

**THE IMPACT OF ELEPHANTS, *Loxodonta africana*, ON WOODY  
VEGETATION IN RELATION TO WATERING POINTS IN  
TSAVO EAST NATIONAL PARK, KENYA.**



**BY**

**JACOB NJARAMBA NGATIA (B.Sc.Biology. UoN)**

**REG. No: I56/76392/09**

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CONSERVATION**

**May, 2014**

## **DECLARATION PAGE**

**This thesis is my original work and has not been presented for a degree in any other university or for any other award.**

**Jacob Njaramba Ngatia**

**Signature.....Date.....**

**This thesis has been presented with our approval as university supervisors**

**Dr. John Githaiga**

**Signature.....Date.....**

**Dr. Robert Chira**

**Signature.....Date.....**

## **DEDICATION**

This thesis is dedicated to my loving parents,

**Anastasia Nyawira Ngatia & Late David Ngatia Kariuki**

Whose continuous encouragement, support and motivation have helped me in completing this thesis.

## **ACKNOWLEDGEMENT**

For the facilitation of my field work from the start to its completion, I am greatly indebted to the support from institutions, colleagues and friends. I would first thank the Kenya Wildlife Service for supporting, funding and granting me permission to conduct the study to its successful completion. Am indebted to my Supervisors Dr. John Githaiga, Dr. Robert Chira and Dr. Shadrack Ngene, for their continuous guidance, support, stimulation and reviewing my thesis chapters. The thesis would not have been completed without their support. I thank Kenneth Kimitei for his technical support by ensuring that I obtained the necessary shape-files for the area and assisting me in developing the necessary maps during the study. Special thanks go to my field assistants in the Tsavo East and Tsavo West research teams for their support in transport, sampling equipments, plant identification and moral support. I thank all my classmates, my siblings Deborah Ngatia, Mary Wambui, John Waigwa and Moses Ndirangu for their encouragements and motivation.

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## **LIST OF ABBREVIATIONS**

- AfESG** - The African Elephant Specialist Group
- ANOVA** - Analysis of Variance
- IEF** - International Elephant Foundation
- IUCN** - International Union for Conservation of Nature
- KWS** - Kenya Wildlife service
- TENP** - Tsavo East National Park

### **Computer Programmes Abbreviations**

- PAST** - Paleontological Statistics
- SPSS** - Statistical Package for Social Sciences

## ABSTRACT

Understanding the relationship between the watering points and elephant impacts on woody vegetation in relation to proximity to these watering points is important in conservation of the elephants particularly their habitat. The study investigated the impact of elephants on woody vegetation around the watering points in Tsavo East National Park, Kenya. It involved evaluating the distribution of elephants in relation to proximity to the watering points, identifying of the major routes utilized by the elephants while accessing the watering points, characterizing woody vegetation along transects from the watering points and evaluating the level of utilization of woody plants along the transects. The study was done between March, 2011 to August, 2011 a period that covered a distinct dry season and wet season. Eight watering points were sampled and plots along 7 km transects from each watering point sampled. The major elephant trails were tracked within a predetermined distance of 7 km from each watering points. A significant positive correlation was observed between the density of woody plants and the distance from the watering points ( $\rho = 0.41$ ,  $df = 108$ ,  $p < 0.01$ ). Woody plants decreased with nearness to the watering points. Dead stumps revealed significant ( $R = -0.27$ ,  $df = P < 0.05$ ) decrease with increased distance from the water points. Elephants (66.6 %) were found to prefer staying near drinking watering points and permanent river ( $\leq 1$  km) especially during the dry season. There was a significant decrease in elephant numbers with increased distance from the drinking water points in dry season ( $\rho = -0.41$ ,  $df = 62$ ,  $p < 0.001$ ) and non significant decrease in wet season ( $\rho = -0.19$ ,  $df = 62$ ,  $p > 0.05$ ). The concentration of elephants has resulted to the destruction of woody vegetation around watering points. Thus, in order to ensure conservation and restoration of woody plants, water points should be provided in strategic points within the park and maintenance of the existing watering points should be done in order to distribute elephants and avoid over utilization of some watering points.

# CHAPTER ONE: INTRODUCTION AND LITERATURE REVIEW

## 1.1. Introduction

The current population of the African elephant (*Loxodonta africana*) is estimated to be about 0.5 million individuals (Blanc *et al.*, 2007). East Africa accounts for about 90 thousand individuals with Kenya accounting for about 35 thousand individuals with the largest population occupying the Tsavo Ecosystem (Ngene, 2011). Although populations may at present be stable or increasing in some sub-regions (Eastern and Southern Africa respectively), the trend is unknown in other regions, and overall there remains insufficient information to show a current trend at the continental level. In some areas the population is being boosted by translocation and re-introduction to conservation areas that once hosted them or supplementing existing populations.

Many authors (Glover, 1963; Ayeni, 1975; Cumming, 1981) have commented on the heavy utilization of rangeland that occur around watering points during the dry season when there is no adequate water to entice large indigenous herbivores away from the trampled areas.

Other similar observations that show the aggregation of elephants near the watering points were found for elephants in Samburu (Thouless, 1995), Maputo elephant Reserve in Mozambique (Boer, *et al.*, 2000), the Kunene region in North West Namibia (Legget, 2006a), the Northern Namib Desert (Viljoen, 1989) and Northern Kenya (Leeuw *et al.*, 2001). Studies done by (Weir, 1972) demonstrated that elephants were being attracted by sodium content around the water holes.

Studies at Tsavo East National Park (TENP) have shown that the intensity of utilization of the artificial waterholes is highest during the dry season and lowest during the rains when wildlife disperse away from the dry season water supplies and utilize other natural water

bodies in the ecosystem (Ayieni, 1975; Western, 1975; Leuthold & Sale, 1973; Albricht, 1995). Utilization of artificial waterholes had resulted in the removal of woody vegetation from around the waterholes and along elephant major transit routes. The effect was more profound around Aruba dam, the largest and oldest artificial water point in the park, (Ayieni, 1975). During prolonged drought, elephants and other animals moved near the Galana river (Glover, 1963). The aggregation of the animals near the narrow riverine belts of Galana river leads to over utilization of the habitat and ultimately high animal mortality, (Ayieni, 1975).

This study aimed at evaluating elephants distribution in relation to distance from the watering points and mapping the major transit routes which they utilize while assessing the water points in relation to woody vegetation patches. It also intended to characterize woody vegetation along the gradient and evaluate the level of woody species utilization by the elephant within predetermined distance from watering points.

## **1.2. Literature Review**

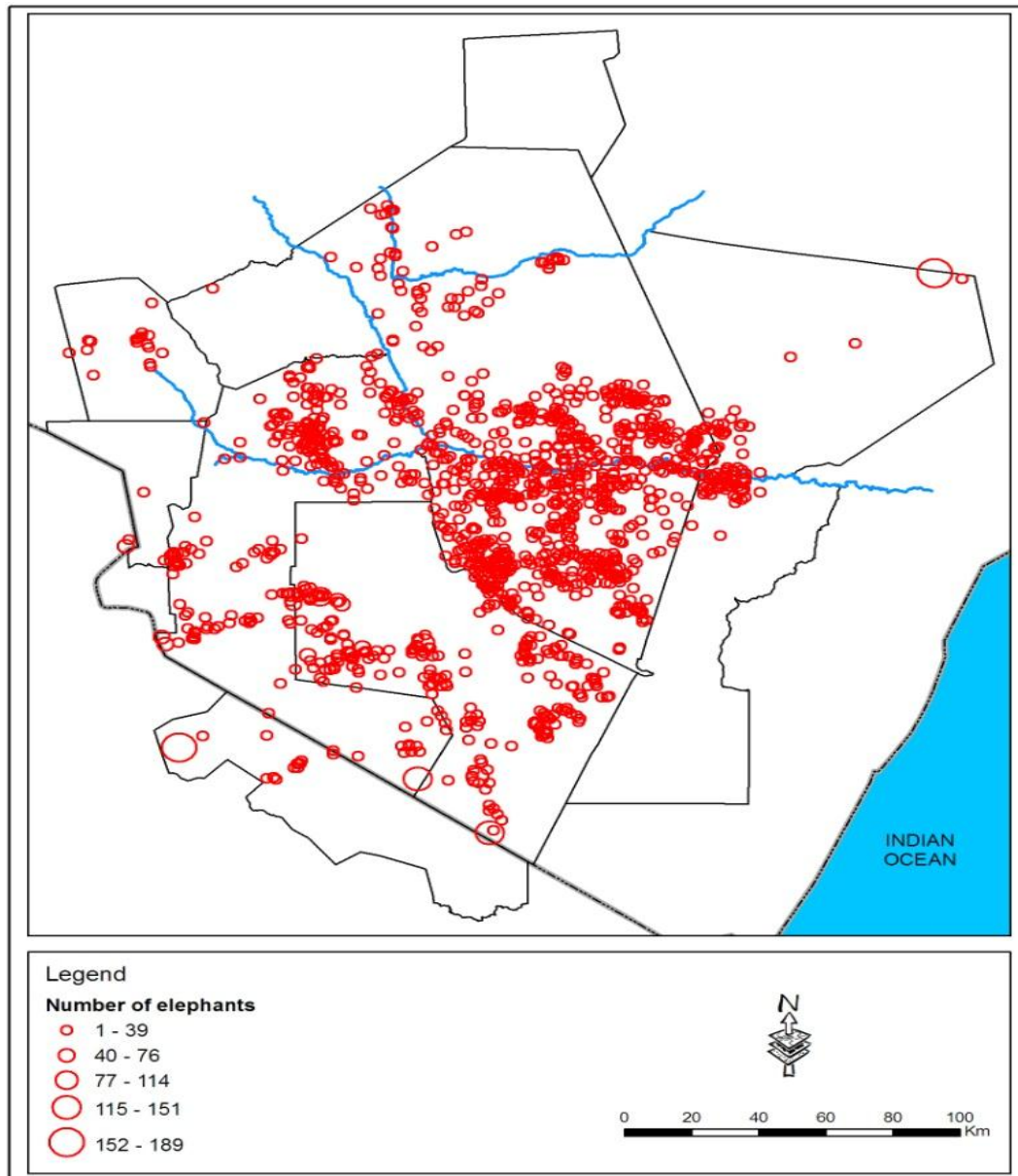
Recent preliminary population estimates suggest a decline in the total population of wild animals since the 1970's. Between 1970 and 1990 the African elephant showed a great decline of about 62% (Western, 1997; Otthichilo, 2000).

The African elephant (*Loxodonta africana*) named by Cuvier (1825) and the Asian elephant (*Elephas maximus*) are the only extant elephant species in the order Proboscidae from a formerly diverse evolutionary radiation. Both genera originated from the sub-Saharan Africa in the early Pleistocene (Sukumar, 2003; Krause, *et al.*, 2006). While *Loxodonta* remained in Africa, *Elephas* moved into Asia during the late Pleistocene (Maglio, 1973).

The currently recognized subspecies within the species of *Loxodonta africana* are *Loxodonta africana africana* or the savanna elephant (Spinage, 1994) and *Loxodonta africana cyclotis* or

African forest elephant (Spinage, 1994). A third sub species is suspected to live in the mosaics of forest and savanna but its taxonomy has not been determined (Blanc *et al.*, 2007; Spinage, 1994). These three categories of elephants interbreed in regions where their ranges overlap (Kingdon, 1997).

The International Union for Conservation of Nature (IUCN) recognizes *Loxodonta africana* as a single species (AfESG, 2009) and has declared the species vulnerable in the 2010 IUCN red listing or threatened species. The 2002 African Elephant Database (AED) report cited 402,067 (definite), 59,024 (probable), 99,813 (possible), and 99,307 (speculative) total numbers of different subspecies of elephants. This has decreased from a population estimate of 27 million elephants in the early 19<sup>th</sup> century. Elephants are widely distributed in East Africa and mostly in the Tsavo-Mkomazi ecosystem (Figure 1).



**Figure 1:** Map showing the distribution of different herds of elephants in Tsavo-Mkomazi Ecosystem (Kenya, 2011). (Source Ngene, 2011)

Elephant populations have been threatened over the years. Severe poaching due to increased demand for ivory, combined with habitat loss from human settlements have led to a dramatic decline in elephant populations in the last few decades. Traditional hunting groups started acquiring better techniques such as use of guns for hunting from the early foreigner traders and explorers, thereby transforming the early culture (Steinhart, 1989; Stone, 1972). Unlike in the early hunting culture where hunters used simple traditional weapons, mainly bows and poisoned arrows which did not cause serious threats to the existence of elephants (Steinhart,



1989), guns made it easier to kill the elephants and accelerated the decline of their populations (Adams, 2004).

Illegal hunting of elephant in Africa reduced their population from about 1.3 million in 1979 to fewer than 650,000 in 1991 (Douglas – Hamilton *et al.*, 1992). Hunting elephants for ivory eliminated them from Northern Africa by the 18<sup>th</sup> century, when the area was still grassland (Cumming, Toit, & Stuart, 1990; Douglas – Hamilton, 1992) and also from the Zambezi flood plains in Zambia (Van Gils, 1988).

Habitat loss and fragmentation are now considered serious threats to surviving elephant populations (MacArthur & Wilson, 1967). Increased insularity of protected areas, management failure and ineffective law enforcement are the main causes for major elephant problems on natural resources, their impact on woody vegetation in the protected areas and their surroundings (Blanc *et al.*., 2007).

Woodlands in natural areas of savanna Africa in general have declined due to expanding human populations in Africa leading to abnormal concentration of elephants in protected areas, as a result of expansion of cultivation and settlement (Anderson & Herlocker, 1973; (Guy, 1976; Dublin & Douglas - Hamilton, 1987). The increase in area used for settlements, logging, development of infrastructure and farming results in fragmentation of elephant habitats and reduction of the elephant range (Blanc *et al.*., 2007 ; Naughton-Treves & Weber, 2001), thereby interfering with their seasonal movements and confinement. Darling, (1960), Field (1971), Western (1989), Waithaka, (1994), Douglas-Hamilton *et al.* (2005) and Dolmia *et al.* (2007), showed that migration and elephant movements are important as they enable elephants to obtain resources such as water, mates, saltlicks, forage and shelter. Elephants also avoid disturbances from human due to hunting, farming and livestock grazing, through migration and seasonal movements.

Habitat fragmentation has a high potential of increasing the rate of species extinction (MacArthur & Wilson, 1967). From island biogeography theory, local extinction may also be caused by confinement of elephant in small and isolated areas which have an adverse effect on the ecology of those areas. Wildlife species are restricted into refuges in islands of habitats affecting their spatial distribution as well as decreasing their reproductive success (MacArthur & Wilson, 1967).

Studies have shown that fire and herbivory are major ecological factors determining the relationship between herbivores and woody plants in savanna ecosystems (Ben-Shahar, 1996; Barnes, 2001; Birkett, 2002). In particular, the African elephant has been known to cause considerable changes in vegetation structure and composition across their range (Western, 1990; Ben-Shahar, 1993; Kabigumila, 1993; Tchamba, 1995; Leuthold, 1996; Barnes, 2001). Elephants encourage succession in areas that have reached a peak and help control bush encroachment (Meik *et al.*, 2002). Studies have also shown that elephants have initiated the decline of woodlands but man-induced fire prevents regeneration (Holly, 1990).

Elephants browsing effects on both seedlings and mature trees prevent the regeneration of the woodlands. They remove dominant hardy vegetation, which is replaced by quick growing vegetation thereby transforming dense woodlands into open grasslands (Laws, 1970; Shannon *et al.*, 2006). An increase in elephant density often leads to a decline in woody vegetation, even local extinction of woody species (Lindsay, 1993).

African elephant browsing strategies involve bark stripping, breaking major branches and uprooting trees that varies in extent with the time spent in an area, creating a mosaic of altered habitats (Western, 1989). The rejuvenation of vegetation is hampered when elephants do not move between forage areas, leading to permanent, potentially degraded alterations in the landscape (Birkett & Stevens-Wood, 2005; De Beer *et al.*, 2006). The productivity and

composition of these plant communities are stable in the short run but may be resilient over long term (Pamo, 1998).

Elephants are important ecosystem engineers in that they create and maintain ecosystems through physically changing the habitat (Jones, Lawton, & Shachak, 1997). They also ingest plants and fruits, walk for miles, and excrete the seeds in fertile dung piles. In this way, new plant species can grow in different areas and can cross fertilize. Most tree species partly rely on elephant for propagation. They also dig holes to expose underground springs and this allows smaller animals to access water in drier times.

The African elephant browse on variety of food plants in different habitats. For instance, they feed on woody trees, such as acacia (*Acacia* spp.), marula (*Sclerocarya birrea Hochst*), mopane (*Colophospermum mopane*) and baobabs (*Adansonia digitata*) (Jachmann, 1989; Lewis, 1991).

At Mwea National reserve, studies showed that elephants prefer woody species such as *Acacia ataxacantha* and *Grewia bicolor* (Chira & Kinyamario, 2009). Other preferred species were *Grewia virosa*, *Grewia tembensis* and *Acacia brevispica*. On the other hand, elephants avoided the coppices of many other woody species notably *Combretum africana*, *Acacia tortilis*, *Acacia mellifera*, *Combretum aculeatum* among others (Chira & Kinyamario, 2009). The Marsabit elephant on high elevation on the other hand was found to consume *Bauhinia tomentosa*, *Phyllanthus sepialis*, *Grewia fallax*, *Acacia brevispica* and *Aspilia mossambicensis* (Ngene & Omondi, 2005; Githae *et al.*, 2007).

According to Field (1971) and Barnes (1982), elephants browse more during the dry seasons because the crude protein content of browse is higher than that of grass. Grass tends to rapidly become fibrous thereby reducing its palatability during the dry season (Field, 1971).

They prefer to stay near permanent water sources during the dry seasons because it is critical for their long term survival (Babaasa, 1994). Elephant damage is seasonal (Laws, Parker & Johnstone, 1975; Barnes, 1982) and during the rainy seasons elephants eat grasses and herbs while in dry seasons they browse and debark trees and bushes. They are known to be selective browsers and they show selective debarking especially during the dry season (Pamo & Tchamba, 2001; Holdo, 2003). When trees and shrubs are debarked by elephants, they become vulnerable to fires, especially during the dry season when most damage occur (Buss, 1961; Laws, 1970).

The concentration of elephants near surface water contributes to a gradient of intensifying impacts on vegetation, termed as piosphere, with the sacrifice zone in close proximity to the water source (Andrew, 1988). This region shows increase in soil nutrients, dung deposition, and trampling, decreases in trees and palatable perennial herbs, and increases in annual and unpalatable herbs and the amount of bare ground, soil compaction, and increased erosion (Belsky, 1995; Thrash, 1998; James *et al.*, 1999). Piospheres may become especially intense around point sources of water such as those provided by boreholes, feeding troughs or artificial pools (Ben-Shahar, 1993; Conybeare, 1991; Owen-Smith, 1996). Conversely, according to Van Wyk & Fairall (1969) and Graetz and Ludwig (1978), areas at distances exceeding 5 km that are normally travelled by herbivores from watering points experience the lowest utilization pressure. Perkins & Thomas, 1993b found an exponential increase in available grazing with increasing distance from watering points.

Tsavo East National Park (TENP) ecosystem is the largest park in Kenya and is home to several families of elephants. Recent aerial counts of elephants conducted, showed that it supports up to 12,000 elephants (Ngene, 2011). It is a relatively flat semi arid ecosystem with varied rainfall distribution patterns. Therefore, water is a great challenge especially during the

period of prolonged drought (Ayieni, 1975). However, it has artificial watering points that provide water reserves for the animals for the greater part of the year and hence making the area more accessible to the wild animals and also stabilizing the ecosystem. Artificial watering points were also constructed to attract wildlife around them and away from the Galana river, the only permanent natural water supply in the park during the dry season (Ayieni, 1975). The natural resources of surface water in TENP include permanent rivers, intermittent rivers, small springs and water holes.

Artificial water supplies in TENP include dams, ponds and artificially enlarged waterholes and boreholes. Dams were built along intermittent rivers. The most important one is Aruba dam which initially covered 85 hectares. The dam is located on the northern side of Voi river and was built in 1952 by the park authorities to provide wildlife with water during dry seasons. However, it has silted over time and does not hold water for a long time. Hence, it is unable to serve wildlife for a long time. Other artificial watering points are waterholes at Voi Safari lodge, Mukwaju bore hole (built in 1966), Ndara borehole (built in 1966) and eleven reservoirs, one at Maungu (built in 1962); two in 1971, and eight (built in 1972) . Pipelines that run parallel to the railway to Mombasa also pass through the park. The pressure break tanks exist in the pipeline and in every dry season the spill- over is visited by wild animals.

These watering points are however in a deteriorating state since they have silted over time and some dry up during the dry season. Only a few remain with water. The only permanent river at TENP is the Galana. Most of the rivers like river Voi are intermittent rivers and may carry water in the sandy riverbed throughout the dry season. This ground water is reached by digging shallow holes in the sand beds as is practiced by both man and animals. Small springs are found at the base of Yatta plateau; the larger hills and mountains, in the dissected plains and uplands. They have low flow of water that become saline during the dry season

and can only satisfy a small number of animals. Numerous natural depressions in the landscape that are filled with water during the rainy season through run-off also are common in TENP. They contain water for varying lengths of time into the dry season. Finally, waterholes of varying depth and size are found on concave bare rocks. They contain water throughout the dry season if not highly utilized. These types of waterholes were already known to the early explorers of the area (Krapf, 1964). Examples include waterholes found at Maungu and Taru hills.

### **1.3. Justification**

Understanding the interaction between large herbivores and their habitats is important in ecosystem conservation. Previous studies have shown that large herbivores show differential use of habitat types to the distribution of food resources, their abundance and permanence throughout the year, and/or proximity of water sources (Merz, 1986; Tchamba & Seme, 1993).

TENP is a critical ecosystem for the survival of many wildlife populations. However, the prolonged dry seasons periodically experienced in this area are a major concern for long-term viability of this important ecosystem. Water becomes a major challenge during periods of prolonged drought (Ayieni, 1975).

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 & Sheldrick, 1964). While the population of elephants in the Tsavo East Ecosystem has been increasing recently, little is known about their habitat preferences and spatial distribution in relation to watering points within the Tsavo East Ecosystem. There is lack of scientific information on the impacts elephants have on woody vegetation around the watering points. The study was motivated by the need to establish the impacts of elephants on woody vegetation along

transects from selected watering points in TENP. There was also a call for understanding the type and extent of damage to the woody vegetation that can be tolerated and its influence on the well being of other herbivores. The findings can be used to answer the question whether elephants can be conserved in TENP ecosystem sustainably and also predict the spectrum of changes that may occur in future in terms of woody vegetation survival. The information is fundamental in advising park management and developing long term conservation strategies of the elephants where the woody species can further be used as indicator category to initiate necessary management of elephants.

#### **1.4. Objectives and Hypothesis**

The main objective was to evaluate the distribution of elephants in relation to proximity to watering points and their influence on woody vegetation.

The specific objectives were to:

1. Identify and map the major routes utilized by the elephants while accessing water points in relation to woody vegetation patches;
2. Characterize woody vegetation and evaluate the level of woody species utilization by the elephant within predetermined distance from watering points;
3. Evaluate the elephants distribution in relation to watering points.

#### **Hypothesis**

The study proposes that by the use of distinct route to watering points, elephants have no serious impact on woody vegetation.

## **CHAPTER TWO: STUDY AREA, MATERIALS AND METHODS**

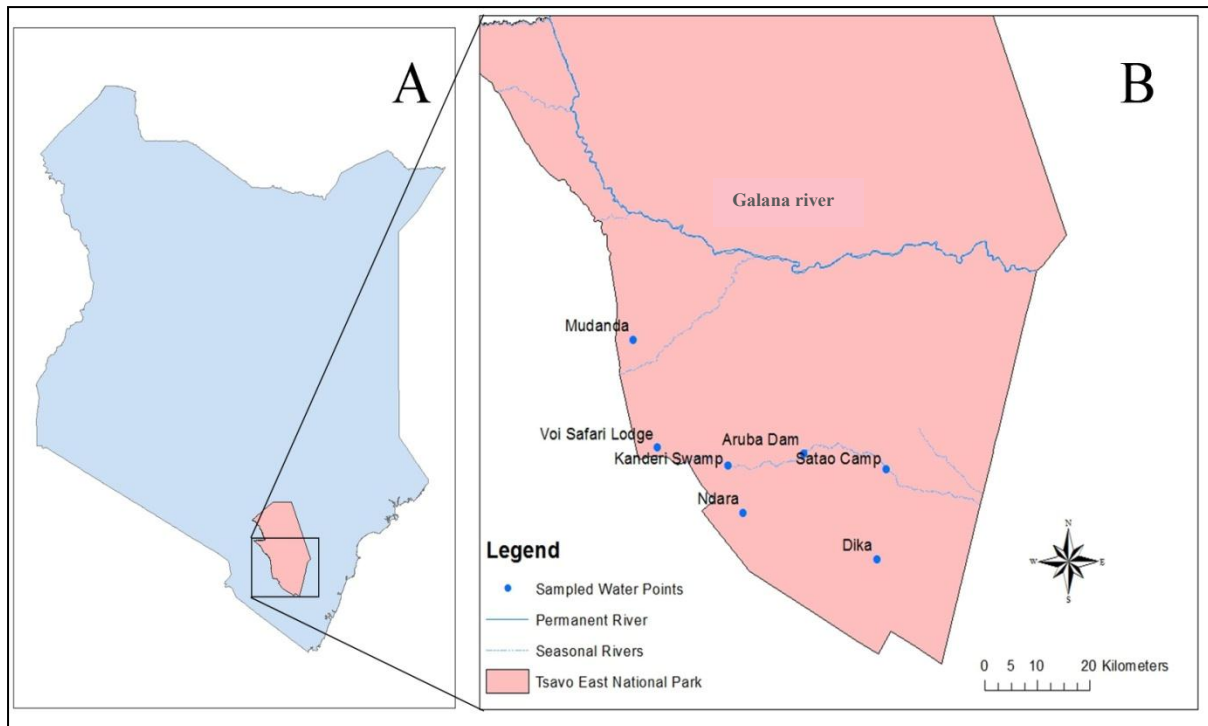
### **2.1. Location of Tsavo East National Park**

TENP is situated in south eastern Kenya in Coast province ( $2^{\circ}46'43''\text{S}$   $38^{\circ}46'18''\text{E}$ ). It is the largest National Park in Kenya (Figure 2). It lies opposite to Tsavo West National Park, also borders other important ecosystems like Chyulu game reserve, South Kitui National reserve and Mkomazi Game Reserve in Tanzania (Ayieni,1975) . It is a vast ( $11,747 \text{ km}^2$ ), flat and semi-arid area with an altitude varying from 150 m - 1,200 m (492 - 3,937 ft.).

### **2.2. Topography**

The topography of the area is dominated by extensive gently undulating plains, only interrupted by hills with their associated foot slopes in the South-west and West. In the North-west and South – east the plains are bordered by undulating uplands. Special features are the Yatta plateau which rises about 1,200 m above the sea level. The plains are developed on various kinds of parental material. The soils are deep, well drained and very acid, near major rivers. Where the landscape has been rejuvenated, the soils are shallow, stoney and fairly rich (Ayieni, 1975).

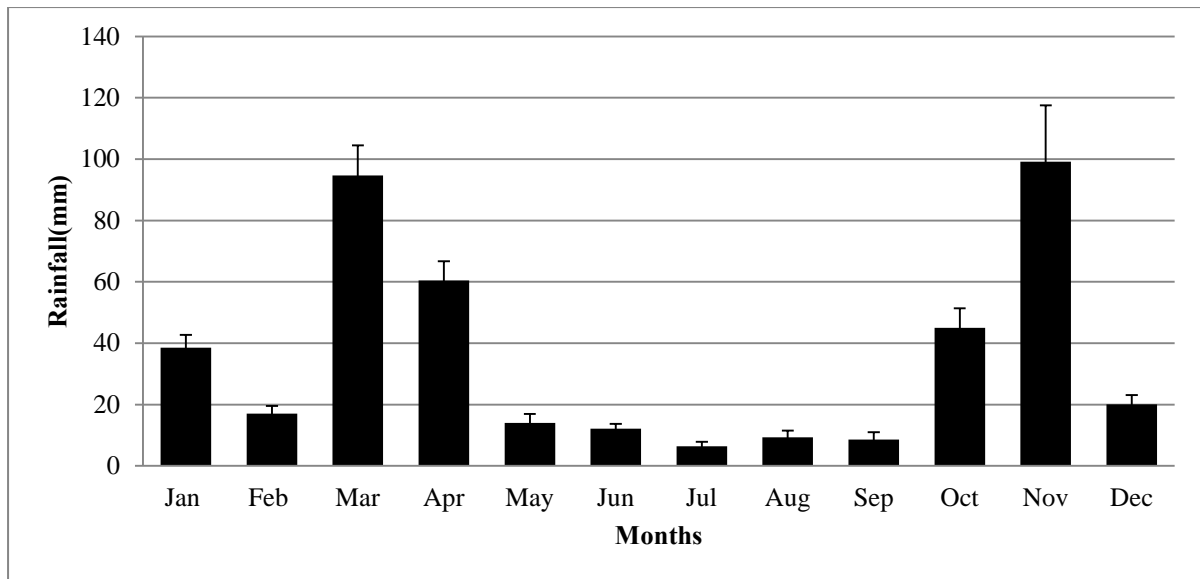




**Figure 2:** Location of TENP in Kenya (A) and studied watering points (B).

### 2.3. Rainfall

Rainfall distribution in TENP is bimodal and is not well distributed over the year. Average annual rainfall ranges from less than 300 mm in the interior of TENP to 900 mm in the extreme south east and 700 mm in the North-West. More than half of the area lies within Agro- ecological zone VI, one third within zone V and one tenth within zone IV. The long rains (March) are important and relatively reliable in the South - eastern part. Short rains (November) are more important in the North-west (Figure 3). The probability that rainfall is less than two - thirds of the potential evaporation in the rainy season varies from 80 to over 90 % in the major part of the area. In the South- East and North-West probability are in the range of 60 to 80%. Temperatures are fairly constant all year round ranging from 27 - 31<sup>0</sup>C in the day time and 20 - 22<sup>0</sup>C at night



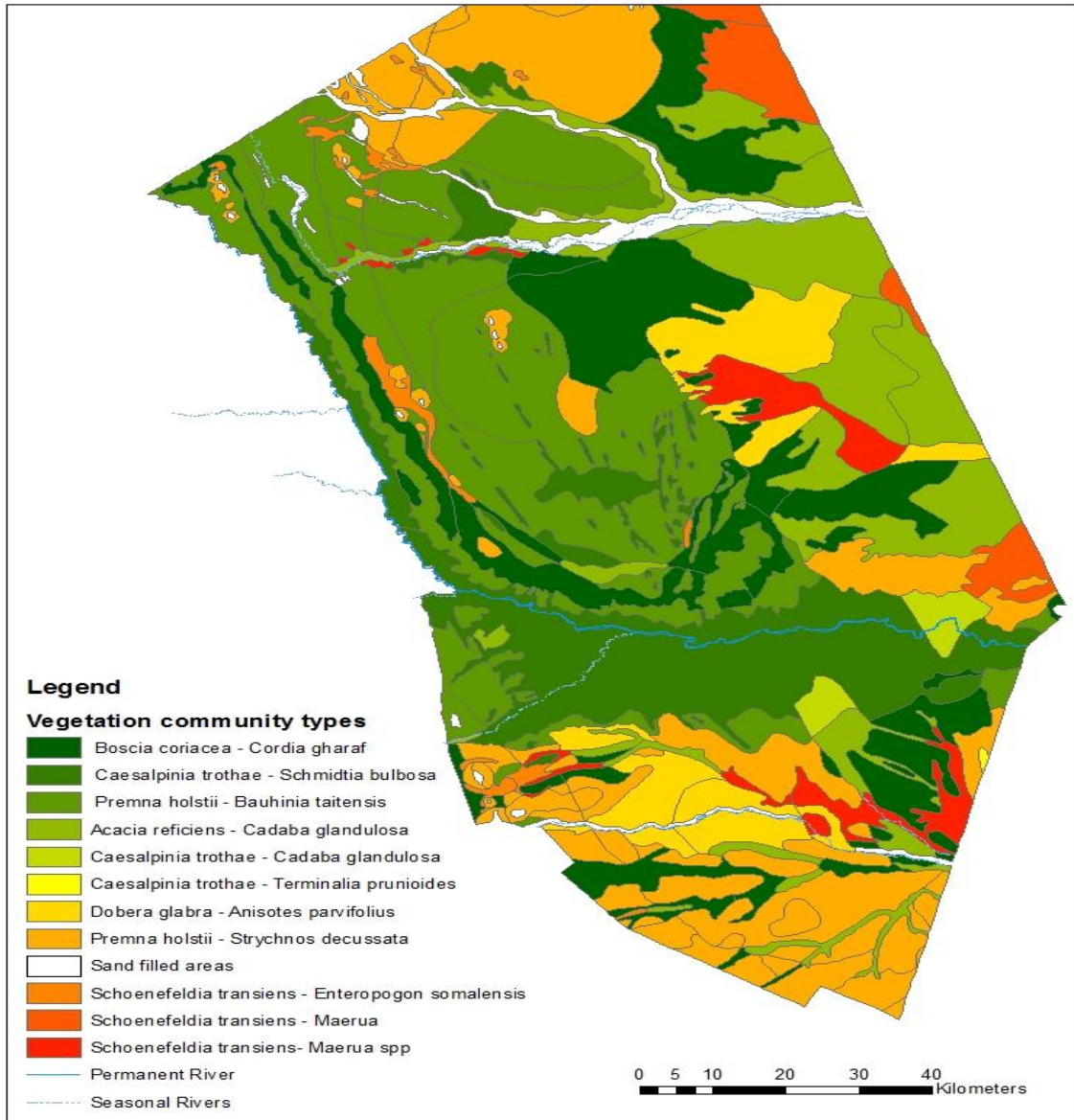
**Figure 3:** Mean ( $\pm$  SE) Monthly Rainfall of TENC. Rainfall data collected between 2008 - 2010 (Source: TENC Research Station, 2011).

#### 2.4. Flora

The vegetation of the area is strongly correlated with soils and climatic conditions. The floristic composition reflects the physical environment. Majority of the vegetation types belong to communities dominated by *Commiphora spp* and *Acacia spp*. Three major groupings have been distinguished namely *Commiphora - Lannea* group (Figure 4), mainly in well drained soils. The structure is wooded grassland. The second is *Commiphora - Acacia* (Figure 4) group, on well drained to imperfectly drained soils. It has more open structure (Bushland). The third is the *Acacia - Schoenefeldia* (Figure 4) group on poorly drained soils. The structure is open bushed grassland or bushland. Dense riverine forest (*Acacia elatior* and Doum Palm *Hyphaene compressa*) and dry shrub (*Suaeda monoica*) cover borders the permanent river Galana (Bax & Sheldrick, 1963).

In the wetter North – Western and South - Eastern areas the *Combretum - zeyheri* and *Diospyros - manilkara* groups are found respectively. Grass cover in all the three groups varies enormously due to differences in climate, structure and land use (Sheldrick, 1963). The

main grass species in the area include *Brachiaria deflexa*, *Tetrapogon tenellus*, *Panicum maximum*, *Aristida adscensionis*, *Chloris roxburgiana* and *Sporobolus helvolus*.



**Figure 4:** Distribution of woody vegetation types in TENP.

## 2.5. Fauna

The fauna in the region include the African buffalo (*Syncerus caffer*), African elephants (*Loxodonta africana*), leopards (*Panthera pardus*), lion (*Panthera leo*), black rhino (*Diceros bicornis*), burchells zebra (*Equus burchelii*), hippopotamus (*Hippopotomus amphibious*),

waterbuck (*Kobus elipsiprimnus*), reticulated giraffe (*Giraffa camelopardilis reticulata*), Grants gazelles (*Gazella grantii*), gerenuk (*Litocranius walleri*), lesser kudu (*Tragelaphus imberbis*), impala (*Aepyceros melampus*), warthog (*Phanocochoerus aethiopicus*), dik-dik (*Madoqua kirkii*), Hunter's Hartebeest (*Beatragus hunteri*), Eland (*Taurotragus oryx*), Fringe-eared Oryx (*Oryx beisa callotis*) among others (Ayieni, 1975).

The avian fauna consists of approximately 500 bird species that have been recorded in the area, they include the ostrich (*Struthio camelus*), migratory kestrels (*Falco naumanni*), sacred ibis (*Threskiornis aethiopicus*), black kite (*Milvus migrans*), crowned crane (*Balearica regulorum*) and lovebirds (*Agapornis spp*) (Ayieni, 1975).

## **2.6. Materials and Methods**

### **2.6.1. Sample site selection**

A grid map was used to determine sampling sites (watering points). Watering points were identified based on their nature and location in the park. An assessment of water source for the identified watering points was also carried out. The watering points were categorized into natural watering points and artificial watering points. A total of eight watering points (four artificial and four natural) were selected for random sampling. The artificial watering points were Aruba dam, Voi safari lodge, Satao waterhole and Ndara water hole. The natural watering points were Mudanda water hole Dika plains water pan, Kanderi swamp and Galana river. Aruba dam and the windmill at the Aruba were treated as a single water point. Sampling was done in wet season (March, April and May) and dry season (June, July, August).

### 2.6.2. Selected control sites

Out of the eight watering points sampled, three watering points ; Aruba dam, Voi safari lodge watering point and Satao watering point had woody vegetation patches at Aruba Lodge, Park headquarters and Satao camp respectively. Elephants had little or no access to the woody vegetation in these areas. These patches were therefore selected as independent sites and used as control / reference sites where one control was set in each of the three watering points. Aruba Lodge which is surrounded by an electric fence has structures such as lodges and a hotel. The lodge is approximately 100 m from Aruba dam. Human activities and the presence of the fence have made the area inaccessible to the elephants. The Voi safari lodge control site was 70 m from the education building and 50 meters from the electric fence. This area was not accessible to elephants hence the vegetation showed no signs of destruction. At Satao campsite there was very little impact by the elephants owing to the presence of the camps and other human activities. The vegetation patches were therefore used as control sites. Sampling was done twice at each site.

In the three control sites, quadrats measuring 20 x 50 m for large trees were selected for random sampling. The orientation of the quadrats was based on nature of the topographic features of the area. Each of the selected quadrat was assigned numbers. The numbers were also written on pieces of paper, folded and put into a basket from where one of the numbers was picked to represent the sampling plots. Nested sampling was done; 20 m x 20 m plots were established at the centre of the selected 20 m x 50 m plots while 1 m x 1 m plots were established at the center of 20 m x 20 m plots. The quadrats were sampled in both wet (March, April, May) and dry (June, July, August) seasons, where all the woody plants were counted. Each individual woody plant was identified and its basal diameter, height and canopy diameter were determined (Barbour *et al.*, 1987). The basal and canopy diameter were estimated by use of a measuring tape and the height estimated by use of a range finder.

Woody plants occurring along plot margins were included if at least half of the rooted system was inside the plot (Walker, 1976). For multi-stemmed plants located at edges of plots, only stems with more than half their base inside the plot were measured and recorded. The Quadrat data were collected between March 2011 and August 2011 as outlined by Barbour *et al.*, 1987.

The length and width of the quadrat were multiplied to give the area. Individual woody plant was enumerated in each quadrat. The data was analyzed for density, relative dominance and diversity. Density was determined by the number of woody plants recorded within each quadrat (Barbour *et al.*, 1987). The diversity index was determined by use of Shannon-Wiener equation (Cox, 1990).

### **2.6.3. Identification and mapping of elephant tracks leading to watering points**

Eight watering points were sampled. A total of eighteen tracks converging at the water points were identified and tracked in the GPS receiver. In each watering point, two elephant tracks were sampled however at the Aruba dam four tracks were sampled due to the high number of tracks found in the area.

Large tracks covered with dung piles around the water points and visual observations of elephant movements to water points was used as indicator of elephant routes to the watering points. Identification of highly utilized tracks was based on the presence of trampling on the tracks and accumulation of fresh dung piles rather than direct observation of elephants utilizing them. Frequency of tracks use was estimated from the appearance of dung (fresh or old) and damaged vegetation (broken branches) on elephant tracks. Way points for the watering points encountered along the tracks were also entered in a GPS.

#### **2.6.4. Woody vegetation distribution around watering points**

At each selected watering point, 7 km long baseline transect was traversed. Direction of each baseline transect from the watering point was determined through a randomization procedure, random numbers were generated using a random number table. Only whole random numbers between 0 – 360 were used as angles that indicated the direction of the baseline transect from the true North (Brits *et al.*, 2002).

The number of transects to be sampled in each watering point was determined by the distance of transect from each watering point. Since each transect was 7 km from the watering point, two transects were randomly placed at each watering point. The first quadrat (20 m x 50 m) was selected randomly at 1 km distance along the baseline transect by assigning numbers to either side of transect and tossing a coin which also had been assigned a number on the either side. One of the sides was picked to represent the first quadrat while the subsequent quadrats were systematically placed at 1 km intervals on the opposite side of the previous quadrat. In each quadrat woody plants were categorized into trees and shrubs. The division was based on the size and shape of the plant. A tree was defined as a woody plant greater than 3 m in height with a single stem which started branching at a minimum height of about 2 m (Anderson & Walker, 1974). This provided a basis of selecting the size of the plots. Quadrats measuring 20 m x 50 m were used to sample trees while 20 m x 20 m plots were used to sample shrubs. 1 m x 1 m plots were used to estimate grass and herbaceous cover which was important in sampling the dry and wet season.

Nested sampling was done; 20 m x 20 m plots were established at the centre of the 20 m x 50 m plots while 1 m x 1 m plots were placed at the center of 20 m x 20 m plots. The plots were delineated using tape measure.

In each quadrat, vegetation data collection procedure was as outlined by Gandiwa & Kativu (2009). Woody plants occurring along plot margins were included if at least half of the rooted system was inside the plot (Walker, 1976). For multi-stemmed plants located at edges of plots, only stems with more than half their base inside the plot were measured and recorded. Height, percentage cover, diameter at breast height and crown diameter were recorded for each tree but only height and percentage cover were also recorded for shrubs. Dead stumps were also identified and recorded. The data used to calculate density estimates which were expressed in terms of hectares. Density was determined by the number of plants per unit area of a quadrat. Relative density is the density of one species as a percent of total plant density. The densities per hectare and dominance in the area sampled were obtained through the following equations (Barbour *et al.*, 1987):

$$\text{Density for species } i = \frac{\text{Number of individual of species}}{\text{Total area sampled}} \dots \dots \dots \text{Equation 1}$$

$$\text{Relative Density} = \frac{\text{Density for species } i}{\text{Total Density for all species}} * 100 \dots \dots \dots \text{Equation 2}$$

$$\text{Dominance} = \frac{\text{Total basal area/coverage for species } i}{\text{Total Density for all species}} \dots \dots \dots \text{Equation 3}$$

$$\text{Relative dominance} = \frac{\text{Dominance for species } i}{\text{Total Dominance for all species}} * 100 \dots \dots \dots \text{Equation 4}$$

The diversity index was determined by use of Shannon- Wiener equation (Cox, 1990). This was calculated using **PAST** (Paleontological Statistics) program version 1.97 in the following equation.



### Shannon – Wiener diversity index

$$H = - \sum P_i \log P_i \dots \dots \dots \text{Equation 5}$$

Where:  $H'$  = diversity,  $P_i = n_i / N$  and  $n_i$  is the number of individuals of a species and  $N$  is the total number of individuals of all species.

#### 2.6.5. Utilization and preference of woody plants around the watering point.

Two transects (7.0 km) were randomly selected in each watering point for sampling. A total of sixteen transects in eight watering points were sampled. Random number table was used to generate random numbers between 0 - 360 which were used as angles that indicated the direction of the baseline transect from the true North (Brits *et al.*, 2002). Plots measuring 20 m x 50 m were systematically placed at 1 km interval as follows; 1.0, 2.0, 3.0, 4.0, 5.0, 6.0 and at 7.0 km along each baseline transect from each water point. The data was collected monthly between March - 2011 and August - 2011. All individual woody plants encountered in each plot were enumerated. Dead woody plants were also included and identified when possible. Information on vegetation utilization by elephants was categorized into six classes (Tchamba, 1995).

- i) Not browsed or slightly browsed;
- ii) A quarter of the woody plant browsed;
- iii) Half of the woody plant browsed;
- iv) Three quarter of the woody plant browsed;
- v) All woody plant browsed and
- vi) Woody plant uprooted.

Woody plants in categories (ii) and (iii) were considered “browsed”, and woody plants in categories (iv) to (vi) were considered “extensively browsed”. Other forms of elephant

utilization recorded, apart from the six classes, were broken branches, broken stem, pushed, debarked and trampled woody plants encountered within the plots.

A semi objective method (Tchamba, 1995) was used to determine and distinguish between preferred woody species from those not preferred in relation to elephant utilization. A preferred food plant was defined as a plant species that was utilized proportionately more frequently by elephants than its abundance in the immediate environment (Petrides, 1975; Viljoen, 1989). A preference ratio was calculated for each species where the percentage of plant species utilized was divided by the percentage availability of that species in terms of abundance.

Elephants tree browsing was determined by estimating the percentage of foliage removed from a given tree species, this was adopted from Anderson and Walker (1974) in elephant browsing preferred plant species. Percentage utilization of woody plants was calculated using the following equation (Petrides, 1975; Ishwaran, 1983; Viljoen, 1989).

$$\% \text{ Utilization (U)} = \frac{\text{Number of fully Utilized woody plants of a given species per unit area}}{\text{Total number of utilized woody plants of all species within same area}} \times 100 \dots\dots\dots \text{Equation 6}$$

$$\% \text{ Availability (A)} = \frac{\text{Number of woody plants of a given species per unit area}}{\text{Total number of woody plants of all species per unit area}} \times 100 \dots\dots\dots \text{Equation 7}$$

$$\text{Preference Ratio} = U / A \dots\dots\dots \text{Equation 8}$$

Elephant utilization of a plant species which had occurred in the previous season was distinguished from the previous damage on the woody plants over two seasons. The previous damage was notable since it becomes characteristically grayish in color after rain soaks in the

exposed inner plant parts (Ben-shahar, 1996; Chira, 2005). To avoid introducing bias in favor of slightly utilized plant species, their partial utilization was converted to fully utilized plants. This was achieved by incorporating weighting factors in the calculation of preference ratios (Barnes, 1976; Viljoen, 1989; Chira, 2005). The number partially utilized plants were converted to the number of fully utilized plants using the weighting factors, where 100% of the canopy of a species was considered removed. The number of quarter - browsed plants (25% of the canopy removed) was divided by four to convert it to number fully utilized plants with 100% canopy removed. The corresponding weighting coefficients for converting various utilization categories were 0.25 for quarter – browsed, 0.50 for half - browsed, 0.75 for three-quarter browsed and 1.0 for all browsed. Preference ratios were tested for linearity and correlation with total density of woody species and relative percentage, abundance of available woody species.

## **2.6.6. Distribution of elephants with distance from watering points**

### **2.6.6.1. Direct counts**

An elephant population count along transects from the watering points was carried out between (March 2011 and August 2011). Road counts along a 7 km transect were conducted from a vehicle. The observer scanned up to a distance of 500 m on either side of baseline transect in open woodlands and 200 m in dense woodlands using a binoculars. The number, sex, age of elephants and their habitats were recorded. This was repeated four times for each watering point in each season. Correlation analysis tested for relationship between elephant locations and distance from the watering points. Significance differences in distribution of elephants in relation to the watering points between wet (March, April, May) and dry (June, July, August) seasons was tested using chi-square test.

### 2.6.6.2. Indirect elephant count

In watering points where elephants were not sighted during the wet season and dry season; the method of dung - pile enumeration was adopted from Barnes (1982) and Barnes and Jensen (1987) and was used for indirect elephant counts as a circumstantial evidence of their presence. This was also done in all watering points for comparison. Such surveys provided estimates of abundance that are comparable with those that count elephants directly (Barnes, 2001) and as precise as estimates derived from aerial surveys (Barnes, 2002).

Sixteen transects measuring 7 km long were established in eight watering points. When a fresh dropping was seen, the following data was recorded (Barnes, 1982).

- a) Distance covered along transect measured by a GPS.
- b) The perpendicular distance  $X_1$  of the dropping from the transect centre line.
- c) Stage of decomposition of the dung pile (classified from stages A to B of decomposition as in Barnes (1982); Barnes and Jensen (1987))
- d) Notes on vegetation type and other features, for instance dry river beds.

Barnes (1982); Barnes and Jensen (1987) method of grading dung-pile by its state of decomposition was adopted as follows;

**Stage A:** Boli intact, very fresh, moist with odor,

**Stage B:** Boli intact, fresh but dry, no odor.

Selection of dung pile for sampling was defined as in stages A and B above. Density of the dung was later calculated to show the distribution along transect from the water point. The data on dung density were further analyzed using non - parametric tests to evaluate differences in usage of the trails in dry and wet season. All dung density values were correlated with corresponding distance values during the analysis to show elephant distribution as a function of distance from the watering point.

### 2.6.7. Data Analysis

Data were entered into the computer using Excel and all statistical analysis were performed using SPSS (SPSS.PASW.Statistics.v18.Multilingual-EQUiNOX), STATISTICA for Windows (Version 6, Statsoft , 2001) and PAST data analysis programs. The data for elephant tracks leading to watering points collected using dung counts along the tracks were entered into SPSS and Mann - Whitney U - test was performed to test for differences in average fresh dung pile per track in wet and dry seasons. ANOVA tests were used to evaluate differences in fresh dung piles sampled in all tracks during wet and dry season. Mapping of the tracks was done using arc view GIS computer program. The program collated field observations and data with map to illustrate elephant tracks leading to watering points. Shannon - Wiener diversity index for various watering points was generated using PAST program and ANOVA was used to test for differences in woody species diversities among watering points. This was done for data on plants. The density of the trees and shrubs were analyzed to determine relationship with distance from the water points using Spearman's rank correlation ( $\rho$ ) analyses. Before the correlation analysis was undertaken, the datasets were visually inspected and tested for normality using the Kolmogorv – Smirnov method (Fowler *et al.*, 1998). The normality was assumed if  $p > 0.05$ . Spearman's ( $\rho$ ) correlation coefficient was used since most of the woody plants density did not follow a normal distribution. ANOVA test was used to test the variation in woody plants densities with seasonality. Tukey - B post range tested for differences in overall density of woody plants, percentage availability, percentage utilization and preference ratio among sampled watering points. Correlation analysis tested significant differences between overall density and preference ratio and between preference ratio and percentage availability. Chi - square test was performed to test differences in the number of dead stumps between wet season and dry season. Pearson product - moment correlation analysis was used to test whether proximity to water points had an effect on the spatial

distribution of elephants. Variation in distribution of elephants with seasonality was tested using one way - ANOVA tests. The strength of the correlations was interpreted using guidelines described by Fowler et al., 1998. The results were considered not significant when the value of the probability of significance (P) was greater than 0.05.

## CHAPTER THREE: RESULTS

### 3.1. Elephant tracks leading to watering points

During study, eighteen elephant tracks with an average distance of 7 km each per track were sampled. Elephants were found to utilize tracks while accessing the watering points. It was found that other herbivores like the Zebras, giraffes and buffaloes also utilized the tracks near the watering points ( $\leq 3$  km). The presence of their footprints and dung along the tracks showed circumstantial evidence of their utilization.

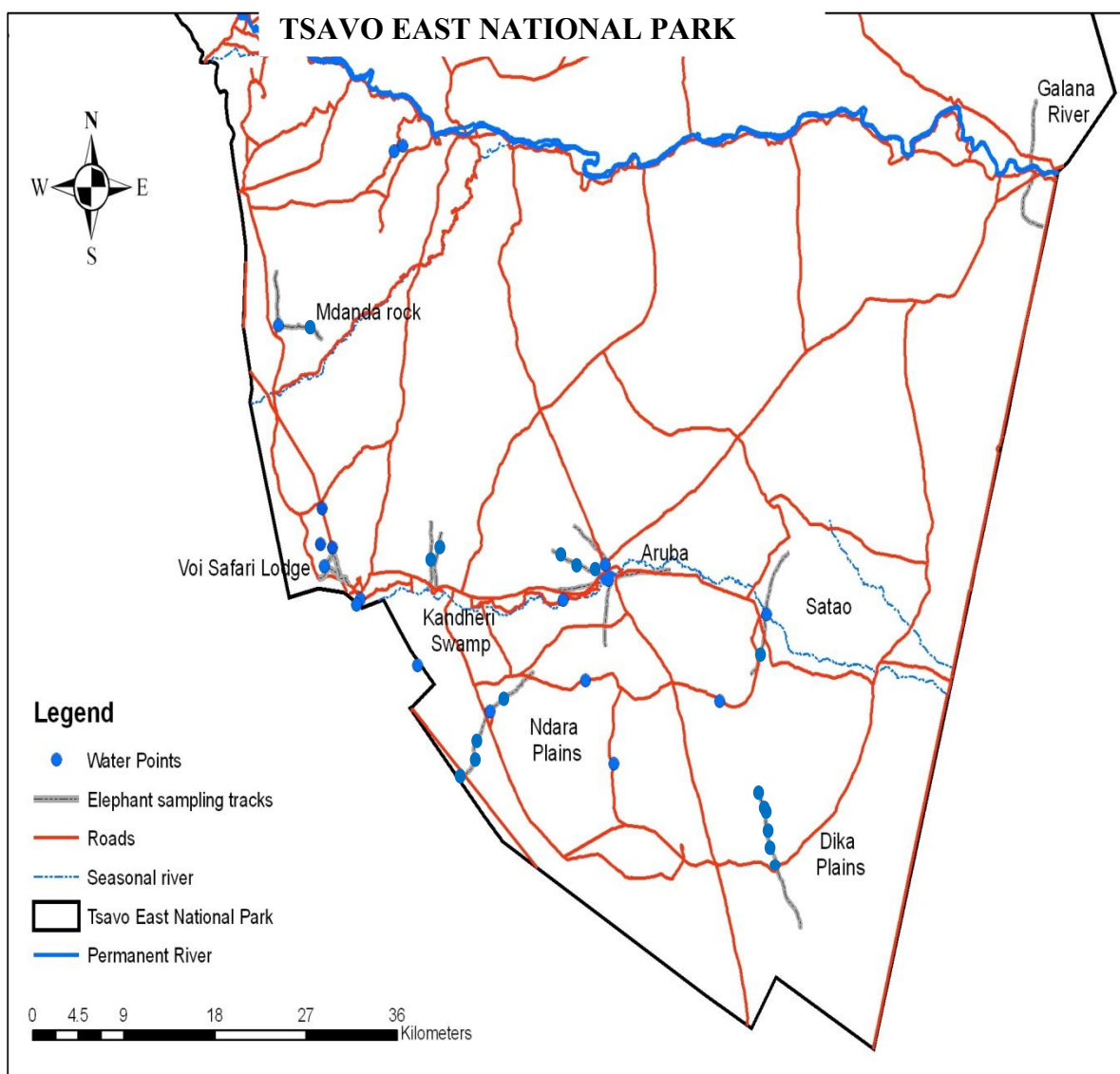
All tracks were characterized by the presence of fresh and old elephant dung. Tracks converged the watering points forming a radial - like pattern and they widened and increased in number near the watering points. Most tracks connected artificial waterholes, natural water pans and ephemeral pools. Some of the water points were dry with no water during the dry season, some muddy while some had little water and were on the verge of drying out. Trampling around these water points was evident.

Aruba dam was found to have more large tracks compared to other watering points. During the dry season (June 2011 to August 2011) Aruba dam had no water and animals were supplemented with water from a wind mill located approximately 100 m from Aruba dam. Figure 5 shows sampled elephant tracks leading to watering points.

Sampling of the eighteen elephant tracks covered a distance of 126 km and a total of 3321 dung piles and 2173 dung piles during wet and dry season respectively (Appendix 1). There was a significant difference in average utilization of the tracks (average fresh dung piles per track) while accessing the watering points ( $U = 91.5$ ,  $n_1 = 18$ ,  $n_2 = 18$ ,  $p < 0.05$ ) in wet and dry season. There was more average fresh dung per trail ( $184.50 \pm 23.12$  dung piles/ trail)

during the dry season compared to the wet season ( $120.72 \pm 15.50$  dung piles/ trail) (Appendix 1).

The seasonal usage (fresh dung piles in all tracks per season) of the tracks between the wet and dry season was also found to vary significantly ( $F_{1, 70} = 4.4, p < 0.05$ ). During the dry season, there was more utilization of elephant tracks as more dung (70.1 %) was recorded compared to the wet season (29.9 %).



**Figure 5:** Sampled Elephant tracks leading to watering points.



### 3.2. Distribution of woody vegetation with distance from the watering points

#### 3.2.1. Aruba Dam

Five woody species were encountered at the Aruba lodge which was used as a control site and was dominated by *Acacia tortilis* that achieved a height of up to about 30 m and a sizeable canopy cover > 55 %. Other woody species encountered in the control site were *Melia volkensii*, *Thylacium thomasii*, *Bauhinia taitensis* and *Boscia coreacea* (Table 1). Most of the ground was bare with small grass and herb cover. The woody plants were growing without any interference from elephants and other herbivores.

**Table 1:** Woody plant species found at Aruba lodge and their relative dominance.

Woody plant type	Species Name	Relative Dominance (%)
Trees	<i>Acacia tortilis</i>	57.89
	<i>Melia volkensii</i>	42.11
Shrubs	<i>Thylacium thomasii</i>	53.33
	<i>Bauhinia taitensis</i>	26.67
	<i>Boscia coreacea</i>	20

% Relative dominance - based on stem basal areas

At a distance of  $\leq 60$  m from Aruba dam, about 48% of the woody vegetation was sprouting and regenerating from high browsing. A patch of dense woody vegetation was recorded at a distance of about 423 m from Aruba dam, 150 m from Aruba lodge and 30 m from the road. The woody vegetation stretched to a distance of about 1 km from Aruba dam.

Based on all the woody plants recorded with distance from the watering points (Appendix 2), trees formed about 1.14 % while shrubs formed about 98.86%. *Acacia tortilis* (32.11 %), *Delonix elata* (27.52 %), *Commiphora africana* (17.43 %), and *Dobera glabra* (14.68 %) were the most common tree species. *Platycliphium voensis* (5.50 %) and other tree species were the least common (3.76 %). *Sericocomopsis pallida* (55.05 %) was the most common shrub; *Boscia coreacea* recorded 11.21 % while 34.74 % of plant species recorded were other

shrubs (Appendix 3a). About 36.23 % of *Cordia sinensis* plant species recorded during wet season was regenerating from damage caused by the elephants during the dry season.

The woody plants in the control site and in areas utilized by elephants were similar. There were, however, differences in proportional dominance between the control site and in areas utilized by elephants for example, *Acacia tortilis* constituted 57.89 % of all trees sampled in the Aruba control site compared to 32.11 % of all trees found in areas utilized by elephants.

### 3.2.2. Voi Safari Lodge water point

*Acacia tortilis*, *Delonix elata* and *Commiphora africana* dominated as tree species at the control site near park headquarters. The shrubs were dominated by *Bauhinia taitensis* (Table 2). The ground had little grass and herbaceous vegetation due to the shade effect of the dense canopy cover.

**Table 2:** Woody plant species at Voi safari lodge and their relative dominance.

Woody plant type	Species Name	Relative Dominance (%)
Trees	<i>Delonix elata</i>	45.55
	<i>Acacia tortilis</i>	18.18
	<i>Commiphora Africana</i>	36.36
Shrubs	<i>Bauhinia taitensis</i>	100

% Relative dominance - based on stem basal areas

Within  $\leq 0.3$  km distance from the watering point, grass species dominated (90 % cover) with scattered woody plants. Saplings of *Acacia tortilis* and *Senna species* (Cassia) were found to grow around the waterhole.

A patch of grassland about 33 hectares was observed within  $\geq 1.5$  km and  $\leq 2.6$  km from the waterhole. Trees constituted 4.66 % of all the woody plant sampled while 95.34 % were shrubs. *Acacia tortilis* (46.15 %) and *Delonix elata* (38.46 %) were the dominant tree species.

Other tree species constituted (15.39 %) of all trees sampled. *Bauhinia taitensis* (63.64 %) and *Boscia coreacea* (13.64 %) on the other hand dominated as shrub species (Appendix 3d). It was evident that woody plant species in the control sites were similar to those found in areas utilized by the elephants.

### 3.2.3. Satao waterhole

The control plot at Satao campsite was found to have trees that formed a dense canopy cover and achieved a height > 20 m. *Tamarinda indica*, *Acacia tortilis*, *Acacia arabica* and *Newtonia hildebrandtii* (Table 3) were the dominant tree species in the campsite. They formed a great canopy cover (80%) and thick diameters at breast height. The shrub community was dominated by *Thylacium thomasii*, *Boscia coreacea* and *Cordia gharaf*.

**Table 3:** Woody plant species at Satao water hole and their relative dominance.

Woody plant type	Species Name	Relative Dominance (%)
Trees	<i>Tamarinda indica</i>	66.67
	<i>Acacia Arabica</i>	33.33
	<i>Commiphora Africana</i>	36.36
Shrubs	<i>Thylacium thomasii</i>	29.41
	<i>Cordia gharaf</i>	11.77
	<i>Boscia coriacea</i>	14.71
	<i>Boscia spp</i>	44.12

% Relative dominance - based on stem basal areas

Within  $\leq 70$  m from the water point, there was an area which was highly trampled and 80 % of the land was bare with no vegetation. The area sampled along transects from the Satao waterhole was mainly grassland interspersed with shrubs. Of all the woody plants sampled, about 0.66 % were trees while 99.34 % were shrubs. *Dobera glabra* was found to be the dominant tree species and constituted about 66.67 % of all trees. The trees extended up to about 2.36 km from the water point. On the other hand, *Sericocomopsis pallida* (50.94 %)

and *Boscia coreacea* (9.94 %) were the dominant shrubs that achieved a height of about 1m  $\pm$  0.05 (Appendix 3e). Most of woody plants species in the campsite were dissimilar to those in areas utilized by the elephant. However, some woody plants were similar in both sampling areas but were different in the proportion of dominance, for example, *Boscia coriacea* constituted 14.71 % in the control site compared to 9.94 % in areas utilized by elephants.

#### **3.2.4. Dika waterhole**

From all the woody plants recorded, 1.30 % and 98.40 % were proportions of trees and shrubs respectively. *Commiphora africana* (52.94 %), *Platycephium voensii* (21.57 %) and *Acacia tortilis* (15.67 %) dominated as trees species. *Sericocomopsis pallida* (20.67 %), *Premna resinosa* (8.72 %) and *Boscia coriacea* (5.37 %) were the most dominant shrubs (Appendix 3b).

Most of the woody plants recorded to a distance of about 85 m from the water point were sprouting and more than three quarter of the woody plant was damaged. *Opuntia stricta* is a widespread weed that was recorded along transect. It was found to be growing along the elephant's trails and beneath trees with large canopy covers like *Delonix elata* and *Platycephium voensi*.

#### **3.2.5. Kanderi swamp**

The swamp is dominated by grass with little woody vegetation, grass species common were *Sporobolus holvolus* and *Cynodon* species. *Newtonia hildebrandtii* (83 %) was the dominant woody plant within the swamp, 80 % of these trees had completely shed leaves. *Acacia tortilis* dominated as the tree species along distance from the swamp and constituted about 40.54 %. *Sericocomopsis pallida* (26.07 %) and *Boscia coriacea* (25.33 %) dominated as

shrubs. Within 1 km from the swamp, *Salvadora persica* was the dominant shrub with a density of  $200 \pm 62.92$  plants / hectare (Appendix 3c).

### **3.2.6. Ndara water point**

*Sericocomopsis pallida* (51.51 %) formed the dominant woody plant around Ndara waterhole. Shrubs formed about 99.80 % of all the woody plants sampled while trees constituted about 0.20 %.

*Acacia brevispica* ( $363.40 \pm 104.37$  plants / hectare) was the dominant species around the water point (Appendix 3f) and around 90 % was regenerating while 10 % were saplings. The saplings had an average height of about  $\leq 0.4$  m. However, during the dry season; about 80 % of *A. brevispica* was removed through utilization by herbivores.

### **3.2.7. Mudada rock waterpoint**

*Commiphora africana* (67.57 %) and *Delonix elata* (13.51 %) were the dominant tree species while *Premna resinosa* (39.20 %) and *Boscia coriacea* (15.74%) dominated as shrubs species around the watering points. However, 76 % *Premna resinosa* sampled had withered out. At the water point, *Lawsonia inermis* (88 %) was dominant woody plant (Appendix 3g). The area is a shrub land and approximately 0.95 % of all the sampled woody plants were trees while about 99.05 % were shrubs.

### **3.2.8. Galana River**

Dense riverine vegetation was found at the Galana river and was dominated by *Hyphaene coreacea* (54 %) and *Acacia eliator* (46 %) as the common riverine trees. *Hyphaene coreacea* achieves height of up to  $35 \text{ m} \pm 0.05$ , (Appendix 3h). *Hyphaene compressa* was also a common riverine tree though recorded outside the sampled plots.

*Suaeda monoica* (74 %) and *Lawsonia inermis* (26 %), on the other hand were the dominant riverine shrubs (Appendix 3h). About 3 % of all the woody plants sampled along transect from the river were trees while about 97 % were shrubs. *Delonix elata* (29.73 %), *Boscia coreacea* (13.51 %) dominated as trees and shrubs species respectively.

### 3.2.8.1. Diversity Index

Diversity in the sampled area varied from one watering point to the other (Table 4). Shannon-Wiener Diversity Index is a measure of diversity which takes both richness and evenness into account. Diversity recorded in areas utilised by elephants in different watering points ranged between 2.08 and 2.91 (Table 4). Diversity was low in the control sites at Aruba dam (1.60), Voi safari lodge (1.39) and Satao (1.62). It differed significantly with diversity in areas utilised by elephants ( $F_{1,4} = 39.43, p < 0.05$ ). There were no differences in diversity among water points ( $F_{7,8} = 2.82, p > 0.05$ ) in areas utilised by elephants.

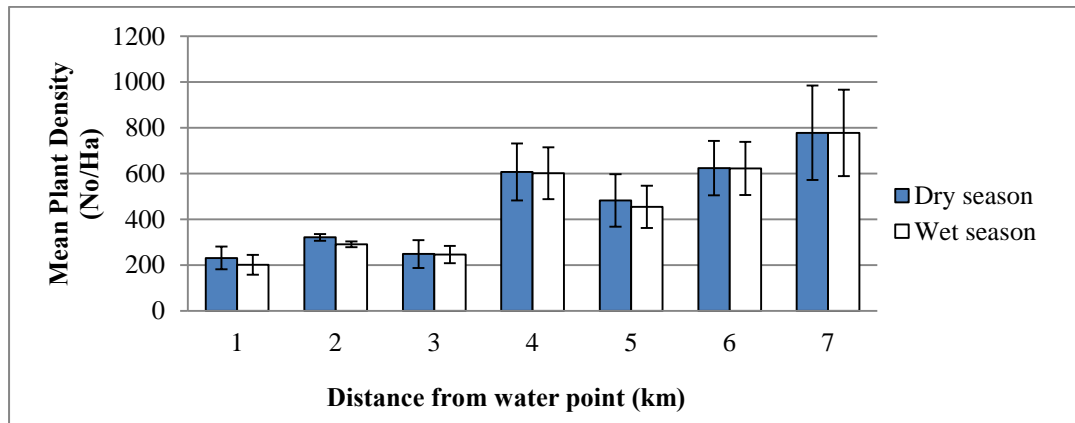
**Table 4:** Shannon - Wiener diversity indices in elephant utilized areas around different water points.

Watering point	Dominance(D)	Shannon- Wiener Diversity(D)
Aruba dam	0.14	2.23
Kanderi	0.09	2.66
Satao	0.15	2.08
Dika	0.09	2.62
Voi safari	0.12	2.36
Galana	0.08	2.82
Ndara	0.06	2.91
Mudanda	0.10	2.57

### 3.2.9. Relationship between woody plants density and distance from the watering points

Different watering points sampled showed variations in plant densities with increase in distance from the watering points (Figure 6). Density of woody plants showed a positive correlation (Appendix 2) with distance from the water points. There was a strong significant increase in woody plants with distance from the water points at Mudanda ( $\rho = 0.82, df =$

12,  $p < 0.05$ ) and Dika watering points ( $\rho = 0.72$ ,  $df = 0.12$ ,  $p < 0.05$ ). There was no significant increase in woody plants with distance from the watering points at Aruba dam ( $\rho = 0.11$ ,  $df = 13$ ,  $p > 0.05$ ), Galana river ( $\rho = 0.03$ ,  $df = 12$ ,  $p > 0.05$ ) and Kanderi swamp ( $\rho = 0.26$ ,  $df = 12$ ,  $p > 0.05$ ).



**Figure 6:** Mean density (SE) of woody plants in sampled plots along the 7 km transects from the watering points.

When a combined analysis of all the plant densities from the watering points was performed, the correlation showed a significant ( $\rho = 0.41$ ,  $df = 108$ ,  $p < 0.01$ ) relationship between woody plants density and distance from the watering points. Density of the woody plants did not vary ( $F_{1, 216} = 1.139$ ,  $p > 0.05$ ) with seasonality.

### 3.3. Elephant woody species utilization and preference ratios around watering points

#### 3.3.1. Preferred woody plants

Elephants mostly preferred five woody species as food items in the Park. There was higher preference for *Bauhinia taitensis* (3.60), *Grewia nematopus* (3.44), *Grewia similis* (3.25), *Acacia tortilis* (3.23) and *Cordia siniensis* (3.01) as evidenced by their higher preference values (Appendix 3). There was low preference for *Delonix elata* (0.00), *Sericocomopsis pallida* (0.00) and *Thylacium thomasii* (0.00) (Appendix 3). Preference values for the rest of

woody species varied among water points (Appendix 3). Roots, trunks and stems of *Boscia coreacea* were found to be utilized during the dry season.

Analysis of woody plants density using Tukey-B post range test found that there was no significant difference in the overall density of woody species (Table 5) among the sampled water points in Tsavo East National Park ( $F_{7, 90} = 0.96$ ;  $p > 0.05$ ). The test also revealed that there were no significant differences in percentage availability ( $F_{7, 90} = 0.6114$ ;  $p > 0.05$ ) and percentage utilization ( $F_{7, 90} = 0.3844$ ;  $p > 0.05$ ) of woody species among sampled watering points. However, elephants differed significantly in their preference ratio for some woody species ( $F_{7, 90} = 2.30$ ;  $p < 0.05$ ) among watering points (Table 5).

Preference ratios shown by the elephants showed a non significant relationship with the overall density of preferred woody plants around Mudanda ( $R = -0.43$ ,  $p > 0.05$ ,  $df = 8$ ), dika ( $R = -0.37$ ,  $p > 0.05$ ,  $df = 8$ ), Kanderi ( $R = -0.25$ ,  $p > 0.05$ ,  $df = 13$ ) and Aruba ( $R = -0.26$ ,  $p > 0.05$ ,  $df = 8$ ) watering points. Examination of the data revealed a significant positive relationship between preference ratios and overall density of preferred woody plants around Satao water point ( $R = -0.44$ ,  $p < 0.05$ ,  $df = 12$ ).

The woody species revealed no relationship between the preference ratio values and the percentage availability; Aruba dam ( $R = -0.45$ ,  $p > 0.05$ ,  $df = 13$ ), Satao ( $R = -0.41$ ,  $p > 0.05$ ,  $df = 12$ ) and Mudanda ( $R = -0.35$ ,  $p < 0.05$ ,  $df = 12$ ). However, there was a relationship between preference ratio values and percentage availability in Ndara watering point ( $R = 0.26$ ,  $p < 0.05$ ,  $df = 8$ ). The results therefore indicated that elephant choice for woody plants was not dependent on the woody plant around the watering points.

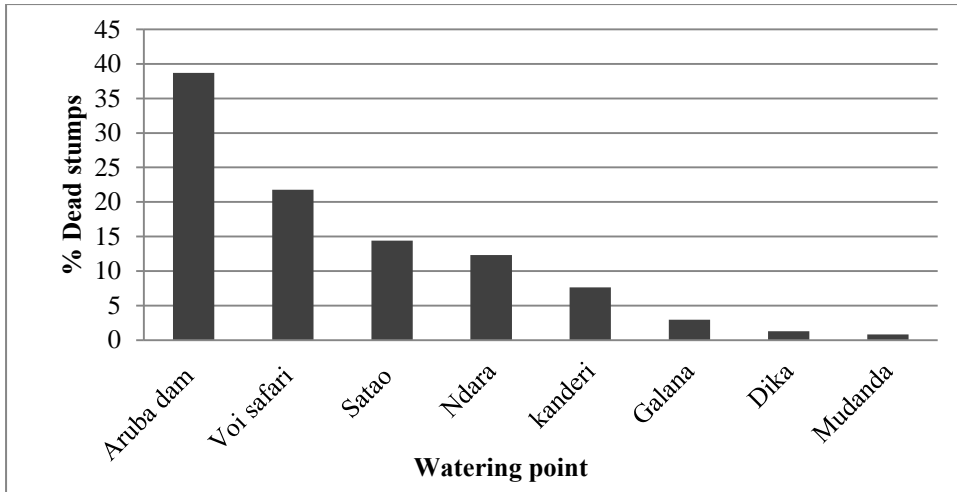


**Table 5:** Woody vegetation mean density  $\pm$  SE, percentage availability, percentage utilized and preference ratio by the elephants.

Watering point	Variable				
	Overall density	Utilised density	%Availability	% Utilisation	Preference ratio
Aruba	253.53 $\pm$ 146.40	58.67 $\pm$ 26.28	6.65 $\pm$ 3.84	6.67 $\pm$ 2.99	1.88 $\pm$ 0.24
Kanderi	73.42 $\pm$ 24.04	16.22 $\pm$ 6.48	4.19 $\pm$ 1.37	6.58 $\pm$ 2.63	1.77 $\pm$ 0.24
Satao	177.76 $\pm$ 93.90	21.43 $\pm$ 7.06	7.07 $\pm$ 3.73	7.14 $\pm$ 2.35	1.83 $\pm$ 0.29
Voi safari lodge	106.71 $\pm$ 59.17	62.67 $\pm$ 46.71	9.44 $\pm$ 3.68	9.89 $\pm$ 7.37	1.18 $\pm$ 0.2
Dika	144.52 $\pm$ 56.32	34.00 $\pm$ 19.09	8.10 $\pm$ 4.49	10.00 $\pm$ 5.61	1.01 $\pm$ 0.29
Galana	39.81 $\pm$ 10.44	15.10 $\pm$ 4.00	4.27 $\pm$ 1.12	6.25 $\pm$ 1.86	1.59 $\pm$ 0.21
Ndara	103.84 $\pm$ 26.83	44.48 $\pm$ 16.08	4.35 $\pm$ 1.08	8.92 $\pm$ 2.23	1.24 $\pm$ 0.19
Mudanda	84.63 $\pm$ 35.57	29.67 $\pm$ 12.73	8.25 $\pm$ 3.47	10.00 $\pm$ 4.29	1.65 $\pm$ 0.34
F-value	$F_{7,90} = 0.9605$	$F_{7,90} = 0.9737$	$F_{7,90} = 0.6114$	$F_{7,90} = 0.3844$	$F_{7,90} = 2.30$
P-value	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$P < 0.05$

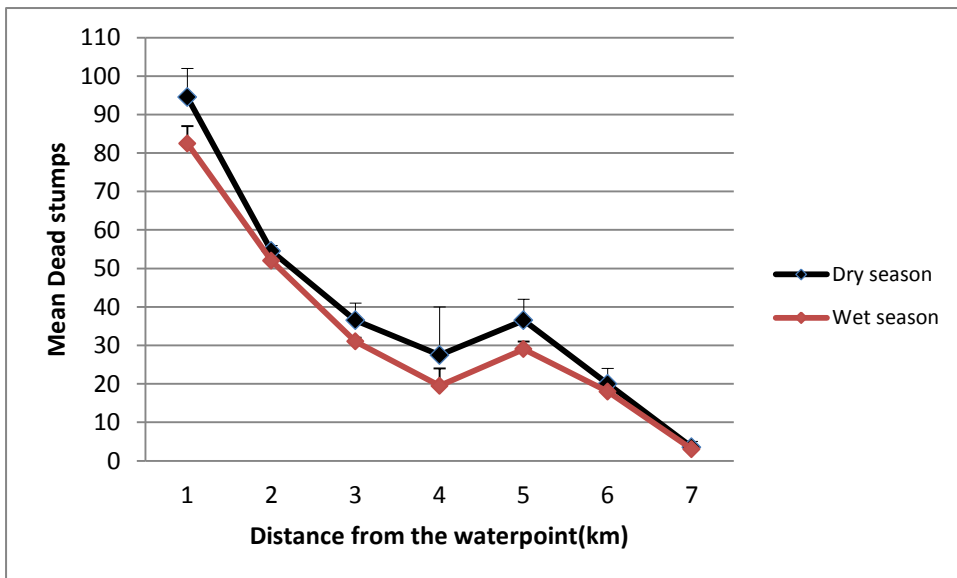
### 3.3.2. Distribution of the dead stumps as a function of distance from the watering points.

Results revealed that there were dead stumps around all the watering points sampled. A total of 235 dead stumps were recorded in all the sampled plots around the watering points. The plots were equivalent to 22 hectares; hence the density of the dead stumps was 11 ha<sup>-1</sup>. About 38.7 % of these dead stumps were recorded along transects from Aruba dam, 21.79 % at the Voi safari lodge waterhole, 14.4 % at Satao waterhole, 12.34 % at Ndara water point, 7.66 % at Kanderi swamp, 2.98 % at Galana river, 1.28 % at Dika water point and about 0.85 % at Mudanda rock water point (Figure 7). During the dry season, the number of dead stumps increased by 16.9 % from the wet season. Increase in dead stumps was as a result of elephant damage. About 83.1 % of the dead stumps recorded during the dry season were remnants from the wet season. Signs of debarking on *Acacia tortilis* stumps and uprooting of *Boscia coreacea* by elephants was evident.



**Figure 7:** Percentage of woody species stumps around sampled watering points.

Most of the dead stumps were *Cordia siniensis* (34.53%) followed by *Grewia similis* (27.36%), *Acacia tortilis* (21.47%) and *Boscia coreacea* at 10.42%. Dead stumps revealed significant decrease ( $R = - 0.27$ ,  $df = P < 0.05$ ) with increased distance from the water point (Figure 8).



**Figure 8:** Summary on distribution of Mean dead tree stumps along transect from all water points.

A cross tabulation between distance from the watering points and differences in number of dead stumps between seasons (dry and wet) revealed that there was no significant difference

in the number of dead stumps between the seasons ( $\chi^2_{0.05, 6} = 0.991$ ,  $p > 0.05$ ) with distance from the water point (Table 6). Most dead stumps were found at a distance of 1 km and 2 km from the water point (Table 6).

**Table 6:** Comparison of dead stumps among seasons

Distance from water point(km)	Number of dead stumps in two Seasons		Total
	Wet	Dry	
1	83	95	178
2	52	55	107
3	31	37	68
4	20	28	48
5	29	37	66
6	18	20	38
7	3	4	7
<b>Total</b>	<b>236</b>	<b>276</b>	<b>512</b>

$\chi^2_{0.05, 6} = 0.991$  is non significant,  $P > 0.05$  level comparing across seasons

### 3.4. Distribution of elephants as a function of distance from the water point

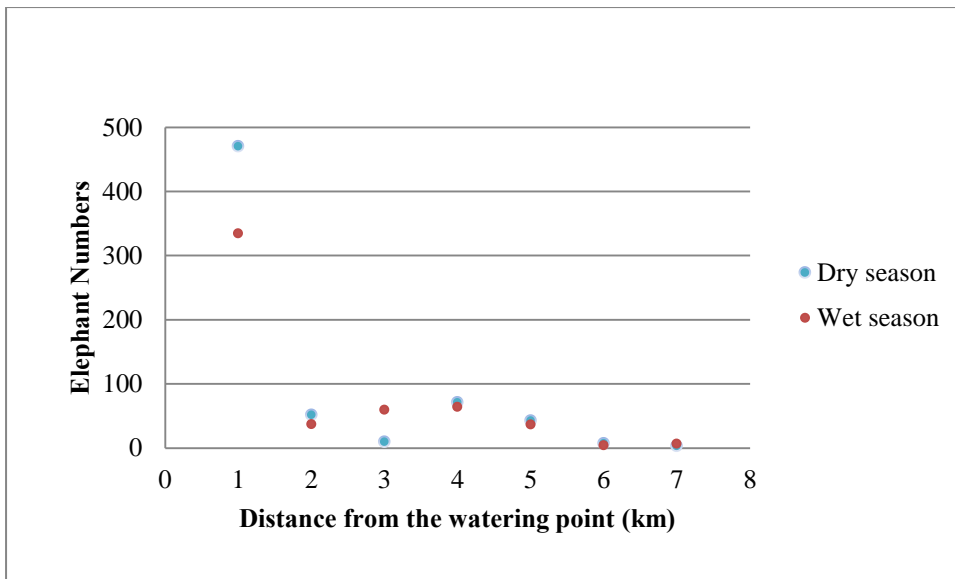
#### 3.4.1. Elephant locations and numbers

When data was analyzed between seasons, the estimated elephant numbers were found to be high in a distance  $\leq 1$  km from all sampled watering points ( $334.3 \pm 10.4$ ) and ( $470.3 \pm 23.8$ ) in wet (March, April, May) and dry (June, July, August) seasons, respectively (Figure 9). A Correlation was done to determine if elephant numbers declined significantly, with increase in distance, during the dry season and the wet season. Elephant numbers were found to decline significantly with increased distance from the drinking water points (Figure 9) during the dry season ( $\rho = -0.41$ ,  $df = 62$ ,  $p < 0.001$ ) but there was no significant decline during the wet season ( $\rho = -0.19$ ,  $df = 62$ ,  $p > 0.05$ ). There were no significant differences in elephant numbers along transects from seven watering points between dry and wet season : Aruba ( $F_{1,12} = 0.17$ ,  $P > 0.05$ ), Voi safari lodge ( $F_{1, 12} = 0.62$ ,  $P > 0.05$ ), Satao ( $F_{1, 12} = 1.86$ ,  $P > 0.05$ ), Ndara ( $F_{1, 12} = 3$ ,  $P > 0.05$ ), Kanderi ( $F_{1, 12} = 0.01$ ,  $P > 0.05$ ), Galana ( $F_{1, 12} = 1.09$ ,  $P >$

0.05) and Mudanda ( $F_{1,12} = 2.08$ ,  $P > 0.05$ ). There was however a significant difference in elephant numbers between dry and wet season at Dika water point ( $F_{1, 12} = 4.6$ ,  $P < 0.05$ ). It was revealed that between wet and dry season, there were no significant differences in elephant counts in natural watering points ( $F_{1, 6} = 0.02$ ,  $P > 0.05$ ) and artificial watering points ( $F_{1, 6} = 0.28$ ,  $P > 0.05$ ). There was no variation in elephant numbers in natural and artificial watering points in both wet ( $F_{1, 6} = 1.56$ ,  $P > 0.05$ ) and dry season ( $F_{1, 6} = 0.27$ ,  $P > 0.05$ ).

Out of 542 elephants encountered during the wet season, 27 % were recorded in Kanderi swamp and natural water pans along transect. However, no elephants were encountered along transect from Galana river and Dika waterhole during the same period. During the dry season, the natural water pans that provide water supplementation were dry and out of 655 elephants encountered, 73 % were found to concentrate within a distance  $\leq 1$  km from permanent artificial and permanent natural watering points.

When a combined analysis for the proportion of elephants counted in both seasons was done, 71 % of the elephants were within a distance  $\leq 1$  km. The proportion decreased with distance from watering points at 2 (8.7 %), 3 (1.2 %), 4 (11.6%), 5 (6.5 %), 6 (0.5 %) and 7 (0.5 %) km. Between 2 km- 3 km, elephant numbers decreased to 10 elephants and then picked up to 71 elephants within 3 km- 4 km during the wet season (Figure 9). This was found to be brought about by availability of more woody plants within 3 km - 4 km.



**Figure 9:** Comparison of elephant distribution between seasons and along transects.

Herds concentrated more around the water points during the dry season compared to the wet season except for the 2 - 3 km and 6 – 7 km from the watering points where the numbers declined. Voi safari Lodge, Satao and Aruba dam were found to be the most visited artificial water holes while Galana river and Kanderi swamp were the most visited natural water points during the dry season. During the wet season, Satao and Aruba dam were the most visited artificial water holes while Kanderi swamp was the most visited natural watering point.

### 3.4.2. Indirect estimation through dung density

During the wet season, elephants were not sighted in some watering points. In both seasons, elephant population density decreased with distance from the watering points in all the eight sampled watering points. The mean ( $\pm$  SE) dung density was  $156.6 \pm 22.8$  and  $149.0 \pm 28.9$  at 95 % confidence limit for all the eight watering points studied during the dry and wet season respectively (Table 7 - 8).

The estimated dung density was highest within  $\leq 1$  km ( $618.9 \pm 17.7$ ;  $532.6 \pm 13.5$ ) in dry and wet season respectively. Dung density was lowest in distance between 6 km and 7 km

(45.7 ± 10.3; ± 21.1 ± 13.8) during dry and wet season respectively. During the wet season there was an increase in dung density (133.8 ± 18.6) within 4 km and 5 km distance compared to the previous range (78.9 ± 12.6).

**Table 7:** The mean dung density estimate (±SE) at 95% CL along transects from the sampled watering points in dry season

Distance from the water point(Km)	Number of Dung piles sighted	Estimated Dung density (dung piles per hectare)	95% CL	CV
0-1	1732	618.9	31.5	9.7%
1-2	253	90.6	5.1	10.7%
2-3	246	88.0	7.0	15.1%
3-4	339	99.8	4.9	10.2%
4-5	268	78.9	4.8	12.9%
5-6	237	74.3	3.9	10.7%
6-7	100	45.7	4.2	15.6%
<b>Total</b>	<b>3175</b>	<b>1096.1</b>	<b>61.4</b>	
<b>Mean</b>	<b>453.6</b>	<b>156.6</b>	<b>8.8</b>	<b>12.1%</b>

**Table 8:** The mean (±SE) dung density at 95% CL along transects from the sampled watering points in wet season.

Distance from the water point(Km)	Dung piles sighted	Estimated Dung piles (per hectare)	95% CL	CV
0-1	1491.2	532.6	40.0	14.3 %
1-2	244.8	81.6	3.5	8.5 %
2-3	223.6	86.0	3.8	8.1 %
3-4	340	100.0	2.0	4 %
4-5	454.8	133.8	9.6	15.1 %
5-6	228	87.7	3.3	7.0 %
6-7	46.4	21.1	1.9	15.2%
<b>Total</b>	<b>3028.8</b>	<b>1042.7</b>	<b>64.1</b>	
<b>Mean</b>	<b>432.7</b>	<b>149.0</b>	<b>9.2</b>	<b>10.3 %</b>

There was a negative relationship between distance from the water point and dung density (Table 9). Dung density decreased significantly with increased distance from the watering

point's in both dry season ( $\rho = -0.39$ ,  $df = 119$ ,  $p = < 0.01$ ) and wet season ( $\rho = -0.26$ ,  $df = 119$ ,  $p = < 0.01$ ).

Combined analysis for both dry and wet seasons using ANOVA found that there were no significant ( $F_{1, 54} = 1.26$ ;  $p > 0.05$ ) differences in distribution of the elephants dung along transects from the eight watering points in both dry and wet season.

**Table 9:** Correlations between the distance from the studied water points and dung density.

<b>Water point</b>	<b>P- value</b>	<b>N- value</b>	<b>r<sup>2</sup></b>	<b>Rho</b>
Voi Safari Lodge	>0.05	13	0.1039	-0.32
Satao	<0.05	13	0.30	-0.55
Dika	>0.05	13	0.15	-0.39
Mudanda	>0.05	13	0.12	-0.34
Ndara	>0.05	13	0.06	-0.46
Aruba Dam	>0.05	13	0.03	-0.18
Galana	<0.05	13	0.37	-0.61
Kanderi	>0.05	13	0.21	-0.46

## **CHAPTER FOUR: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS.**

### **4.1. Discussion**

Elephants were found to be following distinct tracks while accessing watering points (Figure 5). At the Ndara plains, some tracks were found to extend to the park boundary which is unfenced. This is in attempt to access water from the leaking water points along the water pipelines that transports water from Mzima springs in Tsavo West National Park to Mombasa. These pipelines are usually located near the Park boundaries. The communities living around the park boundaries share this resource with the wildlife and the livestock. The water is used for drinking, washing clothes and other household activities. This could be a genesis of human wildlife conflict especially where the water as a resource is shared.

The distribution of elephants was high near the watering points and decreased as a function of distance from watering points; this conformed to results from a previous study by Ayieni (1975) which found that herbivores concentrated around watering points and decreased with distance from the watering points. The results revealed that, large number of elephants recorded around the water point's showed the increased distribution with proximity to the watering points. This has a great impact on the utilization of woody vegetation since it decreases as a function of distance from the water point. It was evident that the elephants utilized the woody vegetation while moving to the watering points since most of the woody vegetation (72 %) along the tracks was highly browsed. In the area around 100 m from the water point, trampling and browsing was very high and the ground was almost bare with many dead stumps and minimal vegetation. The impacts within this distance (100 m) were more pronounced during the dry season. Increased trampling reduces infiltration of water to



the ground hence increasing surface run offs. This may have a negative impact on the fertility of the soil.

The animals especially the large herbivores have influenced the physiognomy and density of the vegetation on a large scale due to trampling around these watering points. In areas where other waterholes were encountered along the transect from the watering points , beneath large trees where elephants access shade , woody plants also decreased.

Woody vegetation at the Mudada watering point showed little utilisation in comparison to the other watering points as there were few elephants visiting the area . This is because the natural watering points sustain water for a short period of time before drying out, hence elephants move to other areas where they can easily access water.

#### **4.1.1. Elephants Utilization of the major tracks while accessing the watering points.**

The tracks identified were decisive and were found to be connecting series of drinking watering points. This suggested that, water availability was one of the underlying factors that influenced elephant track location. Elephant tracks were found to be widespread and heavily used near the watering points as smaller tracks merged to form major tracks. Some of the watering points were found to be completely dry with no water during the dry season. Around the Aruba dam, Satao water point, Voi safari lodge water point, Dika plains water pan, Ndara water point and Galana river, utilization and trampling on the elephant tracks was very high. Heavy utilization of the tracks during the dry season was evident with large density of dung piles noted than the wet season. This means that, the elephants travelled for long distances in attempt to access water resources and they have discovered the shortest and important routes to the major watering points.

#### 4.1.2. Distribution of woody vegetation along transects from the water points.

From the results, it was evident that, the vegetation in the sampled areas was mainly dominated by *Acacia tortilis*, *Delonix elata* and *Melea volkensii* as tree species. These trees were found as isolated trees in bushed grasslands and wooded grasslands. They were common where the tree layer had been destroyed by the elephants. In areas less impacted by the elephants, the dominant shrubs were *Premna holstii*, *Premna resinosa* and *Sericocomopsis pallida*. *Panicum maxima* and *Tetrapogon spp* were the common grass species in areas dominated by *Premna* species and *Sericocomopsis pallida* respectively.

The results revealed that, some species survived across the entire ecosystem. For instance *Sericocomopsis pallida*, *Boscia coreacea*, *Premna* Species and *Cordia siniensis* were the dominant shrubs. *Sericocomopsis pallida* was most dominant of all; it was found to survive in the entire range and was less utilized. This could be as a result of the tolerance ability of *Sericocomopsis pallida* and the creation of browsing lawns supporting intense browsing. Thus, the degree of species composition change is dependent on the type of vegetation that is affected and likely caused by changed competitive patterns as a result of the herbivore related strategy used by different plant species occupying the spot.

*Newtonia hildebrandtii* dominated as a tree species at the Kanderi swamp and was able to survive in this area that experiences periodic floods. At the Galana river *Hyphaene coreacea*, *Hyphaene compressa*, *Acacia eliator* and *Lawsonia inermis* were the dominant riverine vegetation growing on the river margins and they formed a huge canopy cover. They are more threatened by river bank erosion than being damaged by elephants but they have been adapted to survive at the river banks. The riverine vegetation has a substantial capacity to recover from floods, let alone elephant damage (Rountree *et al.*, 2000; Rogers & O'Keefe, 2003). Diversity of woody plants in areas disturbed by the elephants was found to be high

(Table 4) compared to diversity in control areas. It was found to differ significantly with diversity in areas utilised by elephants ( $F_{1, 4} = 39.43$ ,  $p < 0.05$ ). There were no differences in diversity between water points ( $F_{7, 8} = 2.82$ ,  $p > 0.05$ ). The results suggested that elephants had an impact on diversity of woody plants in areas they had visited.

Correlation analysis between distance from the watering point and woody plants density found that there was a significant increase in woody plants with distance from the water points at Mudanda ( $\rho = 0.82$ ,  $df = 12$ ,  $p < 0.05$ ), Dika watering points ( $\rho = 0.72$ ,  $df = 0.12$ ,  $p < 0.05$ ), Satao ( $\rho = 0.65$ ,  $df = 12$ ,  $p < 0.05$ ), Ndara ( $\rho = 0.59$ ,  $df = 12$ ,  $p < 0.05$ ) and Voi safari lodge watering points ( $\rho = 0.55$ ,  $df = 12$ ,  $p < 0.05$ ). This was attributed the increase in elephant numbers with nearness to the watering points hence resulting to reduction in woody plant densities around these watering points.

#### **4.1.3. Effects of elephants on woody vegetation**

The zone adjacent to the drinking watering point and extending to about 70 m from the watering point was highly trampled and woody vegetation destroyed in some of the watering points like Satao, Ndara, Mudanda and Aruba dam.

Woody plants slightly decreased within a distance of about 3 km to 5 km in most of the watering points. It was suggested that elephants foraged within 3 km to 5 km as there was more woody plants that elephant could utilize compared to distance between 0 km and 3km from the watering point. At Mudanda water point there was however no decline in woody vegetation around this distance as it was dominated by *Premna resinosa* which was almost dry and less utilized by the elephants during the dry season. On the other hand, elephant locations increased towards the watering points with the largest concentration being within  $\leq 1$  km from the watering points. This shows that the elephants avoided moving very far from the drinking watering points and they concentrated within this area where they could reduce

the energy involved in travelling whenever they needed water. This translated to the reduction of woody plants.

Elephants impacted Elephants showed higher preference for *Grewia similis*, *Bauhinia taitensis* and *Acacia tortilis* along transects from the watering points as evidenced by their higher preference ratios (Appendix 3). In 7 out of 8 watering points sampled, there were no positive relationship between elephant preference for woody species and percentage availability or woody species overall density. This indicates that the elephants selected woody species regardless of their density.

The trunks, stems and the roots of *Boscia coreacea* were found to be utilized during the dry season. The Leaves were avoided by the elephants as they have a tough and waxy cuticle. *The roots of Boscia coreacea were succulent and elephants were digging them out in attempt to utilize the water from them especially during the dry season.* *Grewia similis*, *Bauhinia taitensis* and *Acacia tortilis* have soft leaves and stems which elephants showed a high preference to.

Elephants impact plants by breaking branches/stems, stripping bark, uprooting plants and toppling trees. The persistence of plant species eaten by elephants is dependent on whether they can cope with herbivory of this nature (i.e. the relative capacity of these species to restrict, resist or compensate for the damage inflicted by re-sprouting and/or re-growth), or whether mortality is balanced or exceeded by recruitment and regeneration (Thomson, 1975). Debarking was observed on mainly *Acacia tortilis*. Most of the dead stumps of *A. tortilis* showed signs of debarking hence elephants had caused mortality of these woody plants.

There was significant decrease ( $R = - 0.27$ ,  $df = P < 0.05$ ) in dead stumps with increased distance from the water point (Figure 8). Likewise, the locations of elephants decreased with

distance from the watering points, this was depicted by the distribution charts (Table 8). The dead stumps distribution around the watering points was found to be high near the watering points. Elephant concentrations near the watering points have resulted to destruction of woody vegetation and hence high density of dead stumps near the watering points.

The fact that dead stumps were more near the watering points and woody plants were few around the watering points suggests high gradient utilization pressure. Few mature trees and shrubs were left near these drinking watering points, this suggested few seed production that can jeopardize future regeneration of woody plants and , therefore, the welfare and uneven existence of woody plants in the park as a whole.

#### **4.1.4. Elephant distribution in relation to proximity to the watering points.**

Tsavo East is a water deficit area being semi arid (Ayieni, 1975) and therefore animals are faced with great challenge of accessing water especially the dry season. Elephants being large herbivores require drinking water at least once in two days (Douglas-Hamilton, 1973) . Some of the seasonal watering points were found to dry out during the dry season and hence more elephants moved to the permanent watering points like permanent artificial waterholes. Elephants were also found to aggregate around permanent Galana river and Kanderi swamp during the dry season. Elephant dug out wells in superficially dry Voi river bed at the Kanderi swamp which provided water.

The assumption of a gradient with browsing pressure diminishing further from the waterhole was found to be generally true. Elephant distribution increased with proximity to the watering points. They did not seem to be restricted in their feeding range by the 7 km radius around the watering points studied.

The results from elephant locations to drinking watering points indicate that elephant concentrated near drinking watering points and the permanent river especially during the dry season. About 66.6% of elephant's locations were within the disturbed area  $\leq$  1km around the drinking watering points. In areas between 3 km- 4 km, elephant's location was about 12.3 %. Here, the location of elephants was also found to be high. This is an indication that elephants avoid moving very far from the watering points to ease the access to drinking watering points. Dung density was high in distance between 4 km – 5 km, it was assumed that elephants moved at night within this range and moved closer to the watering points during the day. This was in accordance with similar observations made for elephant in Marsabit (Ngene, 2009), Samburu (Thouless, 1995), Northern Kenya (Leeuw *et al.*, 2001), Tsavo East National park (Ayieni, 1975; Western, 1975; Leuthold & Sale, 1973; Albricht, 1995) and Maasai mara Game reserve (Khaemba & Stein, 2000).

#### **4.2. Conclusion**

The results from this study have revealed that the unsustainable utilization of the woody plants by the elephants has critically affected the species evenness of the woody plants and the population structure of the vegetation in the park as evidenced by the low density of not only some species but woody plants as a whole near the watering points. High dependency of the elephants on these watering points especially the artificial ones, high population density of elephants around them and shortage of watering points coupled with relentless hot climatic conditions are the major problems that could pose serious threats on these woody plants. With the advent of destruction of woody vegetation and the associated loss of woody plants resources that serve as a source of food for browsers, the environment in the TENP has been immensely disturbed around the water points.

Watering points are highly utilized by the elephants especially during the dry season (as shown in this study) as they provide elephants with water which is an important resource. It can be predicted that until realistic and acceptable alternatives can be found, destruction of woody plants on a large scale will undoubtedly continue, and the resources will be exhausted in the very near future. This, in turn, may lead to land degradation in the form of soil erosion and loss of soil fertility, drying up of natural water pans, decline and even loss of biological resources as well as degradation of Galana river. Ultimately, this may affect the welfare of plants, animals, micro-organisms and the community living around TENP.

I therefore conclude that, the presence of watering points significantly predicts the spatial and temporal distribution of the African elephants which consequently predicts the gradient utilization pressure of woody plants.

### **4.3. Recommendations**

At the time of this study, the condition indicates that a potential elephant problem is present and significant. Elephants contribute to woody species mortality and if trends continue, will cause more serious impact on the habitats. Woody plants densities are declining and this may affect biodiversity negatively. The severity and the rapidity of the changes will depend on elephant densities, change in elephant home ranges (Tchamba, 1995). Therefore, certain recommendations are proposed:

#### **4.3.1. Monitoring Actions**

1. Habitat regeneration should be allowed in highly degraded area where woody plants have been destroyed. This can be done by seasonal closing of these artificial watering points.

#### 4.3.2. Information gaps and research needs

1. More comprehensive study meant to analyze the biological, chemical and physical properties of both water and soils around these watering points in order to establish their effect on growth of woody plants should be done.
2. The effect of elephants on biodiversity, specifically those aspects which are considered critical for ecosystem integrity (e.g. species level effects), or which are featured in the management objectives for specific areas around the watering points as a function of elephant distribution and density. The observation that such impacts are often scale- and site-specific or episodic requires that this be undertaken at a range of spatial and temporal scales and at different sites varying in climate and soil features. Sampling should be designed to detect episodic effects.
3. The rate of change brought about by elephants as a function of elephant density and spatial and temporal distribution is key to managing habitats in elephant areas, and this needs to be specifically quantified. Of value here may be the areas to which new artificial water holes have been dug and elephants have recently started to visit them.
4. The effects of the absence of elephants in some watering points need to be further researched to find out if ecosystems functions can be independent of the process provided by elephants.
5. Tolerance ability of various woody plants like *Sericocomopsis pallida* may be of importance for future evaluations of old and planned new artificial waterholes since different vegetation communities and plant species are affected differently and consideration thereof must be taken. Also the composition of the animal community using the area may influence the response of woody species composition. More extensive



studies of succession are needed in order to understand the underlying causes of these particular vegetation composition changes.

6. Previous studies have shown that different habitats respond differently to elephant impacts and it may be hypothesized that elephant impacts are greater in habitats where they are resource limited for example water accessed from the watering points. Research is needed to quantify elephant resource requirements and to establish how these may be provided in different habitats and protected areas in order to guide the introduction of elephants into new locations and predict risks to woody plants and identify spatial and temporal refuges from elephant impacts.

## REFERENCES

- Adams, W. M. (2004). *Against Extinction: The story of conservation*. Earthscan, London. Sterling, VA, 240 pp.
- AFESG [African Elephant Specialist Group] (2009). *Loxodonta africana*. In IUCN Red List of Threatened species, Version 2009.1 (Ed. IUCN). Cambridge, United Kingdom. [www.iucnredlist.org](http://www.iucnredlist.org)
- Albricht, R. (1995). Where are the Tsavo elephant? GIS modeling of elephant distribution in the Tsavo National Park , Kenya. Msc Thesis, ITC, Enschede, The Netherlands.
- Anderson, G. D., & Herlocker, D. J. (1973). Soil factors affecting distribution of the vegetation types and their utilisation by wild animals in Ngongoro crator, Tanzania. *J. Ecol* , 61 (3), 627-651.
- Anderson, G. D., & Walker, B. H. (1974). Vegetation composition and elephant damage in Sengwa Wildlife Research Area, Rhodesia. *J. S. Afr. Wildl. Manag. Assoc* , 4, 1-14.
- Andrew, M. H. (1988). Grazing impact in relation to livestock watering points. *Trends in Ecology and Evolution* , 3, 336-339.
- Ayieni, J. (1975). Utilization of water holes in Tsavo National Park ( East ). *E. Afr. Wildl. J.* 13, 305-323.
- Babaasa, D. (1994). Status, distribution and feeding ecology of elephants in Bwindi Impenetrable National Park, South Western Uganda. MSc thesis, Makerere University, Kampala.
- Barbour, M. G., Burk, J. H., & Pitts, W. D. (1987). *Terrestrial plant ecology*. 2nd ed. The Benjamin/Cummings Publishing Company, Inc. Menlo Park, California.
- Barnes, D.L. (1976). A review of plant based method of estimating food consumption, percentage utilization, species preference and feeding patterns of grazing and browsing animals. *Proc. Grassld. Soc. Sth. Afr.* 11, 65–71.
- Barnes, M.E. (2001.) Effects of large herbivores and fire on the regeneration of *Acacia erioloba* woodlands in Chobe National Park, Botswana. *Afr. J. Ecol.* 39, 340–350.
- Barnes, R. F. (2002). The problem of precision and trend detection posed by small elephant populations in West Africa. *Afr.J.Ecol* , 40, 179-185.
- Barnes, R. F., & Jensen, K. L. (1987). How to count elephants in forests. African Elephant and Rhino Specialist Group. Technical Bulletin 1: Causeway, Zimbabwe.
- Barnes, R. F.W. (1983). Elephant behavior in semi - arid environment. *Afr. J. Ecol* , 21, 185-196.
- Barnes, R. F. (1982). Elephant feeding behaviour in Ruaha National Park, Tanzania. *Afr. J. Ecol* , 20, 123-136.

- Bax, P. N., & Sheldrick, D. L. (1963). Some Preliminary observations on the food of elephants in the Tsavo Royal National Park (East) of Kenya. *Afr. J. Ecol* , 1, 40-51.
- Belsky, J. (1995). Spatial and temporal patterns in arid and semi-arid savannas. In:L.Hansson, L. Fahrig & G. Merriam (eds) *Mosaic landscapes and ecological processes*
- Ben-Shahar, R. (1993). Patterns of elephant damage to vegetation in northern Botswana. *Biol. Conser* , 65, 249-256.
- Ben-Shahar, R. (1996). Woodland dynamics under the influence of elephant and fire in Northern Botswana. *Vegetatio* , 123, 153-163.
- Birket, A., & Stevens-Wood, B. (2005). Effect of low rainfall and browsing by large herbivores on an enclosed Savanna habitat in Kenya. *Afr. J. Ecol* , 43, 123-130.
- Birkett, A. (2002). The impact of giraffe, rhino and elephant on the habitat of a black rhino Sanctuary in Kenya. *Afr. J. Ecol.* 40, 276–282.
- Blanc *et al.*, (2007). African elephant Status Report. An update from the African elephant database.
- Boer, W. F., Ntumi, C., Correia, A.U. & Mafuca, M.J. (2000). Diet and distribution of elephant in Maputo elephant reserve, Mozambique. *Afr. J. Ecol.* 38, 188 - 201.
- Brits, J., Van Rooyen, M. W. & Van Rooyen, N. (2002). Ecological impact of large herbivores on the woody vegetation at selected watering points on the eastern basaltic soils in the Kruger National Park. *Afr. J. Ecol.* 40, 53-60.
- Brower, J. E., & Zar, J. H. (1977). *Field and laboratory methods for general ecology*. Wm. C. Publishers, Dubuque, Iowa, USA.
- Buss, I. O. (1961). Some observations on food habits and behavior of the African elephant. *J. Wildl. Mgmt* , 25, 131-148.
- Chira, R. M., & Kinyamario, J. I. (2009). Growth response of woody species to elephant foraging in Mwea National Reserve, Kenya. *Afr. J. Ecol* , 47, 598-605.
- Chira, R. M. (2005). The role of elephants in habitat dynamics and its effects on other mammalian species in Mwea National Park. Ph.D Thesis, University of Nairobi, Nairobi.
- Conybeare, A. M. (1991). Elephant occupancy and vegetation change in relation to artificial watering points in a Kalahari sand area of Hwange National Park. Ph. D thesis, University of Zibambwe.
- Cox, G. W. (1990). *Laboratory Manual of General Ecology*. 6th Edition. WCB Publishers, Dubuque, Iowa.
- Cumming, D. H., Toit, R. F., & Stuart, S. N. (1990). African elephant and rhinos: Status survey and action plan. *IUCN* , 72.

Cumming, D. H. M. (1981a). The Management of Elephants and other large Mammals in Zimbabwe. In : Problem in management of locally abundant wildlife animals, (ed) P.A. Jewell, S. Hott and D. Hart 91-118 Academic Press, New York.

Cumming, D. H. M. (1981b). Elephants and woodlands in Chirazira National Park, Zimbabwe. In : Problem in management of locally abundant wildlife animals, (ed) P.A. Jewell, S. Hott and D. Hart 91-118 Academic Press, New York.

Darling, F. F. (1960). Wildlife in African Territory. *Oxford University Press, London , United Kingdom* .

De Beer, Y., kilian, W., Versfeld, W., & Van Aarde, R. J. (2006). Elephant and low rainfall alter woody vegetation in Etosha National Park, Namibia. *Journal of Arid Environments* , 64, 412-421.

Douglas - Hamilton, I., Michelmore, F., & Inamdar, I. (1992). African Elephant Database. GEMS/GRID/UNEP, Nairobi .

Douglas - Hamilton, I. (1992). News and views : Indifference of ivory trade ban. *Oryx* , 26 (1), 1-4.

Douglas - Hamilton, I, Krink, T. & Vollrath, F. (2005). Movement and corridors of African elephant in relation to protected areas. *Naturwissenschaften* 92,158-163

Douglas-Hamilton, I. (1973). On the ecology and behaviour of the lake Manyara elephant. *East African Wildlife Journal* , 11, 401-403.

Douglas – Hamilton, I. (1989). Overview of status and trends of the African elephant. Technical extracts from the ivory trade and the future of the African elephant. Report 1. EEC/WWF African elephant programme, Wildlife Conservation International, Nairobi.

Dublin, H. T., & Douglas-Hamilton, I. (1987). Status and trends of elephants the Serengeti-Mara ecosystem. *Afr.J.Ecol* , 25, 19-33.

Field, C. R. (1971). Elephant Ecology in the Queen Elizabeth National Park, Uganda. *E. Afri. Wildl. J* , 9, 99-123.

Fowler, J., Cohen, L., & Jarvis, P. (1998). Practical Statistics for Field Biology (2nd ed.). Chichester: John Wiley & Sons.

Gandiwa, E. and Kativu, S., (2009), Influence of fire frequency on *Colophospermum mopane* and *Combretum apiculatum* woodland structure and composition in northern Gonarezhou National Park, Zimbabwe. *Koedoe*, 51 (1), Art. #685, 13 p, DOI: 10.4102/Koedoe, v51i1.685

Githae, E. W., Petiot, M. C., Mworira, J. K., & Odee, D. W. (2007). A botanical inventory and diversity assesment of Mt. Marsabit forest, a sub- humid montane forest in the arid lands of northern Kenya. *Afr. J. Ecol* , 46, 39-45.

Glover, J. (1963). The elephant problem of Tsavo. *E. Afr. Wildl. J* , 1. 30-39.

- Graetz, R. D., & Ludwig, J. A. (1978). A method for the analysis for the phosphorus data applicable to range assessment. *Aust. Rangel* , 1, 126-136.
- Guy, P. R. (1976). The feeding behavior of elephant (*Loxodonta africana*) in the Sengwa area , Rhodesia. *South Africa journal of Wildlife Research* , 6, 131-137.
- Holdo, R. M. (2003). Woody plant damage by African elephant in relation to leaf nutrients in Western Zimbabwe. *Journal of Tropical Ecology* , 19, 189-196.
- Holly T. Dublin, A.R.E Sinclair & J. Mc Glade (1990) Elephants and fire as causes of Multiple stable states in the Serengeti –Mara Woodlands.
- Ishwaran, N. (1983). Elephant and woody-plant relationships in Gal Oya, Sri Lanka. *Biological Conservation* , 26, 255-270.
- Jachmann, H. (1989). Food selection by elephants in the 'miombo' biome in relation to leaf chemistry. *Biochemical systematics and ecology* , 17, 15-24.
- James, C. D., Landsberg, J., & Morton, S. R. (1999). Provision of watering points in the Australian arid zone: a review of effects on biota. *Journal of Arid Environment* , 41, 87-121.
- Jones, C. G., Lawton, J. H., & Shachak, M. (1997). Positive negative effects of organisms as physical ecosystem engineers. *Ecology* , 78, 1946-1957.
- Kabigumila, J. (1993). Feeding habits of elephants in Ngorongoro crater, Tanzania. *Afr. J. Ecol* , 31, 156-164.
- Krause, J., Dear, P. H., Pollack, J. L., Slatkin, M., Spriggs, H., Barnes, I., *et al.* (2006). Multiplex amplification of the mammoth mitochondrial genome and the evolution of Elephantidae. *Nature* , 439, 724 - 727.
- Laws, R. M., Parker, I. S., & Johnstone, R. C. (1975). Elephants and their habitats: The ecology of elephants in North Bunyoro, Uganda Clarendon Press, Oxford.
- Laws, R.M., Parker, I.S., & Johnstone, R.C. (1970). Elephant and their habitats in North Bunyoro, Uganda. *East Afr. Wildl. J.* 8, 163-180.
- Leeuw J., Waweru, M. N., Okello, O. O., Maloba, M., Nguru , P., Said, M. Y., Aligula, H. M., Heitkonig , I. M. & Reid, R. S.(2001). Distribution and diversity of wildlife in northern Kenya in relation to livestock and permanent water points. *Biological Conservation.* 100, 297-308.
- Legget, K. (2006a). Effect of artificial water points on the movement and behaviour of desert-dwelling elephants of North- Western Namibia. *Pachyderm* , 40, 24-34.
- Leuthold, W. (1996). Recovery of woody vegetation in Tsavo National Park, Kenya, 1970-94. *Afr. J. Ecol* , 34, 101 - 112.

- Leuthold, W. & Sale, J.B (1973) Movements and patterns of habitat utilization in Tsavo National Park, Kenya. *E.Afr. Wildl.J.*11, 369-384
- Lewis, D. M. (1991). Observations of tree growth, woodland structure and elephant damage on *Colophospermum mopane*, in Luangwa valley, Zambia. *Afr. J. Ecol* , 29, 207-221.
- Lindsay, K. (1993). Elephants and habitats: the need for clear objectives. *Pachyderm* , 16, 34-40.
- MacArthur, R. H., & Wilson, E. O. (1967). The Theory of Island Biogeography. *Acta Biotheoretica* , 50, 133-136.
- Maglio, V. J. (1973). Origin and Evolution of Elephantidae. *Transaction of the American philosophical society* , 63, 1-149.
- Merz, G. (1986). Counting elephants (*Loxodonta africana cyclotis*) in tropical rain forests with particular reference to the Tai National Park, Ivory Coast. *Afr. J. Ecol* , 24, 61-68.
- Naughton-Treves, N., & Weber, W. (2001). Human dimensions of the African rain forest. In: African rain forest ecology and conservation ( Eds. W. Weber, L. J. T. White, A. Vedder & Naughton-Treves). Yale University Press, New Haven, Connecticut , U.S.A.
- Ngene, S. M. (2011). Aerial census of elephants, Tsavo-Mkomazi ecosystems. A report to Kenya Wildlife Service, Nairobi, Kenya.
- Ngene, S. M., Skidmore, A. K., Gils, H., Douglas-Hamilton, I., & Omondi, P. (2009). Elephant distribution around a volcanic shield dominated by mosaic of forest-savanna (Marsabit, Kenya). *Afr. J. Ecol* , 47, 234-245.
- Ngene, S. M., & Omondi, P. (2005). Elephant and man destroy vegetation in Marsabit protected area, Northern Kenya. A technical report to United States Fish and Wildlife Service, Nairobi, Kenya.
- Otthichilo. (2000). An analysis of change in Maasai-Mara Ecosystem of Kenya. Ph.D. Thesis, Wageningen University, Netherlands.
- Owen-Smith, N. (1996). Ecological guidelines for waterpoints in extensive protected areas. *South African Journal of Wildlife Research* , 26, 107-112.
- Pamo, E. T., & Tchamba, M. N. (2001). Elephants and vegetation change in the Sahelo-Soudanian region of Cameroon. *Journal of Arid Environments* , 48, 243–253.
- Pamo, E. T. (1998). Herders and wildgame behaviour as a strategy against desertification in northern Cameroon. *Journal of Arid Environments* , 39.
- Perkins, J. S., & Thomas, D. S. (1993b). Spreading deserts or spatially confined environmental impacts? Land degradation and cattle ranching in the Kalahari Desert of Botswana. *Land Degradation and Rehabilitation* , 4, 179–194.

- Petrides, G. A. (1975). Principal foods versus preferred foods and their relations to stocking rate and range condition. *Biol. Conserv* , 7, 161-169.
- Rogers, K. H., & J, O. (2003). River heterogeneity: Ecosystem structure, function and management, in J. T. du Toit, K. H. Rogers & H.C. Biggs (eds.). *The Kruger experience: Ecology and management of savanna heterogeneity*, pp. 189-218, Island Press, Washington .
- Rountree, M. W., Rogers, K. H., & Heritage, G. L. (2000). Landscape state change in the semi-arid Sabie river, Kruger National Park, in response to flood and drought. *South African Geographical Journal* , 82 (3), 173-181.
- Shannon, G., Page, B., Duffy, K., & Slotow, R. (2006). African elephant home range and habitat selection in Pongola Game Reserve, South Africa. *African Zoology* , 41, 37-44.
- Spinage, C. A. (1994). *Elephant*. University press, Cambridge, United Kingdom .
- SPSS (Statistical Package for Social Sciences) (2006) *Statistical Package for Social Sciences (SPSS) release 16*. New York, USA.
- Statsoft (2002) *Statistica release 6.0* New York, USA.
- Steinhart, E. I. (1989). Hunters, poachers and game keepers: Towards a Social History of Hunting in Colonial Kenya. *The Journal of African History* , 30 (2), 247-264.
- Stone, M. L. (1972). Organized poaching in Kitui district: A Failure in District Authority, 1900 to 1960. *The International Journal of African Historical Studies* , 5(3), 436-452.
- Sukumar, R. (2003). *The living elephant. Evolutionary ecology, behavior and conservation*. Oxford University Press, New York.
- Tchamba, M. N. (1995). The impact of elephant browsing on the vegetation in Waza national Park, Cameroon. *Afr. J. Ecol* , 33, 184-193.
- Tchamba, M.N. (1993) Number and migratory patterns of Savanna elephant in Northern Cameroon. *Pachyderm* , 16, 66 -71
- Tchamba, M. N., & Seme, P. M. (1993). Diet and feeding behaviour of forest elephant in the Santchou Reserve, Cameroon. *Afr.J.Ecol* , 35, 165-171.
- Thouless, C. R (1995). Long distance movements of elephant in Northern Kenya. *Afr. J. Ecol*, 33, 284-297.
- Thrash, I. (1998). Impact of large herbivores at artificial watering points compared to that at natural watering points in Kruger National Park, South Africa. *Journal of Arid Environments* , 38, 315–324.
- Thomson, P. J. (1975). The role of elephants, fire and other agents in the decline of a *Brachystegia boehmii* woodland. *J.S.Afr. Wildl. Mgmt.Ass* , 5, 11-18.

- Van Gils, H.A.M.J. (1988). Environmental profile: western province, Zambia. Enschede; Mongu, ITC ; Provincial Planning Unit. 37.
- Verbeek, M. (2004). Spatial distribution and movements of elephant in the northern Namib desert region of Kaokoveld, Namibia. *S. Afr. J. Zool*, 219, 1-19.
- Viljoen, P. (1989). Habitat Selection and preferred food plants of a desert-dwelling elephant population in the Northern Namib Desert South West Africa (Namibia). *Afr. J. Ecol* , 27, 227- 240.
- Walker, B. H. (1976). An approach to the monitoring of changes in the composition and utilization of woodland and savanna vegetation. *South African Journal of Wildlife Research* , 6, 1-32.
- Waithaka, J. M. (1994). The ecological role of elephant in restructuring plants and animal communities in different eco-climatic zones in Kenya and their impact on land-use practices. Ph. D thesis, Kenyatta University, Nairobi, Kenya .
- Weir, J. (1972). Spatial distribution of elephants in African National Parks in relation to environmental sodium. *Oikos* , 23, 1-13.
- Western, D. (1997). Nairobi National Park is slowly being strangled by development. *swara* , 19 (6) and 20 (1), 19 - 20.
- Western, D. (1990). The ecological value of elephants: A keystone role in African ecosystems. The Ivory trade and the future of the African elephants. Ivory Trade Review Meeting, Gaborone, Botswana, 1989.
- Western, D. (1989). Why manage nature? In: Conservation for the 21st century ( Eds. Western d. and M.C. Pear) . Oxford University Press, New York, U.S.A.
- Western, D. (1975) Water influence and its influence on the structure and dynamics of a savanna large mammal community. *E. Afr. Wildl. J*, 13, 265-286.
- Willem, F. De Boer. (2000). Diet and distribution of elephants in Maputo elephant reserve, Mozambique. *Afr. J. Ecol.* 38, 188-201.
- Whyte, I. J. (1993). The movement patterns of elephant in Kruger National Park in response to culling and environmental stimuli. *Pachyderm*, 16, 72-80.



## APPENDICES

**Appendix 1:** Dung piles sighted along elephant tracks from watering points in both dry and wet seasons

Elephant Track	Length (km)	Watering point	Dry season		Wet season	
			Dung piles sighted	Estimated dung pile/km	Dung piles sighted	Estimated dung pile/km
1	7	Voi Safari Lodge	270	38.57	195	27.86
2	7	Voi Safari Lodge	222	31.71	180	25.71
3	7	Satao	282	40.29	60	8.57
4	7	Satao	150	21.43	125	17.86
5	7	Dika	60	8.57	40	5.71
6	7	Dika	95	13.57	30	4.29
7	7	Mudanda	35	5.00	16	2.29
8	7	Mundanda	36	5.14	14	2.00
9	7	Ndara	150	21.43	125	17.86
10	7	Ndara	186	26.57	136	19.43
11	7	Aruba Dam	240	34.29	180	25.71
12	7	Aruba Dam	140	20.00	126	18.00
13	7	Aruba Dam	220	31.43	116	16.57
14	7	Aruba Dam	255	36.43	166	23.71
15	7	Galana	140	20.00	115	16.43
16	7	Galana	140	20.00	120	17.14
17	7	Kanderi	300	42.86	205	29.29
18	7	Kanderi	400	57.14	224	32.00
<b>TOTAL</b>	<b>126</b>		<b>3321</b>	<b>474.43</b>	<b>2173</b>	<b>310.43</b>
<b>MEAN</b>	<b>7</b>		<b>184.50</b>	<b>26.36</b>	<b>120.72</b>	<b>17.25</b>
<b>STDEV</b>			<b>98.08</b>	<b>14.01</b>	<b>65.76</b>	<b>9.39</b>
<b>SE</b>			<b>23.12</b>	<b>3.30</b>	<b>15.50</b>	<b>2.21</b>
<b>CV</b>			<b>53.16</b>	<b>53.16</b>	<b>54.47</b>	<b>54.47</b>

**Appendix 2:** Correlations of woody plants densities and distance from the watering points.

Water point	P- value	df- value	Spearman's rho
Mudanda	<0.05	12	0.82
Dika	<0.05	12	0.72
Satao	<0.05	12	0.65
Ndara	<0.05	12	0.59
Voi Safari Lodge	<0.05	12	0.55
Kanderi	>0.05	12	0.26
Aruba Dam	>0.05	13	0.11
Galana	>0.05	12	0.03

**Appendix 3a** : Elephant feeding preference ratios for sixteen woody species along transects from Aruba dam.

Species	Total Density/Ha	Density utilised/Ha	%Utilisation (U)	%Availability (A)	(PR) (U/A)
<i>Acacia tortilis</i>	21.67	16.67	1.81	0.56	3.21
<i>Grewia similis</i>	30.00	23.33	2.54	0.78	3.25
<i>Delonix elata</i>	40.00	26.67	2.90	1.04	2.78
<i>Jastisia spp</i>	10.00	6.67	0.72	0.26	2.78
<i>Strychnos dussucata</i>	10.00	6.67	0.72	0.26	2.78
<i>Thylacium thomasii</i>	20.67	13.33	1.45	0.52	2.78
<i>Premna resinosa</i>	30.00	16.67	1.81	0.78	2.32
<i>Cordia siniensis</i>	430.00	216.67	23.55	11.19	2.10
<i>Lawsonia inermis</i>	10.00	3.33	0.36	0.26	1.39
<i>Maerua kirkii</i>	10.00	3.33	0.36	0.26	1.39
<i>Sterculia renchucapa</i>	10.00	3.33	0.36	0.26	1.39
<i>Flaugia virosa</i>	60.00	16.67	1.81	1.56	1.16
<i>Bauhinia taitensis</i>	21.67	16.67	1.81	1.61	1.12
<i>Barlelia taitensis</i>	10.67	6.67	0.72	0.65	1.11
<i>Boscia coreacea</i>	1013.30	196.67	21.38	26.38	0.81
<i>Sericocomopsis pallida</i>	2060.00	346.67	37.68	53.62	0.70

**Appendix 3b:** Elephant feeding preference ratios for eighteen woody species along transects from Dika watering point.

Species	Total Density/Ha	Density utilised/Ha	% Utilisation (U)	% Availability (A)	(PR) (U/A)
<i>Acacia tortilis</i>	21.30	10.00	2.94	1.39	2.11
<i>Grewia similis</i>	421.20	196.67	57.84	27.52	2.10
<i>Premna hostii</i>	10.00	3.33	0.98	0.65	1.50
<i>Strychnos dussucata</i>	10.00	3.33	0.98	0.65	1.50
<i>Commiphora africana</i>	163.40	53.33	15.69	10.67	1.47
<i>Platycelythium voensii</i>	15.00	3.33	0.98	0.98	1.00
<i>Cordia siniensis</i>	22.20	3.33	0.98	1.45	0.68
<i>Cordia monoica</i>	23.40	3.33	0.98	1.53	0.64
<i>Boscia coreacea</i>	364.30	50.00	14.71	23.80	0.62
<i>Sericocomopsis pallida</i>	394.40	13.33	3.92	25.77	0.15
<i>Barlelia taitensis</i>	10.00	0.00	0.00	0.65	0.00
<i>Boscia spp</i>	10.00	0.00	0.00	0.65	0.00
<i>Delonix elata</i>	20.60	0.00	0.00	1.35	0.00
<i>Grewia bicolar</i>	10.00	0.00	0.00	0.65	0.00
<i>Melea volkensis</i>	4.95	0.00	0.00	0.32	0.00
<i>Ochna inermis</i>	10.00	0.00	0.00	0.65	0.00
<i>Plectranthus barbatus</i>	10.00	0.00	0.00	0.65	0.00
<i>Thylacium thomasii</i>	10.00	0.00	0.00	0.65	0.00

**Appendix 3c:** Elephant feeding preference ratios for twenty woody species along transects from Kanderi swamp.

Species	Total Density/Ha	Density utilised/Ha	% Utilisation (U)	% Availability (A)	(PR) (U/A)
<i>Acacia tortilis</i>	172.40	76.67	31.08	9.84	3.16
<i>Barlelia taitensis</i>	16.67	6.67	2.70	0.95	2.84
<i>Salvadora persica</i>	200.00	70.00	28.38	11.42	2.48
<i>Albizia spp</i>	20.00	6.67	2.70	1.14	2.37
<i>Dobera glabra</i>	5.00	1.67	0.68	0.29	2.37
<i>Melea Volkensis</i>	5.00	1.67	0.68	0.29	2.37
<i>Premna holstii</i>	10.00	3.33	1.35	0.57	2.37
<i>Thylacium thomasii</i>	40.00	13.33	5.41	2.28	2.37
<i>Combretum aculeatum</i>	16.67	3.33	1.35	0.95	1.42
<i>Strychnos dussucata</i>	16.67	3.33	1.35	0.95	1.42
<i>Maerua dehydretorium</i>	23.33	3.33	1.35	1.33	1.01
<i>Boscia coreacea</i>	300.00	40.00	16.22	17.13	0.95
<i>Ochna inermis</i>	30.00	3.33	1.35	1.71	0.79
<i>Flaugea virosa</i>	60.00	3.33	1.35	3.43	0.39
<i>Premna resinosa</i>	185.56	6.67	2.70	10.60	0.26
<i>Sericocomopsis pallida</i>	580.00	3.33	1.35	33.12	0.04
<i>Newtonia hidebradntii</i>	16.67	0.00	0.00	0.95	0.00
<i>Combretum spp</i>	16.67	0.00	0.00	0.95	0.00
<i>Delonix elata</i>	16.67	0.00	0.00	0.95	0.00
<i>Platycelythium voensii</i>	20.00	0.00	0.00	1.14	0.00

**Appendix 3d:** Elephant feeding preference ratios for fifteen woody species along transects from Voi safari lodge watering point.

Species	Total Density/Ha	Density utilised/Ha	% Utilisation (U)	% Availability (A)	(PR) (U/A)
<i>Grewia nematopus</i>	12.10	20.00	3.16	0.92	3.44
<i>Bauhinia taitensis</i>	609.20	480.00	75.79	46.24	1.64
<i>Premna holstii</i>	16.60	6.67	1.05	1.26	0.84
<i>Acacia tortilis</i>	41.85	15.00	2.37	3.18	0.75
<i>Platyceythium voensis</i>	4.80	1.67	0.26	0.36	0.72
<i>Premna resinosa</i>	190.00	60.00	9.47	14.42	0.66
<i>Strychnos dessucata</i>	11.20	3.33	0.53	0.85	0.62
<i>Ochna inermis</i>	12.40	3.33	0.53	0.94	0.56
<i>Boscia coriacea</i>	134.50	30.00	4.74	10.21	0.46
<i>Carphalea graucensers</i>	34.40	6.67	1.05	2.61	0.40
<i>Barlelia taitensis</i>	166.40	6.67	1.05	12.63	0.08
<i>Combretum aculeatum</i>	62.10	0.00	0.00	4.71	0.00
<i>Delonix elata</i>	6.10	0.00	0.00	0.46	0.00
<i>Thylacium thomasii</i>	9.90	0.00	0.00	0.75	0.00
<i>Kigelia Africana</i>	6.05	0.00	0.00	0.46	0.00

**Appendix 3e:** Elephant feeding preference ratios for seventeen woody species along transects from Satao watering point.

Species	Total Density/Ha	Density utilised/Ha	% Utilisation (U)	% Availability (A)	(PR) (U/A)
<i>Bauhinia taitensis</i>	23.30	10.00	3.33	0.93	3.60
<i>Cordia siniensis</i>	185.40	66.67	22.22	7.37	3.01
<i>Maytenus senegalensis</i>	9.90	3.33	1.11	0.39	2.82
<i>Barlelia taitensis</i>	19.90	6.67	2.22	0.79	2.81
<i>Grewia virosa</i>	20.00	6.67	2.22	0.80	2.79
<i>Annisote spp</i>	96.60	26.67	8.89	3.84	2.31
<i>Cordia monoica</i>	36.60	10.00	3.33	1.46	2.29
<i>Boscia spp</i>	71.10	10.00	3.33	2.83	1.18
<i>Strychnos dessucata</i>	96.60	13.33	4.44	3.84	1.16
<i>Thylacium thomasii</i>	52.50	6.67	2.22	2.09	1.06
<i>Boscia coracaea</i>	386.70	46.67	15.56	15.37	1.01
<i>Dobeya glabra</i>	40.00	3.33	1.11	1.59	0.70
<i>Sericocomopsis pallida</i>	1350.00	86.67	28.89	53.67	0.54
<i>Premna holstii</i>	100.00	3.33	1.11	3.98	0.28
<i>Cordia gharaf</i>	13.30	0.00	0.00	0.53	0.00
<i>Delonix elata</i>	6.65	0.00	0.00	0.26	0.00
<i>Tamarindas indica</i>	6.65	0.00	0.00	0.26	0.00

**Appendix 3f:** Elephant feeding preference ratios for twenty-one woody species along transects from Ndara watering point.

Species	Total Density/Ha	Density utilised/Ha	% Utilisation (U)	% Availability (A)	(PR) (U/A)
<i>Acacia ataxacantha</i>	105.40	83.33	11.55	4.41	2.62
<i>Acacia brevispica</i>	363.40	263.33	36.49	15.21	2.40
<i>Grewia similis</i>	82.50	53.33	7.39	3.45	2.14
<i>Acacia tortilis</i>	11.20	6.67	0.92	0.47	1.97
<i>Grewia bicolor</i>	39.60	23.33	3.23	1.66	1.95
<i>Cordia siniensis</i>	133.30	53.33	7.39	5.58	1.32
<i>Acacia Senegal</i>	81.20	26.67	3.70	3.40	1.09
<i>Commiphora africana</i>	186.70	60.00	8.31	7.81	1.06
<i>Thylacium thomasii</i>	54.40	16.67	2.31	2.28	1.01
<i>Cordia monoica</i>	22.30	6.67	0.92	0.93	0.99
<i>Lannea triphylla</i>	303.40	76.67	10.62	12.70	0.84
<i>Platycelithium voensis</i>	10.00	1.67	0.23	0.42	0.55
<i>Boscia coriacea</i>	143.60	23.33	3.23	6.01	0.54
<i>Maerua kirkii</i>	22.50	3.33	0.46	0.94	0.49
<i>Barlelia taitensis</i>	72.10	10.00	1.39	3.02	0.46
<i>Premna holstii</i>	29.80	3.33	0.46	1.25	0.37
<i>Sericocomopsis pallida</i>	603.80	10.00	1.39	25.27	0.05
<i>Combretum aculeatum</i>	85.60	0.00	0.00	3.58	0.00
<i>Delonix elata</i>	11.30	0.00	0.00	0.47	0.00
<i>Dobera glabra</i>	5.55	0.00	0.00	0.23	0.00
<i>Sesamothamnus rivae</i>	21.50	0.00	0.00	0.90	0.00

**Appendix 3g:** Elephant feeding preference ratios for fifteen woody species along transects from Mudanda rock watering point.

Species	Total Density/Ha	Density utilised/Ha	% Utilisation (U)	% Availability (A)	(PR) (U/A)
<i>Grewia nematopus</i>	10.10	10.00	3.37	0.98	3.43
<i>Grewia virosa</i>	21.60	16.67	5.62	2.10	2.67
<i>Grewia similis</i>	99.60	76.67	25.84	9.71	2.66
<i>Cordia monoica</i>	10.10	6.67	2.25	0.98	2.28
<i>Cordia siniensis</i>	22.20	10.00	3.37	2.16	1.56
<i>Bauhinia taitensis</i>	328.70	126.67	42.70	32.03	1.33
<i>Acacia tortilis</i>	40.75	13.33	4.49	3.97	1.13
<i>Commiphora africana</i>	31.20	6.67	2.25	3.04	0.74
<i>Boscia coreacea</i>	250.50	26.67	8.99	24.41	0.37
<i>Barlelia taitensis</i>	31.50	3.33	1.12	3.07	0.37
<i>Delonix elata</i>	15.60	0.00	0.00	1.52	0.00
<i>Lawsonia inermis</i>	100.40	0.00	0.00	9.78	0.00
<i>Ochna inermis</i>	11.40	0.00	0.00	1.11	0.00
<i>Platycelithium voensis</i>	9.50	0.00	0.00	0.93	0.00
<i>Strychnos dussucata</i>	43.10	0.00	0.00	4.20	0.00

**Appendix 3h:** Elephant feeding preference ratios for twenty-one woody species along transects from Galana river.

Species	Total Density/Ha	Density utilised/Ha	%Utilisation <b>(U)</b>	%Availability <b>(A)</b>	<b>(PR)</b> <b>(U/A)</b>
<i>Acacia tortilis</i>	9.95	8.33	3.45	1.07	3.23
<i>Grewia similis</i>	24.90	16.67	6.90	2.67	2.58
<i>Bauhinia taitensis</i>	103.30	66.67	27.59	11.07	2.49
<i>Acacia brevispica</i>	22.20	13.33	5.52	2.38	2.32
<i>Acacia eliator</i>	5.60	3.33	1.38	0.60	2.30
<i>Grewia bicolar</i>	12.30	6.67	2.76	1.32	2.09
<i>Baurelia taitensis</i>	45.00	20.00	8.28	4.82	1.72
<i>Cordia monoica</i>	92.30	36.67	15.17	9.89	1.53
<i>Lannea triphylla</i>	10.00	3.33	1.38	1.07	1.29
<i>Balanites aegyptica</i>	11.20	3.33	1.38	1.20	1.15
<i>Maerua kirkii</i>	22.40	6.67	2.76	2.40	1.15
<i>Boscia coracea</i>	146.70	40.00	16.55	15.73	1.05
<i>Balanites glabra</i>	13.50	3.33	1.38	1.45	0.95
<i>Cordia siniensis</i>	19.70	3.33	1.38	2.11	0.65
<i>Premna holstii</i>	23.40	3.33	1.38	2.51	0.55
<i>Combretum aculeatum</i>	74.50	6.67	2.76	7.99	0.35
<i>Delonix elata</i>	36.10	0.00	0.00	3.87	0.00
<i>Suaeda monoica</i>	223.60	0.00	0.00	23.97	0.00
<i>Hyphaene coreacea</i>	11.60	0.00	0.00	1.24	0.00
<i>Lawsonia inermis</i>	14.60	0.00	0.00	1.57	0.00
<i>Sesomothomnus rivae</i>	10.00	0.00	0.00	1.07	0.00

**Appendix 4:** List of plant species encountered along transects from the sampled watering points in TENP

**Aruba dam**

**Family (Bold) and species**

**Mimosacea**

*Acacia tortilis* (Forssk.) Hayne

**Caesalpiaceae**

*Bauhinia taitensis* Taub.

**Acanthaceae**

*Barleria taitensis* S.Moore

*Jastisia* sp

**Lythraceae**

*Lawsonia inermis* Linn.

**Capparaceae**

*Boscia coreacea* Pax

*Maerua kirkii* (Oliv.) F.White

*Thylacium thomasi* Gilg

**Fabaceae**

*Delonix elata* (L.) Gamble

*Flaugia virosa*

**Tiliaceae**

*Grewia similis* K. Schum

**Verbenaceae**

*Premna resinosa* (Hochst.) Schauer

**Amaranthaceae**

*Sericocomopsis pallida* (S. Moore) Schinz

**Sterculiaceae**

*Sterculia renchucapa*

**Loganiaceae**

*Strychnos decussata* (Pappe) Gilg

**Mudanda Waterpoint**

**Family (Bold) and species**

**Mimosacea**

*Acacia tortilis* (Forssk.) Hayne

**Caesalpiaceae**

*Bauhinia taitensis* Taub.

**Capparaceae**

*Boscia coreacea* Pax

**Buseraceae**

*Commiphora africana* (A.Rich) Engl.

**Boraginaceae**

*Cordia monoica* Roxb.

*Cordia siniensis* Lam.

**Fabaceae**

*Delonix elata* (L.) Gamble

**Tiliaceae**

*Grewia nematopus*

*Grewia similis* K. Schum

*Grewia virosa* Wild.

**Acanthaceae**

*Lawsonia inermis*

**Ochnaceae**

*Ochna inermis* (Forssk.) Schweinf

**Leguminosae**

*Platycelythium voensis* (Engl.) Wild

**Loganiaceae**

*Strychnos decussata* (Pappe) Gilg

## **Kanderi swamp**

### **Mimosaceae**

*Acacia tortilis* (Forssk.) Hayne  
*Newtonia hildebrandtii* (Vatke) Torre  
*Albizia* spp

### **Acanthaceae**

*Barleria taitensis* S.Moore

### **Capparaceae**

*Boscia coreacea* Pax  
*Maerua kirkii* (Oliv.) F.White  
*Thylacium thomasii* Gilg

### **Combretaceae**

*Combretum aculeatum* Vent.  
*Combretum paniculata* Vent.

### **Meliaceae**

*Melia Volkensii* Guerke

### **Ochnaceae**

*Ochna inermis* (Forssk.) Schweinf

### **Leguminosae**

*Platycelythium voensis* (Engl.) Wild

### **Verbenaceae**

*Premna holstii* (Gürke) Verdc  
*Premna resinosa* (Hochst.) Schauer

### **Salvadoraceae**

*Salvadora persica* L  
*Dobera glabra* (Forsk.) Poir

### **Amaranthaceae**

*Sericocomopsis pallida* (S. Moore) Schinz

### **Loganiaceae**

*Strychnos decussata* (Pappe) Gilg

## **Satao Waterpoint**

### **Mimosaceae**

*Acacia arabica* var. *adansonii* (Guill. & Perr.) A. Chev.

### **Acanthaceae**

*Anisotes ukambensis* Lindau  
*Barleria taitensis* S.Moore

### **Caesalpiniaceae**

*Bauhinia taitensis* Taub.  
*Tamarindus indica* .L

### **Capparaceae**

*Boscia coreacea* Pax  
*Boscia* spp  
*Thylacium thomasii* Gilg

### **Boraginaceae**

*Cordia monoica* Roxb.  
*Cordia siniensis* Lam.  
*Cordia gharaf* (Forssk.) Ehrenb.

### **Fabaceae**

*Delonix elata* (L.) Gamble

### **Tiliaceae**

*Grewia virosa* Wild.

### **Celastraceae**

*Maytenus senegalensis* Lam. Exell

### **Labiatae**

*Premna holstii* (Gürke) Verdc

### **Amaranthaceae**

*Sericocomopsis pallida* (S. Moore) Schinz

### **Loganiaceae**

*Strychnos decussata* (Pappe) Gilg

### **Salvadoraceae**

*Dobera glabra* (Forsk.) Poir



## **Dika plains**

### **Mimosaceae**

*Acacia tortilis* (Forssk.) Hayne

### **Acanthaceae**

*Barlelia taitensis* S.Moore

### **Capparaceae**

*Boscia coreacea* Pax

*Thylacium thomasii* Gilg

### **Buseraceae**

*Commiphora africana* (A.Rich) Engl.

### **Boraginaceae**

*Cordia monoica* Roxb.

*Cordia siniensis* Lam.

### **Tiliaceae**

*Grewia bicolor* Juss.

*Grewia similis* K. Schum

### **Fabaceae**

*Delonix elata* (L.) Gamble

### **Meliaceae**

*Melia Volkensii* Guerke

### **Ochnaceae**

*Ochna inermis* (Forssk.) Schweinf

*Plectranthus barbatus*

### **Labiatae**

*Premna holstii* (Gürke) Verdc

*Premna resinosa* (Hochst.) Schauer

### **Amaranthaceae**

*Sericocomopsis pallida* (S. Moore) Schinz

### **Loganiaceae**

*Strychnos decussata* (Pappe) Gilg

### **Leguminosae**

*Platycelythium voensis* (Engl.) Wild

## **Voi safari Water point**

### **Mimosaceae**

*Acacia tortilis* (Forssk.) Hayne

### **Caesalpiniaceae**

*Bauhinia taitensis* Taub.

### **Acanthaceae**

*Barlelia taitensis* S.Moore

### **Capparaceae**

*Boscia coreacea* Pax

*Thylacium thomasii* Gilg

### **Rubiaceae**

*Carphalea graucensers*

### **Combretaceae**

*Combretum aculeatum* Vent.

### **Buseraceae**

*Commiphora africana* (A.Rich) Engl.

### **Fabaceae**

*Delonix elata* (L.) Gamble

### **Tiliaceae**

*Grewia nematopus*

### **Bignonaceae**

*Kigelia africana* (lam.) Benth.

### **Leguminosae**

*Platycelythium voensis* (Engl.) Wild

### **Loganiaceae**

*Strychnos decussata* (Pappe) Gilg

## **Galana**

### **Mimosaceae**

*Acacia brevispica* Harms

*Acacia eliator* Brenan.

*Acacia tortilis* (Forssk.) Hayne

### **Balanitaceae**

*Balanites aegyptica* (L.) Delile

*Balanites glabra* Mildbr. & Schltr.

### **Caesalpiniaceae**

*Bauhinia taitensis* Taub.

### **Acanthaceae**

*Barlelia taitensis* S.Moore

### **Capparaceae**

*Boscia coreacea* Pax

*Maerua kirkii* (Oliv.) F.White

### **Combretaceae**

*Combretum aculeatum* Vent.

### **Buseraceae**

*Commiphora africana* (A.Rich) Engl.

### **Boraginaceae**

*Cordia monoica* Roxb.

*Cordia siniensis* Lam.

### **Fabaceae**

*Delonix elata* (L.) Gamble

### **Tiliaceae**

*Grewia bicolor* Juss.

*Grewia similis* K. Schum

### **Arecaceae**

*Hyphaene coriacea* Gaertn.

### **Anacardiaceae**

*Lannea triphylla* (A.Rich) Engl

### **Lythraceae**

*Lawsonia inermis* Linn.

### **Labiatae**

*Premna holstii* (Gürke) Verdc

### **Pedaliaceae**

*Sesamothamnus rivae* Engl

### **Chenopodiaceae**

*Suaeda monoica* Forssk.

## **Ndara Waterhole**

### **Mimosaceae**

*Acacia brevispica* Harms.  
*Acacia senegal* (L.) Wild  
*Acacia* spp  
*Acacia tortilis* (Forssk.) Hayne

### **Acanthaceae**

*Barlelia taitensis* S.Moore

### **Capparaceae**

*Boscia coreacea* Pax

### **Combretaceae**

*Combretum aculeatum* Vent.

### **Burseraceae**

*Commiphora africana* (A. Rich) Engl

### **Boraginaceae**

*Cordia monoica* Roxb.  
*Cordia siniensis* Lam.

### **Fabaceae**

*Delonix elata* (L.) Gamble

### **Salvadoraceae**

*Dobera glabra* (Forsk.) Poir

### **Tiliaceae**

*Grewia bicolor* Juss.  
*Grewia similis* K. Schum

### **Anacardiaceae**

*Lannea triphylla* (A.Rich) Engl

### **Leguminosae**

*Platycelythium voensis* (Engl.) Wild

### **Labiatae**

*Premna holstii* (Gürke) Verdc

### **Amaranthaceae**

*Sericocomopsis pallida* (S. Moore) Schinz

### **Pedaliaceae**

*Sesamothamnus rivae* Engl

### **Sterculiaceae**

*Sterculia rechucarpus*

### **Capparaceae**

*Thylacium thomasii* Gilg