# EFFECTS OF AFRICAN ELEPHANT (*Loxodonta africana)* POPULATION ON VEGETATION AROUND WATER POINTS IN ARABUKO SOKOKE FOREST, KILIFI COUNTY, KENYA

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# DECLARATION

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

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# DEDICATION

I dedicate this thesis to my parents Raphael Kinyanjui and Teresa Wanjiru for their support through my academic journey and believing in me.

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## LIST OF ACRONYMS

| | |
|---|---|
| AERP | Amboseli Elephant Research Program |
| AfESG | African Elephant Specialist Group |
| ANOVA | Analysis of variance |
| ASF | Arabuko Sokoke Forest |
| ASFMT | Arabuko Sokoke Forest Management Team |
| ATBI | All Taxa Biodiversity Inventory |
| AWP | Artificial Water Point |
| CFA | Community Forest Association |
| CI | Confidence Intervals |
| CITES | Convention on International Trade in Endangered Species of Wild Fauna and Fauna |
| DNA | Deoxyribonucleic Acid |
| Dbh | Diameter and Breast height |
| DRC | Democratic Republic of Congo |
| FSC | Faecal Standing Crop |
| GPS | Global Positioning System |
| HEC | Human Elephant Conflict |

| | |
|---|---|
| IBA | Important Bird Area |
| IUCN | International Union on Conservation of Nature |
| KBA | Key Biodiversity Area |
| KEFRI | Kenya Forestry Research Institute |
| KFS | Kenya Forest Service |
| KWS | Kenya Wildlife Service |
| MIKE | Monitoring the Illegal Killing of Elephants |
| SD | Standard Deviation |
| SE | Standard Error |
| SSA | Sub Saharan Africa |
| UNEP | United Nations Environment Program |
| WWF | Worldwide Fund for Nature |

# ABSTRACT

The African elephants (*Loxodonta africana*) are keystone species in its ecosystem. They have been ranked by the International Union on Conservation of Nature (IUCN) as vulnerable species and are of high conservation concern. In Kenya, Arabuko Sokoke Forest (ASF) has been ranked as one of the priority areas for elephant population estimates by the IUCN African Elephant Specialist Group. This study aimed at determining the elephant population density and distribution in Arabuko Sokoke Forest and to assess the impacts of elephants on vegetation around water points within the Forest. Elephant population and distribution was determined using the Faecal Standing crop method which incorporates dung decay rate, defecation and dung density. Elephant dung decay rate was determined by identifying and monitoring 59 fresh dung piles at an interval of 7 days until they completely decayed. Dung decay rate was calculated using the reciprocal of mean survival time. Dung density was determined by counting dung piles along 34 line transects each measuring 1 Kilometre systematically placed at an interval of 5 Km from each other and calculated using the DISTANCE Version 7 software. Impacts of elephants on vegetation were determined by laying two 1 Km long line transects on each of the two water points at Arabuko Swamp and Kwa Muiru respectively. On each line transect, 20m by 10m plots were laid at an interval of 100m. On each plot the variables measured and recorded included: The local name, height, diameter at breast height and the rate of utilization of the plant species; in form of browsing and debarking. Linear regression and analysis of variance were used to determine the statistical difference in the variables in relation to distance from water points. The mean survival time for elephant dung pile in Arabuko Sokoke Forest was estimated to be 147.90 (SE ±6.09) while the elephant dung pile decay rate was 0.0068. Elephant dung density (Y) was 1365.4 dung piles/Km$^2$ (95%, CI=931.6 to 2001.2) while the elephant density (E) was 0.51 elephants/km$^2$. Elephant population in Arabuko Sokoke Forest was estimated to be 215 (95% CI=145 to 318). Both height and diameter at breast height (dbh) had a strong negative relationship with distance from Arabuko Swamp (Height: $P < 0.0001$; $r^2 = 0.605$ and dbh:$P=0.0038$; $r^2=0.1194$ respectively). Around Kwa Muiru water point, there was a strong positive correlation between the distance from water point and height ($P<.0001$;$r^2=0.232$) and diameter at breast height ($P<0.00$; $r^2=0.0009$). Eighty five (85) plant species were recorded around Arabuko Swamp while around Kwa Muiru water point, 99 plant species were recorded. There was a significant difference in species richness ($P=0.023$), diversity ($P=0.005$) and dominance ($P=0.41$) between the two water points. Plant utilization by elephants around the two water points was associated with browsing than debarking. Around Kwa Muiru, browsing was higher with 77.8% of the plant species recorded being browsed compared to 68.2% browsed plant species around Arabuko Swamp. Debarking was high around Arabuko Swamp compared to Kwa Muiru water point with 62.4% and 47.5% of the total plant species recorded being debarked respectively. Compared to other studies done to determine elephant population in Arabuko Sokoke Forest, this study shows that there is an increase in elephant population from the previous estimates. It is therefore vital to continue monitoring their population and the associated ecological effect they have on vegetation on temporal and spatial scale.

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background of the study

Currently, there exists two species of elephants in the world. They are the Asian elephant (*Elephas maximus* Linnaeus, 1758) and African elephant (*Loxodonta africana* Blumenbach, 1797). According to a report by UNEP *et al.* (2013), Asian elephants occur in isolated populations in 13 range states with an approximate total range area of about 880,000 square kilometres. India has the highest population of Asian elephants of between 26,000 to 28,000 (Baskaran *et al.*,2011). The Convention of Migratory Species recognize that there are two distinct sub-species of the African elephant based on their morphological difference. These species are the savanna elephant (*Loxodonta africana* Blumenbach, 1797) and forest elephants (*Loxodonta cyclotis*, Matschie 1900) (Maisels *et al.*,2013).

The savanna elephant (*L.africana*) has been classified as vulnerable while the forest elephant (*L. cyclotis*) has been classified as endangered in the IUCN Red List (Maisels *et al.*, 2013). The IUCN African Elephant Specialist Group (AfESG) estimates the population of African elephants to be between 419,000 to 650,000 (UNEP *et al.*, 2013). They are predominantly found in Southern and Eastern Africa with Botswana hosting the largest single population of about 156,024 and West Africa hosting the lowest population of about 12,035 (Junker, 2008). Kenya has an estimated elephant population of about 35,636, while Arabuko Sokoke Forest (ASF) has over 150 elephants (KWS, 2013a)

Effective conservation of species require that information about their population and distribution, their threats and trends be known. However, according to Blanc *et al.(*2007), research on African elephant population is seldom done, thus the reliability on information of African elephant population size, especially in Southern and Eastern Africa, has reduced. The AfESG has ranked Arabuko Sokoke Forest as a priority habitat area for elephant population surveys (Blanc *et al.*,2007). Moreover, an updated and accurate elephant survey of elephants in ASF is needed (Banks *et al.*,2010)

Over the recent past, both Asian and African elephant populations and range areas have reduced. This decline has been primarily attributed to illegal killing of elephants for ivory and illegal trade of elephant products, habitat loss, land degradation and fragmentation due to human population expansion, urban, agricultural and infrastructural expansion (UNEP *et al.,* 2013; Baskaran *et al.,* 2011). Population dynamics and behaviour of large herbivores are a major driver of habitat modification in the African savannah (Banks *et al.,*2010). Elephant population size increase coupled with contraction in their home ranges makes them responsible for changing vegetation structure (Staub *et al*., 2013 ).

Elephants often influence vegetation structure during dry season when they are predominantly browsers with these effects increasing with increase in their population density ( (Chamaille-Jammes *et al.,* 2007). Therefore, their population dynamics is a key component determining the ecosystem stability. Thus, their protection or removal relate strongly with the function, structure, and security of the other biodiversity and the overall ecosystem. Elephant conservation and management interventions such as their protection in protected areas through fencing and water provisioning have been widely and successful adopted, especially in Africa (Balfour *et al.*,2007). However, according to Van

Aarde *et al.* (2009), the provision of water in artificial water points (AWP) and fencing may lead to unintended impacts on elephant numbers and behaviour. Arabuko Sokoke Forest was ring fenced in 2009 to avoid human-wildlife conflicts, restrict elephant population in the forest, impede illegal settlement and deforestation in the forest (Habel, *et al.,* 2017). An artificial water point at Arabuko Swamp was set up in 2013 to provide water for wildlife within the forest. However, before setting up the artificial water point there was no data showing the impact of elephants on the vegetation composition around the water points. Currently, visible effects on vegetation are being seen and it is therefore important to investigate the impact of ASF elephants on woody vegetation around the AWP.

### 1.2 Problem statement

Arabuko Sokoke Forest is estimated to host between 150 and 180 elephants whose distribution is unknown (KWS, 2013). The elephants are restricted within the forest by an electric fence (Banks *et al.,*2010). The Arabuko Sokoke Forest Elephant Action Plan shows that this elephant population has limited access to water, experiences restricted movement and is exposed to threat of poaching as a result of ring fencing the forest (KWS, 2013a). The forest is an ecological island surrounded with clustered village and experiences a lot of destruction through illegal logging for timber extraction and hunting with poaching being higher in this forest compared to other Eastern Africa coastal arc forests (Amin, *et al.,* 2014). There is therefore a need to establish the elephant population size and its distribution within the forest. ASF has numerous naturally occurring seasonal water pools with only one permanent water point at Arabuko Swamp that is permanently supplies animal water demands (KWS, 2013a). Elephants are water dependent species and tend to concentrate around Arabuko Swamp especially during the dry season which is associated with vegetation disturbance. Prior and after commissioning of Arabuko Swamp, there was no data depicting the impacts of elephants on the vegetation. Therefore, based on this confounding factor within the forest, it is vital for this study to determine the resultant impact of ASF elephant population on vegetation structure and composition around water points.

## 1.3 Research Questions

1. What is the population size of elephants in Arabuko Sokoke Forest?
2. How are the elephants distributed within the vegetation types of Arabuko Sokoke Forest?
3. What are the impacts of elephants on vegetation composition and structure around watering points?

## 1.4 Objectives

### 1.4.1 General objectives

To determine elephant population size, distribution and their impacts on vegetation in Arabuko Sokoke Forest.

### 1.4.2 Specific Objectives

1. To estimate the population size of African elephants in Arabuko Sokoke Forest
2. To determine the distribution of elephants among the major vegetation types in Arabuko Sokoke Forest.
3. To assess the impacts of elephant on vegetation composition and structure in relation to distance from water points.

## 1.5 Hypothesis

$H_0$ There is no difference in elephant population between the major vegetation types in Arabuko Sokoke Forest

$H_0$ Elephant distribution in Arabuko Sokoke Forest is not influenced by the differences in major vegetation type

$H_0$ Vegetation structure and rate of utilization by elephants does not change with distance from water points in Arabuko Sokoke.

## 1.6 Significance of the study

Species numbers often indicate the prevailing health conditions of the ecosystem. Therefore, knowing the population size and distribution of ASF elephant is crucial in determining the forest's elephant carrying capacity. The data collected is also important for setting up the appropriate management goals for the resident elephant population and minimize their effects on their habitats and the overall ecosystem. Moreover, the information is vital in monitoring the effectiveness of the existing ASF management interventions. This study also provides vital data that could be used toupdate the country's elephant inventory database. It also contributes to literature and opening up areas for further research in ASF.

## 1.7 Conceptual framework

Elephant population and distributizon is mainly influenced by food and water availability, restriction by fencing, competition for resource as well as the type of vegetation. Moreover, elephant movement is influenced by their search for food, water and minerals as well as response to disturbance. Surface water availability has a strong influence on elephant movements within their habitat and on the landscape scale. Other than water availability, management options, such as fencing, restrict elephants within protected areas which is an important factor in determining elephant home range areas within protected forest. Vegetation type influence elephant population density and distribution within the vegetation types as elephant will spent most time in areas where food is available to satisfy energy demands of their large body size. Utilization of food plants by elephant in their habitats with presence of their preferred food species and around water is likely to cause changes in their composition and structure affecting food plant survival and availability in future

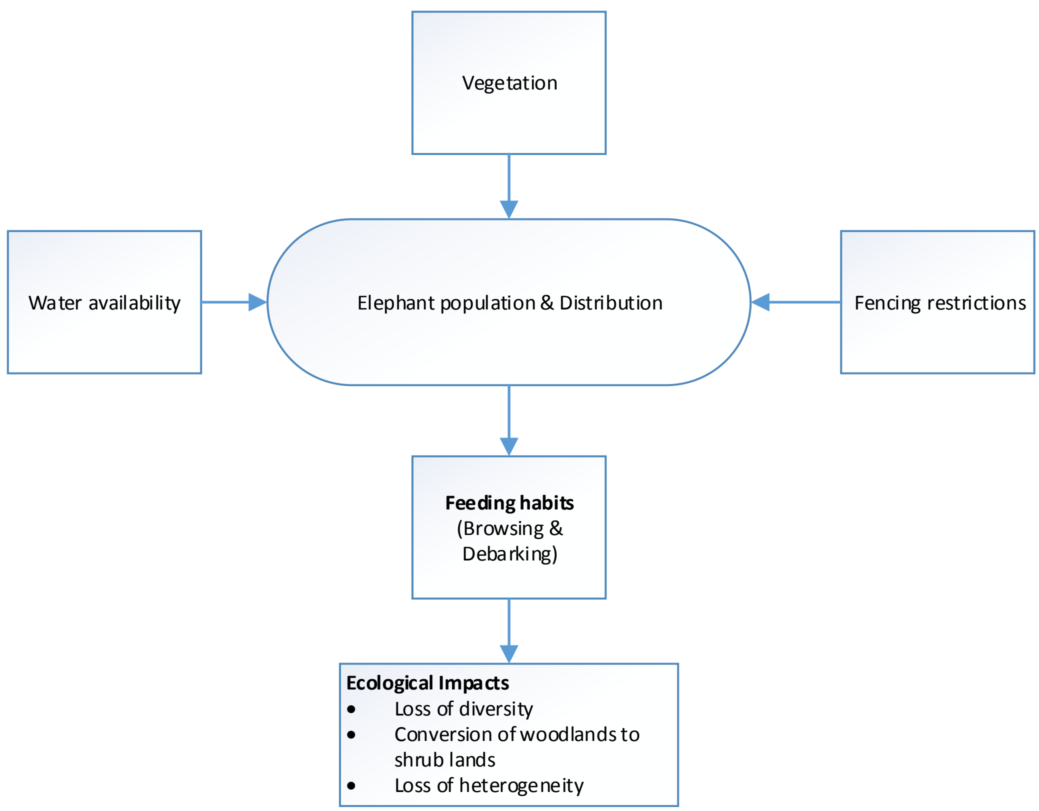



**Figure 1.0.1: Conceptual framework Conceptual framework**

## 1.8 Definition of Terms

| | |
|---|---|
| **Biodiversity Hotspot** | Areas with high diversity and endemism of wild flora and fauna that have persisted for an extended period |
| **Keystone species** | A species that has a disproportionate effect on its environment relative to its abundance. A species whose impact on its community or ecosystem is disproportionately large relative to its abundance. |
| **Piosphere** | Development of gradient of degradation with increasing distance to a water point |
| **Vulnerable species** | A taxon is classified as vulnerable when facing a high risk of extinction in the wild in the immediate future if causal factors persist |

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 African elephant population status and range areas

There are about 470,000 African elephants (WWF, 2016). This is a decline from a population of about 3 to 5 million during the early 20$^{th}$ century. In Kenya alone, the elephant population declined from around 167,000 in 1973 to just 20,000 in 1990s (Ngene, 2012). African elephants once roamed freely across the continent but currently they are confined to smaller confinements within protected areas. However, currently only 20% of the population is under formal protection. Most surveys are concentrated in these protected areas with the areas that have not been surveyed being estimated to be nearly half of the total African elephant range (Blanc, *et al.*, 2007). Moreover, according to IUCN (2013) the reliability of elephant population information has reduced especially in Southern Africa and Eastern Africa.

The African elephant is widely distributed to the South Sahara. The southern Africa accounts for 55% of the total elephants in the continent while Eastern Africa, Central Africa and West Africa hosting 28%, 16% and 2% of the population respectively (IUCN, 2013). The population of African elephant ranges between 419,000 and 650,000 (UNEP, 2013). However, it has been difficult to track the animal trends both at national and continental level. Elephant surveys are seldom conducted at regular intervals, and never systematically across the range or even across a particular country (IUCN, 2013). Eastern Africa is estimated to have about 86,373 ±10,549 from surveyed areas and about 11973 to 12060 elephants in unsystematically surveyed areas. According to an elephant status report released by IUCN in 2016, This population accounts for 62% of estimated known elephant numbers and range areas. In Kenya, elephants occur in both savannah and forest ecosystem. The Tsavo, Laikipia, and Samburu ecosystems are home to the largest population of savannah elephants while the forest population is high in the Aberdare and Mount Kenya ecosystem, with small isolated population occurring in Mount Elgon and Arabuko Sokoke Coastal Forest (Litoro *et al*, 2012). According to a report by Thouless *et al*. (2008), accurate data on elephant status have been recorded in Amboseli, Tsavo, Mara, Samburu and Laikipia ecosystem where ground and aerial counts have been done successfully over years. The Amboseli Elephant Research Project (AERP) has maintained recognition files on individual elephants for 30 years, making this to be the best-known elephant population in the world (Thouless *et al.*,2008). The elephant population in Kenya is about 30,823 with an approximated range area of about 130,725 $Km^2$ (Thouless *et al.*,2016).

## 2.2 Methods of estimating elephant numbers

Modern conservation relies on efficient methods of wildlife estimations (Keeping, *et al*., 2018). According to Selier & Page (2015), reliable game counts that are repeatable and capable of informing the trends in population increase or decline is vital for effective wildlife management. The existing techniques of estimating elephant numbers can be categorised into four: Total counts, sample counts, guesses and camera traps. Each of these methods have their own biases and thus when choosing the method to be used it is important to keep in mind these biases and choose the best method depending on the objectives and level of accuracy required.

### 2.2.1 Total counts

They are used to record elephant numbers either from air or the ground. This method has been widely used for counting large bodied animals in open habitats especially those in the savannah (Norton-Griffiths, 1978). Total counts mostly rely on visual counts of observed herds in large dispersal areas. Aerial count are commonly used in Eastern and Southern Africa while ground counts are seldom used in Africa but sometimes used in India (Blanc,*et al.*, 2007). In the recent times, during total counts digital photos of each elephant group have been taken and compared to observer counts to verify group sizes (Morrison, *et al.*, 2018). This method has a merit of not being affected by topographical conditions and easy interpretation of data. However, it is undercounting may pose biases while using this method if there is improper standardization (Keeping, *et al.*, 2018)

### 2.2.2 Sample counts

In this method randomization is employed with an estimated 3 to 20% of the total area being surveyed along a randomly selected transect within a stratified study area. Sample counts can be in form of either direct or indirect counts. Direct counts are based on elephant sightings, mostly count from the air although they can be conducted on the ground. Aerial counts are used mostly when the terrain is difficult, inaccessible or where large areas need to be surveyed (Songhurst *et al.*, 2015). Aerial surveys are largely used in the African savannah in the Eastern and Sourthern Africa, Atlantic pastoral zones, around oceans and arctic tundra habitats (Songhurst *et al.*,2015). According to Barnes (2002), most sample based surveys yield estimates that vary in precision. Indirect counts involve the use of dung counts to estimate elephant abundance. Elephant dung is counted along a line transect and its density estimated. Elephant population estimates are calculated based on the relationship between dung density, defacation rate and dung decay rate (Blanc, *et al*, 2007). If well conducted dung counts can provide more precise and accurate estimates compared to aerial surveys.

### 2.2.3 Informed guesses

This method has been used for a long period of time. It is a cheap method compared to total and sample counts. In Kenya population estimates taken before 1960, were based on informed guesses. Wardens and people with good knowledge of a particular area would come up with a figure based on the largest herds that they saw, the typical number that they would see in a day in the area, and the area over which the elephants ranged (Thouless, *et al.*, 2008). Although this method yield inaccurate results, it is one of the predictive methods that has been used successfully across Africa.

### 2.2.4 Camera traps

Camera trapping is the use of remotely triggered cameras with infrared sensors that automatically take images of animals passing infront of it. It is a fundamental technique for All Taxa Biodiversity Inventory (ATBI) projects used mostly to identify individuals, as well as determining the relative abundance and the habitat preference of organisms. Camera traps have the merit of being non-invasive and thus have the least effect on the target species. It is also robust to variation in environmental conditions and also efficient in collecting data both during the day and at night and thus provide an opportunity to gain information of highly cryptic species, species distribution and habitat use (Rowcliffe, *et al.*, 2008).

### 2.3 Factors influencing distribution in ecosystems

Conservation action plans and management practices to be implemented in elephant ecosystems require understanding the occurrence and movement patterns of the elephants (Williams *et al.,* 2017). This in turn help in reducing the associated biodiversity decline and/ or loss as a result of habitat damage especially in isolated and fenced protected areas (Fullman & Child, 2013; Williams *et al.,* 2017). Elephant distribution is majorly influenced by water availability especially during the dry season and during the wet season they disperse across their range (Hema *et al*, 2010).

Other factors that influence elephant distribution includes: Shelter, forage, shelter, salt licks, slope angle, elevation and soil fertility among others (Ngene *et al.,* 2009)

### 2.4 Role of Elephants on Ecosystems

Large herbivores and fire play a major role in modelling vegetation structure in Africa's Savannah (Kupika *et al.*, 2014 ). Moreover, changes in the population densities of megafauna in an ecosystem often alter vegetation, soil and terrain with cascading effects to abiotic factors (Asner *et al.,*2016). .The African elephants are architects of their physical environment and have cascading effect on other plant and animal species (Hilbers, *et al*., 2015). They alter and modify their habitat by being agents of seed dispersal, facilitating germination of seeds as well as modifying soil nutrients and conditions (Guldemond & Van Aarde, 2008; Banks *et al.,*2010). It is for this reason that they are referred to as umbrella and keystone species of savanna ecosystems (Pittiglio *et al.,* 2012). Generally, elephant population size and their impacts on ecosystems are directly related (Junker *et al.,* 2008). Staub *et al*. (2013) showed that the influence of elephants on ecosystem is higher compared to other large herbivores because of their large body size which require large amount of food and their diet is more varied than other herbivores. Studies have shown that elephants to be responsible for tree push over, debark and break trees and a general decline in tree density where they exist (De Boer *et al.*,2015). This inturn affects other other browser species mostly leading to decline in these herbivore species. These elephant activities such as toppling of trees have often been associated with decline in population of other faunal species such as raptors, bush pigs and the grysbok (Williams *et al.*,2017).

Elephant activities in any ecosystem often correlates with the abundance and composition of other wildlife fauna species (Williams *et al.*, 2017). Elephants facilitate browser species by not only browsing heavily on trees and converting woodlands into shrub lands but also by coppicing trees and shrubs keeping them below certain maximum height (Makhabu *et al*, 2006; Boer *et al.*, 2015).This in turn favour the mid sized antelopes and increase the abundance of galinaceous birds (Williams *et al.* 2017) According to Kohi (2013), trees whose buds and foliage has been heavily browsed by elephants, produce foliage of high quality and quantity as well as highly nutritious larger shoots. Moreover, the trees also retain their leaves further into the dry season benefiting the other browsers. Studies in Chobe forest in Botswana have shown that elephant mediated changes in vegetation structure through conversion from woodlands to grasslands have been beneficial to grazers such as buffalos, hoippos and white rhinos populations (De Boer *et al.*,2015).

Their presence in an ecosystem also lead to decline in tree species due to the debarking and breaking of trees which further influences floral species especially those sensitive to change in vegetation composition and structure such as birds, browsing species and arthropods in the system (Boer *et al.*, 2015; Banks *et al.*, 2012). This increases chances of these megafauna to disperse seeds as well as trampling and debarking of tree species near water points such as baobabs (Ndoro *et al.*, 2016).

### 2.5 Management options for reducing wildlife impacts on habitat

In Africa native wildlife and humans have coexisted for many years. However, following diversification and change of human activities from traditional to intensified anthropogenic activities, there has been increased risks of predation, compromised quality and availability of resources for wildlife (Bhola *et al.*,2012). Use of both private and public protected areas has been widely adopted as a way of protecting the African elephant population within the continent (Asner *et al.*,2016)Both direct and indirect interventions have been adopted to influence spatial distribution and reduce wildlife impacts on species and their habitats (Hilbers, *et al.*, 2015). Each management option is often associated with ecological effects that are often difficult to detect and predict (Asner *et al.*,2016).

#### 2.5.1 Direct interventions

Wildlife managers employ a number of interventions when reducing wildlife impacts on their habitat. These management strategies include: translocation, culling and contraception which aim at reducing the animal numbers which inturn reduce the intensity of resource use and impacts on other species (Hilbert *et al.*, 2015). These methods are employed to help in controlling the elephant population as well as Human Elephant Conflicts (HEC)

### 2.5.2 Indirect interventions

Indirect methods aim at influencing spatial distribution of animals so that their intensity of resource use and the impact on other species decreases (Hilbers *et al*., 2015). Indirect methods focus on on reducing wildlife harm caused by human activities by restricting terrestrial biodiversity in national parks and reserves (Bhola *et al.*,2012). Fencing and manipulation of surface water sources such as construction or closure artificial water points indirectly assist in controlling wildlife impacts.

#### 2.5.2.1 Fencing

Protected areas act as critical biodiversity reserves for the future (Asner *et al.*, 2016). Fencing of protected areas has been on the increase due to the various threats facing wildlife including over harvesting, human-wildlife conflicts and habitat loss (Shannon *et al.*, 2009). Moreover, fencing enables easy monitoring of poaching as well increase the chance of wildlife sightings to tourists thus revenues earned (Fazio, 2014). Protected areas with elephants have been fenced mainly because these protected areas are associated with crop raiding leading to Human Elephant Conflicts (HEC). In Kenya, it is estimated that 1245 Km of electric fence have been installed around various parks and an additional 1000 Km were under construction in 2016 (Lauren & Adams, 2016). Fencing of protected areas may limit intra and interseasonal movement of elephants within, among and beyond protected areas (Young & Van Aarde, 2010). It also blocks migration routes and corridors thus restricting elephant range areas and fragment habitats (Hema *et al.*, 2010) A study by Whyte & Joubert. (2010) shows that fencing of protected areas create ecological isolations and the confinment reduces elephant foraging ranges leading to disproportionate use of the area. The vegetation is also exposed to increased foraging pressure which may lead to loss of woody vegetation. Studies have shown that in fenced conservation areas, elephants cause loss and extinction of woody and succulent plant species (Coetsee & Wigley, 2016). Moreover, it limit elephant access to natural sources of water (Shannon *et al.*,2009).

#### 2.5.2.2. Manipulation of surface water

Surface water availability is a key resource that influence elephant distribution, range use pattern and population dynamics (Landman *et al.*,2012). Elephant ranging pattern is often influenced by water availability, rainfall and length of rainy season, air temperature and food resource availability during both wet and dry season (Gaugris & Van Royeen, 2009).

In Arid and semi-Arid lands elephant movement is influenced by water availability during the dry season while in wet season they disperse within their range (Hema *et al.,* 2010). Smitt *et al.*, (2007) show that, the construction and closure of Artificial Water Point (AWP) is a suitable way of manipulating impacts on their habitat. Conservation managers also use water availability as a tool for manipulating elephant distribution so as to maintain landscape heterogenity (Landman *et al.*,2012). Provision of water release elephants from the dependency and limitation of natural surface water (Young & Van Aarde, 2010). This inturn may lead elephants to access areas that were previously inaccessible to them (Hilbers, *et al.*, 2015). This reduces daily roaming distance especially during the dry season when elephants concentrate around water points (Young & Van Aarde, 2010). Artificial water points are very important in spatially restricted protected areas lacking permanent water supplies by ensuring all year-round supply of water (Shannon *et al.*,2009). Moreover, it acts as a central point from which visitors can watch elephants. However, management options, such as surface water manipulation often limit natural movement patterns of elephant (Van Aarde *et al.*, 2009). Areas near water points tend to be visited more often than other areas within home ranges, this adds stress to vegetation near water-holes leading to development of a sacrifice area due to additional trampling and grazing (Fazio, 2014). Elephant impact in form of tree pollarding, toppling, debarking and breaking as well as removal of branches often leads to vegetation modification (Simbarashe & Farai, 2015). Water provision for elephants in protected areas may have significant impacts on vegetation and it is therefore important to understand the consequences of manipulating water availability on the ranging behaviour of elephants (Shannon *et al.*, 2009).

**2.4 Research gaps**

African elephant population surveys are seldom done, especially for forest elephants. According to a report by Blanc *et al*. (2007), there is a major challenge in interpreting the African elephant numbers at the continental and national levels. This has been highly attributed to wide knowledge gaps on elephant distribution and abundance. Blanc *et al*. (2007) further showed that guesses still accounts for a large portion of the continental elephant population estimates. Furthermore, substantial number of elephants and their range areas remain unknown. Factors including fencing, seasonal water availability and varying population density confounds the complexity of studying and predicting elephant impacts on vegetation (Landman *et al*., 2012). There are relatively few studies that have tended to describe elephant piosphere effect with very few studies producing long term data. Moreover, the effects of indirect management alternatives such as fencing and surface water manipulation, are poorly studied (Hilbers, *et al.*, 2015)

# CHAPTER THREE

# RESEARCH METHODOLOGY

## 3.1 Study Area

Arabuko-Sokoke Forest (Figure 3.1) is the largest indigenous coastal forest in East Africa. It is situated along the Kenyan coast and transverses Kilifi and Malindi Sub-county at a latitude of 3° 20’ S and longitude 39° 55 E. The forest has an area of 416 square kilometres. Rainfall distribution is bimodal with a mean annual rainfall ranging from 900 mm to 1100 mm. Monthly average temperatures range from 27$^{o}$C to 30°C. The eastern part of the forest lies on a flat coastal plain at an average altitude of about 45 meters above sea level rising to a plateau of about 60–200 meters above sea level in the central and western parts of the forest. Arabuko Sokoke Forest was originally declared as Crown Forest in 1932 and was gazetted as a forest reserve in 1943. The forest is endowed with numerous ephemeral water pans and one artificial water point which serves as the only permanent water source.

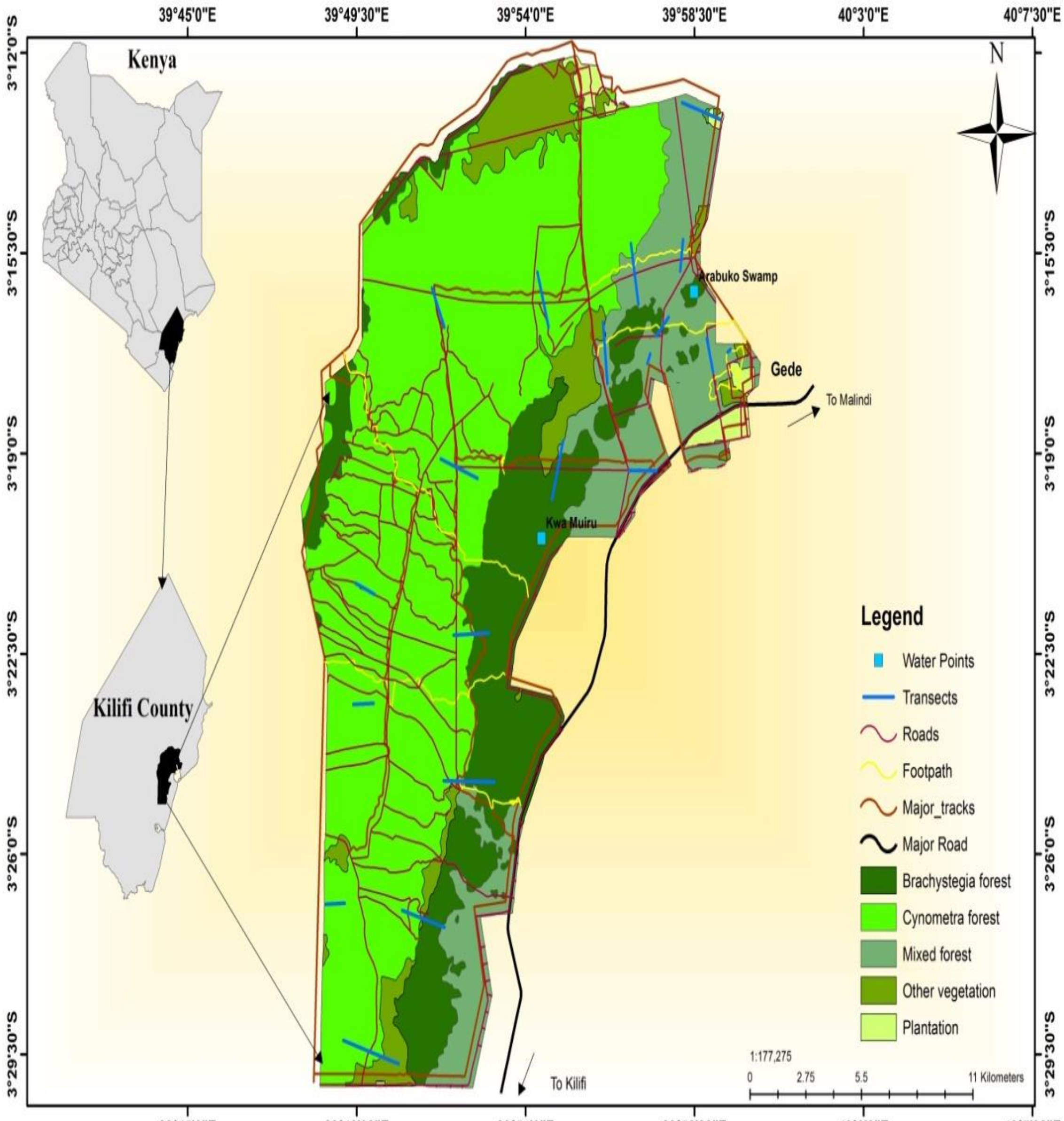



**Figure 3.0.1: Map of Arabuko Sokoke showing the major vegetation types, main transects used (blue lines) and the two water points**

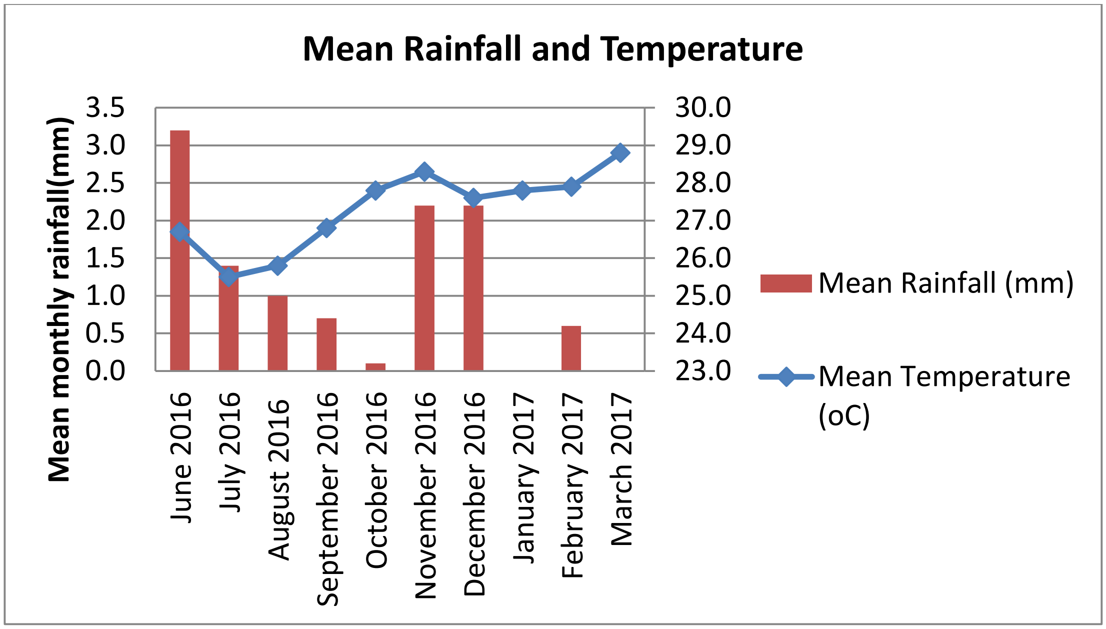



**Figure 3.0.2: Mean monthly rainfall and temperature of Arabuko Sokoke Forest during the study**

**(Source: Msabaha metrological station)**

#### 3.1.1 Floral and faunal Biodiversity

##### 3.1.1.1 Flora

Arabuko Sokoke Forest comprises of three distinct vegetation types, named according to the dominant plant species that coincide with the soil type distribution (Habel, *et al.*, 2017). They include the Mixed Forest, Cynometra forest and Brachystegia woodland. The mixed vegetation which extends to about 7,000 hectares and characterized by a densely packed diverse mixture of tree and shrub species (Banks *et al.*, 2010). The mixed forest type extends on wetter coastal sands in the east of ASF and has a diverse tree flora including *Afzelia quanzensis, Hymenaea verrucosa, Combretum Schumannii Dialium Orientale, Dry*petes *reticulata*, *Manilkara sansibarensis* and the cycad *Encephalartos hildebrandtii* (KFS, 2002). On the North western side of the forest is the *Cynometra* forest vegetation covering about 23,500 hectares and extending towards the western side of the forest. This vegetation zone is dominated by the *Cynometra webberi* with *Manilkara sulcata, Oldfieldia somalensis, Brachylaena huillensis* and *Euphorbia candelabrum* also being abundant although in reducing numbers (Banks *et al.,* 2010). The third vegetation is more open *Brachystegia* woodland covering about 7,700 ha, dominated by *Brachystegia spiciformis* plant. The forest also has a section with plantation vegetation which is composed of *Gmelina arborea* and Eucalyptus species.

#### 3.1.1.2 Fauna

ASF is a biodiversity hotspot, known for high species richness and endemism (Andanje *et al*., 2015). It is a Key Biodiversity Area (KBA), offering a home to a broad range of unique coastal species which are endemic to it and are of conservation concern. The forest has been recognized internationally as an Important Bird area (IBA) in Kenya that require intensive conservation action (Matiku *et al.*,2011). ASF has been ranked by Bird Life International as the second most important forest for conservation of threatened bird species in mainland Africa (KFS, 2002). The forest hosts more than 230 bird species including nine birds on the IUCN list of threatened species (Banks *et al*., 2012). These include the Spotted Ground Thrush (*Zoothera guttate)*, the Sokoke Pipit (*Anthus sokokensis),* Sokoke Scops Owl (*Otus ireneae)*, Amani Sunbird (*Anthreptes pallidigaster)* Clarke's Weaver *(Ploceus golandi)* and the East Coast Akalat (*Sheppardia gunningi sokokensis).* The forest's is also endemic to six taxa of butterflies, three rare, near endemic mammals which include the Golden-rumped Elephant shrew (*Rhynchocyon chrysopygus*), the Sokoke Bushy-tailed Mongoose (*Bdeogale crassicauda omnivora*), the critically endangered Ader’s duiker (*cephalophus adersi)* and the vulnerable African elephant (*Loxodonta africana)*.

### 3.1.2 Socio-economic status

Fifty-one villages with a total population of 110,000 people comprising of 8000 households encircling the forest (Matiku *et al.,* 2013). The local community depends on the forest for their subsistence thus making ASF to be the most depended upon forest in Kenya (Lamech *et al.,* 2014). The average farm holdings size is 6.9 ha (Okoth, 2010). The communities surrounding the forest engage in subsistence farming as their main source of income (Matiku *et al.,*2013). Okoth, (2010) show that an average of 1.6 ha of each farm holding is used to grow maize. Other subsistence crops grown include beans, and cassava. The local community members supplement their income from growing cash crops such as cashew nuts, mangoes and coconut as well as keeping livestock including goats. Lack of grazing grounds and tsetse flies limiting cattle rearing. Local community members also accrue economic benefit from ASF through both licensed and unlicensed fuel wood collection, building materials for both domestic and commercial purposes as well as non-timber forest products including herbal medicine and beekeeping. Butterfly farming which is a community-based income generating activity initiated by the Kipepeo project and the National Museums of Kenya (Matiku, *et al.,* 2013). The forest is a major tourist attraction to bird watchers due to its unique and diverse bird species as well as its location along the coast that makes birding a source of income to the local bird guides (Matiku *et al.,*2013).

### 3.1.3 Threats to the forest

Despite enhanced protection by KFS and KWS, the forest experiences several threats with the major threat being selective illegal logging and poaching of mammals for bush meat. Logging is mainly for timber, firewood, wood carving and building poles while poaching is high because bush meat provides protein and income for local communities in the area (Ndang'ang'a *et al.*, 2016).

## 3.2 Data collection methods

### 3.2.1 Research Design

Dung survey was conducted using the Faecal Standing Crop (FSC) method was used. Dung survey served the purpose of providing the index of elephant abundance and relative distribution. The method requires the determination of elephant dung decay rate (R), Mean defecation rate (D), and dung density (Y). mean defecation rate was based on studies by Barnes & Jensen (1987). Elephant impact on vegetation structure and composition in relation to distance from water points was determined by checking the rate of plant utilization in form of browsing and debarking in quadrats measuring 10m by 10m laid along a 1 Km transect.

### 3.2.2 Sample size and Sampling procedure

Systematic Stratified random sampling design was used, and line transects placed within the study area. Stratification was done according to major vegetation types. In each stratum, parallel 1kilometre line transects were systematically placed 5 Km from each other and running perpendicular to major access roads (Strindberg, 2012;Thomas, *et al.*, 2010).

A natural water point at Kwa Muiru (GPS location (UTM) 0603968 9630698 was selected to study to compare elephant feeding effects on vegetation structure and composition with the artificial water point at Arabuko Swamp (GPS Location (UTM) 0608393 9639209). 10m by 10m quadrat plots were laid at an interval of 100 m along two 1 Km line transects laid radiating from the water points.  Plant species, height, diameter at breast height ($D_{130}$) and rate of browsing or debarking was measured and recorded. Combined line transects and quadrats were used to estimate the influence of elephants on the herbaceous species diversity in relation to the increasing distance from water points. Secondary information was generated from both published and the unpublished materials like books, journals as well as web-based sources.

### 3.2.3 Dung decay rate (r)

To determine the dung decay rate for ASF 59 fresh dung piles were identified within the different habitat types and monitored. Out of the 59 fresh dung piles identified,10.2% (n=6) were in the forest plantation, 32.2% (n=19) in the *Brachystegia* woodland, 47.4% (n=28) in the mixed forest and 10.2% (n=6) in the other vegetation.

**Plate 3.1: Elephant dung pile at stage S1.**

A fresh dung pile in this case was defined as less than one day old (<1day) and the boli were still intact, very fresh, moist with odour (Barnes & Jensen, 1987: Hedge & Lawson, 2006). Once a fresh dung pile was encountered, its' location, number of boli and the habitat type in which it's found was recorded and its GPS coordinates recorded. The identified dung piles were then monitored at an interval of seven to ten days until the dung completely decayed and disappeared (Stage $S_5$). During each monitoring visit, the decay stage was determined and recorded based on CITES MIKE dung survey standards (Hedge & Lawson, 2006).

**Table 3.1: Elephant dung decay stages descriptions**

| Dung Stage | Description |
|---|---|
| **$S_1$** | All boli are intact, moist with odour |
| **$S_2$** | One or more boli (BUT NOT ALL) are intact, fresh but dry, no odour |
| **$S_3$** | No boli are intact, but coherent fragments remain (the fibres are held together by faecal material) |
| **$S_4$** | No boli are intact; only traces such as plant fibres, no coherent fragments are presents |
| **$S_5$** | No faecal material including plant fibres is present |

**Source: (Hedge & Lawson, 2006)**

### 3.2.4 Environmental variables

Climatic variables including daily temperature and rainfall readings were taken from the Msabaha metrological station. The monthly means for each climatic variable was calculated to represent the values for ASF during the time of dung monitoring. Moreover, during each monitoring visit on each dung pile any opportunistic activities of animals especially invertebrates on the dung pile was noted.

### 3.2.5 Dung defecation rate (D)

Defecation rates of forest elephants are often difficult to determine. Existing literature shows that African elephant have a defecation rate of between 16.6 to 37.7 times per day during the wet season, and between 12.0 to 16.6 times per day for during the dry season (Olivier *et al.*,2009). In ASF the mean annual rainfall ranges from 900mm to 1100mm and does not vary much. Therefore, for this study a mean defecation rate of 18.07 per day with a standard error of 0.0698 was used as recommended by Hedge & Lawson, (2006) for areas without pronounced climatic variations.

### 3.2.6 Dung Density (Y)

Dung density (Y) was determined by counting elephant dung piles along 34 line transects each measuring 1 kilometre in length and systematically placed at an interval of 5 kilometres from each other (Barnes *et al.*, 1995). The transects were laid across the forest covering all the major habitat types in the forest and their starting points being placed randomly along the main roads and running perpendicular to the main access roads within the forest (figure 3.1). The start and the end locations of each transect were logged into a global positioning system model GARMIN e-trex.

Dung survey were conducted during the dry season in February 2017 with a team consisting of four members. Once the direction of the transect was chosen, one member walked in front rolling out a 50 m tape measure as well as cutting the transect. Two observers walked along transects slowly one focusing on the left and the other on the right. They stopped once they encounter a dung pile. Once a dung-pile was seen, its stage of decomposition, the perpendicular distance from the centre of the line to the centre of the dung-pile as well as its distance from the start of the transects were measured and recorded without rounding off the values. In this case the measuring tape represented the transect centre line.

When counting and recording the dung piles along transects the following assumptions were made. That the dung piles on the transects were detected with certainty, the dungs were detected in their initial locations and the measurements were exact.

**Plate 3.2: An elephant bull grazing on vegetation along ASF periphery**

### 3.2.7 Impacts of elephants on vegetation composition

A comparative study was conducted to determine the intensity of elephants browsing on woody vegetation and the resultant impact on the vegetation composition and structure in relation to distance from water points. Kwa Muiru water point which is natural seasonal water pool, was selected for comparison with an artificial pool that was permanently supplied with water at Arabuko Swamp. The two water points had similar characteristics, in that, they occurred in the mixed vegetation type and located at the forest edges. The data was collected during the dry season when elephants shifted their diet from predominantly grass to woody species (Wato *et al.*,2016)

The impact of the elephants on the vegetation composition were assessed following the sampling techniques used by Brit *et al.* (2000). At each selected water point, two line transects each measuring 1000 meters and starting from the water point were used. Since the two selected water points occur at the forest edges,  the direction of transects was based on the two cardinal directions from the water points towards the forest interior. The transects were placed 50 meters from elephant tracks in order to minimize track-based effect on vegetation (Fullman & Child, 2013). Plots measuring 20m by 10m (200 $m^{2)}$), were systematically placed at 100 m interval along the 1000 meter transects starting at the water point giving a total of 20 plots per water point. The plots location was recorded using a hand help GPS receiver.

Within the plots, the variables that were measured and recorded include: the local and botanical name of the plant species to the species level, the tree height, the diameter at breast height, tree density and species richness. These measurements were only recorded for woody plants with heights that are equal or above 3 metres ( $\geq$ 3 metres).

The height of woody vegetation (trees) was measured by placing a calibrated  pole against the plant.  The height of the tallest stem was considered for multi-stemmed plants (Ndoro *et al.*, 2016). These measurements were only recorded for woody plants with heights that are equal or above 3.0 m by placing a calibrated pole against the plant. Diameter at breast height for each tree was measured as the circumference at 1.3 metres ($D_{130}$) divided by $\pi$ (Staub *et al.*, 2013). Tree density was measured as the number of live trees present on the plot, while species richness was measures as the total number of woody tree species within the plot (Staub *et al.*, 2013).

Species diversity was calculated using the Shannon Weinner diversity index (H' = _Σ pi ln pi), where **pi** is the proportion of individuals of tree species **i** to the total number of individuals in the community while species dominance was calculated using the Simpson's Dominance index (D).

Damage caused by elephants on vegatation including debarking and browsing was assessed through visual evaluation. Debarking was assessed on a five point (from 0 to 4) category scale as used by Kupika *et al*. (2014 ) and Ndoro *et al.* (2016); where 0 = no damage, 1= slight damage with few scars, 2 = moderate damage with numerous scars, 3 = severe damage with tree scarred deeply, 4 = tree dead or fell. Similarly browsing was assessed on a five-point scale from 0 to 4, where 0=No utilization, 1= Minor utilization with few small branches broken, 2=Moderate utilization with many small branches broken, 3= High utilization with large branches broken, 4= main stem utilization (Fullman & Child, 2013).

## 3.3 Data analysis

### 3.3.1 Dung decay rate (r)

Dung pile decay rate**s** are different between study sites due to spatial and temporal heterogeneity. Taking the assumption that all systems were in steady state, the reciprocal of the mean survival time was used to estimate the mean dung decay rate. The reciprocal of the mean survival time **(T)** is the dung decay rate **(r)** calculated as **r = 1/T.**

ANOVA was used to determine if mean dung survival time varied with habitat. The means were separated with Tukey and significant differences confirmed at $P<0.05$

### 3.3.2 Elephant population density

A total of 1823 dung piles were encountered and counted along 34 transects. The dung count data was managed in MS-Excel and then imported to DISTANCE 7 software for analysis (Buckland *et al.*,2015). Truncating all observations beyond 10 metres, 4% of the dung piles were discarded and 1750 dung piles were fitted in DISTANCE models to generate dung pile density values. The Trunc1000 stratHaz+poly model gave the lowest Akaike Information Criterion (AIC) of 22086.14 and thus was chosen to give the dung pile density per square kilometre which was further used to calculate the elephant density. The mean dung pile survival time and the defecation rate (**D)** as well as their standard errors were incorporated in the DISTANCE model to give the elephant population.

### 3.3.3 Impacts on vegetation

Data recorded for height, *Dbh,* tree density and species richness were managed using Microsoft excel and analysed using PAST version 3.1 statistical package. Microsoft excel 2007 was also used to summarize and make graphical representation as well as to show trend changes in measured variables. Analysis of variance (ANOVA) was done to test for the significant difference in height, *dbh*, tree density and species diversity. Linear regression analysis was used to determine the relationship of the measured variables in relation to distance from water points. Paired t-test was used to compare the tree size (height and *dbh)* of the most utilised tree species between the artificial and natural water points (Kupika *et al.*,2014; Ndoro *et al.*,2016). All statistical tests were conducted at 0.05 level of significance.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Elephant population

### 4.1.1 Dung pile decay rate

A total of 59 fresh dung piles (Stage S1) were identified within the different vegetation habitats and used to assess the dung survival time. The dung piles were monitored until they completely decayed (Stage S5). Elephant dung within the vegetation habitats took between 35 days in the mixed vegetation and 210 days in the open vegetation to completely decay as shown in table 4.1.

**Table 4.1: Mean dung survival time within different vegetation habitats in Arabuko Sokoke Forest**

| Habitat type | Sample size(n) | Minimum survival time (days) | Maximum survival time (days) | Mean decay rate (r) | SD (±) | SE |
|---|---|---|---|---|---|---|
| Exotic forest plantation | 6 | 63 | 175 | 115.50 | 45.09 | 18.41 |
| *Brachystegia* vegetation | 19 | 77 | 182 | 147.00 | 33.24 | 7.63 |
| Mixed vegetation | 28 | 35 | 189 | 137.75 | 51.69 | 9.77 |
| Open vegetation | 6 | 119 | 210 | 191.33 | 36.42 | 14.87 |
| **Total** | **59** | **35** | **210** | **147.90** | **46.75** | **6.09** |

On average, elephant dung in ASF took 147.90 days (SE ± 6.09) to completely decay and therefore the elephant dung decay rate (r) for this forest was 0.0068 per day. A Comparison of the mean dung survival time on each habitat type, showed that dung piles in the open vegetation took longest time to completely decay (191.33 days) compared forest plantation, mixed forest and *Brachystegia* woodland respectively.Analysis of variance test showed that there was a significant difference (*P=0.0269)* in the mean survival time of dung piles between the habitat types.

**Table 4.2: Tukey's pairwise comparison for mean dung survival time between the four vegetation types**

| **Habitat Type** | **Mixed forest** | ***Brachystegia* woodland** | **Forest plantation** | **Open habitat** |
|---|---|---|---|---|
| **Mixed forest** | 0.000 | 0.9689 | 0.6975 | 0.0533 |
| ***Brachystegia* woodland** | 0.6405 | 0.000 | 0.4199 | 0.1445 |
| **Forest plantation** | 1.541 | 2.181 | 0.000 | **0.0027** |
| **Open habitat** | 3.71 | 3.07 | 5.251 | 0.000 |

Mean separation using Tukey's pairwise comparison further showed that there was only a significant difference (*P=0.0027*) in dung survival time between plantation and open vegetation as shown in table 4.2.

### 4.1.2 Elephant population

A total of 1823 dung piles were encountered and counted along the 34 line transects (Appendix 1). Survey efforts were based the total area of the vegetation habitats. *Cynometra* vegetation habitat had the highest number of transects and forest plantation the least transect numbers.

**Table 4.3: Elephant dung distribution as recorded along the line transects laid within Arabuko Sokoke Forest**

| Habitat type | total No of dung piles | No of transects | total length of transects | Elephant dung pile per Km |
|---|---|---|---|---|
| ***Brachystegia* vegetation** | 197 | 10 | 10000 | **0.0197** |
| ***Cynometra* vegetation** | 163 | 12 | 11500 | **0.0142** |
| **Mixed vegetation** | 606 | 7 | 7000 | **0.0866** |
| **Other vegetation** | 752 | 4 | 4000 | **0.1880** |
| **Exotic tree Plantation** | 105 | 1 | 1000 | **0.1050** |
| **Total** | **1823** | **34** | **33500** | **0.0544** |

It was however observed that despite more survey efforts being employed on the *Cynometra* spp. vegetation habitat, only 123 dung piles were recorded in this vegetation. This was 35.6% more than the dung piles encountered in the forest plantation vegetation which had the lowest survey efforts.

The encountered dungs were fitted to DISTANCE softwareTrunc1000stratHaz+poly model to give an elephant. The dung pile density (Y) of 1365.4 dungs piles per square kilometre with a 95% Confidence Interval of 931.6 to 2001.2. The mean dung decay rate (r) including its standard error (147.90, SE=6.09), standard defecation rate of 18.07 (S.E=0.0698) (Hedge & Lawson, 2006) and the elephant dung density (Y) were incorporated into the model to give the elephant density (E) of 0.51 per square kilometre. The estimated elephant population was 215 with 95% Confidence Interval of 145 to 318 elephants as shown in table 4.4.

**Table 4.4: ASF elephant dung pile density (Y), elephant density (E) and population (EP) in major habitats**

| **Habitat type** | **Y per $Km^2$** | **95% Confidence interval of Y** | **E per $Km^2$** | **EP (n)** | **95% Confidence interval of EP** |
|---|---|---|---|---|---|
| *Brachystegia* vegetation | 635.17 | 186.9 - 2158.6 | 0.25 | 18 | 54 – 62 |
| *Cynometra* vegetation | 476.87 | 323.2 - 703.7 | 0.18 | 42 | 28 – 62 |
| Mixed vegetation | 2856.00 | 1043.7 - 7815.0 | 1.07 | 75 | 27 – 205 |
| Other vegetation | 6377.70 | 4820.7 - 8437.5 | 2.39 | 67 | 50 – 87 |
| Exotic tree plantation | 3401.40 | 3015.6 - 3836.7 | 1.27 | 13 | 11 – 15 |
| **Total** | **1365.40** | **931.6 - 2001.2** | **0.51** | **215** | **145 – 318** |

The vegetation zone with the highest dung pile density was within the other vegetation zone with a dung density of 6377.70 (95% CI=4820.7 to 8437.5) and an elephant density (E) of 2.39 per square kilometer. The *Cynometra* vegetation had the least dung pile density of 476.87 (95% CI=323.2 to 703.7) and an elephant density of 0.18 per square kilometer. However, despite the mixed vegetation not having a high dung pile and elephant density, it had the highest elephant population of 75 as shown in Table 4.4.

## 4.2 Elephant distribution

Taking dung piles density as measure of relative abundance and dung pile distribution as a measure of occupancy of elephants in ASF, results from this study show that other vegetation habitat type had the highest dung pile density (Y) of 6377.7 dung piles/$Km^2$ and an elephant density of 2.39 ( table 4.5).

**Table 4.5: ASF elephant dung pile density and elephant density in major habitat type**

| Habitat type | Dung pile density (Y) per $Km^2$ | 95% Confidence interval of Dung pile density | Elephant density (E) per $Km^2$ |
|---|---|---|---|
| *Brachystegia* vegetation | 635.17 | 186.9 - 2158.6 | 0.25 |
| *Cynometra* vegetation | 476.87 | 323.2 - 703.7 | 0.18 |
| Mixed vegetation | 2856.00 | 1043.7 - 7815.0 | 1.07 |
| Other vegetation | 6377.70 | 4820.7 - 8437.5 | 2.39 |
| Exotic tree plantation | 3401.40 | 3015.6 - 3836.7 | 1.27 |
| **Total** | **1365.40** | **931.6 - 2001.2** | **0.51** |

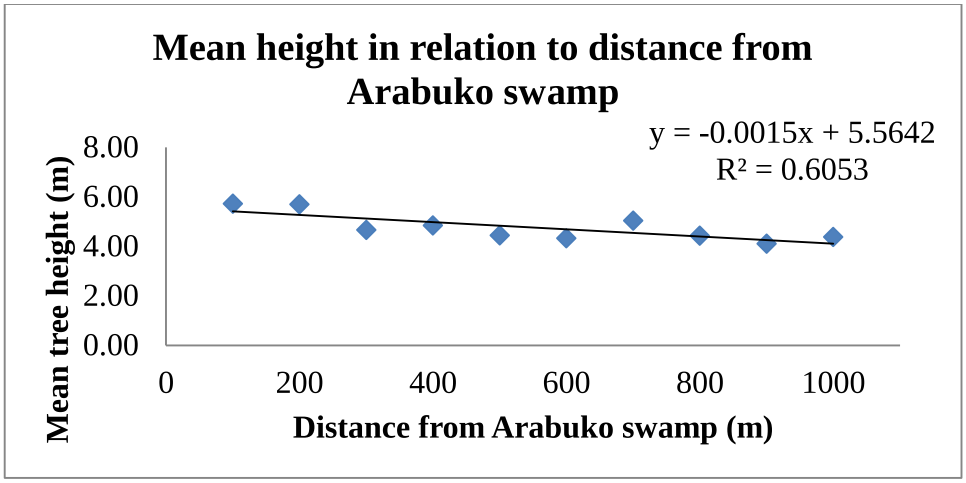
*Cynometra* vegetation had the least dung pile density of 476.87 per squared kilometre and 0.18 elephant density. However, 34.9% of the total elephants were recorded in mixed vegetation, 31.2% in other vegetation types, 19.5% in *Cynometra*, while 8.4% and 6% of the elephants were recorded in the *Brachystegia* and exotic tree plantation vegetation respectively.

## 4.3 Impacts of elephant foraging on vegetation around water points

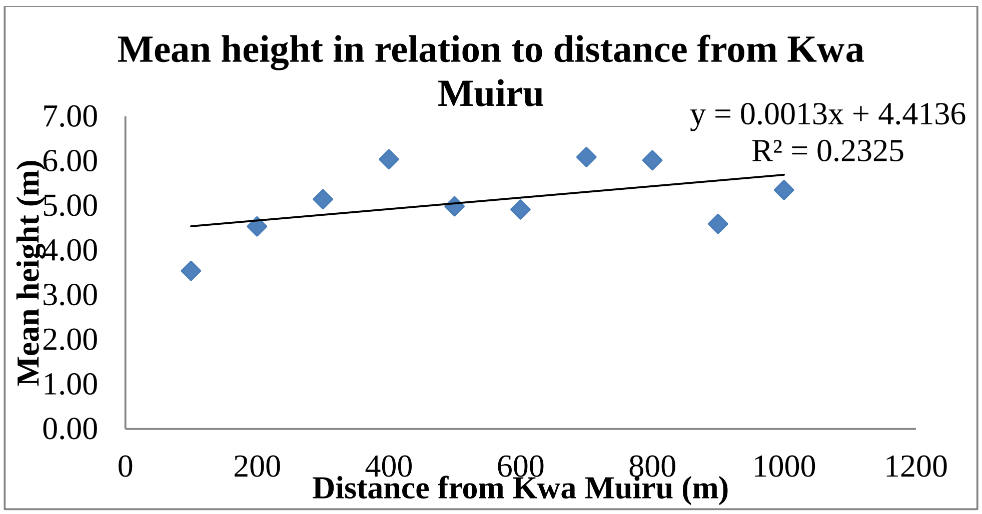
### 4.3.1: Effect on vegetation structure in relation to distance from the water points

#### 4.3.1.1 Height

There was a significant difference (*P<0.005)* between the mean height of trees in all plots set in both water points except in the plots set at 300m and 600m from the water points. Regression analysis showed that there was a strong negative linear correlation between the mean height and distance from Arabuko swamp (r=0.7780; *P*<0.0001) whereas at Kwa Muiru there was a strong positive relationship (r =0.4821; *P*<0.0001) between the mean height and distance from the water point as shown in figure 4.1.




(a)



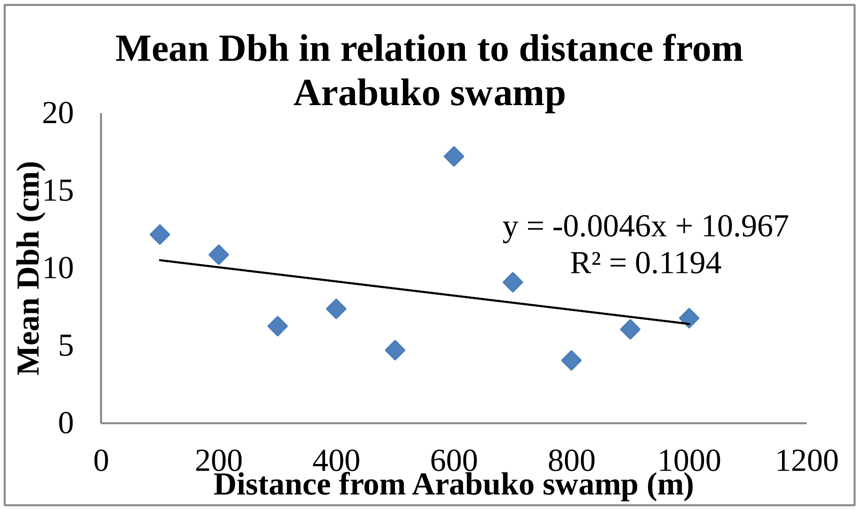

**(b)**

**Figure 4.1:(a) and (b) represent the linear relationship between mean heights in relation to distance from the Arabuko swamp and Kwa Muiru water point respectively**

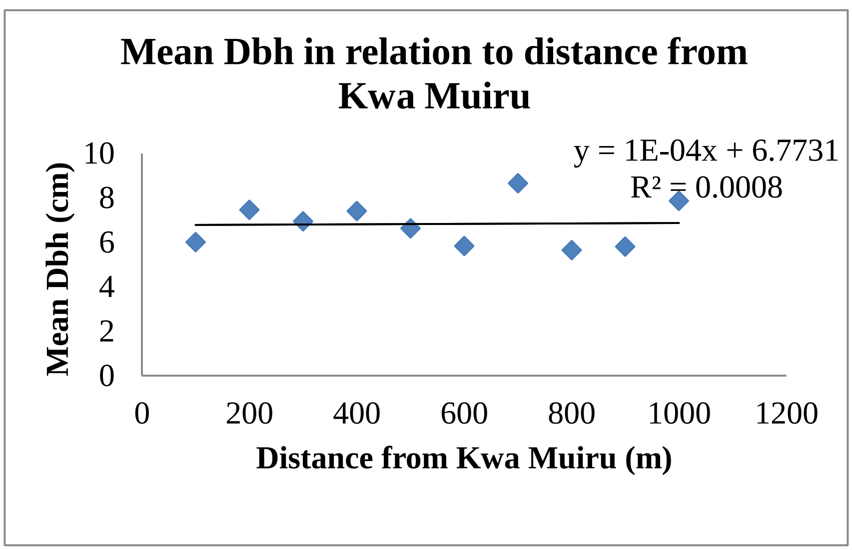
#### 4.3.1.2 Diameter at breast height (Dbh)

There was a significant difference in the Dbh recorded at plots located at only 100m (*p<0.0001)*, 500m (*P=0.0250)* and 800m (*P=0.0434)* from both water points.

There was  a strong negative linear relationship between mean Dbh in relation to distance from Arabuko swamp (*r=0.3455; P=0.0038*). However, at Kwa Muiru there was a strong positive linear relationship (*r =0.02914; P<0.001)* between the mean Dbh and increasing distance from the water point as shown in figure 4.2.




**(a)**

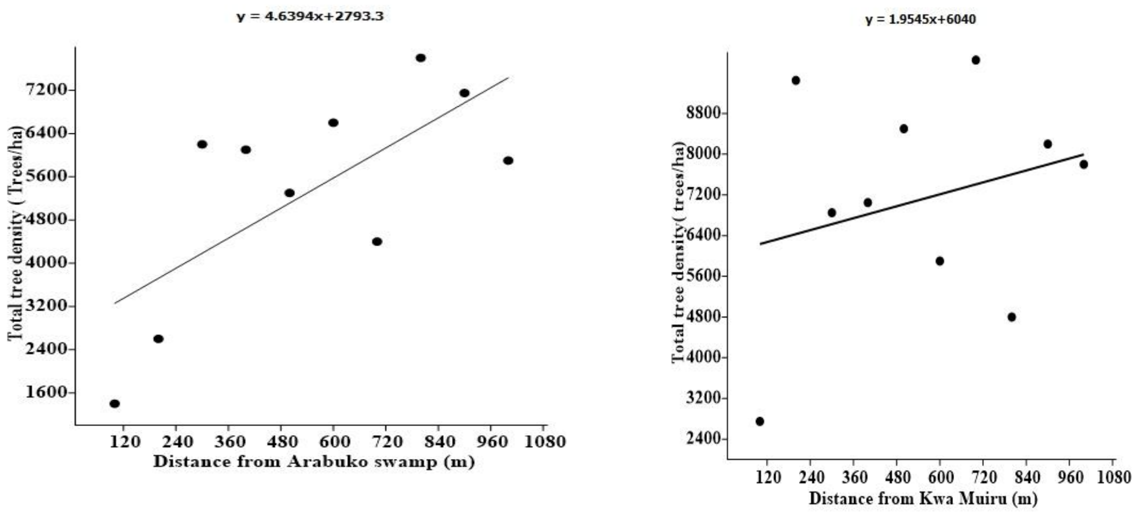



**(b)**

**Figure 4.2: (a) and (b) represent the linear relationship between Diameter at breast height and distance from Arabuko swamp and Kwa Muiru water points respectively**

#### 4.3.1.3 Tree density

Tree density increased significantly with increasing distance from both Arabuko Swamp (*$P=0.0282$; $r^2=0.4870$*) and Kwa Muiru *($P=0.004$; $r^2=0.0742$*) respectively as shown in figure 4.3




(a) (b)

**Figure 4.3: (a) and (b) Linear relationship between tree density in relation to distance from Arabuko Swamp and Kwa Muiru respectively**

#### 4.3.1.4: Species diversity

Kwa Muiru had 99 woody plant species compared whereas Arabuko swamp there were 85 woody plant species. The top five families recorded around Kwa Muiru water point were *Annonaceae, Fabaceae, Rubiciaceae,Tiliacea and Celestraceae* while around Arabuko swamp the top 5 families were *Rubiaceae, Fabaceae, Annonaceae, Euphobiaceae, Sapotaceae, Tiliaceae.* Similarly, the species diversity, richness and dominance was higher at Kwa Muiru than Arabuko swamp as shown in table 4.7.

**Table 4.6: Species diversity (H), Simpson's dominance (D) and Evenness at plots set around Arabuko swamp (AS) and Kwa Muiru (KM)**

| Distance from water point (m) | Richness | | Diversity (H) | | Dominance (Simpson (D)) | | Evenness | |
|---|---|---|---|---|---|---|---|---|
| | AS | KM | AS | KM | AS | KM | AS | KM |
| **100** | 15 | 22 | 2.543 | 2.779 | 0.9082 | 0.9183 | 0.848 | 0.732 |
| **200** | 20 | 45 | 2.801 | 3.149 | 0.9283 | 0.9246 | 0.8232 | 0.5179 |
| **300** | 38 | 34 | 3.168 | 3.083 | 0.9373 | 0.9355 | 0.6252 | 0.6421 |
| **400** | 31 | 35 | 2.846 | 3.091 | 0.9145 | 0.9349 | 0.5553 | 0.6288 |
| **500** | 23 | 32 | 2.731 | 3.013 | 0.9164 | 0.9372 | 0.6674 | 0.6361 |
| **600** | 34 | 33 | 2.924 | 3.052 | 0.9167 | 0.9344 | 0.5475 | 0.6412 |
| **700** | 23 | 53 | 2.321 | 3.407 | 0.7937 | 0.9455 | 0.4430 | 0.5695 |
| **800** | 27 | 29 | 2.565 | 2.943 | 0.8740 | 0.9245 | 0.4815 | 0.6544 |
| **900** | 31 | 41 | 2.746 | 3.217 | 0.8964 | 0.9422 | 0.5028 | 0.6088 |
| **1000** | 36 | 47 | 3.115 | 3.469 | 0.9325 | 0.9601 | 0.6260 | 0.6832 |
| ***P*- value** | **0.0234** | | **0.0057** | | **0.041** | | **0.6734** | |

In table 4.6, a t-test showed that,there was a significant difference ($P< 0.05$) between species richness, diversity and dominance between the two water points.

## 4.3.2: Impact of elephant browsing and debarking on vegetation composition

### 4.3.2.1 Browsing

Around Arabuko swamp 1069 individual trees belonging to 77 species and 29 families were recorded. Around Kwa Muiru 1423 individual trees belonging to 80 species and 38 families were recorded. In both water points, woody plants belonging to *Annonaceae, Combretaceae, Euphobiaceae, Rubiaceae, Sapotaceaee, Tiliceae, Fabaceae, Sapindaceae* families were identified and recorded.

**Table 4.7: Proportional of plants browsed at Arabuko swamp and Kwa Muiru water points under each browsing category**

| Variable | Browsing Categories | Description | Proportion utilized (%) Arabuko Swamp | Kwa Muiru |
|---|---|---|---|---|
| Browsing | 0 | Not browsed | 69.8 | 61.2 |
| | 1 | Tertiary branches broken | 5.6 | 7.2 |
| | 2 | Secondary branch broken | 9.6 | 13.3 |
| | 3 | Primary branches broken | 5.4 | 10.6 |
| | 4 | Main stem utilization | 9.5 | 7.7 |

Out of the total tree recorded at Arabuko swamp, 30.2% (n=323) woody plants belonging to 56 species and 24 families were browsed while at Kwa Muiru 38.8% (n=552) of woody plants belonging to 77 species and 33 families of the total trees recorded were browsed as shown in Table 4.8 and 4.9 respectively.

The highest proportion of the browsed plants on both water points were those that had the secondary branches broken ( Table 4.7). A proportion of 31.9% and 34.2% of the total browsed woody plants recorded at both water points were browsed under this category as presented in figure 4.4.

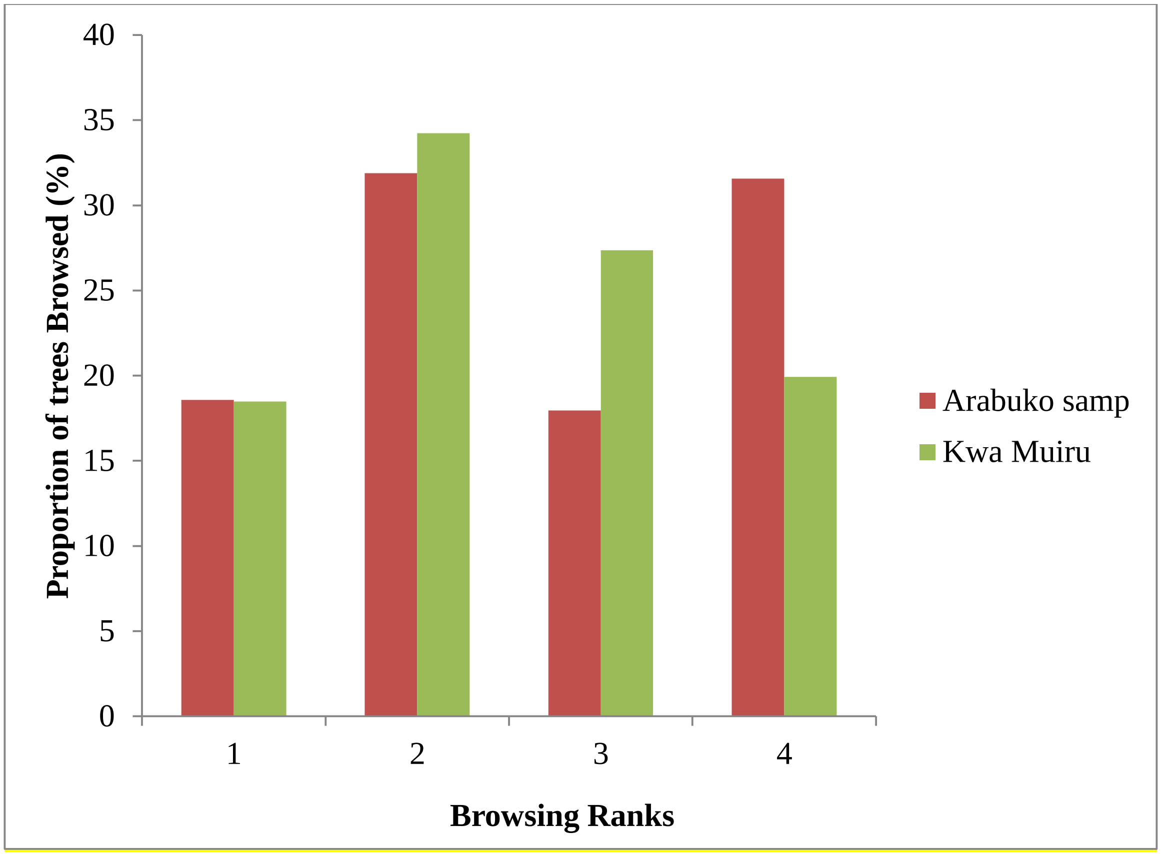



**Figure 4.4: Proportion of plants browsed around Arabuko Swamp and Kwa Muiru water points**

**Table 4.8: Woody plants utilized by elephants around Kwa Muiru water point in ASF (Gir ) refers to Giriama)**

| Botanical name of woody plant at Kwa Muiru | Family name | Total woody plants recorded | Number of plants browsed | Number of plants debarked |
|---|---|---|---|---|
| *Ozoroa obovata* | *Anacardiaceae* | 4 | 4 | 3 |
| *Lannea schweinfurthii* | *Anacardiaceae* | 1 | 0 | 0 |
| *Uvaria acuminata* | *Annonaceae* | 14 | 4 | 0 |
| *Asteranthe asterias* | *Annonaceae* | 19 | 3 | 1 |
| *Annona senegalensis* | *Annonaceae* | 6 | 3 | 0 |
| *Xylopia parviflora* | *Annonaceae* | 2 | 1 | 0 |
| *Uvaria lucida* | *Annonaceae* | 8 | 0 | 0 |
| *Monanthotaxis fornicate* | *Annonaceae* | 7 | 0 | 0 |
| *Landolphia kirkii* | *Apocynaceae* | 48 | 2 | 1 |
| *Tabernaemontana elegoms* | *Apocynaceae* | 1 | 0 | 0 |
| *sarcostemma viminale* | *Asclepiadaceae* | 1 | 0 | 0 |
| *Brachylaena huilensis* | *Asteraceae* | 1 | 0 | 0 |
| *Markhamia zanzibarica* | *Bignoniaceae* | 15 | 7 | 2 |
| *Bourreria petiolaris* | *Boraginaceae* | 2 | 1 | 0 |
| *Commiphora edulis* | *Burseraceae* | 7 | 6 | 1 |
| *Notobux obtusifolia* | *Buxaceae* | 30 | 18 | 2 |
| *Capparis sepiaria* | *Capparaceae* | 9 | 2 | 0 |
| *Maerua triphylla* | *Capparaceae* | 3 | 0 | 0 |
| *Elaeodendron shweinfurthianum* | *Celastraceae* | 13 | 6 | 1 |
| *Salacia madagascariensis* | *Celastraceae* | 19 | 2 | 1 |
| *Maytenus mossambicemsis* | *Celastraceae* | 2 | 0 | 0 |
| *Mystroxylon aethiopicum* | *Celastraceae* | 1 | 0 | 0 |
| *Pleurostylia africana* | *Celastraceae* | 1 | 0 | 0 |
| *Combretum schumannii* | *Combretaceae* | 76 | 54 | 10 |
| *Combretum collinum* | *Combretaceae* | 6 | 4 | 3 |
| *Quisqualis littorea* | *Combretaceae* | 6 | 3 | 0 |
| *Terminalia boivinii* | *Combretaceae* | 2 | 0 | 1 |
| *Metaporana densiflora* | *Convolvuaceae* | 9 | 2 | 0 |
| *Diospyros consolatae* | *Ebenaceae* | 26 | 16 | 4 |
| *Diospyros abyssinica* | *Ebenaceae* | 3 | 1 | 0 |
| *Suregada zamzibarensis* | *Euphobiaceae* | 62 | 26 | 2 |
| *Croton pseudopulchellus* | *Euphobiaceae* | 55 | 14 | 2 |
| *Drypetes natalensis* | *Euphobiaceae* | 11 | 7 | 2 |
| *Phyllanthus reticulatus* | *Euphobiaceae* | 1 | 1 | 0 |
| *Afzelia quanzensis* | *Fabaceae* | 29 | 7 | 2 |
| *Hymenaea verrucosa* | *Fabaceae* | 9 | 2 | 5 |
| *Mimosa pigra* | *Fabaceae* | 3 | 2 | 0 |

| | | | | |
|---|---|---|---|---|
| *Dialum orientale* | | 2 | 1 | 1 |
| *Dichrostachys cinereal* | | 1 | 1 | 1 |
| *Termarindus indica* | | 1 | 0 | 0 |
| *Ludia mauritiana* | *Flacourtiaceae* | 6 | 1 | 1 |
| *Vitex ferruginea* | | 6 | 5 | 2 |
| *Polyalthia stuhlmannii* | *Lamiaceae* | 3 | 1 | 0 |
| *Hoslundia opposite* | | 1 | 1 | 0 |
| *Lonchocarpus busseii* | *Leguminosae-papilionoideae* | 4 | 1 | 1 |
| *Hugonia castaneifolia* | *Linaceae* | 115 | 16 | 1 |
| *Strychnos madagascariensis* | *Loganiaceae* | 48 | 9 | 0 |
| *Gossypioides kirkii* | *Malvaceae* | 15 | 8 | 2 |
| *Turraea robusta* | *Meliaceae* | 20 | 5 | 0 |
| *Trichiliia emetica* | | 15 | 2 | 0 |
| *Ochna mossambicensis* | *Ochnaceae* | 65 | 34 | 3 |
| *Ximenia Americana* | *Olacaceae* | 2 | 1 | 0 |
| *Adenia gummifera* | *Passifloraceae* | 3 | 0 | 0 |
| *Schlecterina mitostemmatoides* | | 1 | 0 | 0 |
| *Antidesma venosum* | *Phyllanthaceae* | 1 | 1 | 1 |
| *Heinsia crinita* | | 120 | 52 | 7 |
| *Feretia apodanthera* | | 88 | 39 | 6 |
| *Polysphaeria parvifolia* | *Rubiceae* | 78 | 29 | 3 |
| *Canthium glaucum* | | 6 | 3 | 0 |
| *Gardenia volkensii* | | 2 | 2 | 1 |
| *Pavetta stenosepala* | | 4 | 1 | 0 |
| *Zanthoxylum chalybeum* | *Rutaceae* | 3 | 2 | 0 |
| *Teclea trichocarpa* | *Rutaceae* | 1 | 0 | 0 |
| *Salvadora persica* | *Salvadoraceae* | 2 | 1 | 1 |
| *Haplocoelum inopleum* | | 44 | 31 | 7 |
| *Lecamodiscuss fraxifolius* | *Sapindaceae* | 7 | 7 | 1 |
| *Allophylus rubifolius* | | 1 | 1 | 1 |
| *Deinbolia borbonica* | | 1 | 0 | 0 |
| *Manilkara sulcate* | | 32 | 18 | 12 |
| *Manilkara zamzibarensis* | *Sapotaceae* | 4 | 2 | 1 |
| *Mimusops obtusifolia* | | 4 | 1 | 1 |
| *Sideroxylon ineme* | | 1 | 1 | 0 |
| *Grewia truncata* | | 22 | 18 | 6 |
| *Grewia plagiophylla* | | 12 | 5 | 1 |
| *Grewia similis* | *Tiliaceae* | 18 | 3 | 0 |
| *Carpodiptera africana* | | 4 | 2 | 1 |
| *Grewia vaughanii* | | 2 | 1 | 1 |
| *Premna chrysoclada* | *Verbenaceae* | 1 | 1 | 0 |

| | | | | |
|---|---|---|---|---|
| *Cissus integrifolia* | *Vitaceae* | 25 | 1 | 1 |
| *Encelophalortos hildebrandtii* | *Zamiaceae* | 1 | 0 | 0 |
| Mwarika (Gir□) | | 51 | 17 | 7 |
| Mgome (Gir□) | | 36 | 13 | 1 |
| Msaji (Gir□) | | 11 | 4 | 3 |
| Oldfieldea somalensis | | 4 | 2 | 1 |
| Mfungamambo (Gir*) | | 3 | 1 | 0 |
| Mboho (Gir*) | | 2 | 1 | 0 |
| Mgandamwe (Gir*) | | 1 | 1 | 1 |
| Mhogo mwitu (Gir*) | | 1 | 1 | 0 |
| Mtsulapengo (Gir*) | | 3 | 0 | 0 |
| Mrusapungu (Gir*) | | 2 | 0 | 0 |
| Mshari (Gir*) | | 2 | 0 | 0 |
| Mbavibavi (Gir*) | | 1 | 0 | 0 |
| Mkirwango (Gir*) | | 1 | 0 | 0 |
| Mtongazi (Gir*) | | 1 | 0 | 0 |
| Mvugula (Gir*) | | 1 | 0 | 0 |
| **Total** | | **1424** | **546** | **120** |

**Table 4.9: Woody plants utilized by elephants around Arabuko Swamp in ASF**

| Species recorded at Arabuko swamp | Family name | Total woody plants recorded | Number of plants browsed | Number of plants debarked |
|---|---|---|---|---|
| *Lannea schweinfurthii* | | 2 | 2 | 0 |
| *Ozoroa obovata* | *Anacardiaceae* | 2 | 0 | 1 |
| *Uvaria acuminata* | | 21 | 5 | 3 |
| *Asteranthe asterias* | | 4 | 4 | 2 |
| *Uvaria lucida* | | 11 | 2 | 1 |
| *Carrissa edulis* | | 3 | 1 | 0 |
| *Polyalthia stuhlmannii* | | 11 | 1 | 2 |
| *Monanthotaxia fornicata* | *Annonaceae* | 1 | 0 | 0 |
| *Carissa tetramera* | | 1 | 0 | 0 |
| *Landolphia kirkii* | *Apocynaceae* | 12 | 0 | 0 |
| *Brachylaena huilensis* | *Asteraceae* | 8 | 2 | 1 |
| *Notobux obtusifolia* | *Buxaeae* | 7 | 0 | 0 |
| *Maerua tryphylla* | *Capparaceae* | 1 | 0 | 0 |
| *Salacia madagascariensis* | | 33 | 6 | 4 |
| *Elaeodendron shweinfurthianum* | | 11 | 2 | 1 |
| *Maytenus mossambicemsis* | | 3 | 2 | |
| *Pleurostylia africana* | *Celastraceae* | 1 | 0 | 0 |
| *Combretum schumannii* | | 19 | 15 | 4 |
| *Combretum illairii* | | 4 | 0 | 0 |
| *Terminalia boivinii* | | 1 | 0 | 0 |
| *Combretum ilarii* | | 73 | 4 | 4 |
| *Combretum collinum* | *Combretaceae* | 3 | 2 | 0 |
| *Suregada zamzibarensis* | | 39 | 18 | 2 |
| *Croton pseudopulchellus* | | 46 | 8 | 1 |
| *Croton menyharthii* | *Euphobiaceae* | 2 | 2 | 0 |
| *Dialium orientale* | | 7 | 7 | 3 |
| *Afzelia quanzensis* | | 2 | 2 | 1 |
| *Brachystegia spiciformis* | | 18 | 1 | 2 |
| *Dichrostachys cinerea* | | 1 | 1 | 1 |
| *Tamarindus indica* | | 1 | 1 | 1 |
| *Hymenaea verrucosa* | *Fabaceae* | 2 | 0 | 0 |
| *Visimia orientalis* | *Guttiferae* | 3 | 2 | 2 |
| *Vitex ferruginea* | | 4 | 3 | 3 |
| *Premna chrysoclada* | *Lamiaceae* | 2 | 1 | 1 |
| *Lonchocarpus buseii* | *Leguminosae-papilionoideae* | 4 | 2 | 3 |

| | | | | |
|---|---|---|---|---|
| *Hugonia castaneifolia* | *Linaceae* | 13 | 4 | 1 |
| *Strychnos madagascariensis* | *Loganiaceae* | 82 | 34 | 10 |
| *Strychnos spinosa* | *Loganiaceae* | 6 | 6 | 3 |
| *Hibiscus micranthus* | *Malvaceae* | 1 | 1 | 0 |
| *Turraea robusta* | *Meliaceae* | 2 | 0 | 0 |
| *Ochna mossambicemsis* | *Ochnaceae* | 13 | 5 | 1 |
| *Ximenia americana* | *Olaceae* | 1 | 1 | 1 |
| *Schlecterina mitostmmatoides* | *Passifloraceae* | 2 | 0 | 0 |
| *Fueggea virosa* | | 2 | 1 | 1 |
| *Phyllanthus reticulatus* | *Phyllanthaceae* | 1 | 0 | 0 |
| *Feretia apodanthera* | | 202 | 58 | 25 |
| *Polysphaeria parvifolia* | | 15 | 5 | 1 |
| *Canthium glaucum* | | 11 | 3 | 1 |
| *Pavetta stenosepala* | | 72 | 3 | 0 |
| *Heinsia crinita* | | 8 | 2 | 0 |
| *Gardenia volkensii* | *Rubiaceae* | 1 | 1 | 0 |
| *Zanthozylem chalybeum* | | 1 | 0 | 1 |
| *Zanthozylem holtzianum* | *Rutaceae* | 2 | 0 | 1 |
| *Haplocoelum inopleum* | *Sapindaceae* | 32 | 20 | 11 |
| *Mimusops obtusifolia* | | 3 | 3 | 2 |
| *Manilkara sulcata* | | 36 | 1 | 16 |
| *Manilkara zamzibarensis* | | 3 | 1 | 1 |
| *Sideroxylon inerme* | *Sapotaceae* | 4 | 0 | 1 |
| *Nesogordia holtzi* | | 25 | 6 | 5 |
| *Nesogordonia holtzii* | | 1 | 0 | 0 |
| *Grewia truncata* | *Sterculiaceae* | 20 | 13 | 4 |
| *Carpodiptera africana* | | 18 | 3 | 2 |
| *Grewia plagiophyla* | | 8 | 1 | 1 |
| *Grewia similis* | | 6 | 0 | 0 |
| *Grewia stuhlmanii* | *Tiliaceae* | 1 | 0 | 0 |
| *Cissus integrifolia* | *Vitaceae* | 19 | 1 | 1 |
| *Balanitesa aegyptica* | *Zygophyllaceae* | 1 | 1 | 0 |
| Mhambo wa birya (Gir) | | 9 | 7 | 3 |
| Mwatsa (Gir) | | 14 | 6 | 6 |
| Oldfieldea somalensis | | 8 | 6 | 3 |
| Laptactina platyphylla | | 20 | 5 | 0 |
| Mwarika (Gir) | | 9 | 4 | 4 |
| Mgome (Gir) | | 14 | 3 | |

| | | | |
|---|---|---|---|
| Mvugula (Gir) | 12 | 3 | 2 |
| Mpepeta (Gir) | 2 | 2 | 2 |
| Chea komba (Gir) | 1 | 0 | 0 |
| Mboho (Gir) | 1 | 0 | 1 |
| Mtsulapengo (Gir) | 4 | 0 | 1 |
| **Total** | **1069** | **306** | **155** |

A total of 85 plant species were recorded at Arabuko Swamp while at Kwa Muiru, 99 species of plants were recorded. *Feretia apodanthera* was most common (n=202) tree species recorded at Arabuko Swamp while at Kwa Muiru *Heinsia crinita* had the most individuals (n=120) accounting for 8.43% of the total plant species recorded. Out of the 85 species recorded in Arabuko Swamp, 58 species were browsed while at Kwa Muiru 79 species were browsed. At Arabuko Swamp, *Feretia apodanthera* species were highly browsed (n=58) while at Kwa Muiru *Combretum schumannii* were the most browsed upon tree species (n=54).

The total tree density of the browsed trees was 1615 trees/ ha and 2760 trees/ha at Arabuko swamp and Kwa Muiru respectively. There was a negative linear relationship between the browsed tree density and distance from both Arabuko swamp ($r^2$ =0.2017; $P$>0.05;) and Kwa Muiru ($r^2$ =0.0651;$P$>0.05) water points as shown in figure 4.5

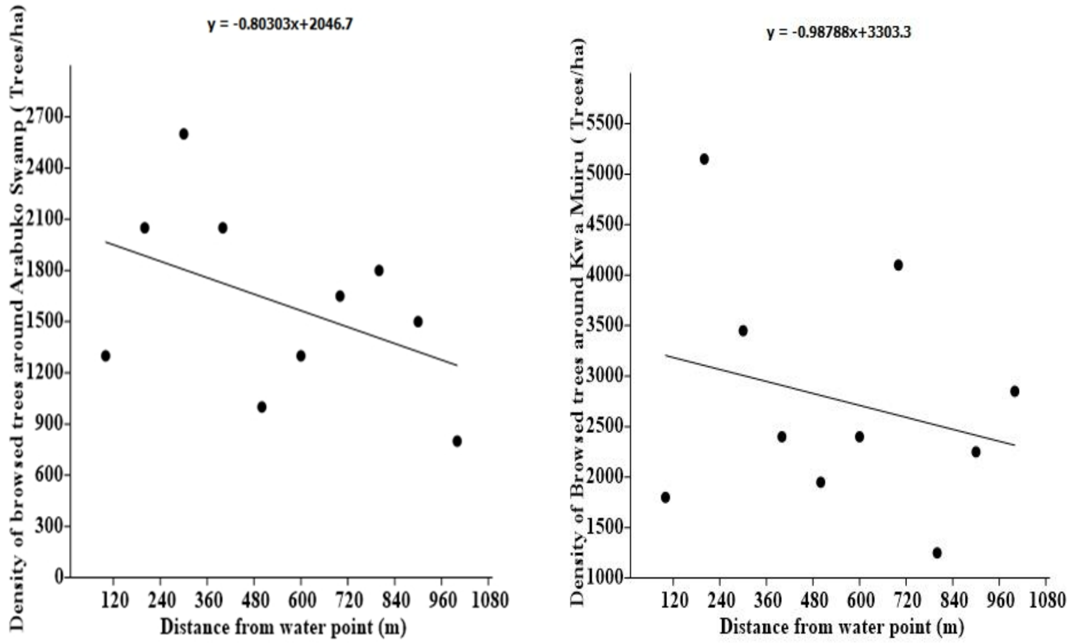



**Figure 4.1: The relationship between the density of browsed trees and distance from Arabuko and Kwa Muiru water point respectively**

#### 4.3.2.2 Debarking

At Arabuko Swamp only 15.2% (n=162) of the total trees recorded were debarked while at Kwa Muiru 8.5% (n=121) of the total trees recorded were debarked as shown in table 4.10.

**Table 4.10: Proportion of plants debarked around Arabuko Swamp and Kwa Muiru water points under each debarking category**

| Variable | Debarking categories | Description | Proportion utilized (%) | |
|---|---|---|---|---|
| | | | Arabuko Swamp | Kwa Muiru |
| Debarking | 0 | No damage | 84.8 | 91.5 |
| | 1 | Slight damage with few scars | 5.2 | 4.8 |
| | 2 | Moderate damage with numerous scars | 4.4 | 1.9 |
| | 3 | Severe damage with tree scarred deeply | 1.7 | 0.7 |
| | 4 | Tree dead or fell | 3.8 | 1.1 |

The highest proportion of debarked trees were those with slight damge with few scars in rank 1. Around Arabuko swamp and Kwa Muiru water point 34.6%% and 56.2% of the recorded debarked trees were slighly damaged in rank one respectively (Figure 4.6)the numbers of trees debarked in each browsing category.

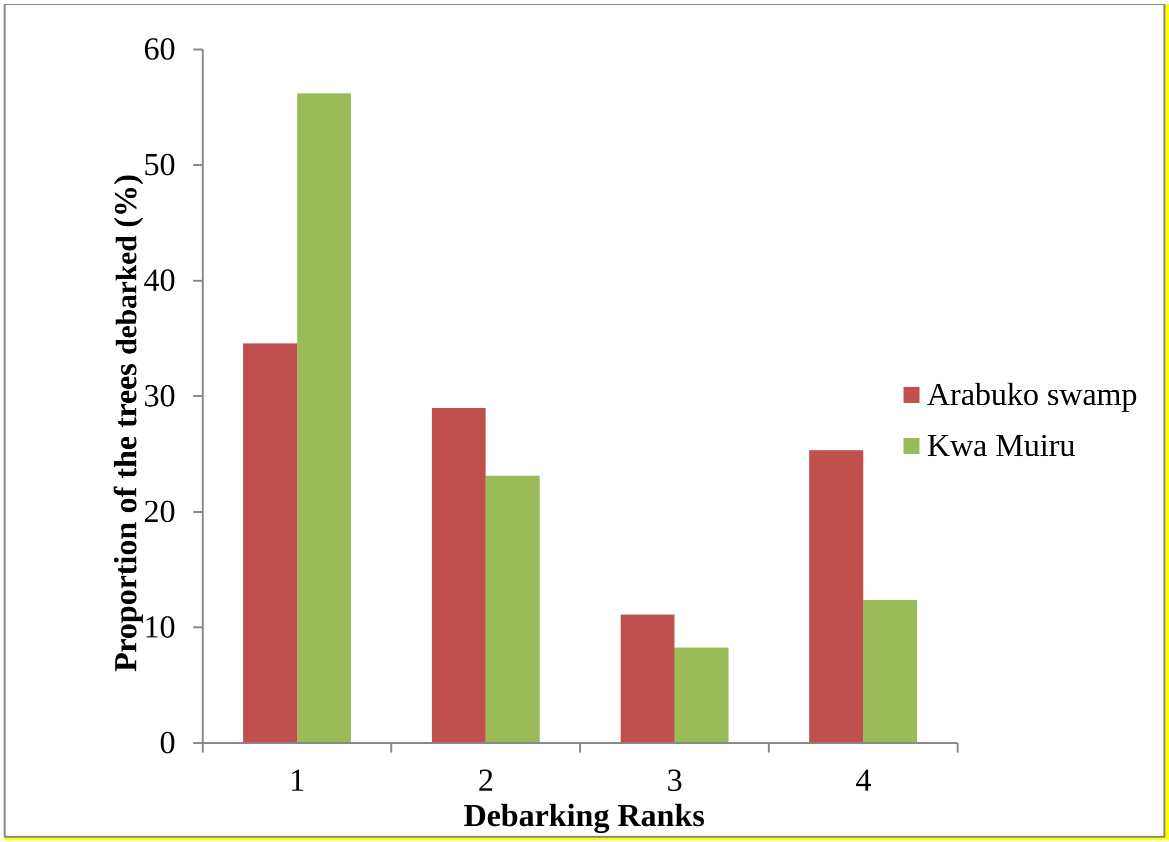



**Figure 4.1: Number of debarked trees in each debarking rank**

At Arabuko Swamp, 53 plant species were debarked with *Feretia apodanthera* being highly debarked (n=25) whereas at Kwa Muiru 47 plant species were debarked with *Manilkara sulcata* being highly debarked (n=12). The total tree density of the trees debarked were 810 trees/ha at Arabuko and 605 trees/ ha at Kwa Muiru.

There was a negative linear relationship between the number of debarked plants and distance from both Arabuko Swamp ($r^2$ =0.3729; $P$>0.05) and Kwa Muiru ($r^2$ =0.0551; $P$>0.05 ) respectively as shown in figure 4.7

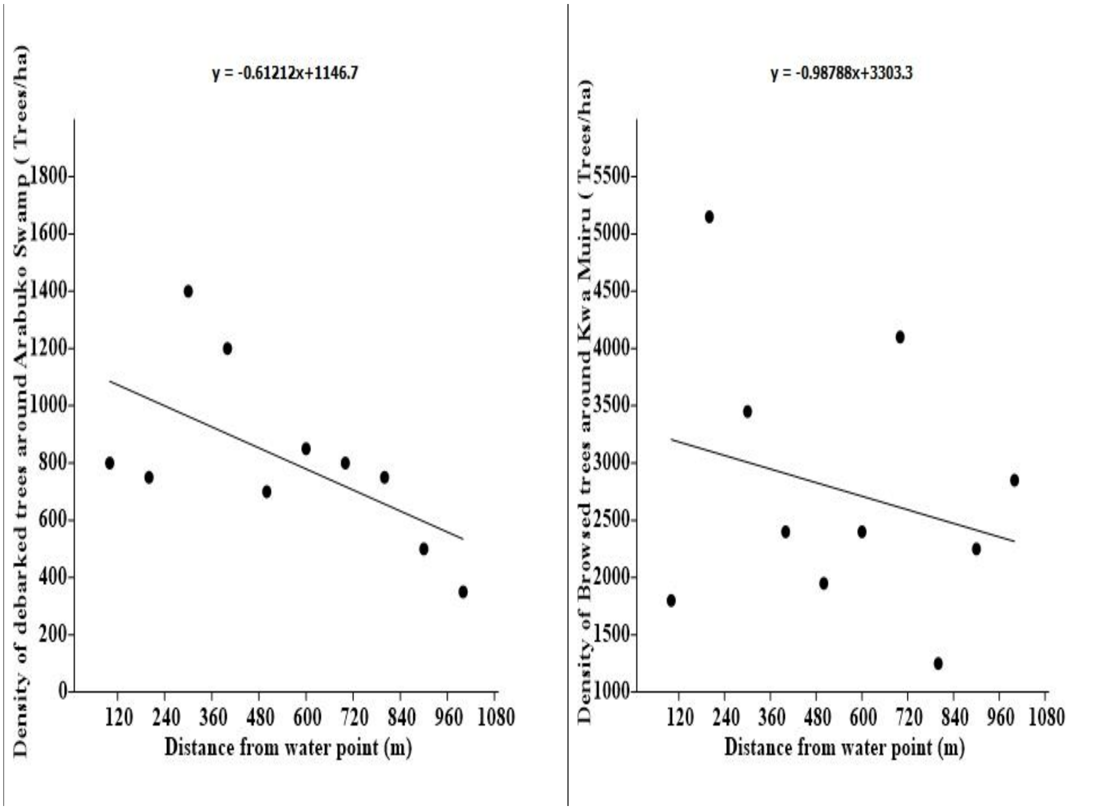



**Figure 4.2: The relationship between the density of debarked trees and distance from Arabuko and Kwa Muiru water point respectively**

### 4.3.3: Impacts of elephants on heavily utilized tree species

It was observed that elephants in ASF browsed on plants more than debarking. Based on the proportion of plant species browsed, five plant species shown in table 4.11 that were commonly browsed in both water points were chosen to show the effect of elephant utilization on their height, *Dbh*, tree density and species diversity.

**Table 4.11: Common plant species highly browsed near Arabuko Swamp and Kwa Muiru water points**

| | Arabuko Swamp | | Kwa Muiru | |
|---|---|---|---|---|
| **Plant species** | **Total** | **Number browsed** | **Total** | **Number browsed** |
| ***Combretum schumannii*** | 19 | 15 | 76 | 54 |
| ***Feretia apodanthera*** | 202 | 58 | 88 | 39 |
| ***Haplocoelum inopleum*** | 32 | 20 | 44 | 31 |
| ***Grewia truncata*** | 20 | 13 | 22 | 18 |
| ***Suregada zamzibarensis*** | 39 | 18 | 62 | 26 |

#### 4.3.3.1: Height

A paired t-test showed that there was no significant difference (*P*>0.05) in the mean height of all the tree species in Arabuko swamp and Kwa Muiru water point as shown in table 4.12. The average height of each plant species between the two water points was found to have no significant difference (*P>0.05).*

**Table 4.12: Mean height (m) of most utilized plant species and t-test -values**

| | ***Combretum schumannii*** | | ***Feretia apodanthera*** | | ***Grewia truncata*** | | ***Haplocoelum inopleum*** | | ***Suregada zamzibarensis*** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Distance from water point (m)** | **Arabuko Swamp** | **Kwa Muiru** | **Arabuko Swamp** | **Kwa Muiru** | **Arabuko Swamp** | **Kwa Muiru** | **Arabuko Swamp** | **Kwa Muiru** | **Arabuko Swamp** | **Kwa Muiru** |
| **100** | 4.45 | 3.10 | 3.50 | 3.30 | 6.63 | 3.88 | 4.50 | 4.00 | 0.00 | 3.50 |
| **200** | 4.55 | 5.18 | 0.00 | 4.62 | 3.34 | 6.13 | 3.65 | 3.80 | 3.72 | 4.51 |
| **300** | 4.45 | 6.34 | 3.58 | 4.48 | 6.08 | 3.20 | 3.65 | 5.38 | 3.66 | 4.13 |
| **400** | 0.00 | 11.00 | 4.02 | 3.25 | 6.70 | 0.00 | 3.93 | 3.60 | 3.70 | 4.05 |
| **500** | 0.00 | 5.83 | 3.74 | 4.27 | 0.00 | 0.00 | 4.91 | 0.00 | 3.85 | 4.25 |
| **600** | 3.00 | 0.00 | 3.75 | 3.49 | 0.00 | 4.20 | 4.25 | 3.48 | 3.87 | 4.67 |
| **700** | 3.84 | 6.03 | 3.92 | 3.99 | 7.50 | 8.40 | 3.30 | 4.82 | 3.73 | 5.80 |
| **800** | 3.90 | 0.00 | 3.97 | 3.93 | 4.44 | 5.10 | 0.00 | 0.00 | 4.23 | 3.00 |
| **900** | 3.45 | 4.80 | 3.99 | 3.82 | 0.00 | 10.00 | 5.40 | 4.14 | 3.30 | 3.99 |
| **1000** | 3.55 | 4.66 | 4.26 | 3.84 | 5.60 | 4.80 | 0.00 | 4.24 | 6.10 | 4.88 |
| ***P*-value** | **0.2787** | | **0.4064** | | **0.7143** | | **0.9865** | | **0.1664** | |

*Combretum schumannii, Grewia truncata* and *Haplocoelum inopleum* had a negative linear relationship (i.e., $r^2$=0.0019, 0.0547 and 0.2298) respectively with distance from Arabuko Swamp while *Feretia apodanthera* and *Suregada zanzibarensis* had a positive linear relationship ($r^2$=0.2893 and 0.4599) respectively with increasing distance from Arabuko swamp. At Kwa Muiru water point *Combretum Schumannii* and *Feretia apodanthera* had negative linear relationship ($r^2$=0.0553,0.0062) with increasing distance from the water point. On the other hand, *Grewia truncata, Haplocoelum inopleum* and *Suregada zanzibarensis* had positive linear relationship ($r^2$= 0.1832,0.0229 and 0.0443) respectively with increasing distance from the water point.

#### 4.3.3.2: Diameter at Breast height

There was no significant difference (*P*>0.05) between the mean diameter at breast height of each plant species between the Artificial (Arabuko swamp) and natural (Kwa Muiru) water points when the data was subjected to a paired t-test.

**Table 4.13: Mean diameter at breast height of the most utilized plants around Arabuko swamp and t-test P-values**

| Distance from water point (m) | *Combretum schumannii* | | *Feretia apodanthera* | | *Grewia truncata* | | *Haplocoelum inopleum* | | *Suregada zanzibarensis* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Arabuko Swamp | Kwa Muiru | Arabuko Swamp | Kwa Muiru | Arabuko Swamp | Kwa Muiru | Arabuko Swamp | Kwa Muiru | Arabuko Swamp | Kwa Muiru |
| **100** | 6.73 | 4.41 | 8.59 | 4.22 | 9.28 | 9.51 | 10.82 | 6.21 | 0.00 | 5.56 |
| **200** | 7.66 | 7.69 | 0.00 | 4.60 | 6.11 | 22.32 | 3.98 | 8.45 | 7.03 | 4.27 |
| **300** | 12.83 | 13.44 | 4.67 | 4.64 | 14.46 | 13.69 | 6.63 | 7.82 | 3.53 | 4.60 |
| **400** | 0.00 | 16.55 | 3.69 | 3.87 | 15.09 | 0.00 | 8.90 | 6.73 | 3.79 | 4.79 |
| **500** | 0.00 | 7.57 | 3.40 | 4.05 | 0.00 | 0.00 | 7.52 | 0.00 | 4.25 | 5.48 |
| **600** | 7.48 | 0.00 | 3.12 | 3.20 | 0.00 | 3.09 | 2.64 | 6.46 | 3.71 | 4.48 |
| **700** | 10.17 | 12.46 | 5.32 | 4.08 | 21.80 | 8.81 | 4.33 | 8.76 | 4.04 | 3.66 |
| **800** | 6.62 | 0.00 | 3.76 | 3.87 | 6.28 | 11.46 | 0.00 | 0.00 | 4.83 | 3.15 |
| **900** | 5.40 | 3.11 | 3.97 | 3.59 | 0.00 | 19.43 | 14.23 | 8.22 | 4.89 | 4.16 |
| **1000** | 2.03 | 8.26 | 13.34 | 5.09 | 5.79 | 38.87 | 0.00 | 6.84 | 8.91 | 5.17 |
| ***P*-value** | **0.5374** | | **0.4396** | | **0.3240** | | **0.9782** | | **0.9678** | |

There was a positive linear correlation between the Dbh of *Feretia apodanthera* and *Suregada zanzibarensis* ($r^2$=0.1278 and 0.3213 respectively) with increasing distance from Arabuko swamp. The mean Dbh of *Combretum schumannii, Grewia truncata, Haplocoelum inopleum* had a negative linear relationship ($r^2$=0.0501, 0.056 and 0.0945 respectively) with increasing distance from Arabuko Swamp. At Kwa Muiru water point *Grewia truncata* had a positive correlation ($r^2$=0.1648) with increasing distance from the water point. However, the mean Dbh of *Combretum schumannii, Feretia apodanthera, Haplocoelum inopleum* and *Suregada zanzibarensis* had negative correlation ($r^2$=0.0761,0.0124,0.016 and 0.1433 respectively) with increasing distance from Kwa Muiru water point.

#### 4.3.3.3 Tree density (trees/ha)

*Feretia apodanthera* had the highest tree density in both water points compared to the other plant species. However, around Arabuko Swamp, *Feretia apodanthera* had a higher tree density (1010 trees/ha) compared to Kwa Muiru water point (440 trees/ha). *Combretum schumannii*, *Grewia truncata* and *Suregada zanzibarensis* had a higher tree density around Kwa Muiru water point compared to Arabuko Swamp as presented in figure 4.8. A paired t-test showed that there was no significant difference ($P$>0.05) in tree density of the tree species between the two water points.

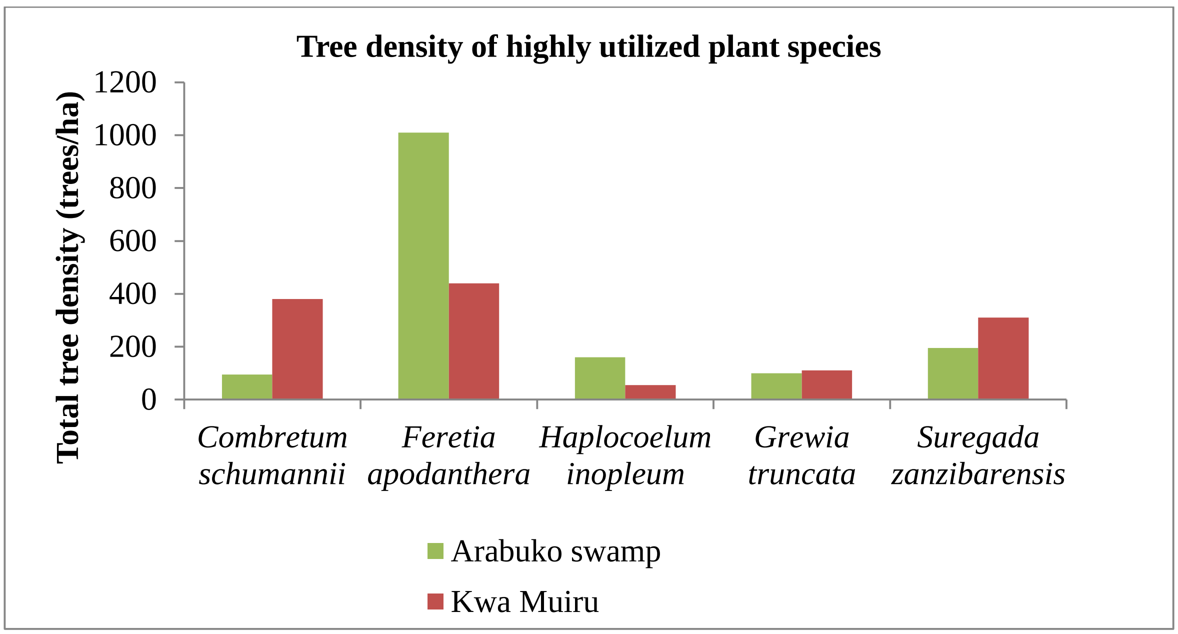



**Figure 4.1: Total tree density (trees/ha) of the most utilized plants around Arabuko swamp and Kwa Muiru water points**

DISCUSSION

## 4.4 Elephant population

### 4.4.1 Dung decay rate

The mean dung survival time and the dung decay rate in this study were almost the same as those by Muoria (2000) which showed that the mean survival time for elephant dung pile in ASF was 151.5 days ±98 (±SD). Similarly, the elephant dung decay rate in this study was also almost similar to the dung decay rate estimates by Muoria (2000), which estimated dung decay rate of Arabuko elephants to be 0.0066 per day. The slight difference in the decay rate in these two studies may be due to the fact that dung decay rate is often influenced by environmental and biological factors that may lead to inter and intra site differences in decay rate (Breuer & Hockemba, 2007; Vanleeuwe & Probert, 2014). Elephant dung decay in ASF was highly variable as it was observed during this study. It took a minimum of 35 days and a maximum of 210 days for elephant dung to fully decompose. This corroborates with results by Vanleeuwe & Probert (2014) that showed mean survival time for dung piles in the coastal forest of Conkouati-Douli National Park in the Democratic republic of Congo ( DRC) varied between 89 and174 days. The large range in the mean survival time in this study may be attributed to environmental factors such as temperature, rainfall and prolonged sunshine. During the study period, temperatures were relatively high with relatively low rainfall as shown in figure 4.2.

Throughout the study period, high temperatures were noted as recorded at Msabaha Metrological Station and presented in figure 4.2. The increase in temperatures in turn prolonged dung survival time and slowed down the dung decay process. This corroborates with a study by Breuer & Hockemba, (2007) which showed that sunshine has pronounced effect on dung decay by baking the dung piles and making them remain inatact for along time.

It was also noted in this study that, there was a difference in mean survival time of dungs between the habitat types. In the open vegetation zone, it took an average of 191.33±36.42 days (± SD) for dung piles to fully disintegrate while in dung piles in the plantation vegetation took the least time of about 115.5 ± 45.05 days (±SD). In areas with little or no canopy, the dungs piles took a longer to fully decompose,which might have been attributed to the sunbaking which prolonged dung pile survival time (Nchanji & Plumptre, 2001;Breuer & Hockemba, 2007).

Other than environmental factors and habitat types influencing dung pile decay, it was observed that invertebrates such as dung beetles and termites attacked the dung piles. Dung beetles were instrumental in the disintegration of the elephant dungs in stage $S_1$ while termites attacked the dungs in stage $S_2$. High activity of the dung beetles on the dungs in stage $S_1$ may have been attributed to the presence of humidity, which often influences the onset of dung beetle activity on elephant dung (Breuer & Hockemba., 2007). It was observed that both dung beetle and termite activity were high in *Brachystegia* vegetation. This may be attributed to the fact that the *Brachystegia* vegetation zone is characterised with large canopies which generally contribute to high atmospheric humidity which in turn influence dung beetle activity.

### 4.4.2 Elephant population

This study found that there were 215 elephants in Arabuko Sokoke Forest. This elephant population was 16.8% more than an estimated population of 184 in 2002 (Thouless *et al.,* 2008; Litoroh *et al.,* 2012) and 70.6% more than a previous estimate of 126 by Muoria (2000) using the same method of elephant population estimation. Although the previous estimates were done before the forest was fenced and the elephants could disperse to other areas, results from this study confirmed that elephant population in ASF is on an increasing trend. Despite the forest being fenced, it was noted during this study that illegal activities within the forest are still high. This was evident by the numerous active footpaths, fresh tree cuttings for timber, small poles and charcoal burning as well as wire traps for small animals including the near endemic golden rumped elephant shrew (*Rhynchocyon chrysopygus)* as shown in plates 4. 3 and 4.4

**Plate 4.1: Freshly cut *Brachystegia speciformis* tree and chopped into timber ready for transport**

**Plate 4.2: A pile of freshly cut poles within the Mixed vegetation zone**

**Plate 4.3: Evidence of charcoal burning within the *Brachystegia* woodland**

These illegal activities are attributed to increased demand for timber as well as the increased dependence on the forest wood and non wood products by the surrounding communities for their subsistence (KEFRI, 2017). These illegal activities pose a threat to the existing elephant population as it increases the risk of them being poached. Therefore, there is a need for adoption of alternative livelihoods and diversification of productive activities in order to increase the productivity of the agricultural lands and reduce reliance on forest products for food, wood andincome. Moreover, KWS,KFS and Comminity Forest Associations (CFA) need to work in collaboration with the surrounding community to ensure that species protection and forest patrols are done regularly.

Over the years, the elephant population estimates in Arabuko Swamp Forest have been carried out using dung counts (Muoria., 2000; Litoroh *et al.*,2012). Although this method of elephant population estimate has been shown to have a merit of providing more precise population estimates (Barnes, 2001), other methods of population survey such as thermal-imaging at Arabuko Swamp may offer a more practical option for elephant population surveys in Arabuko Sokoke forest, particulary at Arabuko swamp which is the only permanent water source. DNA genotyping from elephant dungs may also be used since this method gives more precise elephant numbers compared to dung counts (Barnes, 2001).

Arabuko Sokoke forest has a high conservation value. It is therefore necessaery for KFS and KWS to enhance forest patrols as well as arrest and prosecute people carrying out illegal activities in the forest. In addition, there is need to build the capacity of CFAs around ASF to enable them to participate fully in forest protection. It will also be important for the community living adjacent to the forest to diversify and adopt alternative livelhoods for poverty reduction. Sensitization of the community living around ASF on the importance of the forest and its unique biodiversity is also needed.

## 4.5 Elephant distribution

Elephant distribution within ASF is influenced by the habitat types within the forest. Dung pile density was high in the Other vegetation (Y=6377.7) followed by plantation, mixed, *Brachystegia speciformis* and *Cynometra webberi* vegetation respectively (Table 4.5). The high dung pile density in the Other vegetation, plantation and mixed vegetation may be due to the diverse tree species within this vegetation zone, which offer the elephants a variety of dietary options. It was also observed that in these vegetation types. elephants had high preference for *Balanites wilsoniana* as their diet. This was evident from their dungs in which those in stage $S_2$ to $S_3$ had remains of *Balanites wilsoniana* seeds. Despite more survey efforts being employed in the *Cynometra webberi* woodland and thicket, dung pile density (Y=476.87) and elephant population (n=42) was low in this vegetation zone. This may be due to the fact that within the vegetation, *Cynometra* plant species is a dominant species and thus does not contain the preferred plant species for elephant diet. Moreover, in the *Cynometra* thicket, the plant branches are entangled with each other which make it difficult for elephants to transverse through. These results corroborate with other studies that have shown that forage influence distribution of elephants (Ngene *et al.*, 2009)

## 4.6 Impact of elephant on vegetation

At Arabuko swamp the mean tree height and Dbh reduced with increasing distance from the water point (figure 4.3). On the contrary, the mean tree height and diameter at breast height increased with increasing distance from Kwa Muiru water point ( Figure 4.4). This reduction in mean height and Dbh with increasing distance from Arabuko swamp was against the expectations of the study and therefore the null hypothesis was accepted. The decreasing mean height and dbh with increasing distance from Arabuko swamp may imply that elephants in ASF may be spending most of their time within an area more than 1 Km radius from the water point and just come to the water point to drink water and thus less effect on the tree height and Dbh within the 1 Km radius from the artificial water point. Moreover, it may imply that there may be high utilization of tree while entering the second elephant occupancy area ( 1-2 km from the watering point). This is against the general assumption that the area within 1 Km distance from the water point is a high occupancy area that is characterised by high vegetation damage (Simbarashe & Farai, 2015). The reduction in tree height and diameter at breast height with increasing distance from Arabuko swamp compared to Kwa Muiru where these two variables increased with increasing distance, may imply that damage by elephants in Arabuko Sokoke Forest is associated with artificial water points compared to natural water points. This is in agreement with a study by Gaugris & Van Royeen (2009), which showed that construction of artificial water points in elephant habitats reduce their home ranges, leading them to concentrate their feeding around surface water leading to zones of impacts around water points due to herbivory (Gaugris & Van Royeen, 2009). This may further be supported by other studies in Hwange National Park and Chobe National Park that have shown that elephants influenced woody cover and herbivory was high within the first 2 Km from water points (Chamaillé-Jammes *et al.*,2009; Gandiwa *et al.*,2012). Furthermore, elephants are water dependent species and would spendmost of their time within 15 Km radius from water points, especially during the dry season (Mukwashi *et al.*,2012). The observations on this study, also shows that establishment of artificial water point influence spatio-temporal distribution of water dependent animal species which may lead to animal concentration around water points and prolonged browsing pressure which may lead to alteration of vegetation composition, structure and diversity in case of high elephant density (Kalwij *et al.,* 2010; (Mukwashi, *et al.,* 2012).

Generaly, tree density increased with increasing distance from both the Arabuko swamp and Kwa Muiru water points. These results corroborate with other studies on the influence of elephant on vegetation structure around water points in African protected areas that found that shrub and tree density were low near water points and increased with increasing distance from the water points (Simbarashe & Farai, 2015; Mukwashi *et al.*, 2012). Moreover, other studies have found that presence of elephants even in as low as an elephant density of 0.2 elephants/Km$^2$ lead to decline in tree densities (De Boer *et al*., 2015). The increase in tree density with increasing distance from both water points show that degredation due to elephant herbivory in Arabuko Sokoke Forest occur near the water points confirming that there is a piosphere effect in the study area. Elephant effects on vegetation structure around Arabuko swamp are in agreement with a general assumption that water provisioning lead to degredation on woodland structure due to increased herbivory by large herbivores (Gandiwa *et al.*,2012). Therefore, continous monitoring of impacts of elephants and modification on vegetation structure around Arabuko swamp is vital.

Species diversity was high around Kwa Muiru water point compared to the Arabuko swamp. This may be attributed to elephants spending most of their time atArabuko swap than Kwa Muiru,especially during dry season leading to high vegetation utilization. This in turn led to low species diversity around Arabuko swamp compared to Kwa Muiru water point.

### 4.6.1 Impact of elephant browsing and debarking

Findings from this study showed that elephants in ASF utilized 62 and 75 plant species around Arabuko swamp and Kwa Muiru respectively (table 4.10 and 4.11). This may be due to the fact that elephants are mixed feeders and utilize many species of plants and their diet is more diverse during the dry season than in wet season (De Boer *et al.,*2000). These results corroborates to studies in Hwange National Park have shown that elephants in the park utilize 165 species of plants annually and 22 plant species in a day (Mukwashi *et al.*, 2012) which confirm on the diversity of elephant herbivory within their habitats. Moreover, elephant preferability on some species was observed during this study (table 4.12) with confirms on elephant selectivity and preferability in their dietary options (Mwambola, *et al.,* 2016).

The proportion of plants browsed around the two water points was high around Kwa Muiru water point. At this site, 38.8% of the total plants recorded and having a tree density of 2760 trees/ha were browsed. Whereas around Arabuko swamp, 30.2% of the total plants recorded around the water point and having a tree density of 1615 trees/ha were browsed. In this study area, elephant browsing around water point was associated with the natural water points at Kwa Muiru water point,

Around Arabuko swamp, 15.15% of the total plants recorded were debarked compared to 8.5% of debarked plants in Kwa Muiru. The density of debarked trees at Arabuko swamp was 810 trees/ha compared to 605 trees/ha around Kwa Muiru water point. Debarking of plants as a result of elephant utilization, was associated with the artificial water point at Arabuko swamp. This is because during the dry season, elephants generally moved near permanent water sources (Fullman & Child, 2013). During this time of the year there, leafy vegetation was less available making the elephants to shift their diet to barks as a source of water and nutrients, leading to increased debarking near the water point.

It was generaly observed that debarking was low in both water points compared to browsing within the study area. This may be attributed to the diverse elephant diets,numerous plant species around the water points supplied the elephants with enough nutrients and reducing utilization of the tree barks. It further corroborates with another study by Fullman & Child (2013), that found that elephants preffered to browse near water. Areas that are within 1 Km radius from water points are normaly areas of high elephant utilization (Simbarashe & Farai, 2015). However, during this study , it was observed that around both water points, a large proportion of the trees were not browsed and a very low proportion of the total plants recorded at Arabuko swamp (9.5%) and Kwa Muiru (7.7%) were highly browsed. This suggest that, the level of elephant browsing around water points in Arabuko Sokoke Forest is not a threat to the vegetation. Similarly, only 3.8% and 1.1% of the trees recorded around Arabuko swamp and Kwa Muiru respectively were highly debarked. This shows low level of elephant damage and implies that elephants in ASF do not suffer nutrient difficiency. These findings corroborates with a study by Muoria, (2001) that found that bark use by elephants in ASF was not intensive.

Generally, the low utilization of trees in form of browsing and debarking around the water points in Arabuko Sokoke forest may be attributed to the low elephant population in the forest. A population survey conducted during this study found that ASF hadapproximately 215 elephants and an elephant density of 0.51 per $Km^2$ . Studies within elephant habitats have shown that elephant densities exceeding 2 per $Km^2$ cause damage to almost all trees (Jacobs & Biggs, 2002b;Baxter, 2003).

The density of browsed and debarked plants around both water points was high within the distances close to the water points and decreased with increasing distance from the water points in the study area. These may be attributed to the high elephant herbivory characterised by browsed trees being replaced with coppice and further elephant preference on shorter trees near water points and avoiding taller trees with less accessible vegetation further from the water sources (Fullman & Child, 2013).

**4.6.2 Impacts of elephants on highly utilized tree species.**

Elephants may be generalist in herbivory but they also have preference of some plant species (Mwambola, *et al.*, 2016). In ASF they prefered to utilize *Feretia apodanthera* around Arabuko Swamp while at Kwa Muiru they prefered *Combretum schumannii*. At Arabuko Swamp their utilization of *Feretia apodanthera* may be explained by the fact that *Feretia apodanthera* were more common than the other tree species. However, around Kwa Muiru the elephant did not utilize plants based on abundance but preferred *combretum schumanii* yet *Heinsia crinita* was most common. Nevertheless, they fed on other less abundant species around the two water points ( tables 4.10 and 4.11) which confirms on the selectivity and preferability of elephant feeding behaviour (Boundja & Midgley, 2009). During this study, *Combretum schumannii, Grewia truncata, Haplocoelum inopleum, Feretia apodanthera* and *suregada zanzibarensis* were highly utilized by elephants around the water points. The species of plants utilized by elephants in high frequency in this study were similar to a study by Muoria., (2001) that found that *Manilkara sulcata*, *Strychnos madagascariensis* and *Combretum species* were among the species most utilized by elephants in Arabuko Sokoke Forest. There was no significant difference in Dbh and the average height of the highly utilized species between the two water point except for the mean height of *Combretum schumannii*. This may imply that the elephants in ASF may be utilizing these plant species evenly around both water points which corroborates with a study by Gandiwa *et al.,(* 2012) that found that elephant effect on vegetation around water points is more of utilization rather than destruction.. *Combretum schumannii* was found to be more dominant around Arabuko Swamp and the same time is highly utilized around this water point. It is likely that elephant utilization of this species poses a threat to its future survival in the forest and therefore, regular inventory and monitoring of this plant species should be done.

Increase in elephant population in ASF in future may pose ecological problem since the elephants cannot disperse making them concentrate on sites that meet their forage, drinking and resting activities. From the results in this study more artificial water points should be established in different locations around ASF so as to allow the elephants to roam around the forest and avoid them from utilizing of one site. In doing so ranging behaviour of matriachal herds as well as bulls in relation to distance from water sources should be considered. Moreover according to Gaugris & Van Royeen (2009) with an increasing elephant population, closing and opening of artificial water points may be a delaying tactic and once a population threshhold is reached population control may be necessary.

# CHAPTER FIVE

# CONCLUSIONS AND RECOMMEDATIONS

## 5.1 Conclusion

The elephant population size in Arabuko Sokoke Forest is on an increasing trend. This evident by the general increase in elephant numbers from the previous studies done on elephant population size in ASF before the Forest was fenced. Fencing of the Forest reduced elephant dispersal to other areas and thus the observed elephant population increase.

The elephant population distribution within ASF is influenced by major vegatation types of the Forest. Vegetation habitats with diverse plant species, recorded higher elephant density compared to those vegetations zones with one dominant plant speces.

Plant utilization by elephants around water points were more of utilzation. However, a comparison on the impact plant utilization by elephants around Arabuko Swamp and Kwa Muiru shows that elephant utilization of vegetation around Arabuko Swamp may be destructive as evident through the reduction of structural variables such as height and dbh with increase in distance from water point. The increasing elephant population density as evident in this study coupled with only one permanent water source within the forest may pose a threat to the vegetation around the water points and the resident wildlife in future.

## 5.2 Recommendations

1. Elephant population in Arabuko Sokoke Forest should be monitored periodically
2. More robust methods of wildlife population estimates such as DNA genotyping from elephant dungs and thermal imaging around Arabuko Swamp should be used in future to estimate population size of ASF elephants
3. Additional artificial water point should be constructed and distributed evenly around ASF so as to help reduce the distance traveled by the elephants in order to access water as well as to allow them to roam around the forest and reduce degradation of vegetation around the water points
4. A plant species inventory and close monitoring of changes in vegetation composition and structure in Arabuko Sokoke Forest as a result of elephant feeding behaviour should prioritised by ASFMT.

## 5.3 Areas for further studies

1. There is need to determine the elephant distribution within ASF during both wet and dry season.
2. Further studies will be needed to determine the population structure of elephants in the forest. This will be important because the forest is ring-fenced, and there are no wildlife corridors for elephants to migrate.
3. There is need for an inventory of all plant species in ASF to determine plat species increase or decline due to browsing, debarking or push-overs by elephants.
4. Further studies need to be done to determine the effect of elephant feeding on shrubs and vegetation regeneration in Arabuko Sokoke Forest.

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# APPENDICES

## Appendix 1: Dung pile decay rate monitoring sheet

| DUNG PILE REFERENCE NUMBERS | DATE WHEN THE DUNG PILE IS FOUND | NUMBER OF BOLI | HABITAT TYPE | **DUNG DECAY STAGE**<br>**$S_1$: All boli are intact, moist with odour**<br>**$S_2$: One or more boli (BUT NOT ALL) are intact, fresh but dry, no odour**<br>**$S_3$: No boli are intact, but coherent fragments remain (the fibres are held together by fecal material)**<br>**$S_4$: No boli are intact; only traces such as plant fibres, no coherent fragments are presents**<br>**$S_5$: No fecal material including plant fibres is present** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 | Week 7 |
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## Appendix 2: Dung count along transect data sheet

| Date | | | Line transect | |
|---|---|---|---|---|
| Habitat Type | | | | |
| Transect start point (UTM) | | | Transect end point (UTM) | |
| Compass bearing: | | | Distance at finish (m): | |
| Start time: | | | Finish time: | |
| Team members names: | | | | |
| DISTANCE FROM START | DUNG PILE DATA | | | OTHER NOTES ( ELEPHANT SIGNS E.G STREAMS, SIGHTINGS, SALT LICKS) |
| | Number of Boli | Decay stage ( S1,S2,S3 or S4) | Perpendicular distance (m) | |
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