areas during the dry season.

For the wet season all the respondents agreed that elephants moved further into the lowlands and only encountered them when herding.

5.2. Elephant Suitable Foraging Areas and Forage Density

5.2.1. MLC

MPA elephants feed in the uplands and lowlands surrounding Mt. Marsabit Forest. Through supervised MLC, the area was classified into nine classes, which were later recoded to four classes as shown in Figure 5-4.

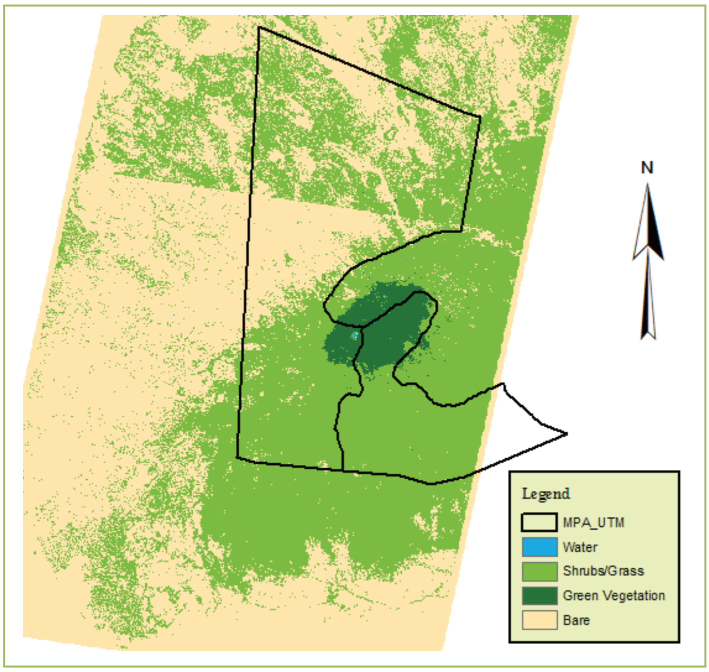


Figure 5-4: Map of Classified cover types in MPA

Accuracy Assessment

The resulting image had varying accuracies between classes as presented in Table 5-1.

Table 5-1: Accuracy assessment matrix

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Green Vegetation	23	17	17	73.91%	100.00%
Water	1	1	1	100.00%	100.00%
Shrubs/Grass	45	47	37	82.22%	78.72%
Bare	28	25	20	71.43%	80.00%
Totals	97	97	75		
Overall Classification Accuracy =77.32%					

The class bare had the lowest producer accuracy of 71.43%. MLC was able to discriminate the different cover types in MPA with an overall accuracy of **77.32%**

Kappa (K^) Statistics

The Kappa statistic for MLC was relatively high at 0.66% as shown in Table 5-2. 0 value indicates no agreement while, perfect agreement is at 1.0 (Mather, 2004)

Table 5-2: Kappa statistic for the MLC

Class Name	Kappa
Green Vegetation	1
Water	1
Shrubs/Grass	0.6031
Bare	0.7188
Overall Kappa Statistics	**0.6559**

The elephant foraging area comprises of the green vegetation and shrubs at the areas surrounding Mt. Marsabit Forest. It falls in and outside the protected area, mainly including the southern part. However, the northern area, with a majority of the bare cover category, is outside elephant forage area. A small tip of the protected area falls outside the ASTER image extent and therefore not considered in the analysis (see Figure 5-5).

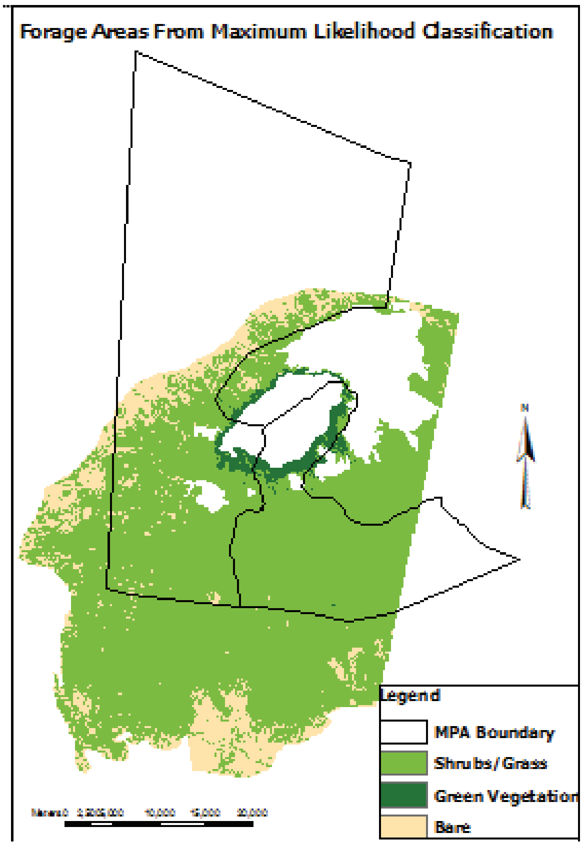


Figure 5-5: Map showing the Area Delineated as Forage from MLC

5.2.2. Spectral Mixture Analysis

Six endmembers were used in this analysis. They included three background components (Sand, Rock/gravel, and Bare soil) and three vegetation components (Green vegetation, Dry/semidry grass and Dry/semidry shrubs)

5.2.2.1. LMM Results

Model Statistics

The model produced undershoots and overshoots for the various endmembers. Dry shrubs had the highest standard deviation while green vegetation had the least. The maximum percentage for the dry shrub of 414% is highly outside the LMM 0-100% range.

The summation constraint *equation 7,* did not work well as the resulting fractions have overshoots. This is clearly shown in the maximum values range with sand fraction having the smallest value at 1.38, while the largest is for dry shrub at 4.14. Undershoots are also high as shown in the minimum column in the LMM output table. The statistics for all the endmembers are summarized in Table 5-3.

Table 5-3: Statistical results for LMM output

Endmember	Minimum	Maximum	Mean	Standard Deviation
Sand	-0.76	1.38	0.04	0.19
Rock/gravel	-0.64	2.34	0.41	0.20
Green vegetation	-0.67	1.66	0.01	0.16
Dry grass	-2.51	3.82	-0.23	0.37
Dry shrub	-5.16	4.14	0.75	0.50
Bare soil	-1.14	1.60	0.06	0.29
RMSE error	0.01	3.76	0.52	0.24

5.2.2.2. Assessment of LMM Goodness of Fit

The goodness of fit for LMM output was tested through assessment *RMSE* and *proportions of pixels with undershoot and overshoot* (Mather, 2004).

I) *RMSE*

This is the residual term (ξ_n) in the mixture equation, the larger it is, the worse the fit of the model. In LMM, an RMSE fraction image is produced and it indicates areas with missing endmembers or incorrect endmembers (Mather, 2004; ENVI help).

To determine endmember combination with the least RMSE, different 'endmember models' were run (see appendix 6). The 7 endmember model had the least mean RMSE= 0.38, but as described by (Gong and Zhang, 1999), a large number of endmembers result to an output affected by instrumental noise. This was apparent from visual assessment of the image hence another 'endmember model' was tested. Among the other models, 6-endmember model had the least mean RMSE (0.52) and at the same time minimum noise effects.

In the RMSE image, Figure 5-6, bright areas indicate poor model performance. These were mostly in hilly areas and craters in MPA. The southern part of the Forage image comprising of rock/gravel and sand endmembers was also poorly mapped. The standard deviation for the RMSE fraction was 0.24 (see Table 5-3).

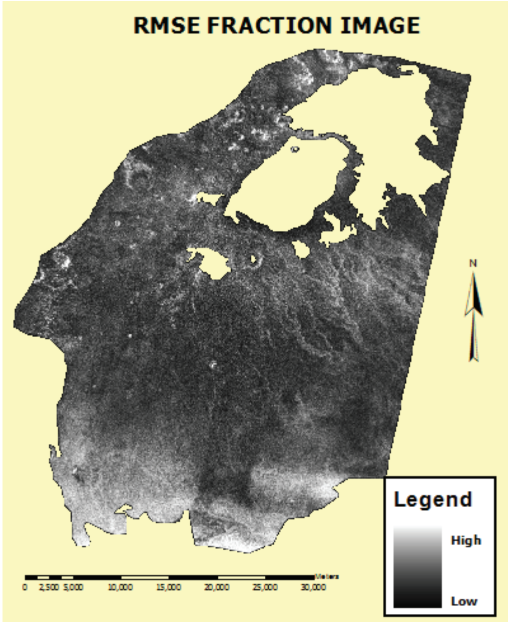


Figure 5-6: RMSE image fraction of 6-endmember LMM output.

II) ***Proportions of Pixels with Undershoots and Overshoots***

Illogical values outside the 0-1 range (undershoots and overshoots) are indicators of poor performance of LMM. However, a small percentage less the 5% is acceptable otherwise; the model does not fit well (Mather, 2004). The output of LMM model in this research therefore shows that the model does not fit well as the minimum and maximum value ranges are outside 0-1, as shown in Table 5-3.

5.2.2.3. Comparison of LMM Green Vegetation Fraction with MODIS EVI

The LMM output of the green vegetation fraction was compared with MODIS EVI. The results show a high correlation with an R^2= 0.68, but MODIS EVI tends to be saturated at 0.5 as shown in the scatter plot in Figure 5-7

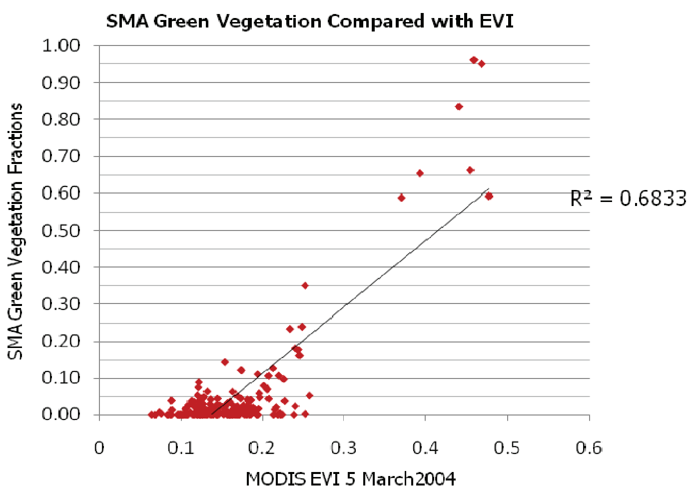


Figure 5-7: Comparative results of LMM green vegetation output with MODIS EVI

5.2.2.4. Map Output

Green vegetation and dry shrub fractions were combined and normalized to logical LMM values i.e.0-100% cover. The values range between 0.0002% and 100%. The areas at the forest periphery and scattered patches at the lowlands show the highest forage cover, while the southern and a few craters in northwestern part comprising of rock/gravel and sand endmembers show the least fractions of forage (see Figure 5-8). A more detailed map is attached in Appendix 7

Figure 5-8: Distribution of Forage cover in MPA

5.3. Elephant Foraging Behaviour

5.3.1. Levy Index Range in Elephant Movement

The results show that elephant are using LF when searching for resources at μ=1.3; therefore the null hypothesis was rejected as elephant movement path is within the Levy index range $1<\mu\leq3$.

5.3.2. Influence of Forage Density on Elephant Foraging Behaviour

After calculating the μs for all the eight study elephants at the different vegetation categories derived from LMM with 900m square grid cells, the relationships were determined using a linear regression. The results show a significant positive relation between μ and forage density (R^2 =0.83, β= 0.911, seβ =0.002; F=19.6; d.f. = 5; P = 0.011<P=.05, hence H_0 is rejected). Table 5-4 and Figure 5-9 summarizes the results. More detailed statistics for the forage image fractions are attached in Appendix 10

Table 5-4: μ at different vegetation densities

Forage Cover Code	μ
5	1.178982
6	1.217276
7	1.220628
8	1.223147
9	1.23481
10	1.244463

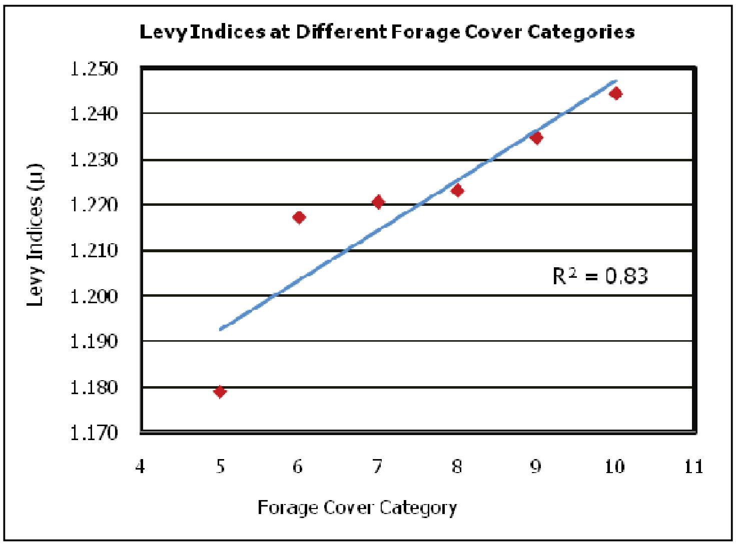


Figure 5-9: μ values at different vegetation densities with 900m square grid cells

Additionally a linear regression was performed for movement data for the four bulls and four cows. Both show a similar pattern portrayed earlier in Figure 5-9. However, the R^2 for females= 0.74 is slightly lower than that for males =0.83, see Figure 5-11

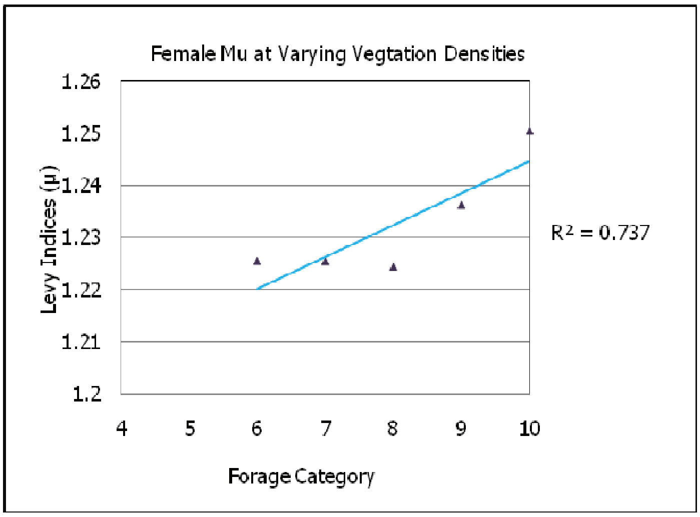


Figure 5-10: Female μs at different vegetation densities

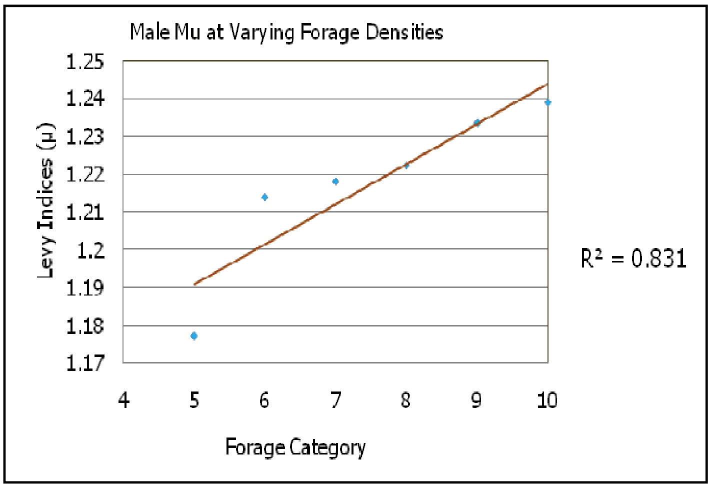


Figure 5-11: Male μs at different vegetation densities

5.3.2.1. Analysis using the 1500mx1500m Validation Grid Cells

The analysis of the effect of forage density on the elephant movement behaviour using 1500mx1500m was done to check whether the size of grid cell would have an influence on the results. The results show minimal differences as presented in Figure 5-12.

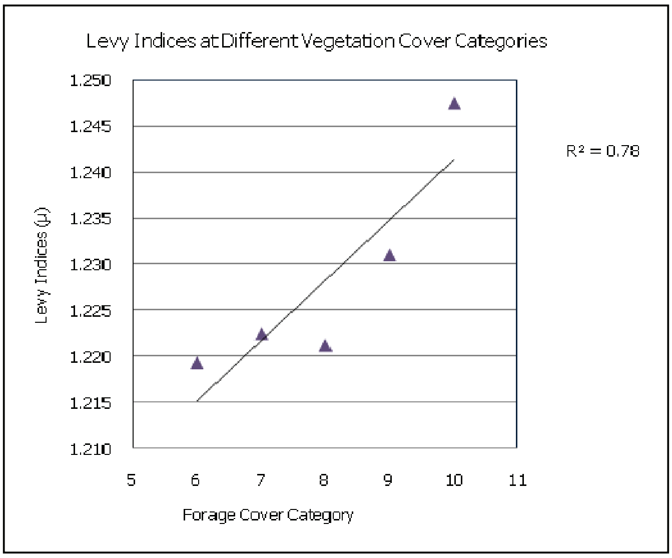


Figure 5-12: μ values at different vegetation densities with 1500m square grid cells

The results show a significant positive relation between Levy index of elephant movement and forage density (β= 0.882, seβ =0.002; F=10.56; d.f. = 4; P = 0.047)

5.3.3. Influence of Gender on Elephant Foraging Behaviour

The calculated μs for males and females are summarized in Table 5-5

Table 5-5: Levy indices for male and female at different vegetation categories

Vegetation Category	Males	Females	Male	Female
6	220	88	1.214	1.226
7	752	382	1.218	1.225
8	1328	648	1.223	1.224
9	1610	1203	1.234	1.236
10	1814	1660	1.239	1.250
Mean			**1.226**	**1.232**

The Multiple Regression results show step 1 Adjusted R^2= 0.80, F=12.42 and step 2, Adjusted R^2= 0.82, F= 21.54, hence forage has a positive effect on μ (P=.01<.05); Gender has significant influence on μ (P=0.051 is marginally significant at P<0.05); while interaction term has no influence on μ (P= 0.84>P= .05). The statistics are presented in Table 5-6, following the method recommended by Field (2005) in reporting Multiple Regression results.

Table 5-6: Results of Multiple Regression on gender influence on μ

Model		Unstandardized Coefficients		Standardized Coefficients	T	F	Sig.
		B	Std. Error	Beta			
1	Constant	1.184	.013		92.926	12.42	.000
	Vegetation Cover	.006	.002	.834	3.878		.008
	Gender	-.011	.018	-.515	-.589		.577
	Interaction term (Forage Cover x Gender)	.000	.002	.189	.213		.838
2	(Constant)	1.182	.008		139.096	21.54	.000
	Vegetation Cover	.006	.001	.866	6.130		.000
	Gender	-.007	.003	-.332	-2.347		.051

The resulting μ for male and female elephant are significantly different, β= -.332, seβ =0.003; P = 0.051, is marginally significant hence rejected the null hypothesis, as P = 0.051 is very close to the threshold values of P=0.05

5.3.4. Influence of time on Elephant Foraging Behaviour

Mean μs for the different feeding peaks were calculated and are summarized in Table 5-7

Table 5-7: Mean μs for elephant feeding peaks at different times of the day

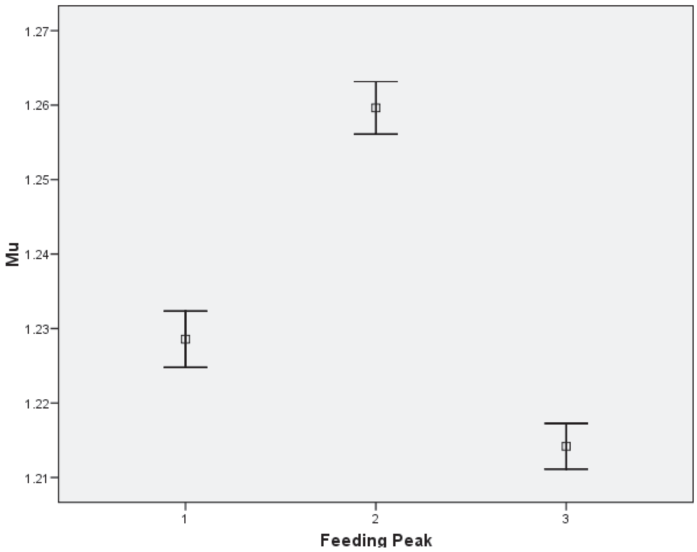
	Morning	**Afternoon**	**Midnight**
1	1.231	1.259	1.211
2	1.223	1.260	1.215
3	1.234	1.258	1.215
4	1.228	1.255	1.211
5	1.229	1.261	1.217
6	1.227	1.265	1.217
Average	**1.229**	**1.260**	**1.214**

The ANOVA test results show that μ is different for the three feeding periods. At d.f.(2, 15), F= 295.3, P= 0.000; then null hypothesis was rejected as P<0.005. The results are presented in Table 5-8 and error bar in Figure 5-13.

Table 5-8: ANOVA test for μ at different elephant feeding peaks

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.006	2	.003	295.297	.000
Within Groups	.000	15	.000		
Total	.007	17			

The mean μ for the three feeding peaks are presented in boxes in the middle of the error bar, while the horizontal bars represent the 95% confidence interval. There is no overlap between the confidence interval of the three feeding peaks hence the mean μ are significantly different.



Legend
Feeding peak axis
1-Morning
2-Afternoon
3-Midnight

Figure 5-13: Error bar for the means of the three elephant feeding peaks

Tukey's HSD post hoc test shows significant differences between all μs for the three feeding peaks P<0.05, as shown in Table 5-9

Table 5-9: Tukey's HSD result for Morning, Afternoon and Midnight μ

Feeding Peak	Feeding Peak	Mean Difference	Std. Error	Sig.
1	2	-.031*	.002	.000
	3	.014*	.002	.000
2	1	.031*	.002	.000
	3	.045*	.002	.000
3	1	-.014*	.002	.000
	2	-.045*	.002	.000

*. The mean difference is significant at the 0.05 level.

6. Discussion

6.1. Elephant Daily Activity Pattern

Elephant daily activity pattern and diet is heavily documented in literature (Koch *et al.,* 1995; Poole, 1996; Stokke, 1999; Cerling *et al.,* 2004). However, there was need to validate this pattern for MPA elephants through interviews and observations. The findings confirm that elephant have feeding peaks at different times of the day. The morning and afternoon feeding peaks were properly understood for MPA elephants, with mention of a resting period around midday. This is in agreement with previous studies (Wyatt and Eltringham, 1974).

From the analysis of the interviews conducted in MPA, given the time brackets used in the interview schedule (see § 2.4.2.2), the respondents agreed on feeding peaks at 09.00-11.00hrs and 15.00-17.00hrs Kenyan time (GMT+3). These periods were used in the analysis for the influence of time on elephant feeding behaviour.

In MPA, the night feeding peak was not properly understood. This is the time when people are back at home as it is limited by the dark hours that start from 18.00hrs to 06.00hrs. It was confirmed in the interviews that the earliest time out was 06.00hrs while the latest time back was 19.00hrs. This is therefore a clear indicator that in MPA, the information for night feeding is limited.

Therefore, for the purposes of this research night feeding peak was majorly based on literature. Elephant night feeding peak is around midnight (Wyatt and Eltringham, 1974). Additionally Ngene *et al* (unpublished) analyzed MPA elephant movement speeds. The speeds are presented in

Figure 6-1 which was used to infer midnight feeding peak.

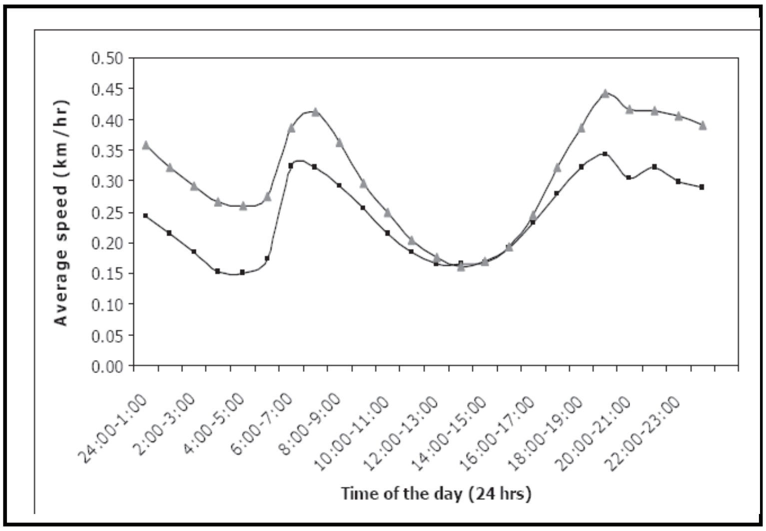


Figure 6-1: Hourly average speed (km/hr) of male and female elephants in MPA for January 2006 to December 2006 (Ngene, *et a*l).

The crests were for high speeds while the troughs were low speed. When feeding, elephants move in moderate speeds, which were shown in the graph as the slope between the crests and the troughs. Theses slopes were in agreement with the confirmed feeding peaks through interviews. Therefore, the night feeding peak was taken to fall between 22.00 to 00.00hrs.

As in other elephant populations, MPA elephant feeding is dependent on the season. Respondents clearly indicated that elephants mainly browsed on trees and shrubs during the dry season, and alternate browsing with grazing in the wet season. This is in agreement with past studies on seasonal changes in elephant feeding behaviour (Wyatt and Eltringham, 1974; Barnes, 1982; Ruggiero, 1992).

Feeding areas in MPA are also dependent on seasonality. In the wet season, the elephants move further away from the protected area to places as far as 150km away. This is the period when there is plenty of water and highly palatable grass and shrubs everywhere. Therefore, areas near Mt. Marsabit Forest are preserved for the harsh dry weather.

In the dry period water, shade and food becomes scarce. Elephants are water and shade dependent (Myra, 2001; Goodall, 2006), hence during periods of shortage they move to areas where they can easily access food, shade and water. In this case, Mt. Marsabit Forest and the immediate surroundings are ideal, as there are permanent water sources in the forest, cool shade in the evergreen forest and easy access to forage in the surrounding areas.

6.2. Elephant Suitable Foraging Areas and Density

MLC, digitization and SMA provided useful tools in mapping elephant foraging areas for the dry season and determining forage density in this research.

6.2.1. Maximum Likelihood Classification

MLC mapped the suitable elephant foraging areas in MPA with an overall accuracy of 77.3% and a Kappa statistic of 0.66, which is considered relatively high. It compares well with published work. The accuracy meets the recommended criteria of 70% per class accuracy but not the 85% minimum overall (Thomlinson *et al.,* 1999).

The issue of classification accuracy in remote sensing is complex and controversial (Wulder *et al.,* 2006). There are concerns, whether the recommended 85% (Anderson *et al.,* 1976; Thomlinson *et al.,* 1999) should be accepted as the threshold for classification accuracy. Wulder *et al* (2006) argue that accuracies towards 80% are unlikely unless the spectral, spatial and temporal resolution of remote sensing data is improved. In fact they suggest that the 'target of 85% overall percent correct should not be used as a criterion to measure success or failure of a land cover mapping'. Land cover mapping accuracies should therefore be determined by intended use (Wulder *et al.,* 2006).

In this research, an accuracy of 77.32% was acceptable as the purpose was a general identification of suitable elephant foraging areas in MPA. The image would further be classified using SMA, which is a better performer than MLC. Furthermore, MPA land covers are very heterogeneous hence, it was difficult to acquire a higher accuracy with the per-pixel MLC.

6.2.2. Spectral Mixture Analysis

LMM was used to determine the relative densities of available forage for elephants for the dry shrub and green vegetation. LMM has been used in a wide range of applications. It is considered superior to per-pixel cover estimation methods such as MLC (Casals-Carrasco *et al.,* 2000; Lu *et al.,* 2004); vegetation indictors such as EVI and NDVI (Elmore *et al.,* 2000; Peddle and Smith, 2005). This is also clearly shown in the comparison of MODIS EVI with LMM green vegetation fraction in this research as the EVI gets saturated at a certain level (see Figure 5-7).Therefore, the assumption put forth in this research is that LMM was able to map elephant forage cover components properly.

Validation of LMM in most cases uses the goodness of fit tests i.e. RMSE and assessment of proportions of pixels with overshoots and undershoots (De Asis and Omasa, 2007). In this research, different endmember models were created and compared on their performance. The best model was selected based on the number of endmembers to explain the number of various cover types, least RMSE and least noise. The 6-endmember model had an RMSE of 0.5 and had least noise compared with the 7-endmemeber model which had a lower RMSE but visible noise in the output fractions (see appendix 6)

The LMM fraction images had overshoots and undershoots, which is a common occurrence. Although the resulting cover fractions should sum to unity and be non-negative, LMM results may be negative or greater than 1 (Smith *et al.,* 2007; Yang *et al.,* 2007). For this to be avoided the conditions listed in §3.4.1 for LMM performance must be met. However, these conditions are limiting due to image used and the covers under study.

The overshoots and undershoots in this research can be attributed to:

i) 'Impurity' of endmembers- Mather (2004) explains that if an endmember used in LMM has more than one land cover type, then this is likely to influence the outcome of the model. For instance, the supervised selection of endmembers as 'pure' from the image with reference field data applied in this research were below 100% cover type. This was more so for the scattered vegetation in MPA. Other than the Mt. Marsabit Forest area, which was excluded in the analysis, it was very difficult to find areas with 100% vegetation cover. The pure pixels for vegetation cover types (green vegetation, dry shrubs and dry grass), were between 80 and 95%, then if there were pixels of greater value, then the outcome would be an overshoot(Mather, 2004). Although laboratory spectra is viewed as the ideal option for provision of endmembers in areas like MPA where the landscape has varying mixtures of pure endmember composition (Mather, 2004), it was not available for this analysis.

ii) Omission of a certain cover type- in MPA the landscape is very heterogeneous with many land cover types. The ASTER image that is used for this analysis has limited number of bands to cope with this complex mixture of land cover types in MPA. If all the cover types were to be selected, which in fact is very difficult if not impossible in reality as Mather (2004) states, then the condition that the number of image bands should be greater than the number of endmembers, should have been met. This is also a challenging condition because researches show that too many endmembers result into the model getting more sensitive to instrumental noise, atmospheric interference and natural variability in spectra (Sabol *et al*., 1992).

iii) Application of a partial constraint in the analysis- For logical results in estimating abundance of cover types in an image, LMM should be fully constrained (Heinz and Chang, 2001). This means that the non-negative and sum to unity constraints should be applied. Nevertheless, the only constraint applied in this research was the sum to unity. This is easier to implement and in fact an available option in ENVI 4.4. The non-negative constraint is 'difficult to implement since it results in a set of inequalities and can only be solved by numerical methods' (Heinz and Chang, 2001).

iv) Correlation of the VNIR spectral bands for the ASTER image used in the analysis - if the spectral bands in the analyzed image are highly correlated this is problematic in the analysis (Tso and Mather, 2001)

Having known that LMM has overshoots and undershoots, different softwares have options for normalization of the results to logical LMM values. With ENVI 4.4 it was possible to combine and eliminate the illogical values of the dry shrub and green vegetation cover fractions to produce an *Elephant Forage Cover Image* with cover fractions ranging from 0.0002 % to 100%. Although these were not exact fractions as they were not converted to match training endmembers, which were less than 100%, the fractions indicated the relative amount of forage available for elephants.

6.3. Elephant Foraging behaviour Using the LF Model

6.3.1. LF in Overall Elephant Movement

Analysis was done on elephant movement data for eight animals recorded at one-hour time intervals from 2005 to 2008. Using the recommended MLE method (Edwards *et al.,* 2007; Edwards, 2008), this research found that elephants use LF when searching for resources at μ=*1.3.* Further analysis on influence of forage density, gender and feeding time of the day on LF in elephant movement also show varying μs in the range $1.2<\mu<1.3$.

There have been doubts on LF in biological encounters (Travis, 2007; Benhamou, 2008). However, application of recommended MLE method in this research shows that elephants use LF when searching for resources. Nevertheless, the findings contradict the previously hypothesized optimal μ at 2, which in fact Edwards (2008) argues may have resulted from use of wrong methods (Viswanathan *et al.,* 1996). Another research on elephants at a higher temporal scale (10, 15, 20 minutes), than the one-hour time interval used in this research relatively compares with the power-law results in this paper although the faulted log transform method was used. They found out that LF in elephants ranged within$1<\mu<2$ (Dai *et al.,* 2007).

In a review article, Viswanathan *et al* (2008) address the issues raised on whether animals use LF when searching for resources. In their conclusion, they state '[we] strongly suspect that many biological organisms do in fact perform Levy walks'. They further call for more research to confirm presence or absence of LF in biological organisms. This research responded to this call and it has confirmed that elephants do use LF when searching for resources.

6.3.2. Influence of Forage Density on Elephant Foraging Behaviour

The results in this research show that forage density has an influence on elephant foraging behaviour along its movement path. Forage density has a significant positive relationship with the Levy indices for elephant movement.

The Levy index is in the range $1<\mu\leq3$. At 1, an animal movement tends to comprise of long flights, while at 2 there is an alternation of long and short move lengths and with μ at 3 short move lengths dominate the movement, like in a Brownian motion. Therefore, an increase in μ means an increase in tortuousity and short moves in the movement path.

Vegetation plays two major roles in elephant survival: source of food and shade. Elephants spend 75% of their time feeding with short stints of rest between feeding peaks (Wyatt and Eltringham, 1974). Water is also an important resource as it is used for cooling and drinking. In MPA during the dry season, temperatures reach highs of 38^0 C hence, elephants need cooling. The positive relationship between forage density and μ could therefore have two explanations.

One is that elephants would prefer to forage in high vegetation density areas instead of making long jumps due to high food availability and at the same time easy access to shade in the hot MPA environment. Second is that being water dependent animals, elephant prefer areas close to water, which is only available in forest area during the dry season. In MPA, dense forage vegetation is close to the forest. This is because rainfall is higher than in other areas and the morning fog of the forest area provides moisture to the neighbouring vegetation therefore keeping it alive and palatable for longer. Consequently, elephants would tend to select foraging sites that have high forage as well as close to water points where they make short moves.

The results are in agreement with a research conducted in Zimbabwe using NDVI that elephants preferred places with high vegetation density (Murwira and Skidmore, 2005). Studies on other species also show a relationship between forage density and animal distribution. A study in Ghana on the Oribi (antelope type) female population shows that they tended to inhabit high forage areas especially in the dry season (Brashares and Arcese, 2002).

6.3.3. Influence of Gender on Elephant Foraging Behaviour

A test of significance on the influence of gender on Levy index shows that gender has an influence on LF. Females tended to have slightly shorter move lengths and more turns than males in higher vegetation densities. Hence, they were probably feeding rather than making long jumps.

It is noteworthy that females tended to avoid low vegetation density areas. During the analysis, it was not possible to compare movement in males and females for forage Cover Code 5 (see Table 4-2) in the square grid cells of 900m, as there was only one flight for females. This suggests that females tend to be more selective on food availability. This agrees with a study conducted in Botswana on sex difference in the African elephant feeding behaviour that females tended to be more selective than males (Stokke, 1999).

Perhaps the selective nature in females can be attributed to demand. Females form family units usually 10-20 individuals or more, while bulls may be solitary or in small bachelor herds (Poole, 1996; Kingdon, 1997; Balfour *et al.* 2007). Thus, higher μ in females than in males can be explained by the needs of a larger group which would prefer to make short moves and more turns whenever they encounter more forage to sustain an adequate supply for all.

6.3.4. Influence of Time on Elephant Foraging Behaviour

Time of the day has an influence on elephant feeding behaviour. μs for the three feeding peaks were significantly different as shown by an ANOVA test. Ranked in order, afternoon μ was highest followed by the morning and least was night feeding peak. This means that in the afternoon elephants foraging path had more turns and shorter moves compared with other feeding peaks in the day.

Perhaps the most logical explanation for the high μ in the afternoon feeding peak is the need to replenish lost energy during hot hours of the day. In MPA, hours prior to this feeding peak are very hot. Consequently, elephants having a high metabolism coupled with their high defaecation rates approximated as 15-20times per day (Nchanji *et al.,* 2008) lose high amounts of energy. This necessitates a little bit more food intake in their next feeding peak which happens to be in the afternoon, to recover the lost energy. They therefore make more turns and short moves feeding instead of long jumps.

On the other hand, the relatively lowμ for the morning feeding peak can be attributed to the relatively high temperatures. 9.00-11.00hrs is a hot period in MPA, hence elephants could be taking long and direct flights from one vegetation cover to another for shade and forage, unlike in the afternoon feeding peak when temperatures are cooler. For the midnight feeding peak, having spent the rest of the day feeding the night feeding is like filling ¾ full system, hence the low μ. Another possible explanation for the low μ at midnight feeding is the cool temperatures and minimal disturbance by man and livestock, thus, they can move comfortably for larger distances.

7. Conclusions and Recommendations

7.1. Summary

In summary, the main objective of this research was to understand how elephants search for forage along their movement path in MPA using the LF Model. The two sub-objectives were achieved by answering the research questions as summarized here:

i) To use the maximum likelihood method to determine whether elephants apply LF when moving in search for resources

- ❖ Do MPA elephant movement lengths follow a power-law distribution?

Elephants use LF in search for resources. The results are summarized in Table 7-1. Levy index is in the range **$1.2 < \mu \leq 1.3$.**

Table 7-1*: Summarized μ and the influence by various study variables*

Analysis	μ
Overall elephant movement	1.300
Forage density	
5	1.179
6	1.217
7	1.221
8	1.223
9	1.235
10	1.244
Linear Regression: forage density and Mu	$R^2 = 0.83$; $\beta = 0.911$, se$\beta = 0.002$; $F = 19.6$; d.f. = 5; $P = 0.011$.
Gender	
Males	
Females	
Multiple Regression: gender, Forage density	Step 1 $R^2 = 0.80$, $F=12.42$ and step 2, $R^2 = .82$, $F = 21.54$. Forage ($P=.01<.05$); Gender ($P=0.05=0.05$);
Feeding peaks :	
Morning	1.229
Afternoon	1.260
Midnight	1.214
ANOVA test: feeding peaks	d.f. (2, 15), $F = 295.3$; $P = 0.000$ then the difference is significant as $P<0.05$.

ii) To determine whether there exists variations in elephant movement path when foraging at varying vegetation densities, at different feeding peaks and between genders using the LF Model.

❖ What areas in MPA are suitable for elephant foraging during the dry season?

In the dry season MPA elephants feed in the areas surrounding Mt. Marsabit, referred as the uplands and lowlands in this research. Suitable foraging areas were mapped using supervised MLC with an overall accuracy of 77.32% and Kappa statistic 0.66

❖ What are the cover percentages of available forage materials for elephants in MPA?

The forage cover fractions for elephant forage constituted of shrubs and green vegetation. They were estimated through SMA using the LMM. A 6-endmember model was used comprising of shrubs, green vegetation, dry grass, soil, rock/gravel and sand. The RMSE was 0.52. Due to the problem of overshoots and undershoots it was not possible to have the exact forage cover fractions from the ASTER image but working cover fractions ranging between **0.0002-100%,** a good indicator on the relative forage density available for elephants.

❖ How does the elephant movement path when foraging respond to varying vegetation densities?

Forage density has an influence on elephant foraging behaviour. LF had a positive relationship with forage density at $\mathbf{R^2 = 0.83}$, β= **0.911**, seβ =**0.002**; F=**19.6;** d.f. = **5**; $\mathbf{P = 0.011 < P = 0.05}$

❖ Are there variations between elephant genders along their movement path when foraging?

Gender had a significance influence on elephant foraging behaviour at **P= 0.051** which is marginally significant, as it is very close to the threshold values of **P=0.05.** The feeding μ for females= **1.232** was slightly higher than male= **1.226**. Females also tended to avoid low forage areas.

❖ Are there variations in elephant movement during foraging at different times of the day?

Elephant portrayed significantly different mean μs for the three feeding peaks: Morning=**1.229** Afternoon=**1.260** and Night= **1.214**; ANOVA test: **d.f. (2, 15), F= 295.3; P= 0.000** the difference was significant as **P<0.05.**

7.2. Conclusions

This research advances science by addressing a controversial issue on whether animals use LF in search for resources. Using GIS and RS techniques for organizing elephant movement data and derivation of forage characteristics, coupled with analysis of the movement data using the recommended MLE method (Edwards *et al.,* 2007; Edwards, 2008), this paper has established that elephants use LF in search for resources. It is noteworthy that although this research assumes MLE is the best method in estimating LF, it does not overrule possibilities of more accurate methods. This is an area beyond the works of this research.

As a recent field in science, LF in biological encounters will likely see new developments. This is evident in recent publications. For instance in 2007, Sims *et al* claimed in their publication that Logarithmic binning with normalization method was a better identifier of power-law exponents in biological organism movement data. In 2008, Edwards recommended the use of MLE as the 'most accurate method' in estimating power-law exponents in animal movement data. He further undermines the recommended Sims et al 2007 Logarithmic binning with normalization method. However, both publications fault the Log Transform method used in previous publications such as (Viswanathan *et al.,* 1996; Marell *et al.,* 2002; De Knegt *et al.,* 2007). It is therefore likely that new developments are underway.

7.3. Management Implications

This research has a significant though not direct contribution in management of MPA. First, the map of the elephant foraging area can be used in determining the extent of the Protected area boundaries. Marsabit Park and Reserve are under revision and so the extent of elephants in this area should be an important factor to consider. Secondly, this research justifies elephant and wildlife conservation in general. Conservation though advantageous is a highly controversial issue with one camp against it while the other is pro-conservation. In Kenya, KWS is the government body with the mandate to protect wildlife in and outside protected areas. This has been an advantage to this research as elephants under protection in Marsabit have been used to address the issue of Levy flights in biological organisms hence advancement in science.

7.4. Recommendations

This research was able to understand elephant foraging behaviour in the dry season. A useful component for future research would be wet season for a more comprehensive understanding of MPA elephant foraging behaviour. Temporal changes of elephant forage covers should also be taken into account.

The SMA method used in this research is reliable for estimation of cover fractions. However, in future some of the most important challenges faced in this research: highly correlated bands in the ASTER image and lack of pure endmembers, should be addressed. Perhaps for endmember selection a spectral library for the various phenological stages of MPA vegetation would come in handy. Use of an up to date image at higher spectral or spatial resolution would improve estimation of forage densities.

References

Adano, W. R. (2002). Current Access Benefits and Threats to Protected Areas: The case of Marsabit Forest, northern Kenya. Pugwash Nederlands preparatory Workshop on Sharing the Planet: People and Biodiversity Conservation. Institute of Social Studies, the Hague, Netherlands.

Anderson, J. R., Hardy, E. E., Roach, J. T. and Witmer, R. E. (1976). A Land Use and Land Cover Classification System for Use with Remote Sensor Data: GEOLOGICAL SURVEY PROFESSIONAL PAPER 964.

Balfour, D., Dublin, H. T., Fennessy, J., Gibson, D., Niskanen, L., Whyte and I.J. (2007). Review of Options for Managing the Impacts of Locally Overabundant African Elephants. Gland, Switzerland., IUCN: 80 pp.

Barnes, R. F. W. (1982). "Elephant feeding behaviour in Ruaha National Park, Tanzania*." African Journal of Ecology 20(2): 123-136.

Bartumeus, F., Catalan, J., Fulco, U. L., Lyra, M. L. and Viswanathan, G. M. (2002). "Optimizing the Encounter Rate in Biological Interactions: Levy versus Brownian Strategies." Physical Review Letters 88(9): 097901.

Bartumeus, F., Da Luz, M. G. E., Viswanathan, G. M. and Catalan, J. (2005). "Animal Search Strategies: A Quantitative Random-Walk Analysis." Ecology 86(11): 3078-3087.

Bartumeus, F., Peters, F., Pueyo, S., Marrase, C. and Catalan, J. (2003). "Helical Levy walks: Adjusting searching statistics to resource availability in microzooplankton." Proceedings of the National Academy of Sciences of the United States of America 100(22): 12771-12775.

Benhamou, S. (2008). "How Many Animals Really Do the Lévy Walk? Reply." Ecology 89(8): 2351-2352.

Blanc, J. J., Barnes, R. F. W., Craig, G. C., Dublin, H. T., Thouless, C. R., Douglas-Hamilton, I. and Hart, J. A. (2007). "African Elephant Status Report: An update from the African Elephant Database. Occasional Paper Series of the IUCN Species Survival Commission." (33).

Brashares, J. S. and Arcese, P. (2002). "Role of Forage, Habitat and Predation in the Behavioural Plasticity of a Small African Antelope." The Journal of Animal Ecology 71(4): 626-638.

Brüssow, H. (2007). The Quest for Food: A Natural History of Eating. New York, Springer Science & Business Media, LLC.

Cary Institute of Ecosystem Studies. "Defining Ecology." Retrieved 17th December, 2008, from http://www.ecostudies.org/definition_ecology.html.

Casals-Carrasco, P., Kubo, S. and Madhavan, B. B. (2000). "Application of spectral mixture analysis for terrain evaluation studies." International Journal of Remote Sensing 21(16): 3039 - 3055.

Cerling, T. E., Passey, B. H., Ayliffe, L. K., Cook, C. S., Ehleringer, J. R., Harris, J. M., Dhidha, M. B. and Kasiki, S. M. (2004). "Orphans' tales: seasonal dietary changes in elephants from Tsavo National Park, Kenya." Palaeogeography, Palaeoclimatology, Palaeoecology 206(3-4): 367-376.

Dabasso, B. H. (2006). Herder knowledge of landscape scale biodiversity monitoring in Marsabit central, northern Kenya. Department of International Environment and Development Studies (NORAGRIC), Norwegian University of Life Sciences. Masters: 120.

Dai, X., Shannon, G., Slotow, R., Page, B. and Duffy, K. J. (2007). "Short-Duration Daytime Movements of a Cow Herd of African Elephants." Journal of Mammalogy 88(1): 151-157.

Davis, S. D. and Mooney, H. A. (1985). "Comparative water relations of adjacent california shrub and grassland communities." Oecologia 66(4): 522-529.

De Asis, A. M. and Omasa, K. (2007). "Estimation of vegetation parameter for modeling soil erosion using linear Spectral Mixture Analysis of Landsat ETM data." ISPRS Journal of Photogrammetry and Remote Sensing 62(4): 309-324.

De Asis, A. M., Omasa, K., Oki, K. and Shimizu, Y. (2008). "Accuracy and applicability of linear spectral unmixing in delineating potential erosion areas in tropical watersheds." International Journal of Remote Sensing 29(14): 4151 - 4171.

De Boer, W. F., Ntumi, C. P., Correia, A. U. and Mafuca, J. M. (2000). "Diet and distribution of elephant in the Maputo Elephant Reserve, Mozambique." African Journal of Ecology 38(3): 188-201.

De Knegt, H. J., Hengeveld, G. M., Van Langevelde, F., De Boer, W. F. and Kirkman, K. P. (2007). "Patch density determines movement patterns and foraging efficiency of large herbivores." Behavioral Ecology 18(6): 1065-1072.

Defries, R. S., Hansen, M. C. and Townshend, J. R. G. (2000). "Global continuous fields of vegetation characteristics: a linear mixture model applied to multi-year 8 km AVHRR data." International Journal of Remote Sensing 21(6): 1389 - 1414.

Dennison, P. E. and Roberts, D. A. (2003). "Endmember selection for multiple endmember spectral mixture analysis using endmember average RMSE." Remote Sensing of Environment 87(2-3): 123-135.

Dolmia, N. M., Calenge, C., Maillard, D. and Planton, H. (2007). "Preliminary observations of elephant (Loxodonta africana, Blumenbach) movements and home range in Zakouma National Park, Chad." African Journal of Ecology 45(4): 594-598.

Douglas-Hamilton, I., Krink, T. and Vollrath, F. (2005). "Movements and corridors of African elephants in relation to protected areas." Naturwissenschaften 92(4): 158-163.

Dublin, H. T. (1996). "Elephants of the Masai Mara, Kenya: Seasonal Habitat Selection and Group Size Patterns." Pachyderm(22): 25-35.

Edwards, A. M. (2008). "Using likelihood to test for Levy flight search patterns and for general power-law distributions in nature." Journal of Animal Ecology 77(6): 1212-1222.

Edwards, A. M., Phillips, R. A., Watkins, N. W., Freeman, M. P., Murphy, E. J., Afanasyev, V., Buldyrev, S. V., Da Luz, M. G. E., Raposo, E. P., Stanley, H. E. and Viswanathan, G. M. (2007). "Revisiting Levy flight search patterns of wandering albatrosses, bumblebees and deer." Nature 449(7165): 1044-1048.

Elmore, A. J., Mustard, J. F., Manning, S. J. and Lobell, D. B. (2000). "Quantifying Vegetation Change in Semiarid Environments: Precision and Accuracy of Spectral Mixture Analysis and the Normalized Difference Vegetation Index." Remote Sensing of Environment 73(1): 87-102.

Envi 4.4 Help Band Math Processes Addition of Three Bands. Help Programme, ENVI 4.4.

Evenari, M. E., Noy-Meir, I. E. and Goodall, D. W. E. (1986). Hot deserts and arid shrublands, B. Amsterdam etc., Elsevier.

Evrendilek, F. and Gulbeyaz, O. (2008). "Deriving Vegetation Dynamics of Natural Terrestrial Ecosystems from MODIS NDVI/EVI Data over Turkey." Sensors 8(9): 5270-5302.

Ferreira, M. E., Ferreira, L. G., Sano, E. E. and Shimabukuro, Y. E. (2007). "Spectral linear mixture modelling approaches for land cover mapping of tropical savanna areas in Brazil." International Journal of Remote Sensing 28(2): 413 - 429.

Field, A. (2005). Discovering Statistics Using SPSS. London, Sage Publications Inc.

Foody, G. M. (2002). "Status of land cover classification accuracy assessment." Remote Sensing of Environment 80(1): 185-201.

Gachanja, M., Kariuki, D., Lambrechts, C. and Munuve, J. (2001). Mt. Marsabit: Forest Status Report. Nairobi, KFWG: 6.

Galanti, V., Preatoni, D., Martinoti, A., Wauters, L. A. and Tosi, G. (2006). "Space and habitat use of the African elephant in the Tarangire-Manyara ecosystem, Tanzania: Implications for conservation." Mammalian Biology 71(2): 99-114.

Gong, P., and Zhang, A., (1999). "Noise effect on linear spectral unmixing." Geographic Information Sciences 5: 52–57.

Goodall, V. L. (2006). Statistical Analyses of Artificial Water-points: Their Effect on the Herbaceous and Woody Structure Composition within the Kruger National Park, Rhodes University. Master of Science.

Guy, P. R. (1976). "feeding behaviour of elephant - loxodanata africana - in the Sengwa area, Rhodesia." In: South African Journal of Wildlife Research, 6(1976)1, pp. 55-63.

Heinz, D. C. and Chang, C.-I. (2001). "Fully constrained least squares linear spectral mixture analysismethod for material quantification in hyperspectral imagery." IEEE Transactions on Geoscience and Remote Sensing 39 (3): 529−545.

Herlocker, D. J. E., Nicholson, M. E. and Allanson, S. E. (1995). Range management handbook of Kenya : Vol. II,10 The climatology of Northern and North - Eastern Kenya II,11 The climatology of North - Western Kenya II,12 Livestock diseases in Samburu, Wajir and Mandera districts. Nairobi, Ministry of Livestock Development (MOLD).

Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X. and Ferreira, L. G. (2002). "Overview of the radiometric and biophysical performance of the MODIS vegetation indices." Remote Sensing of Environment 83(1-2): 195-213.

IUCN (2007). "2007 IUCN Red List of Threatened Species."

Kangwana, K., Ed. (1996). Studying Elephants. AWF Technical Handbook Series. Nairobi.

Kinahan, A. A., Pimm, S. L. and Van Aarde, R. J. (2007). "Ambient temperature as a determinant of landscape use in the savanna elephant, Loxodonta africana." Journal of Thermal Biology 32(1): 47-58.

Kingdon, J. (1997). Kingdon field guide to African mammals. London etc., Academic Press.

Knight, J., Lunetta, R., Ediriwickrema, J. and Khorram, S. (2006). "Regional Scale Land Cover Characterization Using MODIS-NDVI 250 m Multi-Temporal Imagery: A Phenology-Based Approach." GIScience & Remote Sensing 43(1): 1-23.

Koch, P. L., Heisinger, J., Moss, C., Carlson, R. W., Fogel, M. L. and Behrensmeyer, A. K. (1995). "Isotopic Tracking of Change in Diet and Habitat Use in African Elephants." Science 267(5202): 1340-1343.

Kumar, R. (2005). Research methodology : a step - by - step guide for beginners. London etc., Sage.

Laporte, N., Justice, C. and Kendall, J. (1995). "Mapping the dense humid forest of Cameroon and Zaire using AVHRR satellite data." International Journal of Remote Sensing 16(6): 1127 - 1145.

Liu, W. and Wu, E. Y. (2005). "Comparison of non-linear mixture models: sub-pixel classification." Remote Sensing of Environment 94(2): 145-154.

Lu, D., Batistella, M., Moran, E. and Mausel, P. (2004). "Application of spectral mixture analysis to Amazonian land-use and land-cover classification." International Journal of Remote Sensing 25(23): 5345-5358.

Lu, D., Moran, E. and Batistella, M. (2003). "Linear mixture model applied to Amazonian vegetation classification." Remote Sensing of Environment 87(4): 456-469.

Lu, D. S. and Weng, Q. H. (2004). "Spectral mixture analysis of the urban landscape in Indianapolis with landsat ETM plus imagery." Photogrammetric Engineering and Remote Sensing 70(9): 1053-1062.

Manly, B. F. J., Mcdonald, L. L. and Thomas, D. L. (1993). Resource selection by animals : statistical design and analysis for field studies. London etc., Chapman & Hall.

Marell, A., Ball, J. P. and Hofgaard, A. (2002). "Foraging and movement paths of female reindeer: insights from fractal analysis, correlated random walks, and Levy flights." Canadian Journal of Zoology 80: 854-865.

Mather, P. M. (2004). Computer processing of remotely - sensed images : an introduction. Chichester etc., Wiley & Sons.

Mati, B. M., Muchiri, J. M., Njenga, K., De Vries, P. F. and Merrey, D. J. (2005). Assessing Water Availability under Pastoral Livestock Systems in Drought-prone Isiolo District, Kenya. Colombo, Sri Lanka, International Water Management Institute. Working Paper 106.

Moore, D. S., Mccabe, G. P. and Craig, B. A. (2009). Introduction to the practice of statistics. New York, W.H Freeman.

Mueller, T., Olson, K. A., Fuller, T. K., Schaller, G. B., Murray, M. G. and Leimgruber, P. (2008). "In search of forage: predicting dynamic habitats of Mongolian gazelles using satellite-based estimates of vegetation productivity." Journal of Applied Ecology 45(2): 649-658.

Murwira, A. and Skidmore, A. K. (2005). "The response of elephants to the spatial heterogeneity of vegetation in a Southern African agricultural landscape." Landscape Ecology 20: 217-234.

Myra, E. B. (2001). "Effects of large herbivores and fire on the regeneration of <i>Acacia erioloba</i> woodlands in Chobe National Park, Botswana." African Journal of Ecology 39(4): 340-350.

Nagendra, H. (2001). "Using remote sensing to assess biodiversity." International Journal of Remote Sensing 22(12): 2377 - 2400.

Nchanji, A. C., Forboseh, P. F. and Powell, J. A. (2008). "Estimating the defaecation rate of the African forest elephant (<i>Loxodonta cyclotis</i>) in Banyang-Mbo Wildlife Sanctuary, south-western Cameroon." African Journal of Ecology 46(1): 55-59.

Ngene, S. M., Skidmore, A. K., Van Gils, H. and Douglas-Hamilton, I. Elephant distribution around a volcanic shield dominated by forest-savanna mosaic (Marsabit, Kenya), International Institute of GeoInformation Science (ITC), Netherlands 23.

Osborne, P. E., Alonso, J. C. and Bryant, R. G. (2001). "Modelling landscape-scale habitat use using GIS and remote sensing: a case study with great bustards." Journal of Applied Ecology 38(2): 458-471.

Patterson, T. A., Thomas, L., Wilcox, C., Ovaskainen, O. and Matthiopoulos, J. (2008). "State-space models of individual animal movement." Trends in Ecology & Evolution 23(2): 87-94.

Peddle, D. R. and Smith, A. M. (2005). "Spectral mixture analysis of agricultural crops: endmember validation and biophysical estimation in potato plots." International Journal of Remote Sensing 26(22): 4959 - 4979.

Poole, J. (1996). The African Elephant Studying Elephants. Kangwana, K. Nairobi, African Wildlife Foundation.

Powell, R. L., Roberts, D. A., Dennison, P. E. and Hess, L. L. (2007). "Sub-pixel mapping of urban land cover using multiple endmember spectral mixture analysis: Manaus, Brazil." Remote Sensing of Environment 106(2): 253-267.

Pratt, D. J. E. and Gwynne, M. D. E. (1977). Rangeland management and ecology in East Africa. London etc., Hodder & Stoughton.

Quintano, C., Shimabukuro, Y. E., Fernã¡Ndez, A. and Delgado, J. A. (2005). "A spectral unmixing approach for mapping burned areas in Mediterranean countries." International Journal of Remote Sensing 26(7): 1493 - 1498.

Raposo, E. P., Buldyrev, S. V., Da Luz, M. G. E., Santos, M. C., Stanley, H. E. and Viswanathan, G. M. (2003). "Dynamical Robustness of Lévy Search Strategies." Physical Review Letters 91(24): 240601.

Ray, T. W. and Murray, B. C. (1996). "Nonlinear spectral mixing in desert vegetation." Remote Sensing of Environment 55(1): 59-64.

Robinson, G. D., Gross, H. N. and Schott, J. R. (2000). "Evaluation of Two Applications of Spectral Mixing Models to Image Fusion." Remote Sensing of Environment 71(3): 272-281.

Ruggiero, R. G. (1992). "Seasonal forage utilization by elephants in central Africa." African Journal of Ecology 30(2): 137-148.

Shannon, G., Page, B., Slotow, R. and Duffy, K. (2006). "African elephant home range and habitat selection in Pongola Game Reserve, South Africa." African Zoology 41(1): 37-44.

Shannon, G., Page, B. R., Duffy, K. J. and Slotow, R. (2006). "The role of foraging behaviour in the sexual segregation of the African elephant." Oecologia 150(2): 344-354.

Shoshany, M. and Svoray, T. (2002). "Multidate adaptive unmixing and its application to analysis of ecosystem transitions along a climatic gradient." Remote Sensing of Environment 82(1): 5-20.

Shupe, S. M. and Marsh, S. E. (2004). "Cover- and density-based vegetation classifications of the Sonoran Desert using Landsat TM and ERS-1 SAR imagery." Remote Sensing of Environment 93(1-2): 131-149.

Sims, D. W., Righton, D. and Pitchford, J. W. (2007). "Minimizing errors in identifying Levy flight behaviour of organisms." Journal of Animal Ecology 76(2): 222-229.

Smith, A. M. S., Lentile, L. B., Hudak, A. T. and Morgan, P. (2007). "Evaluation of linear spectral unmixing and Î”NBR for predicting post-fire recovery in a North American ponderosa pine forest." International Journal of Remote Sensing 28(22): 5159 - 5166.

Smits, P. C., Dellepiane, S. G. and Schowengerdt, R. A. (1999). "Quality assessment of image classification algorithms for land-cover mapping: a review and a proposal for a cost-based approach." International Journal of Remote Sensing 20(8): 1461 - 1486.

Song, C. (2005). "Spectral mixture analysis for subpixel vegetation fractions in the urban environment: How to incorporate endmember variability?" Remote Sensing of Environment 95(2): 248-263.

Souza, J. C. M., Roberts, D. A. and Cochrane, M. A. (2005). "Combining spectral and spatial information to map canopy damage from selective logging and forest fires." Remote Sensing of Environment 98(2-3): 329-343.

SPSS Inc. (2009). Online help: One-Way ANOVA Post Hoc Tests.

Stokke, S. (1999). "Sex differences in feeding-patch choice in a megaherbivore: elephants in Chobe National Park, Botswana." Canadian Journal of Zoology-Revue Canadienne De Zoologie 77(11): 1723-1732.

Tateishi, R., Shimazaki, Y. and Gunin, P. D. (2004). "Spectral and temporal linear mixing model for vegetation classification." International Journal of Remote Sensing 25(20): 4203 - 4218.

Theseira, M. A., Thomas, G. and Sannier, C. A. D. (2002). "An evaluation of spectral mixture modelling applied to a semi-arid environment." International Journal of Remote Sensing 23(4): 687 - 700.

Theseira, M. A., Thomas, G., Taylor, J. C., Gemmell, F. and Varjo, J. (2003). "Sensitivity of mixture modelling to end-member selection." International Journal of Remote Sensing 24(7): 1559 - 1575.

Thomlinson, J. R., Bolstad, P. V. and Cohen, W. B. (1999). "Coordinating Methodologies for Scaling Landcover Classifications from Site-Specific to Global: Steps toward Validating Global Map Products." Remote Sensing of Environment 70(1): 16-28.

Travis, J. (2007). "Ecology - Do wandering albatrosses care about math? (vol 318, pg 742, 2007)." Science 318(5858): 1866-1866.

Tso, B. and Mather, P. M. (2001). Classification methods for remotely sensed data. London etc., Taylor & Francis.

Uenishi, T. M., Oki, K., Omasa, K. and Tamura, M. (2005). "A land cover distribution composite image from coarse spatial resolution images using an unmixing method." International Journal of Remote Sensing 26(5): 871-886.

USGS Land Processes Distributed Active Archive Center. (19th November 2008). "Vegetation Indices 16-Day L3 Global 250m." from https://lpdaac.usgs.gov/lpdaac/products/modis_product_table/vegetation_indices/16_day_l3_global_250m/v5/terra.

Van Der Maarel, E. E. (2004). Vegetation ecology. London etc., Blackwell.

Verbeiren, S., Eerens, H., Piccard, I., Bauwens, I. and Van Orshoven, J. "Sub-pixel classification of SPOT-VEGETATION time series for the assessment of regional crop areas in Belgium." International Journal of Applied Earth Observation and Geoinformation In Press, Corrected Proof.

Verhoeye, J. and De Wulf, R. (2002). "Land cover mapping at sub-pixel scales using linear optimization techniques." Remote Sensing of Environment 79(1): 96-104.

Viswanathan, G. M., Afanasyev, V., Buldyrev, S. V., Havlin, S., Da Luz, M. G. E., Raposo, E. P. and Stanley, H. E. (2000). "Lévy flights in random searches." Physica A: Statistical Mechanics and its Applications 282(1-2): 1-12.

Viswanathan, G. M., Afanasyev, V., Buldyrev, S. V., Havlin, S., Da Luz, M. G. E., Raposo, E. P. and Stanley, H. E. (2001). "Statistical Physics of Random Searches." Brazilian Journal of Physics 31(1): 102 -108.

Viswanathan, G. M., Afanasyev, V., Buldyrev, S. V., Murphy, E. J., Prince, P. A. and Stanley, H. E. (1996). "Levy flight search patterns of wandering albatrosses." Nature 381(6581): 413-415.

Viswanathan, G. M., Bartumeus, F., S, V. B., Catalan, J., Fulco, U. L., Havlin, S., Da Luz, M. G. E., Lyra, M. L., Raposo, E. P. and Eugene Stanley, H. (2002). "Levy flight random searches in biological phenomena." Physica A 314: 208-213.

Viswanathan, G. M., Buldyrev, S. V., Havlin, S., Da Luz, M. G. E., Raposo, E. P. and Stanley, H. E. (1999). "Optimizing the success of random searches." Nature 401(6756): 911-914.

Viswanathan, G. M., Raposo, E. P. and Da Luz, M. G. E. (2008). "Lévy flights and superdiffusion in the context of biological encounters and random searches." Physics of Life Reviews 5(3): 133-150.

Wall, J., Douglas-Hamilton, I. and Vollrath, F. (2006). "Elephants avoid costly mountaineering." Current Biology 16(14): R527-R529.

Wang, L. and Uchida, S. (2008). "Use of Linear Spectral Mixture Model to Estimate Rice Planted Area Based on MODIS Data." Rice Science 15(2): 131-136.

Western, D., and Lindsay, W. K. (1984). "Seasonal herd dynamics of a savanna elephant population." African Journal of Ecology 22(4): 229-244.

Whyte, I. J. (1996). Studying Elephant Movement. Studying Elephants. Kangwana, K. Nairobi, African Wildlife Foundation.

Wu, C. (2004). "Normalized spectral mixture analysis for monitoring urban composition using ETM+ imagery." Remote Sensing of Environment 93(4): 480-492.

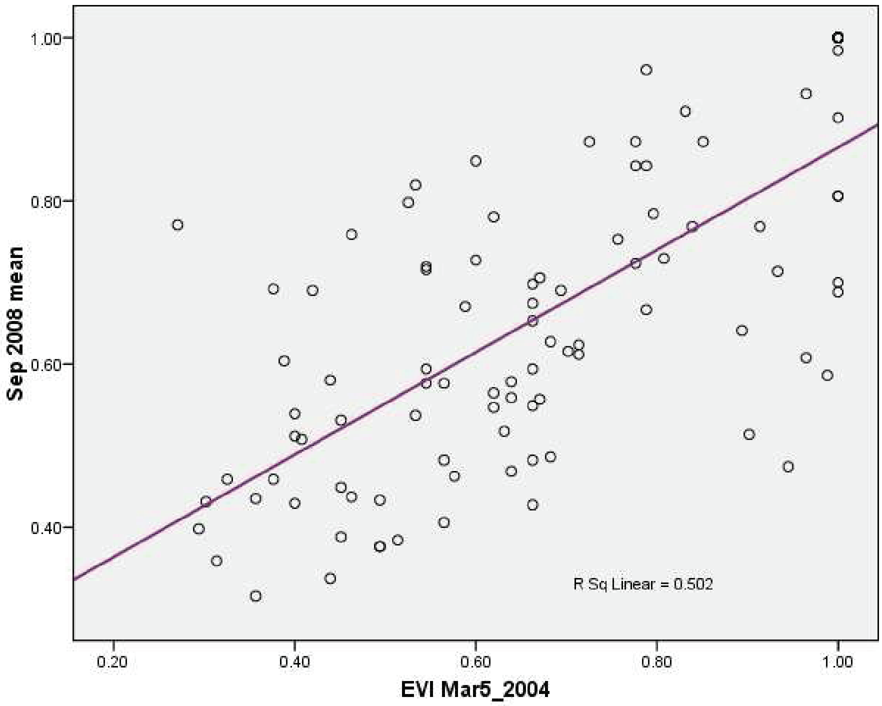
Wulder, M. A., Franklin, S. E., White, J. C., Linke, J. and Magnussen, S. (2006). "An accuracy assessment framework for large-area land cover classification products derived from medium-resolution satellite data." International Journal of Remote Sensing 27(4): 663 - 683.

Wyatt, J. R. and Eltringham, S. K. (1974). "The daily activity of the elephant in the Rwenzori National Park, Uganda." African Journal of Ecology 12(4): 273-289.

Yang, C., Everitt, J. and Bradford, J. (2007). "Airborne hyperspectral imagery and linear spectral unmixing for mapping variation in crop yield." Precision Agriculture 8(6): 279-296.

Appendices

Appendix 1: Scatter Plot and Significance Statistics for MODIS EVI March 2004 and September 2008



Adjusted R^2 =.497, d.f=99

Model statistics

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	F	Sig. Std. Error
1	(Constant)	.238	.045			.000
	EVI Mar5_2004	.627	.063	.708	98.655	.000

Dependent Variable: EVI September 2008 mean

Appendix 2: Training/accuracy Assessment and Endmember Sample Form

Recorder's Name: ________________________DATE:__________________START TIME: ______________

POINT	COORDINATES	SPECIES COMPOSITION	PLANT HEIGHTS		PERCENTAGE COVER ESTIMATES IN 30X30M PLOTS																				COMMENTS
			TREES	SHRUB	TREES				SHRUBS				GRASS				BARE SOIL				ROCK/GRAVEL				
					Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
1.	X: Y:																								
2.	X: Y:																								
3.	X: Y:																								
4.	X: Y:																								
5.	X: Y:																								
6.	X: Y:																								
7.	X: Y:																								
8.	X: Y:																								
9.	X: Y:																								

Appendix 3: Elephant Activity Observation Form

Morning feeding ☐
Afternoon feeding ☐

Recorders Name: ________________________________

Coordinates: X ______________________

Y______________________

Date: ___________

ELEPHANT ID	SEX	ELEPHANT ACTIVITY AT 30MINUTES INTERVAL						
		Start time	5^{th} minute	10^{th} Minute	15^{th} minute	20^{th} minute	25^{th} minute	30^{th} minute
ADDITIONAL INFORMATION								
Group composition								
Vegetation characteristics								
Other								

Appendix 4: Interview Schedule for Elephant Activity

1. How long have you lived here

2. What is your occupation?

3. Is this your permanent residence?

4. Do you own livestock?

5. Have you ever herded livestock?

6. What time do you take out livestock for grazing during
   Dry season
   Wet season

7. Do you encounter elephants when herding livestock?

8. What are elephants doing during
   Early morning (5.00-8.00am)
   Morning (9.00-11.00am)
   Afternoon (12.00-2.00pm)
   Late afternoon (3.00-5.00pm)
   Evening (6.00-8.00pm)
   Night (9.00…..)

9. What time do you take out livestock for watering during
   Dry season
   Wet season

10. How often do you take livestock out for watering?
    Shoats
    Cattle

11. Do you encounter elephants at watering points?

12. What happens when you find them?

13. What time do you return livestock back to their shelter after herding during
    Dry season
    Wet season

14. Are there preferred vegetation types /species by the elephants?

15. Where do elephants browse during
    Dry season
    Wet season

16. Are the elephants involved in crop raids? If so when?

Appendix 5: Table Showing Endmember Separability

Comparing Cover	Cover Name	Jeffries-Matusita	Transformed Divergence
Sand	Rock/Gravel	2	2
	Green Vegetation	2	2
	Shadow	2	2
	Dry Grass	2	2
	Dry Shrub	2	2
	Bare soil	2	2
Rock/Gravel	Sand	2	2
	Green Vegetation	2	2
	Shadow	2	2
	Dry Grass	2	2
	Dry Shrub	2	2
	Bare soil	2	2
Green Vegetation	Sand	2	2
	Rock/Gravel	2	2
	Shadow	2	2
	Dry Grass	2	2
	Dry Shrub	1.99930799	2
	Baresoil	2	2
Shadow	Sand	2	2
	Rock/Gravel	2	2
	Green Vegetation	2	2
	Dry Grass	2	2
	Dry Shrub	2	2
	Bare soil	2	2
Dry Grass	Sand	2	2
	Rock/Gravel	2	2
	Green Vegetation	2	2
	Shadow	2	2
	Dry Shrub	2	2
	Bare soil	2	2
Dry Shrub	Bare soil		
	Sand	2	2
	Rock/Gravel	2	2
	Green Vegetation	1.99930799	2
	Shadow	2	2
	Dry Grass	2	2
	Bare soil	1.9999976	2
Bare Soil	Sand	2	2
	Rock/Gravel	2	2
	Green Vegetation	2	2
	Shadow	2	2
	Dry Grass	2	2
	Dry Shrub	1.9999976	2

Appendix 6: SMA Results Showing RMSE Images for Different Endmember Models

5-endmember model: dry shrub, green vegetation, shadow, rock/gravel, and bare soil
RMSE=.88

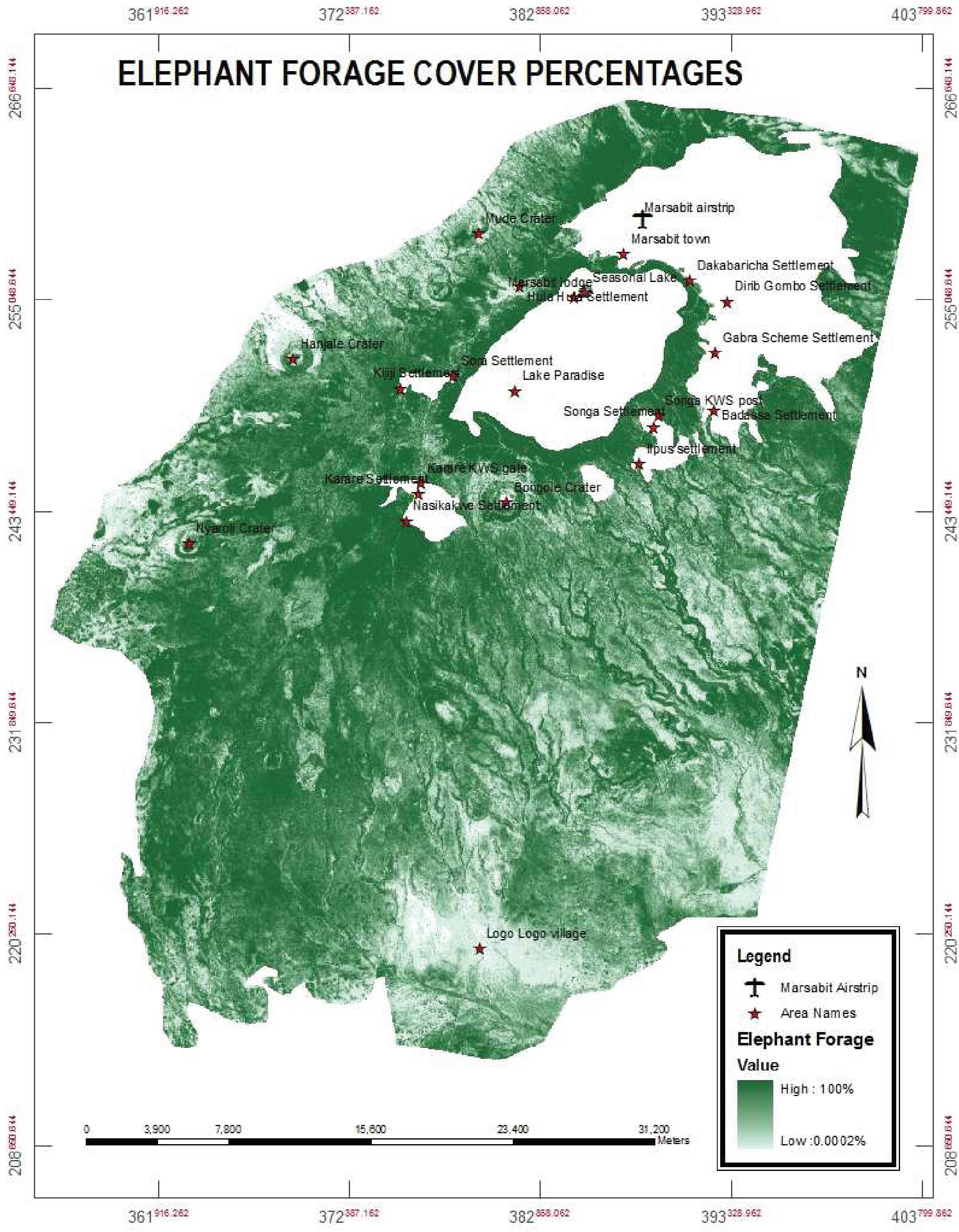
5-endmember model with three background components (bare soil, sand, and rock/gravel) and two vegetation types (green vegetation and dry shrubs). RMSE= .77

4-endmember model: two background components (bare soil and rock) and two vegetation components (green vegetation and dry shrubs)

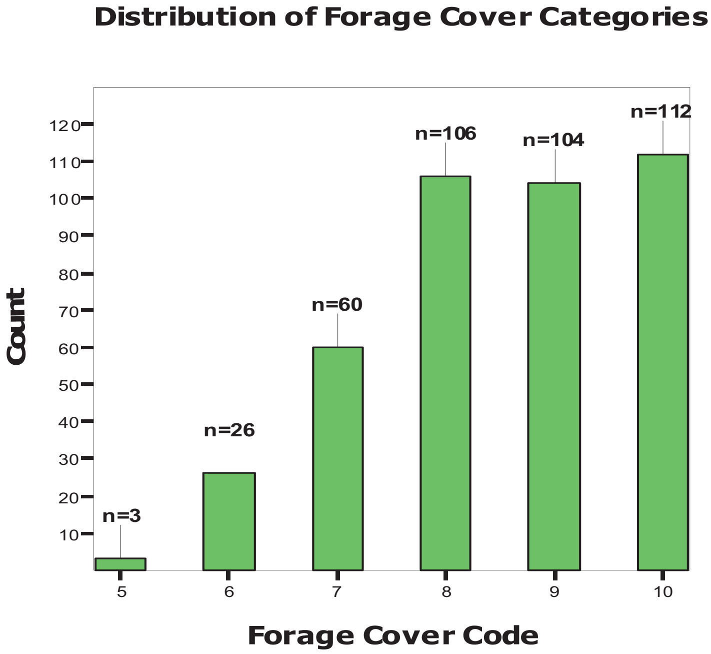
RMSE = 1.068254

7-endmember model: shadow, three background components (sand, bare soil, rock/gravel) and three vegetation components (dry grass, dry shrub and green vegetation). RMSE= 0.380479
Noise apparent in the image

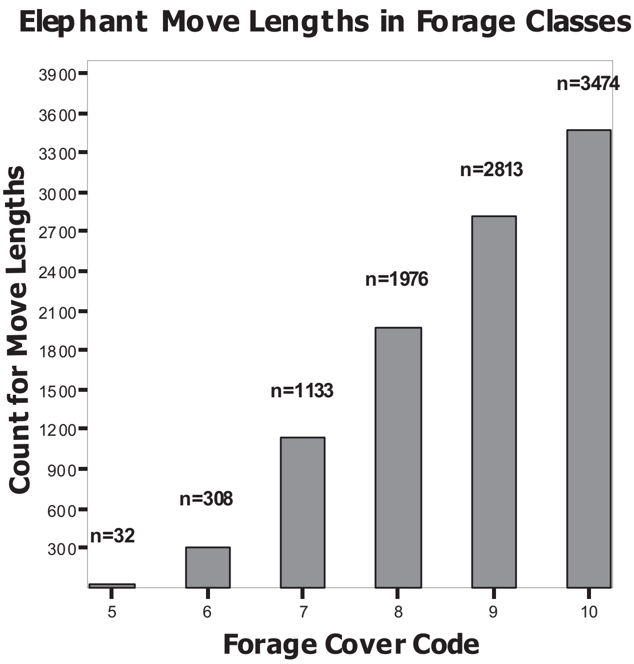
Appendix 7: Elephant Forage Cover Fractions from the 6-Endmember Model.



Appendix 8: The counts for each of the forage cover category are



Appendix 9:Distribution of elephant flights in the varying forage categories.



Appendix 10: LMM forage image fraction statistics for 900x900m grid cells

Minimum	Maximum	Mean Cover	Sum	Cover Code	Standard Deviations
0.00091	1	0.438194	1469.27	5	0.267477
0.000285	1	0.475131	1549.88	5	0.260187
0.000664	1	0.47762	1503.55	5	0.28657
0.000562	1	0.487578	1695.31	5	0.225295
0.000598	1	0.50657	1753.24	6	0.246737
0.003778	1	0.53351	1881.16	6	0.239582
0.000543	1	0.547797	1829.64	6	0.302257
0.002815	1	0.548569	1959.49	6	0.228743
0.000249	1	0.548977	1908.25	6	0.260187
0.000685	1	0.550522	1823.88	6	0.298296
0.00033	1	0.551063	1765.61	6	0.305101
0.002738	1	0.551955	1945.09	6	0.240397
0.00049	1	0.559505	1869.87	6	0.304897
0.001761	1	0.559808	1846.25	6	0.298036
0.005306	1	0.565614	2001.71	6	0.257633
0.001102	1	0.565989	1974.74	6	0.274819
0.000579	1	0.568499	1853.88	6	0.318046
0.000161	1	0.572854	1782.72	6	0.308766
0.000135	1	0.578118	1771.94	6	0.32591
0.002281	1	0.579218	2051.59	6	0.242239
0.000101	1	0.580886	2070.28	6	0.232741
0.000466	1	0.581203	1865.08	6	0.308205
0.001261	1	0.584073	1863.19	6	0.3273
0.001143	1	0.584479	1997.75	6	0.301919
0.002186	1	0.585003	1884.3	6	0.333252
0.000199	1	0.585017	1381.22	6	0.348749
0.000049	1	0.589442	2079.55	6	0.241586
0.000065	1	0.590345	1809.41	6	0.310929
0.000056	1	0.596834	1962.39	6	0.28501
0.000233	1	0.603246	2029.32	6	0.276546
0.000126	1	0.610095	2147.53	7	0.272101
0.000046	1	0.611154	1745.46	7	0.328815
0.000274	1	0.611819	2034.91	7	0.295457
0.000818	1	0.613884	2155.35	7	0.262308
0.005087	1	0.620809	2226.22	7	0.231295
0.000169	1	0.621092	2167.61	7	0.273142
0.000203	1	0.62115	1982.09	7	0.31281
0.000837	1	0.622219	2187.72	7	0.266663
0.002361	1	0.622767	2146.06	7	0.297349
0.000335	1	0.628377	2057.31	7	0.295386
0.000344	1	0.630542	2240.95	7	0.249152
0.001132	1	0.631624	2069.2	7	0.284978
0.000404	1	0.632417	2219.79	7	0.275016
0.001085	1	0.633036	2220.7	7	0.265058
0.000926	1	0.640927	2211.2	7	0.286734
0.000796	1	0.642871	2184.48	7	0.287075
0.000186	1	0.644824	2316.85	7	0.215654
0.000768	1	0.644837	2282.72	7	0.248363

0.00009	1	0.646934	2044.31	7	0.333613
0.000055	1	0.64708	2241.49	7	0.291038
0.000847	1	0.649191	2106.63	7	0.314543
0.00029	1	0.651073	2262.48	7	0.311702
0.000914	1	0.656966	2252.08	7	0.269876
0.000613	1	0.657848	2234.05	7	0.309417
0.000272	1	0.660398	2193.84	7	0.281944
0.000501	1	0.665192	2344.14	7	0.293729
0.036289	1	0.666603	2390.44	7	0.222591
0.000216	1	0.670835	2127.22	7	0.334369
0.001602	1	0.671285	2390.45	7	0.26436
0.004108	1	0.677991	2432.63	7	0.239252
0.002303	1	0.678104	2409.99	7	0.256161
0.000974	1	0.678973	2325.49	7	0.302985
0.000781	1	0.679046	2396.36	7	0.26124
0.001512	1	0.68059	2298.36	7	0.27331
0.000052	1	0.682956	2234.63	7	0.332201
0.002135	1	0.683118	2396.38	7	0.278106
0.000579	1	0.683426	2212.25	7	0.304733
0.00075	1	0.685308	2362.26	7	0.300107
0.000077	1	0.685382	2123.31	7	0.306425
0.001043	1	0.685382	2432.42	7	0.26216
0.001052	1	0.687718	2098.92	7	0.278982
0.002527	1	0.688193	1624.83	7	0.301086
0.000642	1	0.688338	2373.39	7	0.260284
0.006328	1	0.690038	2457.92	7	0.266925
0.000072	1	0.690073	2231.7	7	0.289128
0.00018	1	0.690286	2251.03	7	0.306228
0.004958	1	0.691196	2416.43	7	0.228829
0.006476	1	0.691497	2468.65	7	0.249206
0.001835	1	0.691671	2395.26	7	0.290049
0.002022	1	0.692239	2463.68	7	0.23759
0.019773	1	0.692363	1906.08	7	0.222863
0.001357	1	0.692713	2461.21	7	0.258511
0.00004	1	0.695725	2245.1	7	0.292086
0.000542	1	0.696335	2154.46	7	0.269677
0.000204	1	0.69675	2490.89	7	0.246537
0.000199	1	0.697103	1319.62	7	0.261644
0.012548	1	0.69773	2505.55	7	0.203424
0.000846	1	0.698381	2390.56	7	0.283506
0.006306	1	0.701317	2514.92	7	0.235269
0.001473	1	0.701512	2217.48	7	0.325397
0.001472	1	0.705173	2499.13	8	0.255874
0.000885	1	0.707978	1838.62	8	0.278881
0.000958	1	0.70871	2504.58	8	0.262674
0.000436	1	0.709424	2085.71	8	0.343338
0.000352	1	0.70977	2401.15	8	0.295419
0.002896	1	0.710273	2503.01	8	0.295183
0.002008	1	0.711015	2539.04	8	0.25709
0.010228	1	0.712554	2550.95	8	0.226404
0.002208	1	0.713786	2323.37	8	0.305242
0.001814	1	0.713972	2543.89	8	0.266348

0.001747	1	0.715101	2476.4	8	0.270974
0.005957	1	0.715928	2546.56	8	0.268869
0.00341	1	0.717531	2575.22	8	0.250645
0.000501	1	0.718074	2305.74	8	0.293274
0.003789	1	0.71902	2448.26	8	0.29745
0.002025	1	0.71938	2532.94	8	0.27505
0.002732	1	0.72036	2426.9	8	0.283351
0.000496	1	0.720978	2553.71	8	0.277871
0.001336	1	0.721717	2561.37	8	0.253309
0.001192	1	0.721862	2495.48	8	0.285872
0.001235	1	0.723182	2367.7	8	0.295112
0.000527	1	0.725103	2512.48	8	0.258953
0.002975	1	0.728002	2605.52	8	0.253394
0.001887	1	0.728259	2596.97	8	0.228444
0.00301	1	0.728357	2553.62	8	0.258507
0.000752	1	0.728446	2605.65	8	0.248298
0.004468	1	0.729681	2505.73	8	0.307096
0.001706	1	0.731015	2535.9	8	0.281722
0.001869	1	0.733191	2627.02	8	0.241071
0.000579	1	0.733811	2561.73	8	0.25747
0.000164	1	0.73426	2486.21	8	0.27035
0.001559	1	0.734601	2619.59	8	0.255066
0.010675	1	0.734808	2638.69	8	0.191256
0.039589	1	0.734924	2642.79	8	0.224428
0.001291	1	0.735578	2591.44	8	0.265801
0.006639	1	0.735921	2616.2	8	0.262367
0.031892	1	0.736109	2648.52	8	0.188954
0.002644	1	0.736584	2101.47	8	0.263202
0.009671	1	0.738442	2619.99	8	0.261362
0.000728	1	0.739256	2200.03	8	0.317708
0.004229	1	0.74054	2651.88	8	0.220018
0.003972	1	0.741011	2640.97	8	0.27156
0.004077	1	0.743299	2649.12	8	0.236511
0.012489	1	0.745222	2674.61	8	0.226442
0.004062	1	0.745311	2652.56	8	0.259077
0.006039	1	0.747786	2381.7	8	0.258426
0.002741	1	0.749606	2665.6	8	0.256787
0.004259	1	0.749612	2561.43	8	0.27208
0.001609	1	0.749904	2660.66	8	0.266842
0.000123	1	0.750428	2650.51	8	0.270258
0.003594	1	0.751426	2664.56	8	0.275716
0.015486	1	0.751443	2696.93	8	0.216664
0.003642	1	0.751735	2655.88	8	0.26212
0.001317	1	0.754562	2708.88	8	0.226258
0.000149	1	0.755355	2540.26	8	0.305453
0.000472	1	0.755356	2395.99	8	0.310995
0.011735	1	0.755587	2708.78	8	0.231095
0.001188	1	0.756521	2693.22	8	0.236228
0.017381	1	0.756922	2480.43	8	0.249458
0.000759	1	0.757075	2517.27	8	0.295343
0.002403	1	0.757466	2712.49	8	0.218577
0.002749	1	0.757923	2654.25	8	0.272763

0.000693	1	0.759009	2611.75	8	0.231994
0.007535	1	0.761128	2736.25	8	0.21907
0.006268	1	0.761173	2728.81	8	0.211409
0.001336	1	0.761489	1491	8	0.255915
0.000773	1	0.762091	2722.19	8	0.233631
0.007917	1	0.763441	2714.04	8	0.231279
0.002997	1	0.763765	2632.7	8	0.25705
0.011003	1	0.763769	2748.04	8	0.211017
0.000062	1	0.764171	2637.15	8	0.29017
0.000002	1	0.764971	2726.36	8	0.229185
0.003601	1	0.765874	2744.13	8	0.208418
0.001749	1	0.766003	2652.67	8	0.283304
0.0029	1	0.766523	1825.86	8	0.272579
0.004084	1	0.766848	2706.21	8	0.255849
0.009077	1	0.767064	2756.06	8	0.207949
0.002372	1	0.76892	2748.12	8	0.244069
0.012024	1	0.770874	2772.84	8	0.207475
0.003438	1	0.775946	2708.83	8	0.264831
0.010338	1	0.777287	2792.01	8	0.220319
0.016123	1	0.779761	2803.24	8	0.238755
0.000041	1	0.782311	2748.26	8	0.254853
0.003492	1	0.783059	2801.78	8	0.238497
0.002813	1	0.783152	2726.16	8	0.267511
0.00495	1	0.784026	2804.46	8	0.242883
0.072109	1	0.784756	2811.78	8	0.206337
0.000695	1	0.788359	2835.73	8	0.210809
0.000857	1	0.789502	2787.73	8	0.286024
0.000713	1	0.792668	2846.48	8	0.224536
0.00255	1	0.792675	2796.56	8	0.250441
0.006431	1	0.793969	2856.7	8	0.200286
0.03144	1	0.794786	2849.31	8	0.231535
0.011866	1	0.794956	2858.67	8	0.214087
0.026744	1	0.795074	2860.68	8	0.20661
0.009351	1	0.795524	2844.8	8	0.211361
0.011649	1	0.797374	2604.22	8	0.229144
0.001708	1	0.79816	1855.72	8	0.217776
0.001462	1	0.798223	2828.11	8	0.265514
0.043493	1	0.798794	2873.27	8	0.208177
0.027191	1	0.799564	2877.63	8	0.200202
0.007692	1	0.80125	2858.06	8	0.230232
0.004215	1	0.80203	2868.06	8	0.234589
0.003401	1	0.803148	2864.83	8	0.244526
0.038425	1	0.803984	2867.81	8	0.215226
0.005753	1	0.804549	2846.5	8	0.238441
0.001354	1	0.80601	1386.34	9	0.299102
0.001766	1	0.80883	2282.52	9	0.258947
0.008599	1	0.81054	2853.11	9	0.255766
0.002822	1	0.81068	2430.42	9	0.283437
0.012032	1	0.8119	2913.91	9	0.215515
0.0031	1	0.812551	2674.92	9	0.286826
0.00846	1	0.81294	2924.96	9	0.214044
0.019003	1	0.813323	2924.71	9	0.210693

0.02333	1	0.813467	2926.04	9	0.189386
0.033127	1	0.81397	2927.04	9	0.214148
0.05198	1	0.81428	2928.16	9	0.200139
0.010032	1	0.815075	2862.55	9	0.220171
0.013476	1	0.816196	2716.3	9	0.21371
0.008141	1	0.816433	2935.08	9	0.21772
0.005883	1	0.81651	2924.74	9	0.215818
0.004552	1	0.81673	2928.79	9	0.206513
0.000148	1	0.817247	2910.22	9	0.233664
0.007776	1	0.818774	2925.48	9	0.227622
0.004715	1	0.819881	2908.94	9	0.248989
0.07193	1	0.82677	2976.37	9	0.187134
0.007917	1	0.82923	2979.42	9	0.214225
0.000078	1	0.829653	2930.33	9	0.234773
0.000608	1	0.832934	2927.77	9	0.237761
0.009796	1	0.833105	2995.01	9	0.193679
0.00345	1	0.833218	2997.09	9	0.209705
0.003967	1	0.834569	2986.93	9	0.225296
0.026922	1	0.835777	3003.79	9	0.213506
0.010149	1	0.838864	1913.45	9	0.221349
0.058694	1	0.840072	3024.26	9	0.197008
0.014451	1	0.841358	2990.19	9	0.218513
0.042394	1	0.84223	2643.76	9	0.202298
0.013022	1	0.843832	3031.89	9	0.206967
0.020414	1	0.844901	3039.11	9	0.195304
0.041509	1	0.845466	3041.99	9	0.18299
0.059898	1	0.846112	3041.77	9	0.20306
0.014399	1	0.846253	3027.05	9	0.202453
0.017506	1	0.847983	3042.56	9	0.188865
0.006406	1	0.848833	2510.85	9	0.223055
0.017442	1	0.850645	3060.62	9	0.187235
0.006099	1	0.852834	3042.91	9	0.204791
0.010383	1	0.853722	2041.25	9	0.205316
0.000884	1	0.854857	2972.34	9	0.227359
0.019766	1	0.85584	3062.2	9	0.193177
0.043647	1	0.85739	3083.18	9	0.200582
0.000878	1	0.85759	3078.75	9	0.196903
0.139184	1	0.858162	3089.39	9	0.176304
0.007237	1	0.858283	3085.53	9	0.178543
0.005655	1	0.860547	3086.78	9	0.196263
0.000057	1	0.861047	3098.05	9	0.176293
0.013572	1	0.863031	3106.05	9	0.186178
0.00059	1	0.86308	3101.91	9	0.200607
0.00631	1	0.863228	3080	9	0.21188
0.003781	1	0.86374	3061.96	9	0.210323
0.007466	1	0.864794	3095.1	9	0.18208
0.039212	1	0.864866	3110.93	9	0.170389
0.011767	1	0.864912	3108.5	9	0.188901
0.051326	1	0.867901	1681.99	9	0.178259
0.033411	1	0.868448	3116.86	9	0.175384
0.050964	1	0.868718	3126.52	9	0.16872
0.002592	1	0.869063	2919.19	9	0.244613

0.061273	1	0.869219	3126.58	9	0.189179
0.011931	1	0.870091	3105.35	9	0.179656
0.001067	1	0.870115	3061.94	9	0.208551
0.03818	1	0.870173	3123.93	9	0.178782
0.079654	1	0.870209	3132.75	9	0.176831
0.011347	1	0.870567	3126.21	9	0.182515
0.002831	1	0.871695	3123.29	9	0.204131
0.009827	1	0.872931	2934.79	9	0.184434
0.019432	1	0.874953	3148.96	9	0.174634
0.026205	1	0.876527	2576.11	9	0.171342
0.050943	1	0.877842	1807.48	9	0.186838
0.050342	1	0.879224	2787.14	9	0.167186
0.001138	1	0.880307	3147.1	9	0.188396
0.002068	1	0.880327	2019.47	9	0.200366
0.002565	1	0.880553	3038.79	9	0.231767
0.134933	1	0.883283	3179.82	9	0.150481
0.011736	1	0.884877	3082.03	9	0.179756
0.004246	1	0.885029	1681.55	9	0.222999
0.088608	1	0.885631	3188.27	9	0.16652
0.009018	1	0.886901	2457.6	9	0.174709
0.007086	1	0.886955	3154.9	9	0.214967
0.015705	1	0.887355	3190.93	9	0.190652
0.004217	1	0.88842	2546.21	9	0.163865
0.00047	1	0.889025	3162.26	9	0.200836
0.018323	1	0.88951	3202.24	9	0.176749
0.010796	1	0.890272	3204.09	9	0.170723
0.001222	1	0.891013	2541.17	9	0.208557
0.006504	1	0.891128	3170.63	9	0.213511
0.091248	1	0.891589	3207.05	9	0.164618
0.008771	1	0.89367	3181.47	9	0.186874
0.000207	1	0.89385	3201.77	9	0.186651
0.011583	1	0.894517	3193.43	9	0.18059
0.010826	1	0.894536	3219.44	9	0.181196
0.042609	1	0.895658	3214.52	9	0.182115
0.006776	1	0.897306	3215.94	9	0.180871
0.033064	1	0.897718	3229.99	9	0.154973
0.017799	1	0.900363	3230.5	9	0.165958
0.196538	1	0.900436	3241.57	9	0.14583
0.058875	1	0.900777	3241.9	9	0.157698
0.006087	1	0.901189	3219.05	9	0.209428
0.002425	1	0.90274	3038.62	9	0.223949
0.03846	1	0.902837	2203.83	9	0.158453
0.176296	1	0.903762	3253.55	9	0.147027
0.127131	1	0.904309	3255.52	9	0.146661
0.008688	1	0.905984	3260.64	10	0.169109
0.011185	1	0.906575	2767.78	10	0.16362
0.105403	1	0.907517	3267.06	10	0.142201
0.008996	1	0.908082	2406.42	10	0.178299
0.030494	1	0.909123	3266.48	10	0.157153
0.031409	1	0.910317	3266.22	10	0.14711
0.019957	1	0.910905	3277.44	10	0.152941
0.23078	1	0.911131	3279.16	10	0.136198

0.059915	1	0.911462	1837.51	10	0.166738
0.011223	1	0.912656	3079.3	10	0.190763
0.158173	1	0.91268	2289	10	0.139807
0.0266	1	0.91291	3282.83	10	0.148359
0.263996	1	0.913989	3290.36	10	0.132332
0.007927	1	0.915211	3158.4	10	0.153032
0.216835	1	0.91539	3295.4	10	0.135254
0.022042	1	0.916011	3295.81	10	0.14112
0.006285	1	0.916073	3263.05	10	0.167496
0.246829	1	0.91615	2746.62	10	0.138521
0.003135	1	0.918272	3270.89	10	0.157471
0.006031	1	0.919416	3302.54	10	0.149566
0.070929	1	0.92028	3312.09	10	0.161379
0.011563	1	0.920562	3290.09	10	0.148124
0.008129	1	0.920697	3308.07	10	0.154171
0.186966	1	0.92078	3313.89	10	0.131182
0.042284	1	0.922441	3319.87	10	0.140906
0.003957	1	0.922807	3297.19	10	0.154999
0.000099	1	0.924314	3240.65	10	0.166152
0.008403	1	0.925041	3319.05	10	0.155509
0.055363	1	0.925719	2014.36	10	0.13443
0.056729	1	0.926361	2621.6	10	0.149376
0.004241	1	0.927323	3013.8	10	0.177368
0.187353	1	0.92874	3343.47	10	0.145402
0.016642	1	0.929332	3345.59	10	0.130473
0.001386	1	0.930787	3343.39	10	0.140021
0.204209	1	0.930836	3351.01	10	0.117816
0.028415	1	0.931402	3353.05	10	0.143331
0.005688	1	0.932442	3306.44	10	0.164175
0.042197	1	0.934113	3362.81	10	0.131056
0.024825	1	0.934876	3361.82	10	0.129862
0.264034	1	0.934974	3365.91	10	0.11743
0.058735	1	0.935109	2817.48	10	0.12965
0.005503	1	0.936626	3363.43	10	0.136784
0.012581	1	0.937201	2333.63	10	0.103731
0.003873	1	0.93791	2876.57	10	0.135064
0.001035	1	0.938416	3371.73	10	0.144034
0.000412	1	0.938435	3369.92	10	0.148307
0.017007	1	0.940177	3366.77	10	0.129876
0.109531	1	0.940653	3385.41	10	0.131763
0.020113	1	0.940937	3382.67	10	0.140093
0.059368	1	0.94146	3385.49	10	0.136691
0.007986	1	0.942309	3367.81	10	0.136396
0.006329	1	0.943413	2620.8	10	0.14469
0.039296	1	0.94376	3373.95	10	0.129297
0.031197	1	0.94383	3394.95	10	0.127212
0.024413	1	0.944046	3380.63	10	0.126959
0.01054	1	0.945236	3299.82	10	0.162857
0.001996	1	0.946366	3357.71	10	0.162215
0.150096	1	0.946556	3407.6	10	0.110528
0.203408	1	0.9473	3410.28	10	0.110005
0.252371	1	0.947833	3412.2	10	0.107942

0.041368	1	0.947874	3409.5	10	0.106963
0.080465	1	0.947885	3412.39	10	0.120466
0.001334	1	0.948822	1895.75	10	0.163422
0.001847	1	0.949539	3232.23	10	0.151886
0.14222	1	0.950163	3419.63	10	0.113416
0.170131	1	0.950434	3421.57	10	0.119865
0.014203	1	0.95087	3038.03	10	0.15044
0.003363	1	0.951297	3167.82	10	0.091984
0.010827	1	0.951902	3411.62	10	0.129611
0.018115	1	0.951963	3399.46	10	0.101552
0.087913	1	0.952407	3399.14	10	0.10603
0.107013	1	0.953064	3431.03	10	0.120802
0.003412	1	0.953391	3417.91	10	0.145824
0.119267	1	0.95434	3410.82	10	0.10106
0.185523	1	0.954521	3436.27	10	0.10027
0.004494	1	0.954632	3203.75	10	0.142101
0.028312	1	0.957192	3423.88	10	0.116475
0.037628	1	0.957381	2824.27	10	0.13181
0.004145	1	0.958321	3424.08	10	0.13986
0.034518	1	0.958401	3446.41	10	0.119294
0.073389	1	0.95876	3449.62	10	0.109562
0.044227	1	0.959439	2855.29	10	0.116965
0.009467	1	0.959738	1931.95	10	0.116856
0.033455	1	0.961035	3412.64	10	0.128196
0.367049	1	0.963657	2522.86	10	0.088499
0.033557	1	0.963759	3468.57	10	0.110169
0.026369	1	0.965484	3463.19	10	0.091609
0.20419	1	0.965582	3476.1	10	0.090926
0.01854	1	0.966228	1974.97	10	0.104924
0.051515	1	0.967495	2543.55	10	0.075515
0.135328	1	0.969223	3489.21	10	0.090836
0.119042	1	0.96992	3491.71	10	0.086176
0.394542	1	0.973495	3504.58	10	0.073444
0.341136	1	0.973815	3505.73	10	0.077075
0.058597	1	0.974043	2162.38	10	0.071435
0.59434	1	0.976402	2149.06	10	0.060171
0.444447	1	0.977083	3434.45	10	0.06103
0.069499	1	0.979247	1788.11	10	0.071299
0.247743	1	0.98028	3529.01	10	0.071369
0.08632	1	0.980858	3530.11	10	0.078579
0.396034	1	0.981382	3184.59	10	0.053567
0.130123	1	0.982971	3538.69	10	0.074612
0.411116	1	0.983282	3539.82	10	0.059653
0.055315	1	0.986994	2210.87	10	0.068094
0.125508	1	0.987466	2738.25	10	0.050074
0.468766	1	0.987767	2095.06	10	0.050308
0.013151	1	0.988161	3551.45	10	0.071742
0.027383	1	0.989058	3560.61	10	0.055123
0.233298	1	0.990204	2713.16	10	0.057525
0.47576	1	0.992633	2171.88	10	0.035645
0.345144	1	0.994925	3581.73	10	0.036924
0.571483	1	0.996888	3522.01	10	0.023517