ANALYZING THE DISTRIBUTION OF THE AFRICAN ELEPHANT (*LOXODONTA AFRICANA*) IN TSAVO, KENYA

by Joseph Mbyati Mukeka

The goal of this research was to characterize the distribution of elephants in the Tsavo Conservation Area (TCA) and relate the distribution patterns to biophysical and anthropogenic factors. Elephants in the TCA exhibited spatial clustering at distances between 60 km and 100 km, and were concentrated near the confluence of the Athi, Tsavo, and Galana rivers. Elephant density was negatively correlated with distance to rivers, human settlements density of water holes and was positively correlated with poaching density. Most elephants occurred in areas dominated by woody rather than herbaceous vegetation. Seasonal variation in green biomass captured by Enhanced Vegetation Index (EVI) from MODIS was an important predictor of elephant distribution. A probability distribution model implemented using Maxent used density of water holes, MODIS EVI, and distances to towns to predict the distribution of elephant habitat in the TCA. This map can be used to inform managers in elephant conservation strategies.
ANALYZING THE DISTRIBUTION OF THE AFRICAN ELEPHANT (*LOXODONTA AFRICANA*) IN TSAVO, KENYA

A Thesis

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by
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Dedication

To my loving wife Judy Mwende, my caring mother Dorcas Kavene, and my sister Joyce Kambua who was always there for me in my entire life but who never lived to witness my graduation – R.I.P.

I LOVE YOU ALL
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Thanks to my adviser, Dr. John Maingi for your encouragement and the time you took to get me through to this level. Thanks to Dr. Kimberly Medley and Dr. Thomas Crist for your invaluable advice as part of my committee.

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CHAPTER ONE

1.1 Introduction

Elephant populations in the Tsavo Ecosystem have a long history. Thorbahn (1984) used archeology to explain the utilization of elephants through poaching for ivory trade by the Wambisha in the 15th Century. Even though the actual populations roaming the area are not mentioned, the population of elephant plummeted to low numbers due to hunting for ivory trade allowing open grasslands to revert to thickets (Thorbahn, 1984). Tyrrell (1985) reported the presence of elephants along the Sabaki River in 1890 and attributed the open grasslands in the area to the long term presence of elephants. Tyrrell (1985) remarked on the absence of elephants in the Voi-Tsavo area near the foothills of Taita Hills; which Corfield (1975) attributed to proximity to ivory trade routes. Thorbahn (1985) has attributed the increased elephant population in Tsavo since 1948 to protection from hunting and poaching.

The population of elephants in the Tsavo Ecosystem has been monitored through aerial surveys since the 1960’s (Glover, 1963, Laws, 1969 and KWS, 2008) (Table 1). The Tsavo elephant population in the period preceding 1970 is highly varied, and used questionable techniques for counting elephants so therefore inaccuracies are replete in many of the existing reports (Cobb, 1976). Corfield (1973) reported 5,900 elephant deaths as a result of severe drought between 1970 and 1971. The period between 1970 and 1980 was characterized by high prices of ivory in the international market and heavy poaching in the Tsavo Ecosystem (Sheldrick, 1976; Ottichilo, 1981). Kenya banned hunting of wildlife in 1973, but poaching of elephants continued unabated (Sheldrick, 1976; Ottichilo, 1981). Thus, the 1980s saw the elephant population in the Tsavo Ecosystem decline because of poaching from about 12,000 (Ottichilo, 1981) to an all time low of 5,363 elephants in 1988 (Olindo et al., 1988). Poaching continued unabated until 1989 when the inefficient Wildlife Conservation and Management Department was replaced with the Kenya Wildlife Service (KWS), a state parastatal. This period coincided with a ban on the ivory trade imposed by the Convention on International Trade in Endangered Species (CITES) in 1989 (Armbruster, and Lande, 1993). Since then, poaching has been largely curtailed and the
number of elephants in the Tsavo Ecosystem has increased steadily to approximately 12,000 in 2008 (KWS, 2008).

Table 1: Elephant population in the Tsavo Ecosystem (Data from KWS)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>Inside protected area</th>
<th>Outside protected area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>15603</td>
<td>10799</td>
<td>4804</td>
</tr>
<tr>
<td>1965</td>
<td>20,300</td>
<td>15,685</td>
<td>NA</td>
</tr>
<tr>
<td>1967</td>
<td>35,000</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1980</td>
<td>12,000</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1988</td>
<td>5,363</td>
<td>4327</td>
<td>1039</td>
</tr>
<tr>
<td>1989</td>
<td>6226</td>
<td>5260</td>
<td>966</td>
</tr>
<tr>
<td>1991</td>
<td>6763</td>
<td>5116</td>
<td>1644</td>
</tr>
<tr>
<td>1994</td>
<td>7371</td>
<td>6264</td>
<td>1107</td>
</tr>
<tr>
<td>1999</td>
<td>8068</td>
<td>6677</td>
<td>1391</td>
</tr>
<tr>
<td>2002</td>
<td>9284</td>
<td>8377</td>
<td>940</td>
</tr>
<tr>
<td>2005</td>
<td>10397</td>
<td>9021</td>
<td>1376</td>
</tr>
<tr>
<td>2008</td>
<td>11733</td>
<td>10346</td>
<td>1387</td>
</tr>
</tbody>
</table>

More elephants seem to stay within the protected areas than outside. About 47.5% of the area is outside protected area and the ecosystem suggests source-sink dynamics.

Sound decisions for elephant management should not be based on population size alone because the impacts of elephants on the landscape also depend on how elephants are distributed in the landscape; their group sizes and the intensity at which patches are used within the landscape (Gordon et al., 2004). Dublin and Taylor (1996) note that wildlife data are invaluable in making informed decisions regarding the way in which wildlife should be managed. An increasing elephant population in Kenya raises many questions with regard to elephant conservation. Key among these questions are: (1) what are the preferred habitats for elephants and what factors influence their distribution; (2) in what ways are elephants impacting/changing the ecosystem; (3) are these impacts desirable or not; and (4) are these impacts recoverable or not? The answers to these questions (specifically question one for this research) may help identify and select more effective and sustainable elephant management strategies. Dublin and Taylor (1996) identified three elephant management strategies: 1) minimal or laissez-faire management, which holds that natural systems regulate themselves and
therefore there is no need of human intervention; 2) management for ecological objectives, which holds that due to anthropogenic disturbances, the natural systems cannot regulate themselves and therefore management intervention is necessary to set back the ecological balance; and 3) management for economic objectives that seeks to gain through exploitation of resources (Kangwana, 1996). Which is the best management option or mix of options to adopt in the Tsavo Ecosystem? To develop management alternatives, park managers need to know how elephants are distributed in the landscape and what factors influence their distribution. With this information, it is possible to identify elephant habitat both within and outside protected areas.

The Tsavo Ecosystem occupying approximately 40,000 km$^2$ includes both protected areas and private ranches. A recent wildlife aerial count revealed that 87.5% of elephants were found within protected areas (KWS, 2008b). This confinement of elephants to protected areas has been attributed to increased human settlement outside and adjacent to the parks, and the availability of more forage, water, and better protection from poaching inside the parks (KWS, 2005). According to the KWS (2005), the Tsavo Ecosystem can accommodate up to 20,000 elephants if water is adequately provided. It is however, unclear how this estimate of carrying capacity was calculated. About 47.5% of the Tsavo Ecosystem is in privately-owned areas such as ranches outside the national parks (KWS, 2002). Although these dispersal areas have remained largely unused in the past, this is fast changing as the human population grows (KWS, 2008b). It is essential to realize that the Tsavo Ecosystem is not uniformly suitable for elephants and that different parts have different potential to support elephant and that resources for elephants vary spatially and temporally within the ecosystem. The mere vastness of the Tsavo Ecosystem may not translate into a suitable habitat that can support the increasing elephant population.

1.2 Statement of the problem

Since 1988 the number of elephants in Tsavo has more than doubled but the habitat for elephants has declined drastically and is now mostly confined to national parks and reserves. These developments raise questions on how the elephants utilize the habitat. High concentration of elephants in particular areas manifests itself as degraded habitat through vegetation loss/change as happened in the neighboring
Amboseli National Park (Western & van Praet, 1973). Further, failure to get adequate/suitable food from the ecosystem can also lead to increased human/wildlife conflict as elephant movements increase to search for scarce resources (Smith & Kasiki, 2000). An understanding of elephant distribution and habitat utilization in the last 10 years can provide information to managers on the best ways to adopt for conservation management in the Tsavo Ecosystem in the present and future.

1.3 Justification of study

The Tsavo Ecosystem was chosen for this study because it has the largest elephant concentration in Kenya (KWS, 2002). Cobb (1976) also recorded more than 32 species of large mammals and over 324 species of birds in the Tsavo Ecosystem. The elephant is considered a keystone species that opens up forests and woodlands for other animals and plants and acts as a dispersal agent for plants (Laws, 1970; Dougall and Sheldrick, 1964). The elephant can drastically modify habitat for itself as well as influence the survival of other species (Mills, 1993; Pratt & Gwyne, 1977; Frost et al., 1986; Tafangenyaasha, 1997). Referred to as mega-fauna, a male adult elephant requires about 300 kg (wet) of food per day with tremendous volumes of water for batling (Laws, 1970). The current concern is whether elephants can be conserved within the Tsavo Ecosystem sustainably. This is complicated by the fact that elephants’ dietary preference has for a long time been hotly contested and ranges from browsing to grazing (Laws, 1970). Studies suggest that the composition of elephant food is as varied as the habitat and thus dictated by availability rather than preference (Laws, 1970). While the population of elephants in the Tsavo Ecosystem has been increasing recently, little is known about their habitat preferences and spatial distribution within the Tsavo Ecosystem. What are the characteristics of sites that are preferred by elephants? What are the sizes of these areas and how are they distributed across space? This research sought answers to these questions that are deemed essential for habitat management for the Tsavo Ecosystem elephants.

The only studies examining relationships between elephants and their habitat in the Tsavo Ecosystem are those by Laws (1970s), Dougall and Sheldrick (1964), and Pratt and Gwynnne (1977). Laws (1970) attributed the conversion of bushland to grasslands near water sources to elephants. Dougall and Sheldrick (1964) found
elephants consumed branches, leaves, roots, and bark of many trees but showed a preference for *Acacia* spp. and *Adansonia digitata*. Elephants need water at least two times in a day and rarely travel farther than 40 km from water sources during the dry season (Pratt and Gwynne 1977). Codron *et al.* (2006) found that elephants in the Kruger National Park consumed more grasses than browse. In the Maputo Elephant Reserve, Mozambique, De Boer *et al.*, (2000), found that elephants were predominantly browsers with nearly 60% consisting of browse and less than 31% grass. It is therefore not clear what habitats are preferred by elephants in the Tsavo Ecosystem. This study seeks to identify the habitat preferences for elephants in the Tsavo Ecosystem.

Other studies involving elephants in the Tsavo Ecosystem are those by Otichillo (1980) and Kyale (2006) which focused on elephant poaching. Smith and Kasiki (2000) examined human-wildlife interactions and note that conflicts occurred where humans and elephants compete for land resources. Most of the current knowledge on the African elephant is drawn predominantly from the southern Africa region, which has wildlife management systems that are different from that of East Africa. For example, Tsavo elephants are relatively free ranging whereas South African elephants are enclosed within parks (Dougall and Sheldrick, 1964; Shannon, 2008; Harris *et al.*, 2008). Additionally, climate and vegetation conditions in East Africa are quite different from those in southern Africa. In South Africa the miombo woodlands are abundant whereas in East Africa, the *Acacia-Commiphora bushland* dominates.

Few of the described elephant studies have attempted to link remotely sensed data with elephant census data and none for the entire Tsavo Ecosystem. Harris *et al.*, (2008) used Landsat ETM+ data to create vegetation maps while studying elephant habitat. Young *et al.*, (2009) used 1 km Normalized Difference Vegetation Index (NDVI) to study the effect of the elephant population on vegetation in Kruger National Park. In contrast to most local field-based elephant studies, remotely sensed data in elephant studies allows examination of landscape level relationships between elephants and their habitats.

1.4 Research goals and objectives

The overall goal of this study was to characterize the distribution of elephants in Tsavo Conservation Area (TCA) and relate the observed patterns to biophysical and
anthropogenic factors between 1999 and 2009. This goal was achieved through the following objectives:

1. Describing patterns of elephant distribution between 1999 and 2009
2. Describing the habitat characteristics of locations where elephants are found
3. Creating a land cover map for the Tsavo Conservation Area
4. Relating elephant distribution patterns to biophysical and anthropogenic variables in the TCA.
5. Modeling elephant habitat using significantly correlated factors with elephant density, and developing predictive maps for elephant distribution

1.5 Thesis organization

In the second chapter, I review literature on the various biophysical variables including water, elevation, slope, terrain, vegetation and salt licks and anthropogenic variables including roads, poaching, and human settlements as they relate to elephant distribution. Literature for the *Loxodonta africana* is drawn across Africa predominantly from southern African countries. In this chapter, I also briefly examine the various methods and techniques used in analyzing spatial point patterns to understand these relationships including the standard deviational ellipse (SDE) and the k-function. I also review briefly home range and land cover mapping.

Chapter three provides a geographical description of the study area, data types and sources, and methods I used to analyze these data. Here I provide rationale for using certain parameters in the analyses.

In chapter four, I present the results and provide discussion of the results.

Chapter five provides conclusions that I draw from these findings, limitations of the study, and recommendations from this study as well as possible suggestions for future research work.
CHAPTER TWO

2.1 Review of literature

2.1.1 Elephant interaction with biophysical and anthropogenic factors

Various biophysical and anthropogenic factors interact to influence the suitability of elephant habitat and consequently elephant distribution. The biophysical factors include vegetation (e.g. Laws, 1970; Kinahan et al., 2007; Codron et al., 2006), water (De Boer et al., 2000; Harris et al., 2008), terrain (Beasom et al., 1983; Nelleman et al., 2002; Ngene et al., 2009; Nelleman & Fry, 1995 etc) and salt licks (Mwangi et al., 2004; Belovsky & Jordan, 1981). The anthropogenic factors include human settlements and activities, specifically park facilities - offices, ranger units, roads and airstrips and small town centers; poaching is also an important determinant of elephant distributions (Hoare & Du Toit, 1998; Harris et al., 2008, Ngene et al., 2009).

The diet of an elephant is influenced by food availability and food preference (Laws, 1970). Vegetation is not only a source of food but provides shade for otherwise high ambient temperatures experienced in tropical savannas (Kinahan et al., 2007). Further, elephants are known to damage trees (Druce et al., 2008; Laws, 1970; Christina, 1992; Western & van Praet 1973; Christina, 1992; Tafangenyasha, 1997). Studies by Laws (1970) in Queen Elizabeth National Park, Uganda, indicate that 75% grass, 6% browse, 19%, herbs constitute food composition of an elephant’s diet in a tall-grass area. In another study in the Maputo Elephant Reserve, Mozambique by De Boer et al., (2000) found over 60% of elephant diet was browse while grass accounted for 31% of the diet. Codron et al. (2006) used carbon isotopes to study the dietary preferences of elephants in the Kruger National Park and found high consumption of grasses by elephants. An elephant will use grass to meet its energy requirements, while browse is required for protein (Laws, 1970).

Elephants need water to drink and cool their massive bodies. Elephants show a preference for riverine habitats because of the availability of abundant and high quality forage (De Boer et al., 2000; Harris et al., 2008). Harris et al., (2008) found elephants stayed closer to water sources in the dry season and moved farther from the rivers in the wet season when water was no longer a limiting factor in the arid savannas of...
Etosha National Park (Namibia), the tropical woodlands of Tembe Elephant Park (South Africa) and closed woodlands of Maputaland. In Hwange National Park in Zimbabwe, Chamaille-Jammes et al., (2007) also found that elephants clustered around water holes during the dry season. Several other studies have found that availability of water is the major determinant of elephant distribution, e.g., Kruger National Park, Smit et al. (2006), and Marsabit, Kenya Ngene et al., (2009).

Ruggiero and Fay (1994) found that elephants preferred licks with higher sodium concentration than surrounding soils. Mwangi et al. (2004) while studying geophagy of elephants in Aberdare National Park, Kenya, observed elephants consuming soils in an effort to supplement their sodium intake. Holdo et al., (2002) found consumption of soil by elephants more prevalent among the females than in males. Elephants have been observed to dig more in the ground in areas whose water is low in Na+ (Chamaille-Jammes et al., 2002).

Topography is an important ecological component shown to influence distribution of wildlife (Beasom et al., 1983). Relief affects vegetation and can affect the ecological niche for a species (Chernov, 1985). Ngene et al., (2009) found that elephants utilized higher elevation areas during dry season due to abundance of food resources but avoided higher slopes during rainy season due to slippery surfaces (Ngene et al., 2009). Vector ruggedness measure (VRM) is an important measure of topography and unlike slope can be used on relatively flat grounds where slope may not be effective (Nelleman et al., 2002). VRM is a more effective measure of terrain ruggedness because it quantifies local terrain variation more independently of slope than other methods (Sappington et al., 2007). Sappington et al., (2007) used VRM to study bighorn sheep in Mojave Desert and found VRM to be important in understanding their behavior and distribution of bighorn sheep.

Poche, (1980), Hoare & Du Toit (1998) and Harris et al. (2008) found human disturbance as indicated by proximity to roads, settlements, and campsites inhibited migration elephants. In contrast, Ngene et al. (2009) found elephants concentrated near settlements due to shared nature of limited resources with humans.

According to Laws (1970) heavy poaching forced elephants to spend less time near rivers and waterholes and more time inside protected areas. When poaching threat was removed elephants were found to spend more time near riverine strips (Laws, 1970). Kyale (2006) found poaching was rampant near streams and permanent water
due to higher elephant concentrations in these areas. Ngene et al., (2009) observed that elephants were found near roads because poaching threat was less than in vegetated areas where poachers enjoyed more cover.

2.1.2 Spatial point pattern analysis

One of the objectives of this study was to describe patterns of elephant distribution. Elephant aerial census data are point events which occurred in specific geographical locations in different times. Spatial data analysis describes data of processes that operate in space, the patterns and relationships in such data, and at the same time seeks explanations of such patterns and relationships (Burden, 2003). Point Pattern Analysis (PPA) deals with describing patterns of locations of points and events and testing their statistical occurrence of clustering (Burden, 2003). Originally PPA was used by botanists and ecologists but can be applied on any point patterns observed in space (Chakravorty, 1995). Burden (2003) notes that PPA has found its use in archeology, epidemiology and criminology.

Techniques for describing spatial point patterns are put into two major categories: (1) first-order and (2) second-order processes (Gatrell et al., 1996). First-order properties describe the way in which the expected value (such as mean) for a set of points varies across space, whereas second-order properties describe the correlation between values of the process at different regions in space (Gatrell et al., 1996). Unlike second-order statistics, first-order statistics have global properties and therefore fail to capture local variations in values of points. Examples of first-order statistics include mean and average and those for second-order statistic include the k-function.

2.1.2.1 First order statistics

2.1.2.1.1 Standard deviational ellipse

Wong and Lee (2001) describe standard deviational ellipse (SDE) as an effective tool for visualizing spread of points. Sometimes point locations represent geographical phenomenon that have a directional bias (Wong & Lee, 2001). SDE uses three components to describe and define it; an angle of rotation, deviation along the major
axis and deviation along the minor axis. Geographical phenomenon in point patterns that exhibits a certain directional (skewness) bias is identified by the direction with the maximum spread of points.

Kent & Leitner (2006) made use of geographic profiling by analyzing crime scenes to determine geographic center and estimate areal extents of a serial offender’s activity space, and found the SDE an effective model. Mamuse, et al., (2009) used SDE to model komitiite-hosted nickel sulphide deposits in Australia and found that these deposits depicted a northwest-southeast trend of ore bodies within the cluster.

Although the SDE provides useful insights at a global level, the underlying spatial processes rarely occur uniformly across space and therefore there is need to have a way of testing on this variability if any (Wong & Lee, 2001).

2.1.2.1.2 Kernel estimation

Kernel estimation computes intensity of point patterns by forming a count of events per unit area within a moving quadrant or ‘window’ (Gatrell et al., 1996). A window of fixed size is first defined and subsequently centered on a number of locations superimposed over study region (Gatrell et al., 1996). Weighting of events is done depending on the distance from the point at which intensity is being measured (Gatrell et al., 1996) and is used to obtain smooth estimates of univariate or multivariate probability densities from observed sample observations (Silverman 1986 as cited by Gatrell et al., 1996).

Kernel estimate has been extensively used in epidemiology in estimating the intensity of different events with each other (Gatrell et al., 1996). Bithell (1990) used kernel estimation to assess risk ness in childhood leukemia while providing a better visualization near a nuclear power plant in the Cumbria, U.K. Risk ness in leukemia increased near the facility but smoothed out with increased distance from the center (Bithell, 1990). Ramp et al. (2005) used kernel estimate to model fatalities of various wildlife along a highway in Australia and found that kernel density effectively showed where fatalities (hotspots) were most likely to occur. Kyale, (2006) used kernel estimates to compute poaching densities in Tsavo East National Park, Kenya and found higher poaching incidents occurred near water sources.
2.1.2.1.3 *Elephant home range*

In order to study territory and spacing patterns in animals, home range is adopted to describe an animal’s use of a two-dimensional space (Kie et al., 1996; Anderson, 1982). The simplest definition of a home range is that offered by Burt (1943), "that area traversed by the individual in its normal activities of food gathering, mating and caring for young." The earliest and one of the most widely used method for estimating home range is the minimum convex polygon (MCP) (Kie et al. 1996). MCP computes the home range of an animal by incorporating the farthest points as represented by an animal’s movement location to form a polygon (Kie, et al., 1996).

Gaine et al., (1998) used MCP to study the endangered American Wood Stork (*Mycteria Americana*) in Georgia, United States. Kusak et al., (2005) used MCP to study home ranges and movements of wolves in Croatia. MCP suffers from two disadvantages: a sample size bias in which an increase/decrease affects size of home range computed, and the assumption that home range is a convex polygon, which may not be so in heterogeneous landscapes (Anderson, 1982). Kernel estimators are better and can be used to detect core use area. Leuthold & Sale (1973) showed that Tsavo West and Tsavo East elephant home ranges were on average 340km$^2$ and 1580km$^2$ respectively using GPS enabled collars.

2.1.2.2 *Second order statistics*

2.1.2.2.1 *K-function*

Ripley (1976) introduced K-function or Ripley’s K statistic to assess if the magnitude of clustering is uniform over different spatial scales (Wong & Lee, 2001). The k-function postulates that the occurrence of an event at any point in a region $R$ is independent of other event occurrence and is equally likely over the whole of $R$ (Gatrell et al., 1996). Thus for a process that is homogeneous and shows no spatial dependence the expected number of events within a distance $d$ for an event chosen randomly is give by the following equation (Gatrell et al., 1996).

$$K(d) = \pi d^2$$
This implies that for clustered events, more points will be observed at short distances i.e. for small values of \( d \), observed \( k(d) \) is greater than \( \pi d^2 \) and for dispersed or regular pattern \( k(d) \) is lower than \( \pi d^2 \) (Gatrell et al., 1996; Wong & Lee, 2001). K-function is used to detect clustering at different scales by comparing the relationship between point counts and the size of \( d \) to that in a random distribution (Wong & Lee, 2001). A major weakness of the K-function is that it suffers from edge effect and to reduce this effect, a buffer can be created (Haase, 1995).

K-function is widely used in plant ecology to study community organization (Haase, 1995). Gaine et al., (1998) used K-function to determine distances at which foraging American Wood Stork occurred and found that distances differed with habitat use and proximity to each other. Ramp et al., (2005) used the network K-function (a modified version of K-function) used to capture linear geometry to study clustering of fatalities along a highway in Australia and found that different species had different spatial scales at which clustering occurred.

### 2.1.3 Land cover mapping

Remote sensing provides a cost-effective, consistent, and timely method for mapping land cover and monitoring changes in the landscape (Lillesand, et al., 2003). Two of the widely used classification methods are supervised and unsupervised classification logic (Jensen, 2005). Supervised classification requires *a priori* knowledge through a combination of fieldwork, interpretation of aerial photography, map analysis, and personal experience while unsupervised classification uses the computer to group pixels with similar spectral characteristics into unique clusters according to some statistically determined criteria (Jensen, 2005). Supervised and unsupervised classification algorithms output is a classification map that consists of hard, discrete categories e.g., forest and grasslands (Jensen 2005).

A modified supervised classification and regression tree analysis (CART) that is non-parametric and capable of handling non-linear relationships, exploratory analyses and feature selection has been used to create land cover maps (Tottrup, et al., 2007). The CART “is a supervised algorithm that takes a set of calibration data to establish the relationship between the response variable and the explanatory variables.” (Tottrup, et
CART incorporates ancillary data e.g. slope and DEM (Strahler et al., (1978) which have the ability to increase classification accuracy (Lawrence & Wright, 2001) and applies a recursive division on both independent variables (spectral channels and ancillary variables) and dependent variables (classification classes) to achieve a certain threshold specified by the user (Quinlan, 1993).

CART operates by recursively splitting data until nodes are achieved using explanatory variables (Quinlan, 1993). The explanatory variables are the spectral and ancillary data (continuous or categorical) and the response variable is the land cover class list (Lawrence & Wright, 2001). The final product of a CART is a classification tree which is a “series of rules that can be used for unknown observations to predict likely class membership” (Lawrence & Wright, 2001)

Lawrence & Wright (2001) used CART to make a land cover map for the Greater Yellowstone Ecosystem (about 20,900km²), and found elevation when used as ancillary data effectively separated forests from active agriculture with an overall accuracy of between 68% – 92%.

2.1.4 Moderate Resolution Imaging Spectroradiometer – Enhanced Vegetation Index (MODIS-EVI)

Earth Observing System (EOS) collects global data and MODIS is one of the instruments launched on Terra satellite to acquire data at frequent intervals (Campbell, 2007). MODIS provides a number of datasets one of the most important being vegetation indices such as Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). Vegetation Indices are spectral transformation of two or three bands that are designed to enhance contribution of vegetation properties (Huete et al., 2002). NDVI is one of the most widely used Vegetation Indices (Xiao et al., 2003); however, it suffers from soil background effects, saturation effects, and atmospheric degradation (Xiao et al., 2003). Liu and Huete (1995) developed another Vegetation Indice known as EVI which attempts to reduce weaknesses associated with NDVI (Xiao et al., 2003).

MODIS acquires data at a temporal resolution of 1-2 days (NASA, 2009) and has a spatial resolution of 250 m – 1000 m. MODIS-VI products are designed to provide consistent spatial and temporal comparisons of global vegetation conditions that can
monitor photosynthetic activity (Justic et al., 1998). Vina et al., (2008) used MODIS-NDVI to map panda habitat in China and found MODIS-NDVI a suitable indicator of biomass. Muukkonen and Heiskanen (2007) used 8-day periods, 250 m MODIS-NDVI composites to estimate biomass in Finland and found MODIS provided the best accurate estimate for biomass. Loarie et al. (2009) used MODIS-EVI time series data to study seasonal use of landscape by elephants across 7 southern Africa countries and found that elephants preferred areas with average higher EVIs.

2.1.5 Elephant habitat modeling using Maximum Entropy Modeling

Species distribution models (SDM) are used for estimating the potential for species to occur in areas not previously surveyed and rely on a species’ relationship with its environment to depict areas within a region where the species is likely to occur; i.e. statistical modeling methods offering the opportunity to derive predictive distribution maps from species occurrence and environmental data (Guisan and Thuiller, 2005). They increase understanding of environmental correlates of species distribution patterns and become tools in conservation planning, support management plans for species recovery and mapping of suitable sites for species reintroduction, suggest unsurveyed sites of high potential occurrence of species and can also help assess impact of climate, land use and environmental changes on species distribution (Guisan and Thuiller, 2005). Two types of SDMs can be generally distinguished: (i) methods that use both presence and absence data to examine statistical association of environmental correlates and (ii) presence – only methods (Giovanelli, et al., 2010).

Maxent is a general-purpose method for generating predictions or inferences from incomplete information (Phillips et al., 2006). Maxent generates probabilities of occurrence across area of study based on environmental conditions prevailing in areas where species have been observed. Maxent gives its output in three forms: raw, cumulative and logistic formats (Baldwin, 2009). Logistic format is the most recommended for it provides estimates of the probability occurrence as predicted by the included environmental variables with ability to import the results to a GIS environment to map probability distributions (Baldwin, 2009). Baldwin, (2009) notes that, even though the percentage contribution of each variable is given in final model, the jackknife approach is most recommended since each variable is analyzed in terms of its
importance. Further, response curves can be used to show impact of selected variables on probability.

Maxent requires only presence data and environmental data for the study area, utilizes both continuous and categorical data, and employs efficient deterministic algorithms and Maxent probability distribution also has a concise mathematical definition (Phillips et al., 2006). Further, Maxent employs regularization to avoid over fitting around clustered locations (Baldwin, 2009; Phillips et al., 2006). According to Phillips et al., (2006), Maxent suffers from lack of transferability and therefore more studies are required to enhance this model.

Phillips et al., (2006) used Maxent and Genetic Algorithm for Rule-Set Prediction (GARP) (a binary prediction) to model habitat suitability for Bradypus variegates and Microryzomys minutus in southeastern America and found that Maxent was a better predictor of these two species than GARP. Hernandez, et al., (2008), carried out a study to compare Maxent, Mahalanobis Typicalities, and Random Forests algorithms to predict distribution of eight bird and eight mammal species in central Andes and found that Maxent produced the most consistent results in varying conditions.

2.2 Research hypothesis

The working hypothesis of this research was that areas with high elephant densities had a greater abundance of food and water resources for elephants throughout the year. Vegetation indices have been found to be good predictors of biomass (Anderson et al., 1997; Huete et al., 1997) and were therefore used in this study to investigate how biomass varied through time in the study area. Higher vegetation index values mean more biomass and therefore more food available for elephants and subsequently, higher elephant densities. It was anticipated that elephant densities would be lower as distance to streams increased. It was also expected that there would be higher elephant densities around highly poached areas as poachers target these areas for quick kills.
CHAPTER THREE

3.1 Data and methods

3.1.1 Study area

The Tsavo Ecosystem covers approximately 40,000 km$^2$ (KWS, 2002) and falls between latitude $-1.6^\circ$N and $-4.5^\circ$S, and longitude $37.4^\circ$W and $40.0^\circ$E (Figure 1). The ecosystem includes two of the largest parks in Kenya, the Tsavo East National Park (TENP) about 12,000km$^2$ and the Tsavo West National Park (TWNP) about 9,000km$^2$ (KWS, 2005). The TENP and the TWNP were gazetted in April 1948 as Tsavo National Park (TNP), but were later split to the two parks in May 1948 to improve management (KWS, 2002). The Chyulu National Park (CNP), the South Kitui National Reserve (SKNR) and rarely mentioned Ngai Ndethya National Reserve (NNNR) are three other protected areas included in the Tsavo Ecosystem. The Mkomazi National Reserve (MNR) is in Tanzania and has been included also as it borders TWNP at the south western end. The remaining area outside parks and reserves is mostly private ranches and local settlements (KWS, 2002). This study focuses on the TENP, TWNP, CNP, SKNR, and NNNR in a 10km buffer zone surrounding it in what is called the Tsavo Conservation Area (hereafter referred to as TCA) (KWS, 2008a; Figure 2).
The TCA lies between 400 m and 2175 m above sea level (ASL) and experiences temperatures between $20^0\text{C}$ and $30^0\text{C}$ (Wright & Gunston, 1988). Most of the TCA is low-lying receives rainfall between 100 mm – 1200 mm per annum and appears to closely follow relief in a south-east north-west direction (Figure 2). According to Wright & Gunston (1988), rainfall is bi-modal with 'short rains' and 'long rains'
occurring November – December and April – July, respectively. The highest rainfall is obtained during the short rains (Pócs, 2007). Increasing relief makes TWNP receive higher amounts of rainfall than TENP (Figure 2 & 3)

Figure 2: Average rainfall (mm) 2000-2008 overlaid on DEM
Data from KWS – TCA. Rainfall may vary greatly some years.
Figure 3: The bimodal rainfall of the Tsavo Ecosystem

Most of the TCA is dominated by an *Acacia-Commiphora* bushland consisting of species such as *A. tortillis*, *A. drepanolobium*, and scattered trees such as *Adansonia digitata* and *Delonix elata* (White, 1983). Most of the southern part of the TCA and the Galana area are dominated by savanna grasslands. Montane forests are found in the higher elevation areas of the Chyulu Hills (Pócs, 2007). Permanent sources of water are found along the Tsavo River and the Athi River which join to form the Galana River. Seasonal rivers include the Tiva and Voi rivers. Riverine species including *Acacia elatior* and *Hyphaene compressa* are found along the permanent rivers while swamps are also found around Lake Jipe (KWS, 2002).
3.2 The Data

3.2.1 Elephant data

The KWS conducts an aerial wildlife census once every three years between late January and early February. This is done using aircrafts that fly at speed of about 80 miles per hour at about 200 ft to 300 ft above ground (Douglas-Hamilton, 1997). Transects are flown on a west-east or south-north direction depending on the conditions of wind and terrain. Distance between transects is maintained between 1-2km depending on vegetation cover and wildlife distribution (Figure 4). Only the large herbivores are counted as they are easier to spot and count from low flying aircraft and employing Global Positioning System (GPS) receivers. Observations of elephant and other wildlife are recorded as points based on their geographic location (Figure 4) and a data sheet filled to keep tally of the number and type of species observed at that location.
Figure 4: Aircraft flight lines and waypoints of observed elephants for 2005 aerial census.

The horizontal/vertical lines are GPS tracks representing path flown by the aircraft. Distance between tracks is maintained at 1 km or more. Points represent number of observed elephants on that location.
Data for elephant counts are available for the years 1999, 2005 and 2008, and are stored in the KWS headquarters under the Elephant Program office and KWS GIS Section. All data in non-projected coordinate system were projected to UTM Zone 37S. The datasets were clipped using TCA shape.

Radiotelemetry elephant data were provided by the Tsavo Research Office. These data comprise of elephant movements between August 2005 and July 2006 of elephants that were fitted with GPS collars to monitor their locations after being translocated from Shimba Hills National Reserve (KWS, 2008a). KWS employs this technology to monitor endangered species like the Grevy Zebra and the Rhino (KWS, 2008a). These data were used to compute elephant home range for the TCA and provide a band width used to calculate kernel densities.

### 3.2.2 Satellite data

To examine the relationships between elephant distribution and vegetation, a land cover map for the study area was prepared using landsat ETM+ data. Five Landsat ETM+ images covering the study area were downloaded from United Stated Geological Survey (USGS) as this area falls in two columns (167 and 166) three rows (63, 62 and 61) of this satellite (Figure 5).

**Table 2: Landsat ETM+ image details**

<table>
<thead>
<tr>
<th>Path/Row</th>
<th>Date of acquisition</th>
<th>Cloud cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>167/61</td>
<td>03/04/2001</td>
<td>0</td>
</tr>
<tr>
<td>167/62</td>
<td>03/04/2001</td>
<td>0</td>
</tr>
<tr>
<td>167/63</td>
<td>03/04/2001</td>
<td>0</td>
</tr>
<tr>
<td>166/62</td>
<td>01/22/2000</td>
<td>20</td>
</tr>
<tr>
<td>166/63</td>
<td>03/04/2001</td>
<td>20</td>
</tr>
</tbody>
</table>
Figure 5: Study area and Landsat ETM+ image coverage

To minimize phenological difference between the images, anniversary or near-anniversary date images were obtained. Only those images with cloud cover less than 20% were downloaded and used for this land cover map (Table 2). The five separate Landsat ETM+ images were mosaicked using ERDAS Imagine software to form one complete image that was masked with the TCA shape to extract the study area image.
MODIS-EVI data at 250 m resolution were used to track bi-monthly changes in greenness in the TCA for the period 2001 – 2008. These data were sought and downloaded from the United States Geological Survey (USGS) site. These data were imported into ERDAS Imagine and re-projected from the sinusoidal projection to UTM Zone 37S. The MODIS-EVI bands were then layer stacked into a 184 band image for the period 2001-2008. The 184-band MODIS-EVIS was then subset to the study area.

3.2.3 GIS layer data

GIS data available for this study included biophysical variables such as rivers, rainfall and water holes (artificial and supplemented), and a DEM. Anthropogenic variables included roads, settlements (towns/market centers, hotels/lodges, park facilities, campsites and ranger posts), locations of poached elephant carcasses, and airstrips. Most of these data were availed from KWS GIS; however, 1:50,000 scale topographic sheets obtained from Survey of Kenya and georeferenced to UTM Zone 37S were also digitized to obtain missing baseline data for the area. Landsat ETM+ data at 30 m spatial resolution were also used to digitize streams, roads, and water holes in the study area. These data complement those digitized from topomaps as in some cases, the later were out of date (Figure 6).

A database on elephant mortality is maintained at KWS Headquarters in Nairobi. Data for the period 1992-2009 were obtained and all elephant mortality records attributed to poaching were selected and used to create a shapefile with all the poached elephant locations. The shapefile was then reprojected to UTM Zone 37S.

Data on airstrips and lodges for TCA were obtained from the TENP and TWNP Research offices. Radiotelemetric data for the period August 2005 to July 2006 to monitor movements of translocated elephants were obtained from TENP Research Office. Five elephants had been sighted between 80 – 103 times and were used in this study.

Analysis of vegetation communities in the TCA was enhanced by taking more than 500 aerial and ground photographs using Nikon Coolpix 600 camera integrated with a GPS (Figure 7). These photos were downloaded together with the spatial information and hyperlinked in ArcGIS 9.3 during image analysis.
Figure 6: Selected data of some biophysical and anthropogenic variables.
Figure 7: Aerial and ground photograph points taken during the research

Ground photographs were taken along roads, while aerial photographs were taken from a light aircraft.
3.3 Methods

The various data, methods used on these data and results are represented in a flow chart below (Figure 8).

Figure 8: Schematic representation of data, methods and results

3.3.1 Analyzing elephant spatial distribution

3.3.1.1 Standard deviational ellipse analysis

Applying the Spatial Statistics Tool, weighted SDEs were computed for the aerial census point data for the years 1999, 2005 and 2008. A one standard deviation ellipse was chosen which translates to about 68% of the point features and the weight field was set to the field containing the number of elephants counted in that waypoint.
3.3.1.2 **Multi-distance spatial cluster analysis – (K – function)**

Distance spatial cluster analysis was done for the aerial census data using Spatial Statistics Tools. The weight field was set to number of elephants counted and the increment distance was set to 24700 m (24.7 km), the computed home range of Tsavo elephants.

3.3.1.3 **Kernel estimation analysis**

3.3.1.3.1 **TCA elephant home range**

Kernel estimation requires specification of a search radius to be used during the computation of the density surface. The radiotelemetric data were used to calculate the home range for 5 elephants that had been sighted between 80 – 103 times using the MCP analysis tool in ArcGis 9.3. Computing home range using MCP requires that an utilization distribution (UD) be defined that specifies the percentage points to be included (Gaine et al.,1998). An UD of 100% was used in this study to give the maximum home range possible.

To compare aerial census data with other variables, all data were rasterized. Using ArcGIS 9.3 Spatial Analyst, kernel densities were created for the elephant datasets 1999, 2005 and 2008. The search radius (width) used was 24.7 km calculated from the home range. Output cell size was set to 30 m.

Cell values from the density surfaces were extracted by using the elephant count data for each year. Analysis for correlation was done in JMP statistical software package.

3.3.2 **Examining elephant relationship with biophysical and anthropogenic variables**

Twelve GIS data layers were created in order to determine if they were related to the density of elephants. Raster layers for straightline distance to (1) rivers, (2) airstrips, (3) lodges, (4) management points (offices, ranger outposts, park gates and railway line posts) (5) water supplement points, and (6) towns were created using Spatial Analyst in
ArcGIS. Density better quantifies spread across space than distance and therefore a line density was computed for the roads. A simple density surface and kernel density functions in Spatial Analyst were used to create density surfaces for natural waterholes and for poaching respectively. Elevation information was obtained directly from the DEM layer while slope in degrees and VRM were calculated. Cell size for all these surfaces was kept at 30 m.

The Spatial Analyst Tool and the respective yearly aerial census data were used to extract the cell values from these surfaces. All the pixel values were first tested for normality before being analyzed for correlation using JMP statistical software package.

3.3.3 Land cover mapping

The aerial and ground images were hyperlinked in ArcGIS and using the Landsat ETM+ image of the study area, training areas were created in ERDAS Imagine software. Each training area was created using an area of interest (.aoi) file and saved independently. Training areas were based on physiognomic classification where present vegetation is identified based on criteria that can be observed directly (Pratt et al., 1966). This association is between grasses, woody plants, shrubs, and bushes. Where possible subdivisions based on dominant species were identified.

See5 (C5) decision tree classification program (RuleQuest Research, 2001) to create a land cover map was used. The See5 program searches for an accurate decision tree to predict an array of training cases. The decision tree is simplified and converted to production rules where each rule is composed of if-then statements (Hodgson et al., 2003). Each rule is composed of one or more conditions, all of which must be met for the rule to be evaluated as true. The program employs an information gain ratio method in tree development and pruning, and has many other features including boosting and crossvalidation (RuleQuest Research, 2001). Construction of a decision tree classifier use of training samples representative of the 12 land cover types targeted for mapping was done. These training samples were obtained from the Landsat ETM+ image and georeferenced aerial and ground photographs that had been taken during the field work.
The independent variables were a seven band image of six Landsat ETM+ bands and one NDVI band that had been generated from the Landsat ETM+ images. Finally the land cover map was assessed for accuracy.

Spatial Analyst and elephant count data for three years were used to extract the cell values for each vegetation category and the percentage number of elephants in each category was computed.

### 3.3.4 Using MODIS time series data to predict elephant distribution

MODIS-EVI data comes in bi-monthly composites that provide high temporal resolution, but lower 250 m spatial resolution. Higher temporal resolution enables MODIS data to capture vegetation changes better than Landsat ETM+ data and therefore its use in examining elephant distribution was carried out. The MODIS data were used to (1) analyze elephant distribution based on PCAs, and (2) examine elephant distribution based on season.

PCA was applied to a 184-band image consisting of bi-monthly EVI images between 2001 and 2008 and 15 components were created. PCA is a data compression method that reduces data dimensionality by summarizing most of the information in the image into a few bands or principle components (Table 4). Further, these components were layer stacked with elephant densities for 1999, 2005 and 2008 to enable for pixel value extraction.

Examining PCA relationships with elephant densities required the use of samples which were obtained based on binomial distribution. Pixel values from the 184 band image were extracted and a spearman correlation rank analysis done in JMP statistical software.
Table 3: MODIS-EVI composite image with 184 bands

<table>
<thead>
<tr>
<th>Date Composite Acquired</th>
<th>Year/Band</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2001</td>
</tr>
<tr>
<td>Jan_01_16</td>
<td>1</td>
</tr>
<tr>
<td>Jan_17_Feb_1</td>
<td>2</td>
</tr>
<tr>
<td>Feb_2_18</td>
<td>3</td>
</tr>
<tr>
<td>Feb_18_March_5</td>
<td>4</td>
</tr>
<tr>
<td>Mar_6_21</td>
<td>5</td>
</tr>
<tr>
<td>Mar_22_Ap_6</td>
<td>6</td>
</tr>
<tr>
<td>Ap_7_22</td>
<td>7</td>
</tr>
<tr>
<td>Ap_23_May_8</td>
<td>8</td>
</tr>
<tr>
<td>May_9_24</td>
<td>9</td>
</tr>
<tr>
<td>May_25_Jun_9</td>
<td>10</td>
</tr>
<tr>
<td>June_10_25</td>
<td>11</td>
</tr>
<tr>
<td>Jun_26_Jul_11</td>
<td>12</td>
</tr>
<tr>
<td>Jul_12_27</td>
<td>13</td>
</tr>
<tr>
<td>Jul_28_Aug_12</td>
<td>14</td>
</tr>
<tr>
<td>Aug_13_28</td>
<td>15</td>
</tr>
<tr>
<td>Aug_29_Sep_13</td>
<td>16</td>
</tr>
<tr>
<td>Sep_14_29</td>
<td>17</td>
</tr>
<tr>
<td>Sep_30_Oct_15</td>
<td>18</td>
</tr>
<tr>
<td>Oct_16_31</td>
<td>19</td>
</tr>
<tr>
<td>Nov_1_16</td>
<td>20</td>
</tr>
<tr>
<td>Nov_17_Dec_2</td>
<td>21</td>
</tr>
<tr>
<td>Dec_3_18</td>
<td>22</td>
</tr>
<tr>
<td>Dec_19_Jan</td>
<td>23</td>
</tr>
</tbody>
</table>

In order to examine elephant seasonal distribution, values from the 184 MODIS-EVI layers were extracted using the aerial census data for the three years and a further classification of these values put them into three seasons wet, mild dry and dry (Table 5). The average EVI values were calculated for each season. Overall average EVI values for the entire 184 layers were also computed. Using JMP statistical software, a non-parametric correlation analysis was done.
Table 4: Seasonal breakdown of the TCA

<table>
<thead>
<tr>
<th>Season</th>
<th>Month</th>
<th>No. of Two Week Composites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>March, April, May, November, December</td>
<td>80</td>
</tr>
<tr>
<td>Mild dry</td>
<td>January, February, June, July</td>
<td>64</td>
</tr>
<tr>
<td>Dry</td>
<td>August, September, October</td>
<td>40</td>
</tr>
</tbody>
</table>

3.3.5 Modeling elephant geographical distribution using Maxent

Maxent requires presence-only data for the species of interest. This data set consists of geographic coordinates of recorded presence sites for elephants obtained during each aerial wildlife census. Maxent accepts the presence-only data in a comma delimited format. The presence-only data layer is used together with a set of environmental/anthropogenic variables that influence or are related with presence of elephants. Maxent uses a generalized dissimilarity model (GMD) to create an environmental space which when combined with a kernel regression algorithm will create an output layer that estimates the likelihoods of occurrence of a given species at all sites (Elith et al., 2006). The area under the Receiver Operating Characteristic curve (AUC) is the statistic used to measure ability of the model to discriminate between sites where a species is present or absent an indication of how useful the model is for prioritizing areas in terms of relative importance as habitat for a species (Elith et al., 2006). AUC ranges from 0-1, where score of 1 imply perfect discrimination, 0.5 indicates predictive discrimination that is no better than random and values <0.5 indicate worse than random performance (Elith et al., 2006). As a rule of thumb, a model should have on AUC > 0.75 of discrimination and perform better than random, AUC > 0.5. Situations where the model fits the data, but predicts badly are the ones described as “worse than random” (Elith et al., 2006).

Maxent predictive capability is affected by significantly correlated variables and therefore to avoid this problem, multiple correlation analysis was done to eliminate such variables e.g. DEM was correlated with slope, VRM, and PC4. Three raster variables (water holes, PC4, and towns) were used and converted to ESRI ASCII format .CSV files forming the format accepted by Maxent. The 2008 aerial census data were used since these were the latest. A random test points of 25% was used and jackknife
chosen to measure variable importance. Output was both in logistic and GIS grid format.
CHAPTER FOUR

4.1 Results and discussion

4.1.1 Explaining spatial distribution of elephants

4.1.1.1 Tsavo elephant home range

MCP home ranges for five of the elephants monitored between August 2005 and July 2006 indicated a minimum and maximum home range of approximately 400km$^2$ and 1900km$^2$ respectively (Table 5, Figure 9). Elephant with collar ID 400 was sighted the most and had the smallest home range size contrary to the idea that MCP range increases with increasing number of sightings (Anderson, 1982). These results are consistent with those of Leuthold & Sale (1973) who showed that Tsavo West and Tsavo East elephant home ranges were on average 340km$^2$ and 1580km$^2$ respectively (Leuthold & Sale, 1973). Home range has significant implications for conservation as it can indicate the availability of resources. Elephants that inhabit areas with adequate resources will tend to have lower home ranges than those that need to travel long distances in search of scarce resources.

Assuming the maximum MCP home range and a circular shape, the band width for all calculations in this research were taken to be 24.7km, the maximum radius an elephant moves within the TCA. This ensured that all areas traversed by the elephant were included during computation of kernel density.

Table 5: MCP – home range

<table>
<thead>
<tr>
<th>Collar ID</th>
<th>No. of sightings</th>
<th>MCP (km$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>103</td>
<td>436.58</td>
</tr>
<tr>
<td>360</td>
<td>80</td>
<td>866.22</td>
</tr>
<tr>
<td>200</td>
<td>96</td>
<td>636.73</td>
</tr>
<tr>
<td>100</td>
<td>102</td>
<td>1091.97</td>
</tr>
<tr>
<td>20</td>
<td>96</td>
<td>1917.23</td>
</tr>
</tbody>
</table>
Figure 9: MCP home range for elephants in the TCA
4.1.1.2 Standard deviational ellipse and kernel densities of elephants

The results from SDE showed that elephant populations were concentrated at the central part of the TCA (Figure 10 & 11). The SDE rotational angles along the major axis ranged between 68° – 80° in a northeasterly orientation and an upward shift from 1999 to 2005, and to 2008. Elephants displayed the most spread in 2005 as is indicated by the large SDE area (Table 6). SDE results show a spatial concentration but not significant directional bias an indication that certainly not one linear variable is able to explain the distribution of elephants in this conservation area. Ngene et al. (2009), found that six factors accounted for elephant distribution in Marsabit National Park - Kenya

Mean elephant densities increased by about 20% as total elephant population for the three years increased (Table 7). The higher the elephant population, the higher the spread as indicated by the standard deviation figures (Table 7). The average densities are consistent with other recommendations for elephant densities of 0.25-0.54 elephants per km² (Boshoff et al., (2002), but these distributions further indicate an over concentration of elephants at particular areas. Armbruster et al., (1993) recommended an overall density of 1.20 elephants/km² for the Tsavo Ecosystem.
Figure 10: SDEs and kernel densities elephant population.
SDEs overlay areas of highest elephant densities. Kernel densities for 1999 and 2005 show separate spots for elephant concentration while 2008 show a more continuous spread.
Figure 11: Combined SDEs of the three periods

A northeasterly shift from 1999 to 2005 and to 2008. The general area of elephant concentration remained largely unchanged. The SDEs less than ellipsoidal shape point to not a geographical bias.
### Table 6: Elephant SDE values

<table>
<thead>
<tr>
<th>Year</th>
<th>Rotation - degrees</th>
<th>Area of ellipse (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>68</td>
<td>7784</td>
</tr>
<tr>
<td>2005</td>
<td>51</td>
<td>8272</td>
</tr>
<tr>
<td>2008</td>
<td>80</td>
<td>7215</td>
</tr>
</tbody>
</table>

### Table 7: Elephant kernel density ranges

<table>
<thead>
<tr>
<th>Year</th>
<th>Range Elephants/ km²</th>
<th>Mean Elephants/ km²</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>0.166 – 1.494</td>
<td>0.269</td>
<td>0.347</td>
</tr>
<tr>
<td>2005</td>
<td>0.254 – 2.290</td>
<td>0.317</td>
<td>0.430</td>
</tr>
<tr>
<td>2008</td>
<td>0.287 – 2.580</td>
<td>0.343</td>
<td>0.428</td>
</tr>
</tbody>
</table>

#### 4.1.1.3 Multi-distance spatial cluster analysis - K – function

SDEs and kernel density analyses provide useful global measures to the overall spatial distribution of elephants in the TCA but fail to capture local variations in distribution. K-function seeks to examine at what distances the elephant clustering occurred or did not by examining the same elephant aerial census data. The results indicate that clustering occurred at shorter distances \( k(d) > \pi d^2 \) i.e. observed is greater than expected) and dispersion at farther distances \( k(d) < \pi d^2 \) i.e. observed is less than expected), (Gatrell et al., 1996) (Figure 12). Critical distances for other years occurred up to about 61km, 74km and 98km for 1999, 2005 and 2008 respectively showing a decreased spatial clustering with increased elephant population. This can attributed to what Laws (1970) described as “the discrete geographical distribution of concentrations of elephants related to particular home ranges.” (Laws, 1970, p.4). Further, elephants exhibit social behavior where the basic social unit is the family (Poche’, 1980) and therefore live together rather than individually.
Figure 12: Spatial clustering of elephants for 1999, 2005, and 2008

ArcGIS graphic outputs of k-function analyses. When observed is greater than expected, spatial clustering occurs up to the distance where the lines intersect. Distances beyond this intersection indicate a dispersion mode. Confidence interval: 95%
4.1.2 Land cover mapping

There were 12 broad vegetation types identified in the TCA based on field surveys and interpretations of aerial photos and satellite images: Forest, grassland, woodland, Water, Lava, bare grounds with scattered trees, seasonally flooded grasslands, urban, bare bright soils and sand bars, acacia woodland, Commiphora thickets, and annual grasslands/herbaceous/barren land (Table 8, Figures 13-21). Clouds and shadows were also isolated during classification.

Bare soil with scattered trees land cover type was the most dominant accounting for about 30%, followed by acacia woodlands contributing about 25% of the total land surface area (Table 9). Woodlands and forest cover increase from south west to northwest closely bearing on the rainfall gradient and elevation increase (Figure 22). Annual grasslands/herbaceous/barren land was found only in the TENP along the Galana river. Clouds and shadow covered a not significant part of the southwestern part of TENP too.
<table>
<thead>
<tr>
<th>Class no</th>
<th>Land cover type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Forest</td>
<td>Occur mostly on top of the Chyulu ranges and a few other hills on elevations above 1300m ASL (Figure 13).</td>
</tr>
<tr>
<td>2.</td>
<td>Woodland</td>
<td>Occur mostly in the north western parts of the TCA at lower elevations next to forest land cover. It comprises of semi-evergreen - <em>combretnum sp</em>, <em>Croton dichogamus</em> and riverine vegetation e.g. <em>Acacia robusta</em>, <em>Lawsonia inermis</em> (Figure 14).</td>
</tr>
<tr>
<td>3.</td>
<td>Lava</td>
<td>Occurs mostly on and around Chyulu ranges in the TWNP. A volcanic rocky ground, but sometimes the rock is occupied by woody vegetation such as <em>Diospyros mesipiliformis</em>, <em>Pappea capensis</em>, and <em>Dombeya burgessae</em> (Figure 15).</td>
</tr>
<tr>
<td>4.</td>
<td>Commiphora thicket</td>
<td>Mostly occur in the middle of the protected areas. Thickets are almost impenetrable by humans. Common species include <em>Commiphora africana</em>, <em>Commiphora baluensis</em>, <em>commiphora campestris</em>, <em>Commiphora schimperi</em>, <em>Acacia sp.</em> (Figure 16).</td>
</tr>
<tr>
<td>5.</td>
<td>Bare grounds with scattered trees</td>
<td>These are found through out most of the study area except on the hilly areas. Species composition is varied and include <em>Acacia sp.</em>, <em>Boscia coriacea</em>, <em>Boscia angustifolia</em> (Figure 17).</td>
</tr>
<tr>
<td>6.</td>
<td>Acacia woodland</td>
<td>This type is found through the entire TCA and is interspersed with bare grounds. Major species are <em>acacia sp.</em> e.g. <em>Acacia tortilis</em> (dominant). It greens up during the dry season (Figure 18).</td>
</tr>
<tr>
<td>7.</td>
<td>Seasonally flooded grasslands</td>
<td>Occur mostly in the southern part of TWNP occurring on low lying areas characterized with poor drainage (Figure 19).</td>
</tr>
<tr>
<td>8.</td>
<td>Grassland</td>
<td>These are found mostly in Chyulu hills, limited areas in the entire TCA and along rivers (Figure 20).</td>
</tr>
<tr>
<td>9.</td>
<td>Annual grasslands/ herbaceous/ barren land</td>
<td>These are found along Athi river in the middle of TENP. Soils are bright and rocky. For the largest portion of the year these areas are barren and green up only briefly after rains (Figure 21)</td>
</tr>
<tr>
<td>10.</td>
<td>Water</td>
<td>Includes lakes, dams, water holes and permanent rivers</td>
</tr>
<tr>
<td>11.</td>
<td>Urban</td>
<td>These include areas that have continuous settlements and act as centers of trade.</td>
</tr>
<tr>
<td>12.</td>
<td>Bare bright soils and sand bars</td>
<td>Found in completely degraded areas and along river banks.</td>
</tr>
</tbody>
</table>
Figure 13: Forest on Chyulu ranges

Figure 14: Woodland
The inset is *Combretum sp.*, found on foothills of Chyulu ranges.
Figure 15: Lava land cover type
The Common species found here is *Pappea capensis* (inset)

Figure 16: Commiphora thickets
Greyish – *Commiphora africana*, Greenish stem – *Commiphora sp.*, Elephants can penetrate these thickets.
Figure 17: Bare ground with scattered trees
Soil color may vary from place to place.

Figure 18: Acacia woodland
Umbrella shaped *Acacia tortilis* is the dominant woodland.
Figure 19: Seasonally flooded grassland

Figure 20: Grassland

Grassland on Chyulu ranges
Figure 21: Annual grasslands/herbaceous/barren land
Table 9: Land cover types, area and percent cover

<table>
<thead>
<tr>
<th>SNO</th>
<th>Land Cover type</th>
<th>Area(Km²)</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forest</td>
<td>430.7</td>
<td>1.29</td>
</tr>
<tr>
<td>2</td>
<td>Grassland</td>
<td>949.4</td>
<td>2.84</td>
</tr>
<tr>
<td>3</td>
<td>Woodland</td>
<td>3976.3</td>
<td>11.90</td>
</tr>
<tr>
<td>4</td>
<td>Water</td>
<td>85.7</td>
<td>0.26</td>
</tr>
<tr>
<td>5</td>
<td>Lava Wooded</td>
<td>349.2</td>
<td>1.05</td>
</tr>
<tr>
<td>6</td>
<td>Bare Soil with Scattered Trees</td>
<td>11649.6</td>
<td>34.88</td>
</tr>
<tr>
<td>7</td>
<td>Seasonally Flooded</td>
<td>3004.6</td>
<td>8.99</td>
</tr>
<tr>
<td>8</td>
<td>Urban</td>
<td>17.3</td>
<td>0.05</td>
</tr>
<tr>
<td>9</td>
<td>Bare/Bright Soil</td>
<td>127.1</td>
<td>0.38</td>
</tr>
<tr>
<td>10</td>
<td>Acacia Woodland</td>
<td>8757.5</td>
<td>26.22</td>
</tr>
<tr>
<td>11</td>
<td>Commiphora thickets</td>
<td>2793.1</td>
<td>8.36</td>
</tr>
<tr>
<td>12</td>
<td>Annual grasslands/herbaceous/barren land</td>
<td>1263.1</td>
<td>3.78</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>33403.6</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>
Figure 22: Land cover map of the TCA

Most forest and woodland land cover types dominate TWNP, while Bare soils and scattered trees dominate TENP. Some classes e.g. urban are too small to be observed in a map of this scale.
4.1.2.1 **Accuracy assessment**

The overall errors of omission percentages indicate that *Commiphora* thickets (85.5%) has been most wrongly assigned to other land cover types, while errors of commission indicate that acacia woodland (72.6%) had the highest assignment to other classes (Table 10). This research indicates that acacia woodland is likely to be confused with bare ground and scattered trees during classification process. This difficult in separating these classes from other land cover types indicate that they are highly associated and mixed up with other classes. Three land cover types (forest, water and lava (wooded) had classification accuracy of > 90% indicating that these classes are easier to separate due to their distinctive spectral signatures. Four classes (forest, grassland, water, and Annual grasslands/barren land) had a producers accuracy > 80%, while an equal number had producers accuracy <50% (woodland, urban, acacia woodland and Annual grasslands/barren land). The overall accuracy was 59.2% and a kappa statistic of 0.535.

The use of one season images for land cover mapping and failure to use multispectral images further contributed to low accuracy. Use of aerial photos taken from moving aircraft may have contributed to drop in accuracy percentage due to the angle at which the camera captured the images and that it was not possible to take photographs directly below.
Table 10: Error matrix for the TCA land cover map

<table>
<thead>
<tr>
<th>Reference Image</th>
<th>Forest</th>
<th>Grassland</th>
<th>Woodland</th>
<th>Water</th>
<th>Lava</th>
<th>Bare ground with scattered trees</th>
<th>Seasonally flooded grasslands</th>
<th>Urban</th>
<th>bare shrubs and sand bars</th>
<th>Acacia woodland</th>
<th>Commiphora thickets</th>
<th>grasslands/herbaceous/bare land</th>
<th>Total</th>
<th>PA%</th>
<th>EO% (100-PA)</th>
<th>EC% (100-CA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>71</td>
<td>0</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>85</td>
<td>83.5</td>
<td>16.5</td>
<td>0</td>
</tr>
<tr>
<td>Grassland</td>
<td></td>
<td>0</td>
<td>27</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>32</td>
<td>84.4</td>
<td>15.6</td>
<td>37.2</td>
</tr>
<tr>
<td>Woodland</td>
<td>0</td>
<td>4</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>70</td>
<td>41.6</td>
<td>58.4</td>
<td>72.6</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>49</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>49</td>
<td>100</td>
<td>0</td>
<td>5.8</td>
</tr>
<tr>
<td>Lava</td>
<td>0</td>
<td>0</td>
<td>19</td>
<td>0</td>
<td>31</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>58</td>
<td>53.4</td>
<td>46.6</td>
<td>3.1</td>
</tr>
<tr>
<td>Bare ground with scattered trees</td>
<td>0</td>
<td>8</td>
<td>19</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>133</td>
<td>9</td>
<td>0</td>
<td>4</td>
<td>43</td>
<td>15</td>
<td>54.5</td>
<td>45.5</td>
<td>32.8</td>
</tr>
<tr>
<td>Seasonally flooded grasslands</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>8</td>
<td>46</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>58</td>
<td>73.1</td>
<td>26.9</td>
<td>50.5</td>
</tr>
<tr>
<td>Urban</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>21</td>
<td>33.3</td>
<td>66.7</td>
<td>30</td>
</tr>
<tr>
<td>Bare bright soils and sand bars</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>65.6</td>
<td>34.4</td>
<td>16</td>
</tr>
<tr>
<td>Acacia woodland</td>
<td>0</td>
<td>2</td>
<td>12</td>
<td>0</td>
<td>1</td>
<td>22</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>32</td>
<td>4</td>
<td>2</td>
<td>84</td>
<td>38.1</td>
<td>61.9</td>
<td>72.2</td>
</tr>
<tr>
<td>Commiphora thickets</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>29</td>
<td>9</td>
<td>0</td>
<td>61</td>
<td>14.5</td>
<td>85.5</td>
<td>70</td>
</tr>
<tr>
<td>Annual grasslands/barren land</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>57</td>
<td>80.3</td>
<td>19.7</td>
<td>36.7</td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>43</td>
<td>106</td>
<td>52</td>
<td>32</td>
<td>198</td>
<td>93</td>
<td>10</td>
<td>25</td>
<td>115</td>
<td>30</td>
<td>90</td>
<td>865</td>
<td>80.3</td>
<td>19.7</td>
<td>36.7</td>
</tr>
<tr>
<td>CA(%)</td>
<td>100</td>
<td>62.8</td>
<td>27.4</td>
<td>94.2</td>
<td>96.9</td>
<td>67.2</td>
<td>49.5</td>
<td>70</td>
<td>84</td>
<td>27.8</td>
<td>30</td>
<td>63.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall accuracy (%)</td>
<td>59.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kappa statistic</td>
<td>0.535</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: CA, consumer’s accuracy; PA, producer’s accuracy; EO, errors of omission; EC, errors of commission.
4.1.3 Relating elephant population distribution with biophysical and anthropogenic variables

The various biophysical and anthropogenic variables were tested for normality using the Shapiro-Wilk test before any correlations between the variables and elephant density were performed. The normality tests revealed that most of the variables were not normally distributed. As a result, all correlation analyses were based on the non-parametric spearman’s rank correlation.

Among the topographical variables, elevation was found to be negatively correlated with elephant density (Table 11). This finding suggests that elephants avoid higher elevation areas perhaps due to limited food at higher elevations (Ngene et al., 2008). Slope and VRM showed positive correlations with elephant densities for the three years. VRM showed a higher positive correlation than slope in predicting elephant distribution and therefore indicates that it is a better predictor than slope. Gently sloping landscape indicated by low VRM can serve as repository for water, minerals and vegetation all important factors contributing to elephant distribution (Sappington et al., 2007).

Natural water hole densities showed negative correlation with elephant density indicating that elephants avoided these areas contrary to Harris et al. (2008) who noticed that elephants remained close to natural water sources in Etosha N.P. in Namibia. Distances to supplement water points had a negative correlation indicating that they were built to target areas with high elephant numbers but lacked water (Table 11). These results show that water is a powerful determinant for elephant distribution and are consistent with those Ngene et al., (2009) and Chamaille-Jammes et al., (2007).

Distance to lodges was one of the human influences that showed a weak negative relationship with elephant density ($r \sim -0.300^{**}$) throughout the period. Most tourist facilities are built in areas with dense vegetation so as to blend with the environment and these facilities have been known to build artificial water points with salt being added to attract wildlife for closer viewing and visitor satisfaction (KWS, 2008a). Other human influences such as management points showed negative but non-significant relationships with elephant density. The preceding discussion is in agreement with those of Hoare & Du Toit (1998) and Harris et al. (2008) who found that human
settlements were negatively correlated with elephant density. Towns however, showed a positive relationship with elephant densities for 1999 and 2008. Most town centers are normally built in areas with water sources and these could be potential areas for elephant utilization. Road density and elephant density were positively correlated. Roads are built where there are concentrations of wildlife not only to enhance visitor satisfaction, but also to improve security.

Poaching showed a positive correlation with elephant density with the strongest correlation being 1999. Poachers are more likely to poach in areas with high elephant densities as this increases their chances of killing elephants efficiently and getting away before they are detected by authorities (Kyale, 2006). The correlation between poaching density and elephant density decreased in both 2005 and 2008. This decrease maybe the result of beefing up of security in the parks and the continuation of the CITES ban on trade in ivory (KWS, 2008). In spite of this drop in poaching, an increase between 2005 and 2008 indicates the possibility of resurgence in poaching. This can be attributed to the anticipated opening up ivory trade by CITES conference that was held in March 2010, but that was not implemented (KWS website).

Table 11: Elephant density, Spearman’s ρ correlations and their probabilities

<table>
<thead>
<tr>
<th>Variable/Year</th>
<th>1999</th>
<th>2005</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM (m)</td>
<td>-0.303**</td>
<td>-0.072*</td>
<td>-0.294**</td>
</tr>
<tr>
<td>Slope (degrees)</td>
<td>0.130**</td>
<td>0.119**</td>
<td>0.087**</td>
</tr>
<tr>
<td>VRM</td>
<td>0.159**</td>
<td>0.115**</td>
<td>0.120**</td>
</tr>
<tr>
<td>Simple density for water points</td>
<td>-0.249**</td>
<td>-0.604**</td>
<td>-0.223**</td>
</tr>
<tr>
<td>Distance to water supplement (m)</td>
<td>-0.011</td>
<td>-0.428**</td>
<td>-0.335**</td>
</tr>
<tr>
<td>Distance to rivers (m)</td>
<td>-0.409**</td>
<td>0.248**</td>
<td>0.023</td>
</tr>
<tr>
<td>Distance to airstrip (m)</td>
<td>0.123**</td>
<td>0.006</td>
<td>-0.011</td>
</tr>
<tr>
<td>Distance to lodges (m)</td>
<td>-0.292**</td>
<td>-0.293**</td>
<td>-0.149**</td>
</tr>
<tr>
<td>Distance to towns (m)</td>
<td>0.190**</td>
<td>-0.003</td>
<td>0.272**</td>
</tr>
<tr>
<td>Distance to management point (m)</td>
<td>-0.101**</td>
<td>-0.427**</td>
<td>-0.143**</td>
</tr>
<tr>
<td>Density of roads</td>
<td>0.189**</td>
<td>0.288**</td>
<td>0.083*</td>
</tr>
<tr>
<td>Density of poached elephants</td>
<td>0.482**</td>
<td>-0.199**</td>
<td>0.234**</td>
</tr>
</tbody>
</table>

(* p <0.05;  ** p < 0.01)
4.1.3.1 Elephant density and land cover type

Approximately 40% of elephants occurred in areas dominated by scattered trees with bare soil the largest class in area. Another 20% of the elephants were found in acacia woodlands (Table 12). Acacia woodlands are an important food for elephants and have been known to provide resting places from the high ambient tropical temperatures. Multiple sightings of elephants were made in areas dominated by Acacia woodlands during the research (Figure 23). Less than five percent of elephants were found in grasslands. Most grassland areas are found on Chyulu ranges on elevations that elephants do not utilize. Seasonally flooded grasslands showed higher utilization of about seven percent than grassland. Seasonally flooded regions may serve as potential reservoirs of food sources when other areas dry up. Other classes e.g. lava-wooded, forest, and bare/bright soils did not have significant numbers of elephants (<1%) indicating their low utility for elephants. Forests are found on hilly areas while wooded lava is either bare or its very rough terrain is difficult to walk for elephants. Riverine woodlands are an important component of elephant as they provide food during dry season and are a vital source of crude protein (Laws, 1970).

Table 12: Land cover type and percentage of elephants found

<table>
<thead>
<tr>
<th>Land cover type</th>
<th>Percent elephants found</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1999</td>
</tr>
<tr>
<td>1 Forest</td>
<td>0.434</td>
</tr>
<tr>
<td>2 Grassland</td>
<td>4.759</td>
</tr>
<tr>
<td>3 Woodland</td>
<td>12.585</td>
</tr>
<tr>
<td>4 Water</td>
<td>0.213</td>
</tr>
<tr>
<td>5 Lava Wooded</td>
<td>0.00</td>
</tr>
<tr>
<td>6 Bare Soil with Scattered Trees</td>
<td>38.542</td>
</tr>
<tr>
<td>8 Urban</td>
<td>0.00</td>
</tr>
<tr>
<td>9 Bare/Bright Soil</td>
<td>0.2133</td>
</tr>
<tr>
<td>10 Acacia Woodland</td>
<td>18.344</td>
</tr>
<tr>
<td>11 Commiphora</td>
<td>6.133</td>
</tr>
<tr>
<td>12 Bare/Annual Grasses</td>
<td>10.092</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
</tr>
</tbody>
</table>
Figure 23: An association of elephants with trees
Elephants shading from the scorching sun in Tsavo East N.P. at Mudanda rock under Acacia tortilis trees. Notice the broken branches of the trees indicating browsing.

Figure 24: A supplement water hole
Concentration of elephants is indicated by the degraded ground around the water hole that fades with distance from the water point. Other wildlife (red arrow) drink from these water sources too.
4.1.4 MODIS as a predictor of elephant distribution

Elephant densities for the three years showed the highest correlation to the fourth principal component (PC4 hereafter) out of the 15 components (Table 13). Further analyses to understand this relationship showed that PC4 was closely positively related to EVI values for the months of April and November (Table 14). These two months represent the wet season period in this area. Analyses based on seasons confirmed these results that PC4 is positively related with the wet season which means more green biomass as indicated by increased EVI values (Table 15).

Mean wet season EVI values were highest but both wet and mild dry season pixels registered greater fluctuations than dry season pixels (Table 16). These high fluctuations can be explained by the erratic nature of rain in the TCA. Elephant distribution showed a negative correlation with average EVI for all the seasons (Table 16). Correlations for wet seasons were higher than those of other seasons possibly an indication that areas with higher biomass e.g. hilly areas were less accessible to elephants and that elephant population were more spread. Elephants select most nutritious food available as opposed to most available food following seasonal changes in forage quality (Osborn, 2004). Loarie et al. (2009) note that well wooded areas and closed woodlands have highest EVIs but may not be used by elephants, a finding that corroborates their research.

Table 13: Correlations for principal components and kernel densities

<table>
<thead>
<tr>
<th></th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
<th>PC5</th>
<th>PC6</th>
<th>PC7</th>
<th>PC8</th>
</tr>
</thead>
<tbody>
<tr>
<td>KD99</td>
<td>-0.215**</td>
<td>-0.059</td>
<td>-0.059</td>
<td>-0.521**</td>
<td>0.093</td>
<td>-0.086</td>
<td>-0.098</td>
<td>0.217**</td>
</tr>
<tr>
<td>KD05</td>
<td>-0.173**</td>
<td>-0.026</td>
<td>-0.045</td>
<td>-0.471**</td>
<td>0.141**</td>
<td>-0.160**</td>
<td>-0.261**</td>
<td>0.153**</td>
</tr>
<tr>
<td>KD08</td>
<td>-0.181**</td>
<td>-0.210**</td>
<td>-0.037</td>
<td>-0.553**</td>
<td>0.319**</td>
<td>-0.018</td>
<td>-0.464**</td>
<td>0.339**</td>
</tr>
</tbody>
</table>

(* p <0.05; ** p < 0.01)

Only the first 8 of the 15 component relationships are shown. Information packed in components decreases with increased component number and so did the relationship.
Table 14: Monthly correlations for PC4

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>-0.235*</td>
<td>-0.202*</td>
<td>0.111</td>
<td>0.342*</td>
<td>0.276*</td>
<td>0.253*</td>
<td>0.203*</td>
<td>0.153*</td>
<td>0.135*</td>
<td>0.178*</td>
<td>0.378*</td>
<td>0.002</td>
</tr>
</tbody>
</table>

(* p <0.05; ** p < 0.01)

Table 15: Seasonal and PC4 correlations

<table>
<thead>
<tr>
<th>Variable/Year</th>
<th>Mean EVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Wet EVI</td>
<td>0.403**</td>
</tr>
<tr>
<td>Average Mild EVI</td>
<td>-0.160**</td>
</tr>
<tr>
<td>Average Dry EVI</td>
<td>0.039</td>
</tr>
</tbody>
</table>

(* p <0.05 and p > 0.01; ** p < 0.01)

Table 16: Correlations between average MODIS-EVI for different seasons and elephant densities

<table>
<thead>
<tr>
<th>Variable/Year</th>
<th>1999</th>
<th>2005</th>
<th>2008</th>
<th>Mean EVI</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Wet EVI</td>
<td>-0.472**</td>
<td>-0.378**</td>
<td>-0.332**</td>
<td>2439.90</td>
<td>496.94</td>
</tr>
<tr>
<td>Average Mild EVI</td>
<td>-0.216**</td>
<td>-0.104**</td>
<td>-0.048</td>
<td>2090.92</td>
<td>439.22</td>
</tr>
<tr>
<td>Average Dry EVI</td>
<td>-0.325**</td>
<td>-0.215**</td>
<td>-0.205**</td>
<td>1419.63</td>
<td>269.62</td>
</tr>
<tr>
<td>Average EVI</td>
<td>-0.406**</td>
<td>-0.300**</td>
<td>-0.254**</td>
<td>2095.12</td>
<td>410.99</td>
</tr>
</tbody>
</table>

(* p <0.05; ** p < 0.01)

4.1.5 Modeling the geographic distribution of *Loxodonta africana* in Tsavo

The logistic output model was chosen because it is easier to interpret as values are scaled to fit between 0 and 1 of probability of presence. During the execution of the model, 25% of the sample records were set aside for testing how well it performed. The omission on test samples were a very good match to the predicted omission rate, the omission rate for test data drawn from 25% sample. Test omission line lay below the
predicted omission line because the test and training data were derived from the same spatially autocorrelated presence data (Figure 25).

Test to the fit of the model through receiver operating characteristics (ROC) of sensitivity and specificity showed that the model useful (AUC>>0.5) in this case (Figure 26) (Baldwin, 2009). Sensitivity shows how correctly the data predicted presence of *Loxodonta africana* while specificity showed a quantitative measure of the correctly predicted absence (Baldwin, 2009) with AUC significantly greater than 0.5 for both.

![Figure 25: Omission and predicted area for *Loxodonta africana*](image)

**Figure 25: Omission and predicted area for *Loxodonta africana***
Figure 26: Sensitivity vs specificity for *Loxodonta africana*

The model was able to predict other suitable areas as habitat for elephants in the TCA based on the presence data derived from the aerial counts (Figure 30). The maps are probabilistic and warmer colors show areas with better predicted conditions for elephant use.

4.1.5.1 Examining the variable contributions to the model

Species distribution modeling requires identification of variables that matter most for the species being modeled. Maxent uses several ways and one of the most important outputs is a table showing the relative contribution each variable had to the model (Table 17). Water holes density emerged as the most important variable to predicting elephant distribution in the TCA. The TCA is a water deficient area characterized by high temperatures and therefore water determines elephant distribution significantly.
The jackknife approach is another method for assessing variable importance which works by excluding a variable each time the model is run (Baldwin, 2009). Jackknife gives variable performance in terms of importance in explaining the species distribution and amount of unique information each variable provides (Baldwin, 2009). Jackknife tests of variable importance results indicated that water density had the highest gain when used in isolation and therefore had the most useful information by itself (Figure 27-1). Water holes decreased the gain most when omitted indicating that it had the most information that was not present in other two variables. However, PC4 was predicted as the slightly more effective variable for predicting distribution (Figure, 26-3) a finding supported by the increase in importance of PC4 in the test gain plot (Figure 27-2). This implies that even though water holes helped in good fit to the training data (Figure, 27-1), PC4 generalizes better on the test data. PC4 is a component of EVI and it makes sense green biomass could be the most important determinant of elephant distribution in the TCA.

The third method of examining variable importance is two fold: (1) production of response curves of how each variable responded when all other variables were kept at their average sample value (Figure 28), and (2) Maxent model produced when only the corresponding variable were used (Figure 29). Both of these response curves show similar trend as there were no correlations between these variables and these results can therefore comfortably be interpreted as they appear here.

### Table 17: Heuristic estimate of relative variable contributions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percent contribution 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of water holes</td>
<td>47.1</td>
</tr>
<tr>
<td>PC4</td>
<td>33.5</td>
</tr>
<tr>
<td>Distance to towns</td>
<td>19.4</td>
</tr>
</tbody>
</table>
Figure 27: Jackknife test results for variable importance

Note: dtwn – distance to towns, kdwh – density of water holes, PC4 – fourth principal component. When dtwn was used alone it achieved almost no gain, so distance to towns is not by itself useful for estimating the distribution of Loxodonta africana. The lighter blue lines bars indicate the amount of useful information that is contained in other variables.
Figure 28: Marginal response curves

These represent logistic predictions as each variable is varied. The y-axis represents predicted probability of suitable conditions. There was an increased prediction of suitable conditions with increase in distance to towns and water density which tapers as certain thresholds were reached. There was a negative correlation between probability of presence and PC4. As EVI increased, less locations were found suitable.
Figure 29: Single variable response curves.

Note the similarity between figure 27 and this figure. Examining each variable in absence of the other variables does not seem to change the prediction of presence. This further verifies the fact that these variables are not correlated at all.
4.1.5.2 Predicted probabilistic geographic distribution map of *Loxodonta africana* in the TCA

The model was able to predict the geographic distribution of the *Loxodonta africana* in the TCA based on the three variables (Figure 30). The highest likelihood of finding an elephant in the TCA for this map was about 0.90 and occurred along and near rivers mostly. This underlines the important role water plays to determine elephant distribution in this area. The Chyulu hills, the southern tip of TWNP, and most of SKNR were identified as being unsuitable for elephant distribution. The Chyulu Hills were unfavorable due to the elevation that inhibits elephant habitation (Ngene *et al.*, 2009), and the two other regions are very arid and lack water and suitable food resources.

Maxent was also able to identify other suitable areas that did not have elephant occupancy during 2008 (Figure 30). However, Maxent was also able to classify areas with elephants as unsuitable distribution areas such as the southwestern part of Chyulu Hills (Figure 31).
Figure 30: predicted probabilistic *Loxodonta africana* habitat range in the TCA. Elephant geographical occurrence appeared concentrated on the central part of the TCA. Notice the unsuitable gap occurring near Galana River in TENP. This represents the area covered with Annual grasslands/barren land indicating its very low utility for elephants.
Figure 31: Reclassified probabilistic distribution map

Very low <0.1, Low 0.1=> and < 0.4, Medium =>0.4 and <0.6, and High =>0.6. High elephant presence were found mostly in TENP.
CHAPTER FIVE

5.1 Conclusions, limitations of study and recommendations

5.1.1 Conclusions

One of the main objectives of this research was to describe the spatial patterns of the elephants in the TCA. SDEs showed less than ellipsoidal elephant population concentrations indicating that not a single variable with geographical bias orientation could explain distribution of elephants in the TCA. Elephants in the TCA exhibit clustering and multi-distance spatial clustering occurred between 60 km to 100 km. Elephant concentrations at different parts of the TCA were much higher than the recommended density of 1.2 elephants per square kilometer (Ambruster et al., 1993).

The home range of the Tsavo elephants has little changed since 1970s when Leuthold & Sale (1973) computed the last known MCP of $340 \text{km}^2$ – $1580 \text{km}^2$ to $400 \text{km}^2$ – $1900 \text{km}^2$ calculated in this research. This is an indication that elephants’ movement and behavior was similar and that the TCA can still accommodate these movements.

Elephants in TCA tend to be generally associated with woody vegetation types than other vegetation types as grasslands. Bare ground with scattered trees is the single most important land cover type identified in the TCA with highest percent (about 40%) number of elephants. Acacia woodlands form a major food component of elephants and are green during dry seasons had about 20% of elephants in the three years this study covered. The low accuracy scores during accuracy assessment underscore the difficulties in separating land cover types e.g. *acacia* woodland and *commiphora* thickets. This not withstanding, one has to differentiate between accuracy and usefulness of the map made and realize that as details increase (i.e. no. of classes increases) accuracy decreases as similarity too increases and separating classes gets more complex. The map obtained from this research was useful in helping unravel the relationships between elephants and vegetation types since no previous map existed for this area.

Among the various biophysical and anthropogenic variables examined artificial water was identified as the most important indicator of elephant presence. These findings echo TCA manager’s belief that if water were provided Tsavo could probably
host higher elephant population. Lodges were good indicators of elephant presence while topography a biophysical factor did not seem to significantly affect elephant population distribution. The positive correlation between elephant density and density of poached elephants suggests that poaching is likely to occur in areas with higher population.

Seasonal elephant distribution variations indicated that wet season was more negatively correlated with elephant densities than both mid dry and dry seasons using MODIS-EVI high temporal resolution data. PC4 was identified as the most important component that had the highest correlation with elephant densities for all the years.

Maxent maximum entropy model was effective for modeling elephant geographical distribution. Maxent results were consistent with those of correlation analysis with PC4 and water being identified as the most important predictors of elephant distribution in the TCA respectively. Further, the probabilistic map was able to identify other areas suitable for elephant use and also point to areas with little or no use by elephants.

5.1.2 Limitations of study

A major limiting factor for this study was time and resources given the vastness of the area. A detailed study can be more successful if these two conditions are met. It was impossible to visit some areas and those that visited adequate time was not spent to gather enough data.

Water salinity and or salt licks are an important component impacting on elephant distribution (De Boer et al., 2000). This research did not examine this variable due to limited resources and future research should therefore endeavor to include this variable.

The land cover map made, which is the first to be made for this region should be enhanced by using multispectral images and employing use of images taken at different seasons of the year. This would capture vegetation types better than one time images used in this study.

Finally, it may be useful to carry out change detection in this ecosystem to assess the significance of habitat change to assess the dominance by bare soils with scattered trees.
5.1.3 Recommendations

With the realization that elephant distribution is clustered and that one of the most important determinants is water, efforts should be to distribute water evenly to those areas that the Maxent model was able to identify as potential habitat areas because of other factors such as food resources. This would reduce pressure around the few water sources and further avoid the radial degradation of the TCA consistent with other recommendations practiced in other countries in order to manage elephant over abundance (Chammaille-Jammes et al., 2007).

Poaching is likely to occur in areas where elephant population is high or in those areas that Maxent identified as potential habitats and therefore resources such as deployment of security forces should be managed in a way to include all the areas depending on this likely distribution map.

Human influence should be assessed with view to quantifying its impact on elephant habitat. For instance, the construction of water holes and provision of salts near them to attract wildlife by lodges should be reconsidered. Roads construction may take significant areas suitable for elephant habitation and therefore planning should be done before new ones are built.

Some of the elephant census should be conducted at different times of the year in order to better gauge utilization of the park across different seasons. This may provide more insights into elephant distribution in the TCA when water and food are no longer limiting factors.
REFERENCES


