FACTORS INFLUENCING BATS ASSEMBLAGE STRUCTURE AND ACTIVITY PATTERNS IN ARABUKO-SOKOKE FOREST AND ADJACENT FARMLAND, GEDE, MALINDI-KENYA

BY

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DECLARATION

DECLARATION BY THE CANDIDATE

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

12th August 2021
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We confirm that this research work was carried out by the student with our supervision and submitted with our approvals as university supervisors.

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DEDICATION

I dedicate my work to biology students from Africa, who will dare to choose to study the diverse and interesting life of bats. It is also dedicated to my wife Elizabeth Kamene, for her continued support and our children: Victor, Safari and Sonia, for their understanding during many dad's nocturnal vigils looking for bats.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ASF	Arabuko-Sokoke Forest
BRA	Brachystegia Woodland
COC	Coconut trees dominated farms in farmland
CYNO	Cynometra Forest
CR	Critically Endangered
DBH	Diameter at Breast Height
DD	Data Deficient
EN	Endangered
IUCN	International Union for Conservation of Nature
KFS	Kenya Forest Service
KWS	Kenya Wildlife Service
LC	Least Concern
MIXFa	Mixed trees farms in farmland
MIXFo	Mixed Forest
MAN	Mango trees dominated farms in farmland
NMK	National Museums of Kenya
NT	Near Threatened
PCQ	Point-Centred Quarter
VU	Vulnerable
UPGMA	Unweighted Pair Group Method with Arithmetic Means

ABSTRACT

Many coastal forests in eastern Africa are highly threatened by human activities, which have reduced most of them into small fragments that are in continuous disturbance. Arabuko-Sokoke Forest (ASF) is the only remaining, biggest coastal forest in eastern Africa, which currently exist as an 'island' in the midst of human-dominated landscape. This study was undertaken in the interior of ASF and agricultural areas east of this forest, here referred to as 'farmland' mainly to investigate factors which influenced bats community structure and their activity in both habitats, as well as understand local people's perceptions about bats. Bats composition and their flight activity were sampled with mist-nets. Insectivorous bat activity was investigated with Pettersson D240x ultrasound detector, always tuned to 33 kHz. Bat roosts were mapped and bats in them sampled. Insectivorous bats invertebrates prey abundance was sampled with solar powered lights (DP Light DP-6005A) traps, in 12 different stations each in ASF and farmland. Point-centred Quarter (PCQ) method was used to sample woody vegetation in ASF and in the farmland. A semi-structured questionnaire was used to investigate attitudes toward bats of 394 people living around ASF. A total of 25 bat species were recorded in both study sites; including 25 in the farmland and 19 in ASF. The ASF had higher bat diversity than farmland (H', ASF: 1.48 ± 0.2, Farmland: 1.33 ± 0.1). However the farmland had higher bat species richness than ASF (Chao1, ASF: 19 [19-25], farmland: 24 [24-32] species [0.95% CI]). In total 5,217 individuals of bats were captured, 82.9% in farmland and 19.1% in ASF. Thirteen roosts occurred in the farmland and only one in ASF. The mean flight activity of individual bats captured in mist-netted (fruit and insectivorous bats combined) in each hour in the farmland was (425.3 ± 95.1, N=10), and in ASF (88.4 ± 11.2, N=10). There was a significant difference between the medians of captured bats per hour in both habitats (U=9.5: p <0.0025, Mann-Whitney U-Test). A total of 14,727 insectivorous bats echolocation calls (passes) were recorded, including 10,552 in the farmland and 4,175 in ASF. The mean number of bat passes in farmland was (152.9 ± 13.2), while in ASF was (60.5 ± 4.6). There was a significant difference in the activity of insectivorous bats in both study sites (df = 68, t = -8.671, P <0.05). A total of 6,557 individuals of insectivorous bats invertebrates prey were captured in both study sites: 52% in the farmland and 48% in ASF. The mean number of insectivorous bats invertebrates prey captured per night in the farmland was (260.5 ± 52.9, N=12), and in ASF (200.3 ± 36.4., N=12). There was no significant difference between the medians of insectivorous bats invertebrates prey captured in both study sites (U=61: p >0.544, Mann-Whitney U-Test). The mean Diameter at Breast Height (DBH) of trees were significantly larger in the farmland than in ASF (t (838) = 6.8934; P = 0.0001). The mean % understory vegetation thickness of ASF was (38.2 ± 1.9) and that of farmland was (5.8 ± 2.3). There was a significant difference in the % understory vegetation thickness in both study sites (df = 209, t = -16.634, P <0.05, N = 210). The farmland had many fruit trees (385) which produce large fruits eaten by frugivorous bats, as compared to indigenous fruit trees (166) in ASF producing small fruits. Three main factors explained the higher bat abundance, species richness and activity in the farmland than ASF. First, the farmland had many bat roosts (13), some hosting multiple species and in large numbers (one limestone cave had more than a million individual bats), than in ASF (one). Second, large concentration of cultivated fruit trees (mango, cashew nut and neem trees), in the farmland produced fruits which when ripe, attracted many fruit bats (3,397) in the farmland as compared to few fruit bats (733) captured in ASF. Third, the openness of understory and canopy habitat in farmland facilitated bat flight as compared to the thick interior of ASF, which constrained foraging as well as bats movement. For example, although both study sites had the same insectivorous bats invertebrate prey abundance, still large number of insectivorous bats occurred in the farmland (930) than in ASF (157). In addition, many individuals of Egyptian Slit-faced Bat *(Nycteris thebaica*) a clutter tolerant bat species were captured in the farmland (40) than inside ASF (14). The findings of this study underscore the importance of the farmland habitat around ASF for bats conservation, and the need for more research in agricultural landscapes, in order to understand their roles in bats conservation in Africa. Majority of respondents associated bats with evil and implicated them in destruction of farmer's fruits. About one-third reported active killing of bats or destruction of their roosting places; and similar number did not see any benefits of bats to humans. The elderly and more educated people had more positive attitudes toward bats than others. Females showed more negative attitudes toward bats and more beliefs to myths about bats than males, while the males had more hostile behaviour toward bats than females. To address the prevailing negative attitudes about bats around ASF, there is need to intensify bat education awareness among youths and females.

STRUCTURE OF THESIS

Chapter one discusses the background of the study, main goal, specific objectives, research questions and hypotheses. Chapter two reviews the literature about bats, their biology, distribution, roles in the environment, economic significance of bats to people, habitat structure and bats distribution as well as threats to bats, and finally perceptions and attitude about bats. Chapter three provides information on the two study sites: ASF and farmland (agricultural areas) around this forest, as well as brief descriptions of methods used to collect data under each objective. Chapter four presents the results of diversity and abundance of bats in and around ASF. Chapter five presents the results of flight activity of bats captured in mist-nets as well as insectivorous bats monitored with Pettersson D240x ultrasound detector. Chapter six presents results on insectivorous bats invertebrate prey abundance and diversity in ASF and in the farmland. Chapter seven provide results on the vegetation structure and fruit trees abundance in both study sites. Chapter eight presents results on knowledge, attitudes and perceptions of bats by the local people living on the eastern part ASF. The last chapter, number nine summarizes the findings of this study, provide a general discussion, and conclusion as well as recommendations made from the study about further bat research, conservation and policy implications.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

About 7% of the world is covered in tropical forests, and supports about 60% of all global species (Laurance, 1999). The continuous deforestation of tropical forests is among the greatest threats to global biodiversity (Brooks *et al*., 2002). Regrettably, forest destructions will continue in the future, and consequently will lead to extinction of many tropical forest species (Bradshaw *et al*., 2009). For example, about 40% of earth's land area is under crop cultivation (FAOSTAT, 2011), and five billion hectares of land under crops and livestock farming exceeds the total area covered by the remaining forests worldwide (Power, 2010). Although for a long time biodiversity research has been undertaken in protected areas, current research indicate that agroecosystems, also host sizeable amounts of biodiversity (Foley *et al.*, 2005), and continue to attract much research interests (Wickramasinghe *et al.*, 2003). Therefore, understanding the role of agroecosystems in biodiversity conservation is important, in order to properly manage them, so as they continue to meet human needs as well as enhancing the long term survival of biodiversity found in them.

The order Chiroptera (bats) is the second largest taxonomic group of mammals (Kunz and Pierson, 1994) after the order Rodentia. The flight ability of bats enables them to exploit large areas (both natural and agricultural) in a single night (McCracken *et al.*, 2012). The impact of forest degradation on bats in Africa, however is poorly understood. However, the number of people in Africa will increase five-fold in the next century, from 0.6 billion in 1990 to 2.8 billion by 2100 (Bongaarts, 1994). The demand to open more natural areas for crop cultivation, livestock grazing and expansion of human settlements and infrastructure, which is associated with human population increase in Africa, will inevitably affect the survival of many forest bat species. Even though some research has suggested a low dependence of bats on intact forests (Goodman *et al*., 2005), there is evidence that certain species require undisturbed forested habitats to forage (Kofoky *et al*., 2007). Unfortunately, the effects of habitat degradation on bats in Africa is still unclear (Meyer *et al*., 2016), hence the need to do more research in this area.

The coastal forests in eastern Africa are very important for conservation of global biodiversity, because of the large number of endemic and globally threatened species (Myers *et al.*, 2000). The forests (160 in total) in Kenya and Tanzania, are recognized as important for biodiversity conservation globally (Burgess *et al*., 2003), because of many endemic plants and vertebrate and invertebrate species found in them (Myers *et al*., 2000). However, important as these forests are for conservation of global biodiversity, they are highly threatened by human activities. The negative anthropogenic activities in these coastal forests have affected the diversity and distribution of many species. For example, Golden-rumped Giant Sengi (*Rhynchocyon chrysopygus*), an endemic species to Kenya and found in ASF, is listed as globally endangered (IUCN, 2019), due to habitat loss in its original habitat range and wildlife hunting. Continuous destruction and degradation of coastal forests in Kenya (Burgess *et al*., 2003), will continue to affect the distribution and survival of many species, bats included.

One of the biggest (416km^2) coastal forest in Kenya and in East Africa is Arabuko-Sokoke Forest (Bennun and Njoroge, 1999). Despite the importance of ASF for biodiversity conservation, the forest cover around it has completely disappeared (Kelsey and Langdon, 1984), and ASF is currently surrounded by human settlements and agricultural areas. The continuous decline of habitat quality in ASF as result of legalized firewood collection; illegal extraction of timber, charcoal and poles might affect species diversity and abundance. Although birds (Fanshawe, 1993), plants (Robertson and Luke (1993), invertebrates (Lange, 2003) and mammals (Jackson *et al*., 2019) studies have been undertaken in ASF, no detailed bat research has been undertaken in ASF. However, sporadic collection expeditions have been undertaken in ASF in the past, and voucher specimens collected and deposited with Mammalogy Section-National Museums of Kenya (NMK). Nevertheless, no comprehensive study has ever compared bat diversity in a coastal forest with that of the surrounding agricultural landscape in Kenya, to understand the significance of each habitat for bat conservation. The differences in vegetation structure and other resources such as invertebrate prey abundance for insectivorous bats, distribution and abundance of fruit trees producing fruits eaten by fruit bats, as well as roosts distribution might influence the abundance and distribution of bat assemblages in ASF and farmland around it.

1.2 Problem statement

Although some ecological studies on bats have been undertaken in Kenya (McWilliam, 1987; Webala *et al.,* 2004; Webala *et al.,* 2006; Webala *et al.,* 2009; Webala *et al.,* 2014; Wechuli *et al.,* 2016; López-Baucells *et al.,* 2016) none have been undertaken in and around ASF. Moreover, much of ASF is an 'island' in the midst of agricultural and human settlement areas. However, bats are not restricted to natural areas; their mobility allows them to exploit agricultural areas and man-made infrastructure as well. It is possible, therefore, that bats found in ASF may also exploit agricultural areas around this forest, either for foraging or roosting. However, no study has simultaneously investigated bats in ASF as well as in adjacent human-modified areas, to understand the role of each habitat in the conservation of the bats.

Indigenous people have interacted with wildlife throughout their lives, which has resulted in accumulation of immense knowledge, as well as myths and cultural beliefs about many species of wild animals. In the case of bats, there is much misconception and negative cultural beliefs perpetuated by print and electronic media, and unsubstantiated tribal folklores all over the world. Superstitions and ignorance by the general public can lead to direct killing of bats or destruction of their roosts (Altringham, 1996). Therefore, in order to develop appropriate interventions for conservation of Kenyan bats, there is need to document indigenous knowledge, and attitudes towards bats. Along the Kenyan coast, such studies are essential because there are many limestone caves, and man-made structures used by bats (Musila *et al.*, 2019a). In addition, there are also many negative beliefs and myths about bats, that still persist among local people (Musila and Mbau, 2010).

1.3 Significance of the study

Bats are important to the environment especially for their roles in invertebrates carnivory and regeneration of the forests. Thus, knowledge about bat species which occur in ASF and the adjacent farmland would help us to understand the roles played by these species in forest regeneration, seed dispersal and crop pest control. The current study was based in ASF and the farmland around this forest. No data was available on bats species richness in ASF, and the farmland around it, to determine the presence of species of bats that are habitat specialists, only restricted to the interior of ASF. If such bat species existed, they would be lost with continuous degradation of ASF, while others which are habitat generalists persisting in disturbed areas outside ASF, would be unaffected by anthropogenic activities. This information would be required to make decision on how best to conserve bats in the both study sites.

The ability of bats to fly potentially enables them to forage in ASF and nearby farmland. Bats my also roost inside ASF at day time and forage in the farmland at night and vice versa. In that case therefore, although current efforts are mainly directed at conservation of ASF because it is legally protected, this may not fully ensure the survival of some bat species. This is because some bat species may depend on resources found in private and un-protected lands, where owners could make decisions that may affect the existence of bats. Bats are also known to use man-made structures for roosting (Lopez-Baucells *et al*., 2017). The presence of bats in peoples' houses and other facilities, increase the interaction between these animals and people, and development of cultural beliefs about them. This study also investigated attitudes toward bats among local people in the farmland, to understand what they do when they encounter bats, because their actions may support or undermine the survival of these species. This information was important because it would help in formulating the best bat conservation strategies to employ and to engage local people around ASF.

1.4 Main goal of the study

The broad goal of the study was to investigate factors affecting bat community structure and activity patterns in ASF and adjacent farmland, as well as human-bats interactions around the forest.

1.4.1 Research objectives

1. Investigate bat species diversity and abundance in ASF and adjacent farmland.
2. Investigate bat activity patterns in ASF and adjacent farmland.
3. Describe the vegetation structure and abundance of fruit trees resources in ASF and adjacent farmland.
4. Investigate insectivorous bats invertebrate prey abundance and diversity in ASF and adjacent farmland.
5. To investigate how gender and age influence perceptions and attitudes towards bats in the study area.

1.4.2 Research questions

1. Does the interior of the natural forest (ASF) and the adjacent farmland have the same bat species richness and abundance?
2. What is the activity patterns of bats inside the natural forest (ASF) and in the adjacent farmland?
3. How does vegetation structure and fruit trees abundance affect the distribution of bat species inside ASF and in the adjacent farmland?
4. Is the abundance of insectivorous bats invertebrate prey in the interior of ASF and in the adjacent farmland the same?
5. How do attitudes and perceptions of local people about bats change with gender and age group?

1.4.3 Research hypotheses

1. The interior of ASF and farmland will have the same bat species richness because bats are highly mobile.
2. The farmland and interior of ASF will have the same patterns of bat activity.
3. Highly cluttered habitats and those with higher abundance of fruit trees resources will have similar bat species diversity and abundance.
4. There will be no differences in the diversity and abundance of invertebrates in ASF and in the adjacent farmland.
5. There are will be no differences in the attitudes and perceptions about bats between gender and age groups of local community in the study area.

CHAPTER TWO: LITERATURE REVIEW

2.1 Evolution of bats

Bats (order Chiroptera), are the only mammals group which can fly (Happold and Happold, 2013). To fly they use their flexible wing structure, aided by a special forelimbs characterised by significantly extended manual digits (Hill and Smith, 1984). Although the evolutionary history and physical origins of bats is not well known (Gunnell and Simmons, 2005), the first record of existence of bats is known to have appeared in the early Eocene period (about 51 Mya) in Northern America (Simmons and Geisler, 1998). Bats are closely related to carnivores, whales, shrews, moles, horses and anteaters, and not flying lemurs as was previously supposed (Teeling *et al*., 2000).

2.2 Classification of bats

Bats are divided into two sub orders: Megachiropterans (megabats, fruit bats) comprises the fruit-nectar-feeding bats, while the microchiropterans (microbats, insectivorous bats) feed on invertebrates, especially insects. Only three species in the family Desmodontinae, found in South America, are vampires (feed on blood) Koopman, 1993). Bats are not blind, but have eyes which see (Taylor, 2000), and the two major groups use different signals to explore the environment. Insectivorous bats use echolocation, a form of ultrasonic signals emitted into the environment by an individual bat, which bounces back as an echo and is processed by a bat brain to locate prey or avoid obstacles in their flight path (Neuweiler, 1989). Fruit bats use vision and their sense of smell to locate food in the environment (Taylor, 2005).

There are eleven families of bat in Africa, all of them represented in Kenya (Musila *et al*., 2019b). These include Pteropodidae (Fruit bats), Rhinolophidae (Horseshoe bats), Hipposideridae (Leaf-nosed bats), Megadermatidae (False vampire bats), Rhinopomatidae

(Mouse-tailed bats), Emballonuridae (Sheath-tailed bats), Nycteridae (Slit-faced bats), Molossidae (Free-tailed bats) and Vespertilionidae (Vesper bats) (Happold and Happold, 2013). The Family Miniopteridae (Long-fingered bats), which was previously included as a subfamily of Vespertilionidae (Simmons, 2005) is now recognized as a valid family (Miller-Butterworth *et al*., 2007). Kitti's Hog-Nosed Bat (*Craseonycteris thonglongyai*) weighing less than 2.0g is the tiniest bat in the world, with most of biggest bats, in the genus *Pteropus* weighing up to 1.5 kg (Fenton, 1992). The largest bat species in Kenya is Hammer-Headed Fruit Bat (*Hypsignathus monstrosus*), with a forearm measuring 120-139mm, and weighs 290-419g (Happold and Happold, 2013). The variation in bat sizes, their flight ability, and different methods of foraging enables them to exploit a wide assortment of habitats, from less disturbed, to highly modified agricultural and urban areas. However, large bats, especially most of the fruit bat species have large wingspan, and have limited ability to manoeuvre their way in thick habitats, and thus tend to forage in more open areas (Fenton 1990; Brigham *et al*., 1997).

2.3 Ecological importance of bats

2.3.1 Pollination by bats

Fruit bats feed on fruits, pollen, leaves or nectar (Marshall, 1983). During foraging, fruit bats visit flowers of many plants, move loads of pollen with their bodies, and thus help in plants pollination (Eguiarte *et al*., 1987). The African baobab (*Adansonia digitata)* for instance, is reported to be pollinated by fruits bats (e.*g.*, African Straw-coloured Fruit Bat (*Eidolon helvum*), Gambian Epauletted Fruit Bat (*Epomophorus gambianus*), Wahlberg's Epauletted Fruit Bat (*Epomophorus wahlbergi*) and Egyptian Rousette (*Rousettus aegyptiacus*) Djossa *et al*., 2015). Flower-visiting phyllostomid bats (New world leaf-nosed bats) comprises about 30 species in South American rainforests (Emmons and Feer, 1990). Pollination aid in fruit formation, which when mature are eaten by many animals, bats included, and their dispersal assist in the regeneration of plants in the natural areas and agricultural areas.

2.3.2 Seed dispersal by bats

Frugivorous bats have a modified digestive tract (Hansen *et al*., 2008), which allows rapid passage of food through its guts (usually less than 30min) Tang *et al*., 2007). This reduces large amounts of mechanical and chemical damage to seeds (Lobova *et al*., 2003), and hence, increases the viability and germination of ingested seeds when released to the environment. Fruit bats are the most abundant and diverse vertebrate group in many tropical forests (Bonaccorso, 1979). In Africa and neotropics forests, fruit bats account for more than 90% of the seed rain falling on the forest floor (Medellin and Gaona, 1999). Bats are effective seed dispersers because of their ability to forage far away from their roosts. For instance, fruit bats can travel as far as 50km in a single night during foraging (Eby, 1991). The distribution and abundance of fruit bats in the environment has been shown to be influenced by fruiting plants (Marciente *et al*., 2015). In additiom, fruit bats consume about 50-250 percent of their body weight in fruits each night (Thomas, 1984). Thus, large quantities of fruits are eaten each night, with most of the fruit fragments including seeds, being discarded far and wide in the environment. Subsequently, the declining population sizes of fruit bats, is likely to affect forests restoration in the long run, as a result of the reduction in the quantity of plants seeds dispersed into the environment.

2.3.3 Bats and insectivory

About 70% of all bat species are insectivorous feeding on different types of invertebrate prey (Jones and Rydell, 2004). Some of the major invertebrates eaten by bats are also crop pests which destroy many cultivated crops and farmers expend millions of dollars in eradication (Kunz *et al*., 2011), often by spraying hazardous chemicals to the environment. Although estimates on insectivorous bats herbivory on agricultural pests are few and anecdotal, some studies offer some insights. For example, during lactation, small insectivorous bats consume about hundred percent of their body mass nightly (Kurta *et al*., 1989). In south-central Texas, USA for instance, the financial cost of Mexican Free-Tailed Bat (*Tadarida brasiliensis*) as insect-pest control agent in cotton farming industry has been estimated to be about $741,000 per year (Cleveland *et al*., 2006). The African continent has many insectivorous bat species, which occur in large numbers in the environment, but their roles in pest control in agricultural crops has not been evaluated, and hence the need for continued conservation of these species.

2.4 Bat and diseases transmission

Bats are known reservoirs and sources of several microorganisms that causes life threatening zoonotic diseases and other pathogens to humans (Plowright *et al*., 2017). About 200 viruses have been associated with bats (Allocati *et al*., 2016). For instance, of the 12 species of lyssaviruses; viruses which cause rabies, a deadly disease which causes inflammation of brains in both animals and people, 11 have been isolated from bats (Banyard *et al*., 2013). The main drivers of the emergence of bats zoonotics include agricultural expansion into forests, deforestation and urbanization (FAO, 2011). These factors increase the contacts between people and bats, and hence increases opportunities for transmission of these diseases (Daszak *et al*., 2001). In addition, some communities in Africa hunt and eat bats (Anti *et al*., 2015), which predisposes people to bat related disease transmission. Bats also roosts in man-made structures such residential houses, schools, temples and bridges (Jung and Threlfall, 2016). As human population increase in Africa, with consequent destruction of natural bat roosts, it is expected more bats will continue to colonise man-made infrastructures, and this coexistence will probably increase potential risks of bat related diseases transmissions to humans.

2.5 Bats socio-cultural importance

Since time immemorial, animals have played important roles in the cultures and customs of human society. They have inspired formation of poems, metaphors and similes (Zandi, 2013), songs, proverbs and sayings. Some animals are liked while others are detested. The attitude a person has towards an animal is determined by the information they have about that animal, how they perceive it, and the nature of the associations they have developed with the particular animal over time (Drews, 2002). Bats in addition to other animals such as snakes, bugs and mice are animals which are mostly feared by many people (Robins and Regier, 1991). Bats have a bad reputation among general public (Allocati *et al*., 2016). The way people in a given area perceives the environment is basically influenced by their thought process as well as how they act towards different animals and plants (Khan *et al.*, 2013). Beliefs to myths, which permeate fear about animals often result into direct persecutions of animals (Fita *et al*., 2010). Thus, the attitude local people have about bats around ASF, can negatively or positively affect bats survival in the long run.

2.6 Distribution and species diversity of bats

2.6.1 Global distribution of bats

There are more than 1300 species of bats in the world, 221 in Africa and 104 in Kenya (Happold and Happold, 2013; Voigt and Kingston, 2016; Musila *et al*., 2019b). Bats are found in all continents except in Antactica, polar region and few isolated oceanic islands (Koopman, 1984; Kunz and Pierson, 1994). Species richness of most taxa, bats included decreases as one move away from the equator (Hillebrand, 2004). About 80% of bat species worldwide occur in the tropics (Willig *et al*., 2003), with the greatest diversity of insectivorous bats being found in the tropics (Willig and Selcer, 1989).

2.6.2 Relationship between bat species and their habitat

Habitat complexity and heterogeneity are two main habitat characteristics which are thought to structure bats assemblages. Heterogeneity can be defined as the understorey thickness or openness of a habitat, while complexity refers to habitat types classified by different height levels (Fahr and Kalko, 2011). Forest habitats have different layers from the ground to the forest canopy. Some species of bats only fly high above the ground (Kunz and Kurta 1988), some below the canopy, while others constantly use the entire vertical forest stratification (Bernard, 2001). For example, in African tropical forests up to nine species of fruit bats can coexist together (Wolton *et al.*, 1982), with bat species selecting to roost or forage at different height levels in the forest habitat (Henry *et al*., 2004). Therefore, because of the differences in habitat structure between the interior of ASF and farmland, it is expected each habitat would be utilized differently by bat species. For example, in the interior of ASF, some bat species may fly or forage below the forest canopy and be easily captured in mist-nets, while others may exclusively forage above the forest canopy and be impossible to capture. In addition, some studies have shown that more open habitats are more used by bats than those overly closed (Humes *et al*., 1999). Probably, this would mean that, habitats with more open undergrowth, as is the case of the agricultural areas around ASF, may be more used by bats for foraging or general commuting from one place to another.

The diversity and abundance of bats in a place, may also be affected by the availability roosting sites (Cotterill and Ferguson, 1999). Thus, areas with many suitable bat roosts would have many individuals of bats, as bats come out to feed at nightfall and as they return again to roost at dawn. Although it has been suggested that bats are not affected by habitat loss because of their mobility (Schulze *et al*., 2000), some species may be affected. For example, Meru National Park and Bogoria National Reserves in Kenya, were richer in bat species, as compared to agricultural areas around them (Webala *et al*. (2004); Wechuli *et al*., 2016). In addition, habitat structure may influence the abundance of forest resources used by bats, and thus the changes in bat species richness and diversity. The availability and distribution of food (soft fruits when ripe, pollen) influences the distribution and abundance of bats in the environment (Fenton and Rautenbach, 1998). Therefore, the availability of fruiting trees, which produce fruits targeted by foraging frugivorous bats, between the ASF and adjacent farmland, my determine the number of frugivorous bats mist-netted in each habitat.

2.6.3 Bat activity in the environment

Most bats are nocturnal, except a few pteropodids (fruit bats) species which are diurnal in islands without day predators (Cox, 1983). Bats spend the day time in roosts and emerge in the evening mainly to forage (Eckert, 1982). Bat flight activity can be described as the movement of an individual bat out of its day's roost, into the airspace at night to forage or commute to suitable feeding or drinking areas. Bat flight activity can be documented directly with mist-nets captures (Kunz and Brock, 1975) and indirectly with ultrasonic detectors (Fuentes-Montemayor *et al*., 2012).

Bat activity can be influenced by several factors including food (invertebrates prey, fruits and pollen), moonlight and habitat structure and predation avoidance. More open habitats have been shown to be more actively used by bats, as compared to other habitats which are more cluttered (thick) (Kalko *et al*., 1996). Because the understorey (undergrowth) cover in ASF is very thick, it would be probably used less by bats foraging or commuting below the forest canopy, and thus consequently reduce the number of individuals captured in mist-nets or signals detected with ultrasonic bat detectors. On the contrary, the farmland has many open areas which are potential bat flight paths. These open areas would probably facilitate more individual bats to use this habitat for foraging or commuting, and thus increase the number of bats captured in mist-nets and signals detected in farmland than those recorded in ASF. The time insectivorous bats become active appears to be a trade-off between the availability of prey and emergence of their predators (especially owls (Jones and Rydell, 1994). Insectivorous bat diversity and activity are also associated with the abundance of insects (Rautenbach *et al*., 1996). Areas with abundant insect prey, which can easily be tracked and captured by insectivorous bats, would be more actively used for foraging, than areas where food prey is scare and difficult to capture. Resource availability (e.g. fruit trees and roosts) within forest and the matrix can also shape bats composition (Estrada-Villegas *et al*., 2010).

2.7 Threats to bat species and their habitats

Human beings are the main causes of threats to bats and their habitats. The main threats include habitat loss, negative perceptions, bush-meat trade, destruction and or modification of roost sites. Although bats are long lived animals (about 31 years) compared to their small body sizes (Tuttle and Stevenson, 1982), their reproductive biology makes them highly prone to population declines. For example, bats have a slow reproductive rate, with often one and rarely two young being born annually (Racey, 1982). Thus, any rapid population decline of a bat species, may not easily recove due to the slow rate of reproductive rate of the order.

2.7.1 Destruction and or modification of roosting sites

Bats spend more than half of their lives in roosts (Racey, 1982). Bats are not known to create their own roosting areas (Kunz and Lumsden, 2003). However, they select an assortment of suitable areas to roosts including tree foliage, natural caves, hollows in trees, and a variety of human infrastructure (houses, bridges, culverts (Kunz and Pierson, 1994). Roost availability affects bat species distribution and associations (Kühnert *et al*., 2016). Areas with many bat roosts used by different species, is likely to have high bat diversity as well as activity. Bat roosts are found everywhere, both in the protected areas and outside, in urban and rural areas.

Roosts outside protected areas are highly prone to destruction by humans, through conversion to other uses that are not compatible to bat conservation. Some bats roosts especially caves are frequently visited by many people, which causes continuous disturbance to roosting bats. For instance, Large Slit-faced Bat (*Nycteris grandis*), abandons preferred roosts after disturbance, returning there several days later (Fenton *et al*., 1993). Bat roosting in man-made structures, or trees near proximity to people are not tolerated but are either killed with catapults (Musila and Mbau, 2010), sprayed with chemical poisons, or roost trees are cut down or pruned to chase bats away (Webala *et al*., 2014).

2.7.2 Hunting bats for bush-meat

Individuals of bats are also hunted for bush-meat by local people worldwide. Bush-meat hunting has contributed significantly to population declines of fruit bats in Asia (Epstein *et al*., 2009; Kamins *et al*., 2011). Bush-meat hunting of *E. helvum* in West Africa is causing population declines of this species (Struebig *et al*., 2007). Although no bush-meat hunting of bat has been documented to occurs in Kenya, it is important to note that individuals of *E. helvum* also found in Kenya migrate, to West Africa where massive hunting of the species has been recorded (Kamins *et al*., 2011).

2.7.3 Habitat degradation and fragmentation

The rapid increase in human population, and its demand for land for crop and livestock farming, settlement and development of other man-made infrastructure will continue to increase the size of human-modified ecosystem globally. The disappearance of natural vegetation which supports fruits and invertebrate communities, which bats depend upon for their survival might affect some bat species and their abundance. Human population increase will also result in the destruction or alteration of roosting areas mainly caves and foraging areas. For tree-roosting bat species, the destruction of forests and woodlands has a negative effects the on distribution and survival of different species of bats in a given area (Fenton and Rautenbach, 1986).

2.7.4 Evictions of bats roosting in man-made structures

Many bat species roost in man-made structures, such as traditional huts, schools, offices and bridges (López-Baucells *et al*., 2017). The main threats to wild animals, especially bats that lives in close association with people are also humans (Voigt *et al*., 2016). Some people are not tolerant to bats living in their houses. People fear bats for the diseases they are likely to transmit to them, as well as because they are a nuisance for odors and dust from their droppings (Razafindrakoto *et al*., 2011). Thus, some people therefore, kill bats directly using various methods, or try to evict them with application of chemical poisons (Bayat *et al*., 2014). Although, no information exists on the number of individuals of bats lost each year globally from direct killing or implementation of unfriendly eviction procedures, most likely large numbers and diverse populations of bats are being lost annually.

2.8 The importance of coastal forests in Kenya and East Africa

Most of the forests along the east African coast occur in between 0-500 m above sea level, and straddle southern Somalia, through Kenya and Tanzania to southern Mozambique (Habel *et al*., 2017). A total of the remaining 160 coastal forests patches in Kenya and Tanzania were recognized as one of the 35 global biodiversity hotspots (Mittermeier *et al*., 2009). This hotspot, now known as 'Coastal Forests of Eastern Africa Biodiversity Hotspot', has many endemic species including: at least 1,500 plants, 16 mammals, 22 birds, more than 33 amphibians and 50 endemic reptiles (Lovett and Wasser, 1993; Myers *et al*., 2000). Although these forests are important repositories of biodiversity, they are highly fragmented and in continuous state of encroachment and disturbance (Burgess *et al*., 2003). The size of the remaining coastal forests in eastern Africa, as well as their habitat conditions is on a declining trend to the detriment of the common, globally threatened and endemic species. Furthermore, in many Kenyan coastal forests very limited if any bats research has been undertaken. Because bats are able to fly from one place to another, they are capable of exploiting resources (fruits, invertebrate prey, roosts) both in protected forests and adjacent matrix. Some coastal forest fragments especially in Kenya are very small (Bennun and Njoroge, 1999), and may not on their own support the survival of some bat species that range widely. Thus, the role of coastal forests and agricultural areas around them, in sustaining bat biodiversity in Kenya need to be investigated.

CHAPTER THREE: STUDY AREA AND GENERAL METHODS

3.1 Introduction

This chapter provides information on the characteristics of the study area including location, altitude, soils, weather conditions, vegetation, animals and conservation issues affecting biodiversity conservation. The methods used to collect various types of data on bats, their activity; vegetation, invertebrates and people are also briefly described.

3.2 Description of the study area

3.2 1 Location and conservation status

This research was conducted in two study sites located adjacent to each other: the interior of Arabuko-Sokoke Forest (ASF) and adjoining human-modified habitats in the eastern part of the forest, here collectively referred to as 'farmland' (Fig. 1). The ASF is found in Kilifi County, about 20km from Malindi, at a latitude of -3.5167S and longitude 39.8167E, and elevation of less than 200m above sea level (Bennun and Njoroge, 1999; Muchiri *et al*., 2001). The ASF is a legally protected area managed by Kenya Forest Service (KFS), in partnership with Kenya Wildlife Service (KWS), National Museums of Kenya (NMK) and Kenya Forestry Research Institute (KEFRI) (ASFMP, 2002).

The farmland around ASF is the largest habitat in the area (Fig. 1). It is dominated by areas of crops cultivation, human settlements, development infrastructure (small towns and village markets), and social amenities (schools, hospitals, and roads). Study sites in the farmland were in different villages located in between Matsangoni to Msabaha (Fig. 1 (area in between two arrows in the east). Field work was conducted in the interior of ASF and farmland in between March 2014 to December 2016.

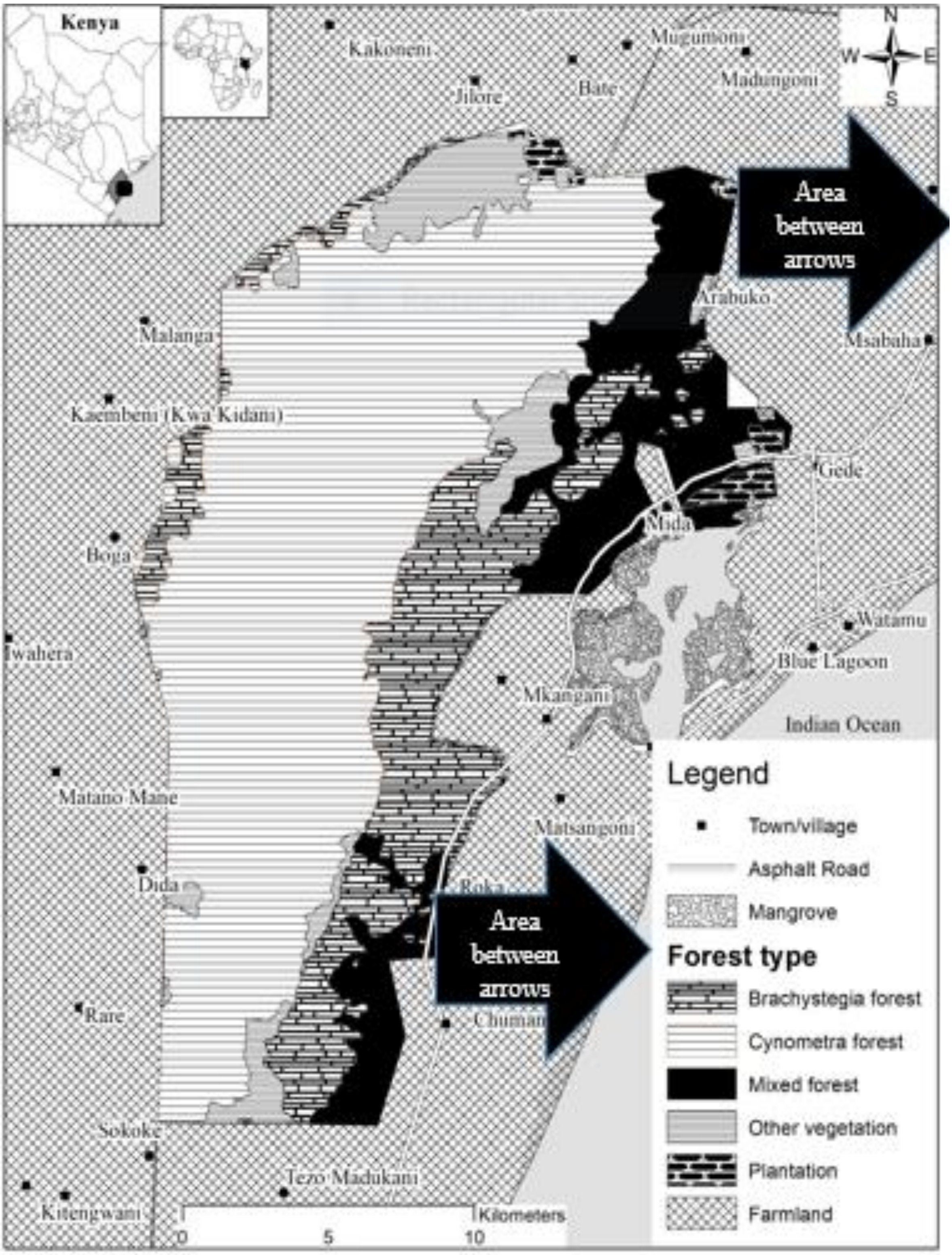

Figure 1. A Map of the study areas showing the different vegetation types in the interior of ASF and the farmland.

3.2.2 Climatic condition of study area

Due to the close proximity of ASF and farmland, the weather (rainfall, temperature, winds, humidity) conditions are the same. The mean daily temperature around ASF is 25° C, with little monthly variations throughout the year. The hottest month was March (28.6^{0}C) and coolest was June (26.7^{0}C) (ASFMP, 2002). The mean temperature reading from Msabaha, a meteorological field station about 10 km from the forest, for the month of February 2015 was (28.6° C ±0.1, N=28 days), June 2015 (26.7° C ± 0.4, N=28) and November 2015 (27.9° C ± 0.2, N=28).

The areas around ASF experience high relative humidity throughout the year because it adjoined to the Indian Ocean (ASFMP, 2002 (Fig. 1). The mean relative humidity recorded from Msabaha meteorological field station, for February 2015 was (69.6 ± 0.2, N=28 days), June 2015 (39.56 ± 0.3, N=28) and November 2016 (77.0 ± 0.7, N=28).

Rainfall around ASF is bimodal in pattern. Monsoon winds occurring between April and June bring heavy rains (long rain season), followed by a short rain season in between November to December each year (ASFMP, 2002). The average annual rainfall ranges from 600m to 1000 mm (Bennun and Njoroge, 1999). January to March (dry season) are the driest months. The mean rainfall recorded from Msabaha meteorological field station, for February 2015 was (0.5mm ± 0.1, N=28 days), June 2015 (2.6mm ± 0.8, N=28) and November 2015 (2.9mm ± 0.8, N=28).

3.3. Characteristics of soils, flora and fauna

3.3.1 Soil characteristics

There are two main types of soils (red and grey sand) in the interior of the ASF and in the farmland. The grey sand soil which is well drained and infertile, occur in the mixed and

Brachystegia (miombo) woodland, and at most 5 km from the coastline into the farmland. The red soils are deep and heavily leached and are found more inland, especially in *Cynometra* forest (ASFMP, 2002). The clearance of the natural vegetation in the farmland and continuous cultivation of crops reduces soil fertility, which may affect growth of wild plants, and invertebrates which are the main prey items of insectivorous bats.

3.3.2 Natural vegetation

About 600 plant species are found in ASF (ASFMP, 2002). The plant community in ASF is classified into three broad vegetation types (Fig. 1). Mixed forest (7, 000 ha (Fig. 2), comprises of relatively dense, tall and undifferentiated trees growing on grey sands. *Cynometra* forest (23,500 ha), is a lowland evergreen dry forest, with closed canopy and the undergrowth is interwoven with numerous saplings and lianas, making it impenetrable to walk through. The *Cynometra* forest (Fig. 3) which occurs on red soils and is mainly characterised by evergreen *Cynometra webberi* trees, as well as *Manilkara sulcata* and *Oldfieldia somalensis* and few scattered individuals of *Brachylaena huillensisis* trees. *Brachystegia* woodland (Fig. 4) (7,700 ha), is a form of 'miombo' lowland forest dominated by *B. spiciformis* (Bennun and Njoroge, 1999; Robertson and Luke, 1993). The canopy and understorey of the *Brachystegia* woodland is more open and relatively easy to walk through, than the other two forests types (Fig. 2, 3). Because of the high density of trees and shrubs in ASF, the inside of this forest was less windy. In the interior of ASF, bats were sampled in the three different vegetation types (*Brachystegia* woodland, *Cynometra* forest and Mixed forest).


Figure 2. Mixed trees forest in the interior of ASF.


Figure 3. *Cynometra webberi* trees dominated forest in the interior of ASF.

Figure 4. *Brachystegia spiciformis* trees dominated woodland in the interior of ASF.

Almost all indigenous woody plants in ASF have been cleared in the farmland by the local people, to open land for farming and human settlements. The main exotic fruit trees cultivated in the individual farms were mango (*Mangifera indica*), cashew nut (*Anacardium occidentale*), neem (*Azadirachta indica*) and coconut (*Cocos nucifera)*. The actively cultivated fruits trees were preferred for their fast growing and as sources of household income and multiple useful products. Other trees occasionally found in the farms were Indian almond (*Terminalia catappa)*, casuarina (*Casaurina equesitifolia)*, guava (*Psidium guajava)*, sugar-apple (*Annona squamosa)* and gamhar (*Glmelia arborea*). Casuarina was preferred as fast growing tree for provision of building poles and timber. Few baobab trees found in the farms were at least about 3-5 km from each other.

The mango, cashew nut, coconut and neem trees remain evergreen annually; hence their leafy canopies could possibly be used by bats for roosting. Some farms were dominated by either coconut or mangos trees, while others had a mixture of these trees. The study sites in the farmland, were individual compounds (farm/s), used by households for settlement and crops or trees cultivation. These farms were selected by visiting individual households, and visually estimating the % of cultivated trees in each farm. The mango farms (Fig. 5) had at least 50% dominance by mango trees; coconut farms >50% coconut trees (Fig. 6); while the mixed tree farms (Fig. 7) had at least 50% coconut trees, 20 % cashew nuts and mango trees. Bat sampling was only undertaken in farms where landowners did not ask for any kind of compensation from our research activities. The understory habitat of the farmland was very open, and could allow people or animals to wander about without obstruction. Due to the openness of the farmland habitat the area experienced regular breeze from the nearby Indian Ocean.

Figure 5. Mango trees dominated farms in the farmland in the eastern part of ASF.

Figure 6. Coconut trees dominated farms in the farmland in the eastern part of ASF.

Figure 7. Mixed trees farms in the farmland on the eastern part of ASF.

3.3.3 Animal community

A total of 73 mammal species are found in ASF (Jackson *et al*., 2019). Those of major conservation concerns include the Critically Endangered (CR) Ader's Duiker (*Cephalophus adersi*), endmic to Kenya and endangered (EN) *R. chrysopygus*, Vulnerable (VU) Sokoke Dog Mongoose (*Bdeogale omnivore*) and African Elephant (*Loxodonta Africana* (IUCN, 2019). Limited information exist about bats, rodents, forest shrews (Genus *Crocidura*) and small carnivores of ASF.

There are 270 bird species known from ASF, six of which are globally threatened (ASFMP, 2002). These include Sokoke Scops Owl (*Otus ireneae* (EN), Spotted Ground Thrush (*Zoothera guttata* (EN), Sokoke Pipit (*Anthus sokokensis* (EN), East Coast Akalat (*Sheppardia gunningi* (VU), Amani Sunbird (*Athreptes pallidigaster* (EN) and Clarke's Weaver *Ploceus golandi* (Endemic to Kenya (EN) Bennun and Njoroge, 1999). Other species recorded in ASF include lizards (21 species), snakes (41), tortoises (2), butterflies (more than 100) and amphibians (25) ASFMP, 2002). Lange (2003) and Bank *et al*. (2010) respectively described the snails and arthropod community of the forest.

Large and medium sized wild mammals have been completely wiped out in the farmland, mainly by hunting and destruction of suitable indigenous habitat for their survival. However, the following wild animals were recorded during my fieldwork in the farmland: One individual of Common Bush Duiker (*Sylvicapra grimmia*); Dwarf Galago (*Galagoides cocos*) were heard calling and some individuals seen at night in the cashew nut trees, and a few individuals of White-bellied Hedgehog (*Atelerix albiventris*). The most common bird species in Gede and Watamu towns, and other small village shopping centres were Indian House Crow (*Corvus splendens*) and Black Kite (*Milvus migrans*). Two gecko species Baobab Gecko

(*Hemidactylus platycephalus*), Barbour's Gecko (*Hemidactylus barbouri)* were opportunistically collected from the farmland and deposited with the NMK Herpetology Section.

3.4 Threats to biodiversity in study area

3.4.1 Threat to biodiversity in ASF

The rapid increase in human population around ASF is probably the single most serious threat to this forest and it biodiversity (Ongugo *et al*., 2008). More than 54 villages occur around ASF and depend on ASF for the supply of firewood for heating and cooking (ASFMP, 2002). The old and big trees are more easily the target of loggers, while old trees which die and start to decay are collected as firewood. Firewood is obtained legally by applying for a permit from KFS or illegally. Mogaka (1992), estimated that over 30,000 poles and 610 tons of fire woods were removed from ASF annually. The low number of KFS and KWS rangers posted to guard the forest, is not adequate to patrol the whole forest regularly, which makes it difficult to control illegal logging for timber, wood carving, building poles and charcoal burning (Habel *et al*., 2017). Bush-meat hunting, using wire snares and other traditional traps is rampant in ASF. More than 1, 000 local households living around ASF illegally hunt and capture a wide assortment of mammal species from this forest annually (FitzGibbon *et al*., 1991). The widespread and uncontrolled bush-meat hunting has probably contributed to the decline in the population size of *C. adersi*, which has become very rare, and has not been seen in the forest for many years.

3.4.2 Threat to biodiversity in farmland

Majority of inhabitants around ASF are subsistence farmers (ASFMP, 2002). The initial occupants of the area in 1960s, were allocated 12 ha of land per household for settlement and farming. However, with rapid human population increase over the years, the land has been sub-divided into small farms (< 2 ha) among the relatives, with very few farms of 12 ha now remaining. Farms were cultivated with different agricultural crops such as maize, cassava or peas. In addition the individual farms were planted with neem, mango, cashew and coconut trees, while others were left unattended and encroached by weeds. The sizes of cultivated farms will continue to decline with time, and after many years much of the farmland will possibly be converted to an urban area, as a result of increasing human population and process of urbanisation.

Much of the eastern part of ASF was more urbanised, with rapidly growing population of people from other parts of Kenya. Villages around Gede, Watamu and along the road to Malindi and Mombasa had more electricity connection, and better rural access roads. Most of the farms had at least about two traditional houses roofed with dry coconut leaves (makuti), and walls constructed of building poles and plastered in mud. Other compounds had big modern houses constructed of coastal coral stones, plastered with cement and roofed with corrugated iron sheets, most of which were in use, while a few others had been abandoned and unused by people. A few compounds had abandoned water well dug in the past and used as sources of water. These different types of houses were potential roosts for many bats species. Urbanisation, human population increase and proliferation of man-made structures, will increase potential roosting environments for bats, but also will amplify human-bat interactions, which eventually may threaten survival of bats in the farmland.

3.5 General materials and methods

3.5.1 Research design

The broad goal of the study was to investigate factors influencing bat community structure and activity patterns in ASF and adjacent farmland, as well as human-bats interactions around the forest. The taxon under investigation was bats, that are broadly divided into fruit and insectivorous bats. Two study sites were going to be the focus of the research namely inside ASF and farmland. The first important ecological question to address was; which species of bats were found in both study sites? This question was closely linked to: if these two study sites had bats; which one was actively used more for foraging and what were the differences in the bat community structure and composition between these sites?

The two study sites could possibly have the same or different bat species richness and abundance. In addition, they could be used the same way or differently by bats. If bat diversity and abundance, as well as use between ASF and farmland was not the same, there would be need to investigate factors causing these differences. A literature review indicates four main factors likely influence the abundance and distribution of bats in time and space. These include distribution and availability of roosts, fruit trees abundance (fruits eaten by fruit bats), invertebrate prey abundance (eaten by insectivorous bats) and habitat structure. Areas with many bat roosts tend to have more bats captured in mist-nets or detected with ultrasonic detectors. Fruiting trees attract many foraging frugivorous bats when fruits ripen. Open areas with abundant invertebrate prey abundance attract many foraging invertebrate prey abundance, as compared to thick habitats, where the same prey may be available but difficult to track and capture by these bats. Bats occur inside and outside protected areas, and interact frequently with people during foraging, or when they roost in man-made structures used by people. Since there is a worldwide negative perceptions about bats, attitudes and perceptions were investigated toward bats among people living in the eastern part of ASF, to understand whether their actions toward bats would either enhance or undermine the survival of bat species and their habitats in the study area. Research design steps followed are illustrated below (Fig. 8).

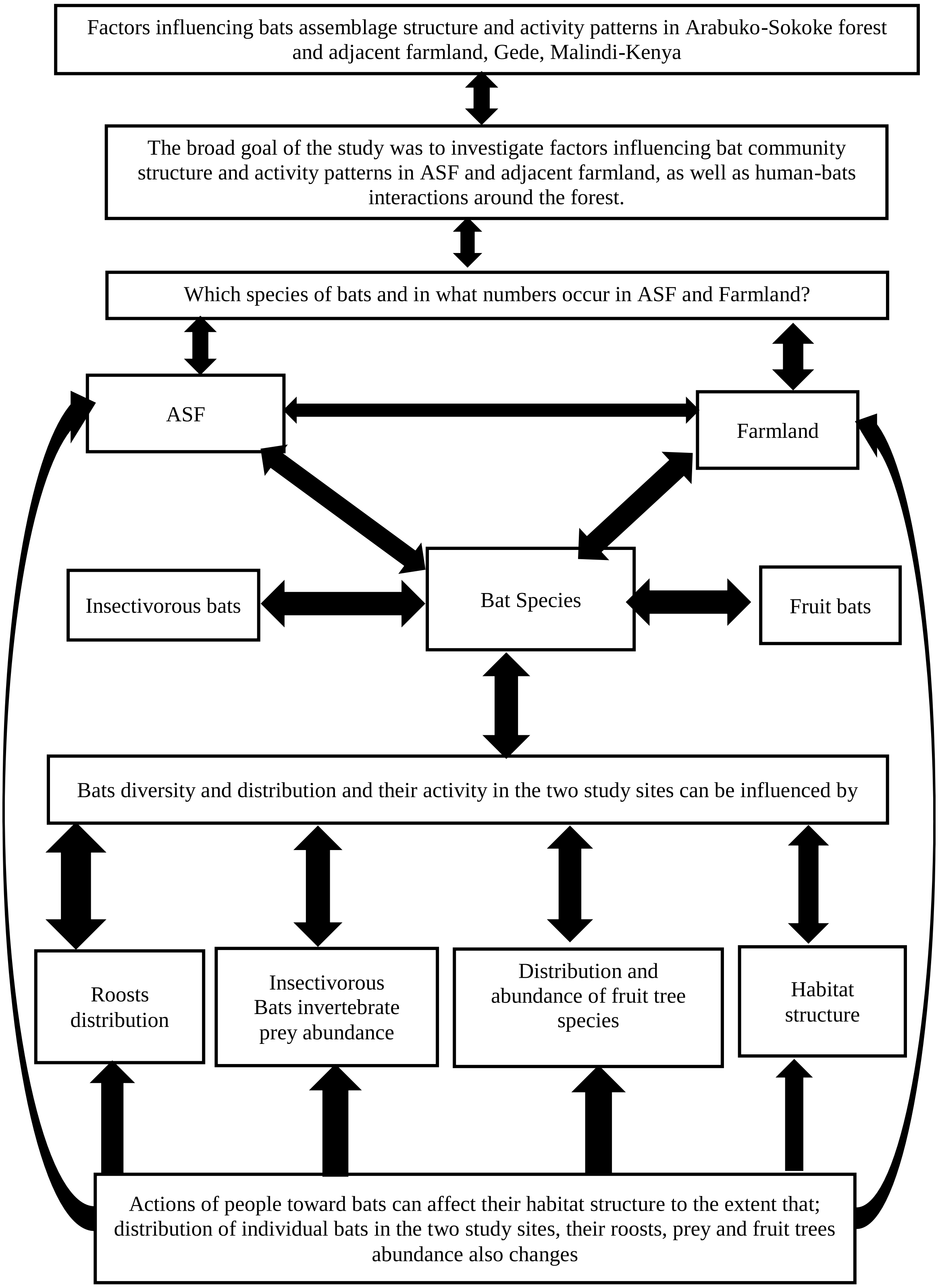

Figure 8. Conceptual framework of the research study

3.5.2 Bats mist-netting method

Mist-netting is widely used in many bat community studies (Blake and Loiselle, 2009). Mist-nets set at three metres above the ground were used to survey bats in ASF and farmland. The nets had four shelves, with a mesh of 16mm, 12m in length and 2.5m in width (Manufacturer, Ecotone Company, based in Poland). A total of five mist nets were used to capture bats in different sampling stations in the three vegetation types in the farmland (mango, coconut and mixed farms) and in the interior of ASF (*Brachystegia* woodland, *Cynometra* forest and Mixed forest). Bats were surveyed in three main different seasons (dry, long rains, and short rains) in seven field expeditions in the study area. During each survey, an equal number of stations were used to sample bats, in each of the three different vegetation types both in ASF and in the farmland. Mist-nets were monitored for varying duration of hours each night, but the sampling effort was consistent in each vegetation type in both habitats in each survey and season. In addition, the total length of net used in each vegetation type, in both habitats was the same in each survey. Sampling was done alternately, one day in ASF and the next in the farmland, to reduce bias associated with daily changes in weather conditions, which may affect bat activity or availability of invertebrates for insectivorous bats. Nets were also moved to a new sampling station each night, in order to reduce bias associated with decay in trapped bats, when they avoid mist-nets, after they learn their presence as a result of repeated sampling in the same location (Kunz *et al*., 2009). To compile a comprehensive checklist of bats in the study area, bats were also sampled from roosts encountered.

3.5.3 Bat activity surveys methods

Bat activity can be described as the presence of an individual bat in the airspace, after it emerges from its roost to forage or commute to suitable feeding or drinking areas. An area with large number of trapped bat in a given time (e.g. one hour), or count of many insectivorous passes (echolocation calls) has high bat activity. In this study bat activities were investigated using mist-net captures and ultrasonic detectors. During bat mist-netting surveys, the time of capture of each individual of all bat species was recorded, throughout the entire duration nets were monitored in each sampling station. In addition at the same bat mist-netting stations in the interior of ASF and the farmland, bat echolocation calls (passes) were also counted, using a Pettersson D240x ultrasound detector (Manufacturer, Pettersson Elektronik ABTM Company, Uppsala City, in Sweden) set in heterodyne mode (Estrada *et al*., 2004).

3.5.4 Sampling of invertebrates prey

Insectivorous bats exploit a wide variety of invertebrates as food prey, by foraging in different habitats and height levels above the ground. Because the interior of ASF and farmland had marked differences in habitat structure, it was predicted that this would influence the abundance of invertebrate prey and insectivorous bat species richness and activity. Invertebrate prey were sampled at night by use of solar lights (DP Light DP-6005A) http://en.dpled.com) Sanyal *et al*., 2013) in 12 different sampling stations both in ASF and farmland.

3.5.5 Assessment of bat habitat structure

Habitat characteristics play an important role in structuring animal communities. Point-Centred Quarter (PCQ), a plotless vegetation survey method (Cottam and Curtis, 1956; Bryant *et al*., 2005) was used to characterise vegetation structure in the both study sites. A total of 210 survey points, were used to describe the vegetation structure both in ASF and farmland. The main vegetation data collected from each PCQ point included tree species, percentage canopy and understory cover, Diameter at Breast Height (DBH), tree crown diameter and distant between trees.

3.5.6 Human-bats interactions survey methods

To investigate bat-human interactions around ASF, people living at most 1 km around three large bat roosts (limestone caves), and others living at most 3 km away from these caves were interviewed. To document their responses I used semi-structured questionnaires.

CHAPTER FOUR: BATS DIVERSITY IN ARABUKO-SOKOKE FOREST AND ADJACENT FARMLAND

ABSTRACT

Bats diversity and abundance were investigated in ASF and the farmland using mist-nets erected at 3M above the ground. Bat species in roosts were sampled with hand nets and their population sizes estimated. A total of 25 bat species were recorded both in ASF and the farmland. This included 19 in ASF and 25 in farmland. A total of 18 bat species occurred both in ASF and farmland. Moloney's Mimic Bat (*Mimetillus moloneyi*) was recorded exclusively in ASF, while six bat species were recorded solely in the farmland and not in ASF. Bat species diversity in ASF was (H'= 1.48 ± 0.2) while that of farmland was (1.33 ± 0.1), but the farmland had higher bat richness than ASF (Chao1, ASF: 19 [19-25], farmlands: 24 [24-32] species [0.95% CI]). In both study sites 5,217 individuals of bats were captured; 82.9% in the farmland and 19.1% in ASF. Fruit bats (*R. aegyptiacus* and *E. wahlbergi*), were the most common bat species (represented by 79% of all captured bats) in both study sites, while the most commonly captured insectivorous bat species was Heart-nosed Bat (*Cardioderma cor* (11.9%). A total of 14 bat roosts were found in the study area, which included 13 in the farmland and only one in ASF. Although, the farmland outside ASF was exceedingly degraded, bats still occurred in it; which emphasizes its importance for conservation of bats in the study area.

4.1 Introduction

Human-driven habitat changes and loss pose the greatest threat to global biodiversity (Barlow *et al*., 2016). These anthropogenic activities continue to convert the remaining tropical forests in Africa to human-modified areas or agroecosystems (Williams-Guillén *et al*., 2016). Bats have the ability to fly and and are capable of exploiting different types of habitats in the environment (Treitler *et al*., 2016). However, this does not mean they are unaffected by habitat modifications and disturbance. Hence, the need to continue to study bats in protected areas and neighbouring agricultural landscapes around them, so as to understand the roles of agroecosystems in their conservation. This study investigated 1). Bat species richness and diversity, 2). their composition and abundance, and 3). types of roosts and their characteristics in ASF and in the adjacent farmland. Because the two study areas; ASF and farmland were adjoining each other it was expected that the two habitats would have the same bat species richness. However, the marked differences in habitat structure and other resources in ASF and farmland could result in different bat species assemblages.

For example, the dense understory cover in ASF could result into reduced exploitation by bats that forage below the canopy. This would result in low rate of capture of some bat species. Besides, bat activity is generally lower in thick and cluttered habitats than in open areas (Kalko *et al*., 1996). Resource availability (e.g. fruit trees and roost sites) in the environment could also shape bat species composition. The farmland around ASF had many cultivated fruit trees, such as mangos and cashew nuts, which are sources of food for frugivorous bats. Roost availability is also known to influence bat species distribution and association (Kühnert *et al*., 2016). Thus, I predicted that the farmland would have higher relative abundance of insectivorous and frugivorous bat species than the interior of ASF. This assumption was also confirmed by data from my preliminary surveys in both habitats in March 2014, in which showed that the farmland had higher overall bat species richness and abundance (17 spp., 144 individuals), than that in ASF (10 spp., 63 individuals). This study sought to validate this assumption and the supportive preliminary findings.

4.2 Materials and Methods

4.2.1. Bat surveys

Mist nets set at 3M above the ground were used to capture bats in 81 mist-netting stations (Table 1, Fig. 9) in the three vegetation types in ASF and in the farmland (Musila *et al*., 2019c). The distance between any two bat mist-netting stations was approximately 1.5km from each other. Mist nets in a station were erected at most 100m from each other. Because roads through ASF were narrow (maximum width of 4m), the mist-nets (12m length) were erected slantwise across these roads. In the farmland, nets were erected in open areas cleared of trees or in openings in between tree rows. Stations in ASF and farmland were sampled alternatively, one day in the forest and the next in farmland, to reduce the decrease in bat captures by repetitively sampling in the same station as previously done by Kunz *et al*. (2009) and Castro-Arellano *et al*. (2010).

Table 1. Bat sampling seasons, dates, time and effort in ASF and farmland.

Survey month	Season	Survey hours (start-end)	Surveyed hours/ night (A)	Nets(m) /habitat (B)	No. of mist-nets /station (C)	No. of nights - ASF (D)	No. of nights - farmlands (D)	Total sampling effort - ASF	Total Sampling effort - farmlands
Nov-2014	Short rain	19-24	5	12	5	9	9	**2700**	**2700**
Feb-2015	Dry	19-01	6	12	5	12	12	**4320**	**4320**
Jun-2015	Long rain	19-01	6	12	5	12	12	**4320**	**4320**
Nov-2015	Short rain	19-05	10	12	5	12	12	**7200**	**7200**
Feb-2016	Dry	19-05	10	12	5	12	12	**7200**	**7200**
Jun-2016	Long rain	19-05	10	12	5	12	12	**7200**	**7200**
Nov-2016	Short rain	19-23	4	18	2	12	12	**1728**	**1728**
TOTAL						**81**	**81**	**34668**	**34668**

Note-The total effort in ASF and farmland was calculated by multiplication of (A*B*C*D) (net meter/hours (nmh).

Mist-nets were checked twice each hour throughout the night. All captured bats were kept in a large cloth bag, and released at each bat mist-netting station after recording the following information for each individual of a bat captured; time found in the net, species identity, breeding status, sex, weight, age and forearm length. These variables are important for species identification and assessment of reproductive condition of individual bats. To assess the rate of bats recapture in each sampling station, a number of bats were marked by being wing punched and released, and then those individuals which were recaptured in the same sampling station recorded and released again.

In between November 2014-November 2016, seven bat sampling surveys were undertaken in ASF and adjacent farmland. Sampling effort varied slightly between surveys, but was always the same between vegetation types in ASF and farmland (Table 1).

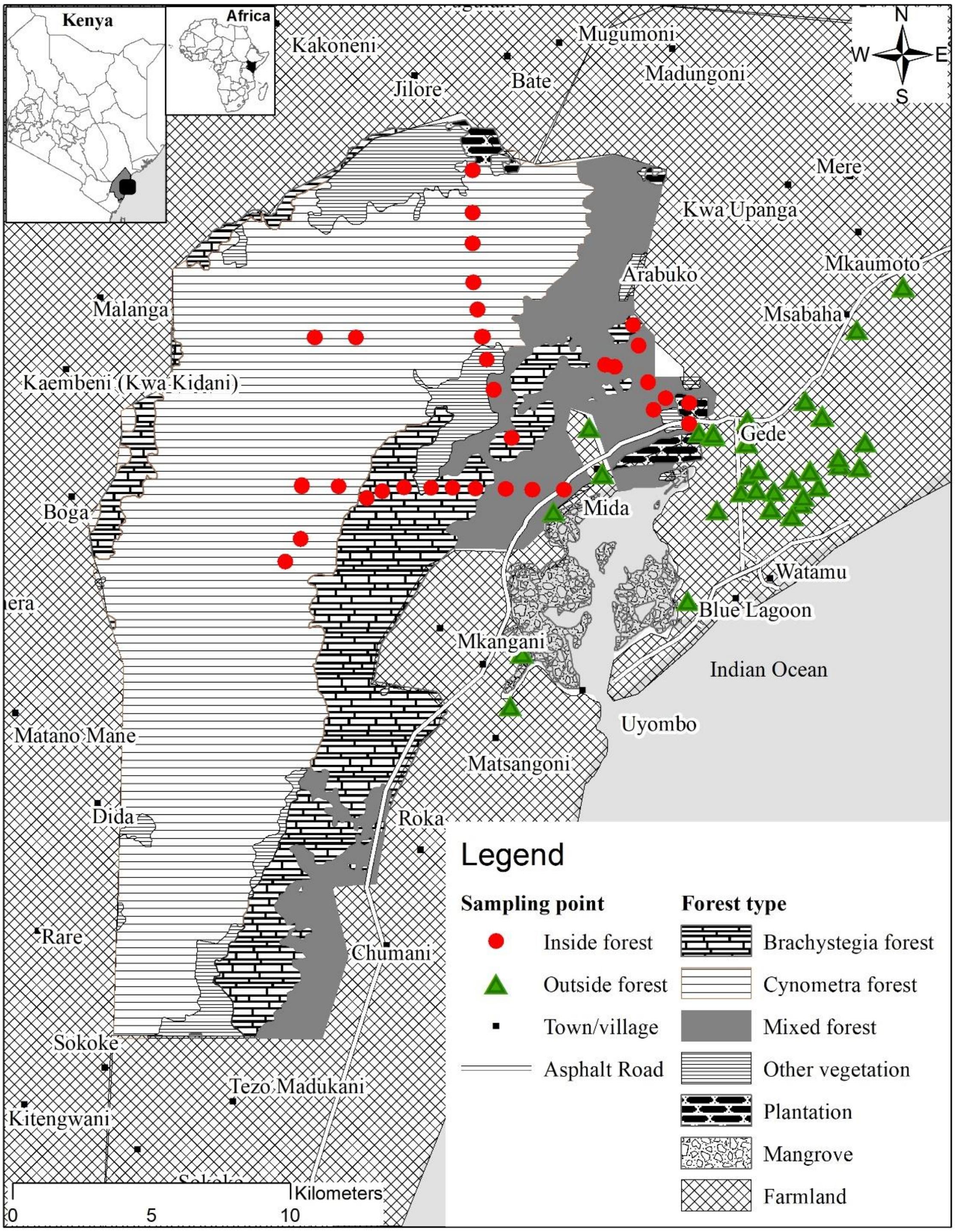

Figure 9. Map of the study area showing the different vegetation types and sampling stations in ASF (red dots) and farmland (green triangles).

Bats were also surveyed opportunistically from roosts, by interviewing the local people around the study area to help locate any existing roosts. Specifically, during socioeconomic surveys, respondents were asked to give information about places (e.g. trees, caves or houses) where they knew bats roosted in large numbers. Reported roosts were visited to check whether bats were still roosting in them. This was followed by directly capturing some with hand nets as they flew out of active roosts. The number of bats in each roost was also estimated visually as done by Flaquer *et al*. (2007) in other studies.

Bat identification keys developed by Monadjem *et al*. (2010) and Patterson and Webala (2012) were used to identify bats in the field. Voucher specimens collected from the field were also compared with bat specimens preserved at Mammalogy Section Lab-National Museums of Kenya (Appindex 1). The classification provided by Happold and Happold (2013) is used for scientific and English names. Voucher specimens were collected for some species, preserved in 70% ethanol, and deposited with the Mammalogy Section-NMK.

4.2.2 Data analysis

To estimate the total sampling effort in each site site (ASF, farmland) the product of length of all nets was multiplied with all hours worked during each expedition as done by Medellín (1993) Table 4.1). To estimate the relative abundance of bats in each study site (ASF, farmland), the total number of bats captured were divided with total sampling effort in each study site. EstimateS 9.1.0, a program that uses data on species richness and abundance was used to construct bat species estimate curves. To estimate the total bat species richeness in ASF and farmland Chao1 and Jacknife1 (Chao, 1987; Colwell *et al*., 2012) were used. Bat species diversity in both study sites and different vegetation types was calculated with Shannon-Wiener Index ($H^{/}$) of diversity (Shannon and Weaver, 1963). To compare the similarity of bat species between ASF and farmland Morisita % similarity index was used (Morisita, 1959). Unweighted Pair Group Method with Arithmetic Mean (UPGMA) dendrograms, were used to classify bat species among different vegetation types, using their presence or absence as well as the abundance of each species. To compare seasonal changes in the distribution of captured bats by sex and age, and breeding conditions, data for three bat species (*R. aegyptiacus*, *E. wahlbergi* (fruit bats) and *C. cor* (insectivorous bat) was used. This was because the three species were captured each night in large numbers in the entire survey and also in each season. The UPGMA dendrograms, were analyzed with PAleontological STatistics (PAST 3.16) program (Hammer *et al*., 2001).

4.3 Results

4.3.1 Diversity and species richness of bats

In total, 25 bat species were recorded in the two study sites (some selected bat photos (Appindex 2). This included 19 species in ASF (Table 2) and 25 in the farmland (Table 3). Eighteen bat species occurred both in ASF and farmland. Three individuals of *M. moloneyi* were captured exclusively in ASF and not in the farmland (Table 2). A total of five bat species solely occurred in the farmland and not in ASF. These included Hildegarde's Tomb Bat (*Taphozous hildegardeae*), Egyptian Tomb Bat (*Taphozous perforatus*), Harrison's Giant Mastiff Bat (*Otomops harrisoni*), Rendall's Pipistrelle (*Neoromicia rendalli)*, White-winged Pipistrelle (*Neoromicia tenuipinnis*) and Dark-winged Lesser House Bat (*Scotoecus hirundo*) (Table 3). Two bat species (*T. perforatus* and *T. hildegardeae*) were captured directly from roosts with hand nets in the farmland, but not from mist-net surveys. The Morista's similarity index between ASF and farmland was 65.8%. The coconut dominated farms in the farmland had the largest number of bat species (19) recorded, while in ASF it was *Cynometra* forest (16). The farmland rarefaction curves nearly reached the plateau (Fig. 10) and estimated higher bat species richness in this habitat than in ASF (Fig. 11). The same pattern was depicted by Jacknife1 with an an estimated of 22.95 (± 1.9 SD) bat species in ASF and 25.98 (± 1.3) in the farmland. Chao1 estimated 19.33 (19.0-25.0 95% CI) species in the forest and 24.5 (24.0-32.3) species in the farmland. The bat assemblage structure in the farmland was dominated by frugivorous bats, which consequently resulted into higher evenness inside ASF (ASF: 0.48 ±

0.1) than in the farmland (0.22 ± 0.05). Consequently, the diversity was slightly higher in ASF (Shannon-Wiener index forest: H/=1.48 ± 0.2, than in farmland: H/=1.33 ± 0.1). A total of 1,148 bats were wing punched; 1136 in the farmland and 53 in ASF. Only 12 (1.1%) were recaptured at the same mist-netting station in the same night in the farmland, and none in ASF and cumulatively 98.9% (1136) of the marked bats were not recaptured.

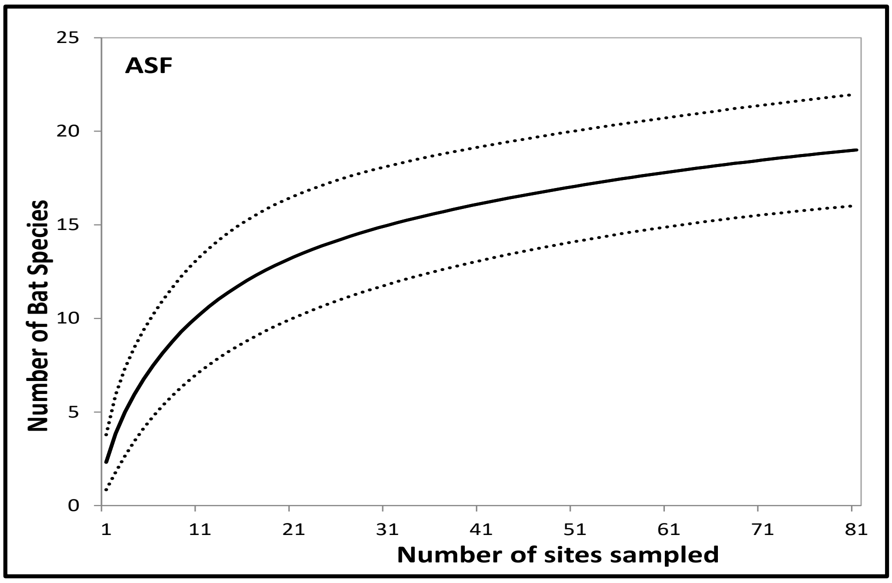

Figure 10. Bat species estimate curve for the farmland indicating species richness expected values (solid line) and the 95% confidence intervals (dashed lines).

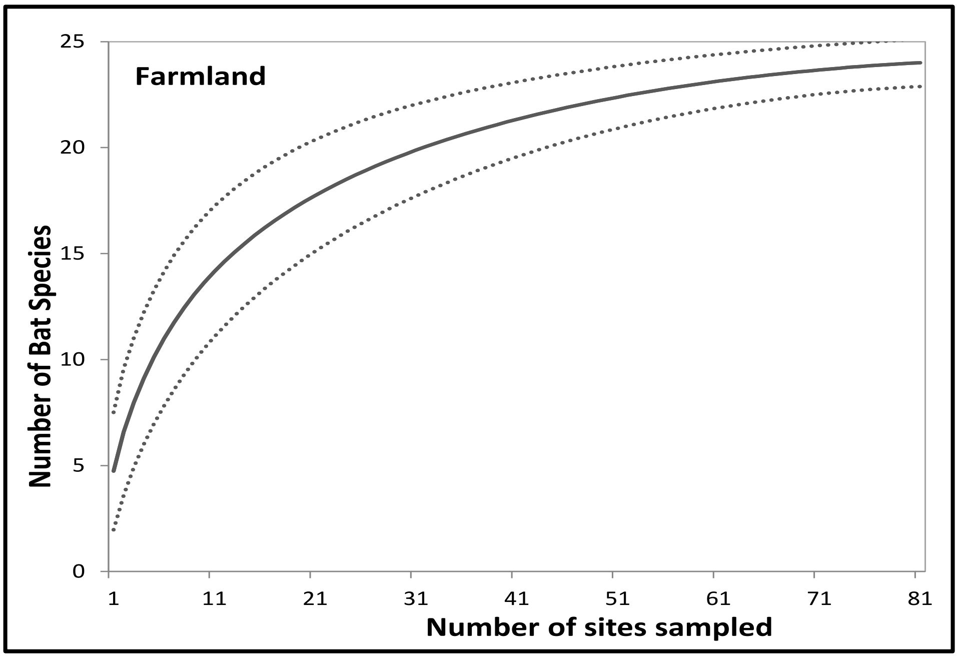

Figure 11. Bat species estimate curve for the interior of ASF indicating species richness expected values (solid line) and the 95% confidence intervals (dashed lines).

Table 2. Bat species, diversity and their abundance in different habitat types in ASF

	IUCN Status, 2019	Arabuko-Sokoke Forest			Total capture
Vegetation Types		**CYNO**	**BRA**	**MIXFo**	
Pteropodidae					
1. *Eidolon helvum*	NT			1	**1**
2. *Epomophorus wahlbergi*	LC	206	59	153	**418**
3. *Rousettus aegyptiacus*	LC	27	59	228	**314**
Rhinolophidae					
4. *Rhinolophus deckenii*	NT	8	1	1	**10**
Hipposideridae					
5. *Hipposideros caffer*	LC	13			**13**
6. *Macronycteris vittata*	NT	7	6	7	**20**
Megadermatidae					
7. *Cardioderma cor*	LC		2		**2**
Emballonuridae					
8. *Coleura afra*	LC	1	10	6	**17**
9. *Taphozous mauritianus*	LC	1			**1**
Nycteridae					
10. *Nycteris thebaica*	LC	1	13		**14**
Molossidae					
11. *Chaerephon pumilus*	LC	3			**3**
Miniopteridae					
12. *Miniopterus minor*	DD	14		5	**19**
13. *Miniopterus cf inflatus*	LC	1	1		**1**
Vespertilionidae					
14. *Mimetillus moloneyi*	LC			3	**3**
15 *Neoromicia capensis*	LC	2	3		**5**
16. *Neoromicia nana*	LC	15	4		**19**
17. *Nycticeinops schlieffeni*	LC	1	4	8	**13**
18. *Pipistrellus rueppellii*	LC	5			**5**
19. *Scotophilus trujilloi*	LC	1	3	7	**11**
No. of species		16	12	10	**19**
No. of insectivorous bats		73	47	37	**157**
No. of fruit bats		233	118	382	**733**
No. of bat individuals		306	165	419	**890**
Trap Stations/Vegetation type		27	27	27	**81**
Net Meter Hours (Nmh)		11556	11556	11556	**34668**
Relative abundance (Bats/ Nmh)		0.03	0.01	0.04	**0.0**

Legend: *Cynometra* Forest (CYNO), *Brachystegia* Woodland (BRA) and Mixed Forest (MIXFo)

Table 3. Bat species, diversity and their abundance in different habitat types in farmland.

	IUCN Status, 2019	Farmland			Total capture
Vegetation Types		**MAN**	**COC**	**MIXFa**	
Pteropodidae					
3. *Eidolon helvum*	NT	4			**4**
2. *Epomophorus wahlbergi*	LC	400	271	363	**1034**
1. *Rousettus aegyptiacus*	LC	888	744	727	**2359**
Rhinolophidae					
4. *Rhinolophus deckenii*	NT	10	5	15	**30**
Hipposideridae					
5. *Hipposideros caffer*	LC	2	8	13	**23**
6. *Macronycteris vittata*	NT	17	11	14	**42**
Rhinonycteridae					
7. *Triaenops afer*	LC	1	4		**5**
Megadermatidae					
8. *Cardioderma cor*	LC	146	215	260	**621**
Emballonuridae					
9. *Coleura afra*	LC	1	3	19	**23**
10. *Taphozous mauritianus*	LC	5	2		**7**
Nycteridae					
11. *Nycteris thebaica*	LC	6	12	22	**40**
Molossidae					
12. *Chaerephon pumilus*	LC	2			**2**
13. *Otomops harrisoni*	VU		10	1	**11**
Miniopteridae					
14. *Miniopterus minor*	DD	2	10	3	**15**
15. *Miniopterus cf inflatus*	LC	1			**1**
Vespertilionidae					
16 *Neoromicia capensis*	LC	3	1	2	**6**
17. *Neoromicia nana*	LC	10		2	**12**
18. *Neoromicia rendalli*	LC		1		**1**
19. *Neoromicia tenuipinnis*	LC		5	1	**6**
20. *Nycticeinops schlieffeni*	LC	13	1	6	**20**
21. *Pipistrellus rueppellii*	LC		3	1	**4**
22. *Scotoecus hirundo*	LC		8	2	**10**
23. *Scotophilus trujilloi*	LC	16	30	5	**51**
No. of species		18	19	17	**23**
No. of insectivorous bats		239	329	366	**930**
No. of fruit bats		1288	1015	1090	**3397**
No. of bat individuals		1527	1344	1456	**4327**
Trap Stations/Vegetation type		27	27	27	**81**
Net Meter Hours (Nmh)		11556	11556	11556	**34668**
Relative abundance (Bats/Nmh)		0.13	0.12	0.13	**0.1**

Note: Two additional bat species captured directely from roosts in farmland not included in this table
Legend: Mango (MAN), Coconut (COC), and Mixed (MIXFa).

4.3.2 Bats abundance and their seasonal trends

In total 5,217 individuals of bats were trapped in the entire study, including 82.9% in the farmland and 19.1% in ASF (Table 2, 3). The mean number of captured bats in the farmland was (618.1 ± 11.6, N=7), and in ASF (127.1 ± 38.8, N=7). There was a significant difference between the medians of bats captured in ASF and farmland (Mann-Whitney U-Test, U=4: p <0.0069) Fig. 12). Of 5,217 bats, fruit bats were the most abundant (79.2%), while insectivorous bats were less common (20.8%). The most abundant bat species were individuals of two fruit bats (*R. aegyptiacus* and *E. wahlbergi*), which were represented by 79% of all individuals of bats captured in the interior of ASF and the farmland. Overall the most commonly captured insectivorous bat species were *C. cor* (11.9%), followed by Trujillo's House Bat (*Scotophilus trujilloi* (1.2%), Striped Leaf-nosed Bat (*Macronycteris vittata* (1.2%), Egyptian Slit-faced Bat *Nycteris thebaica* (1.03%) and African Sheath-tailed Bat (*Coleura afra* (0.77%). Of the three different vegetation types in ASF, the mixed forest had the numerous number of inviduals of fruit bats trapped (381). In the farmland majority of fruit bats were trapped in mango trees dominated farms (1288). Inside ASF, *Cynometra* habitat had the most numerous capture of insectivorous bats (73), while in the farmland it was farms with mixed cultivated trees (366 (Table 3).

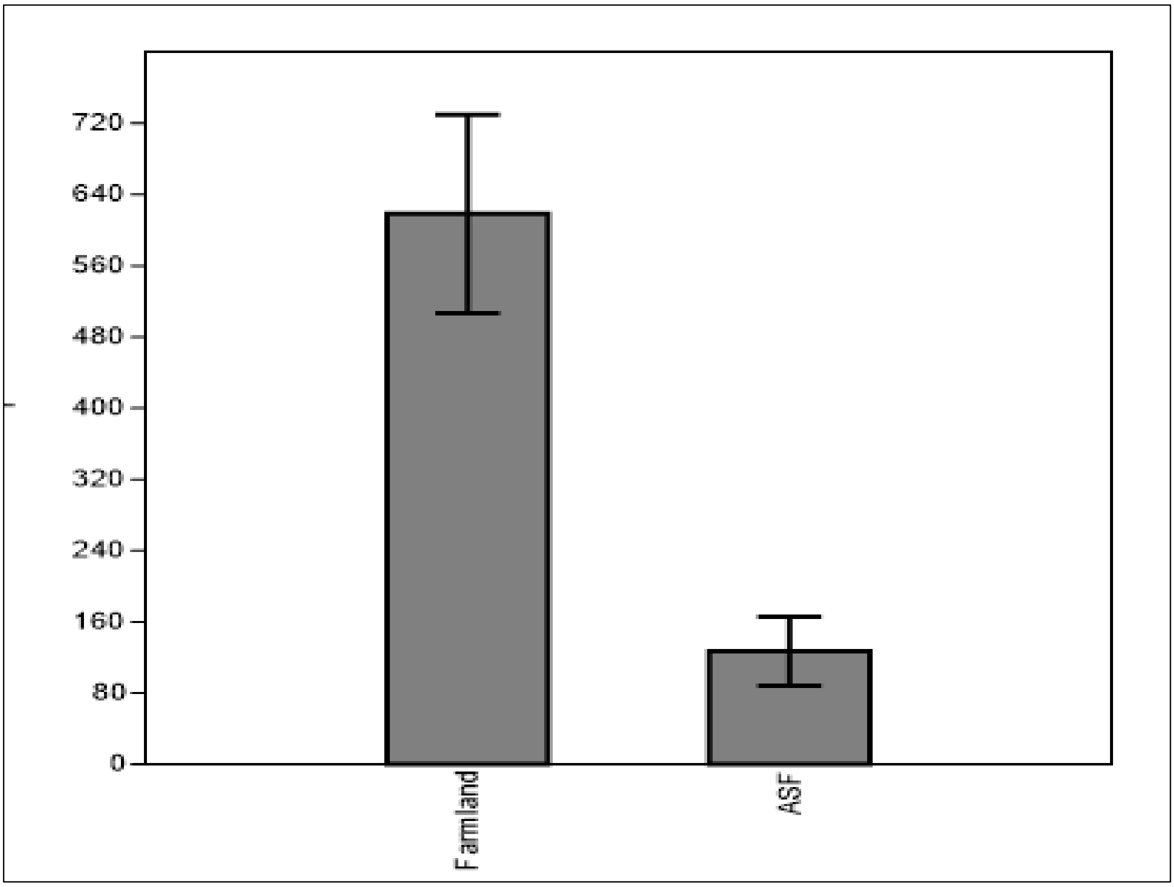

Figure 12. The mean number of individual bats captured in each study site (Error bars are standard errors).

The UPGMA dendrograms showed that species abundance clearly separated the forested habitats from the farmland habitats (cophen. correl. = 0.959; Fig. 4.6a) while the incidence or species analyses showed a greater similarity of species composition of bat assemblages present in mango farms and in the three forested habitat types (cophen. correl. = 0.891; Fig. 13a,b).

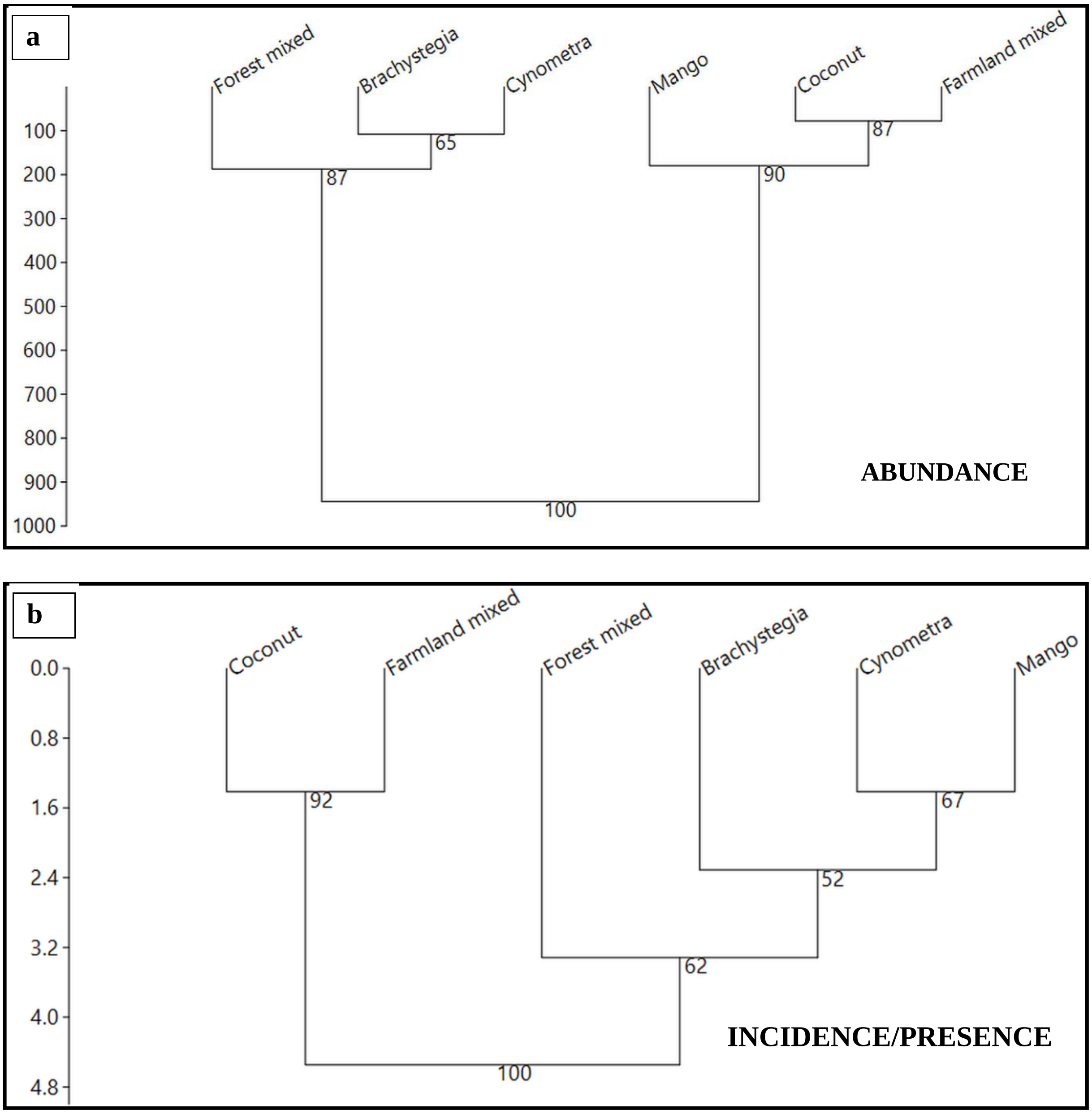

Figure 13. UPGMA dendrogram (Ward's method with Euclidean distance and 40 bootstraps), on the differences of bat assemblage among vegetation types in ASF and farmland based on species abundance (a) and incidence (b).

4.3.3 Bat roosts in ASF and in the farmland

A total of 14 bat roosts were found in the study area, which included seven limestone coral caves, three trees and four man-made roosts (Table 4). Of the 14 roosts, 13 occurred in the farmland and only one was found in ASF. Roosts found on private land were not under any kind of legal protection. All roosts in farmland were used by 13 bat species for roosting, and only one species one roosted inside a latrine in ASF (Appindex 3). Ten different bat species roosted in the limestone coral caves, with Ali Baba/Makuruhu Cave (A) and Kaboga Cave (F) being used by multiple species, but the former having the largest bat population (Table 4). Individuals of *C. cor* were found in five different limestone coral caves.

Table 4. Bat roost types in ASF and farmland, estimate of bats population in them, and different bat species found in each roost.

Type of Roost	**A***	**B***	**C**	**D***	**E***	**F***	**G**	**H***	**I**	**J***	**K**	**L**	**M**	**N**	
Estimated Number of bats	>1000,000	7,000	200	200	100	200	50	5,000	50	50	10000	100	50	2	**R/S**
1. *Eidolon helvum*											+				**1**
2. *Epomophorus wahlbergi*			+												**1**
3. *Rousettus aegyptiacus*		+													**1**
4. Hipposideros caffer	+			+				+							**3**
5. Macronycteris vittata								+							**1**
6. Triaenops afer	+							+							**2**
7. Cardioderma cor				+	+	+	+	+		+					**6**
8. *Coleura afra*	+							+				+			**2**
9. *Taphozous hildegardeae*	+							+							**2**
10. *Taphozous mauritianus*														+	**1**
11. *Taphozous perforatus*						+									**1**
12. *Nycteris thebaica*									+				+		**2**
13. *Miniopterus cf inflatus*	+							+							**2**
14. *Miniopterus minor*	+							+							**2**
Total Species/Roost	**6**	**1**	**1**	**2**	**1**	**2**	**1**	**8**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Legend: Ali Baba/Makuruhu Cave (A); Watamu Police Station Cave (B), Gede Market Tree Roost (C), Lion Cave (D), Panga Yambo Cave (E), Uyombo Cave (F), Borehole Roost (G); Kaboga Cave (H), ASF Latrine Roost (I), Kanani Cave (J), Malindi *E. helvum* Tree Roost (K), *C. Afra* Building Roost (L), Eco-Camp House Roost (M) and *T. mauritianius* Coconut Tree Roost (N); + bat species recorded in a roost; R/S-number of roosts at which a bat species occurs; *Limestone bat cave.

4.3.4 Seasonal changes in bats abundance

Many individuals of bats were captured in the dry season (mean 1420.0 ± 364.9, N=3), than in wet (mean 1062.6 ± 276.9, N=3) and short rain (mean 942.0 ± 242.8.9, N=3) seasons. However, there was no significant difference in the sample medians of captured bats among different seasons (Kruskal-Wallis Test, H=1.422, df=9, p>0.05, N =10). One individual of *E. wahlbergi* was captured in mist net in the farmland with a ripe fruit of *A. occidentale*.

4.3.5 Age sex structure and breeding status of bats

Out of 5,217 bats trapped during this study, 52.3% were females and 45.6% were males; the rest (2.1%) could not be sexed because they were very young (juveniles) and impossible to sex. About 84.4% of the bats were adults while 14.2% were sub-adults and juveniles. Majority of the sub-adults bats were individuals of *R. aegyptiacus* (564) followed by E. *wahlbergi* (165). The largest number of individuals of *R. aegyptiacus* (1243) and *C. cor* (256) were captured in the dry season; while those of *E. wahlbergi* (651) were captured in short rain season (Fig. 14). The largest number (490) of sub-adults bats were captured in dry season (February to March), followed by long (145 (June-July) and short rain seasons (107 (November-December). About 65.6% of the bats were not breeding, while 31.1% of bats were in breeding condition. Those breeding included 1,052 males with engorged testes, 184 lactating females (teats which when slightly pressed would exude milk), 356 pregnant and 32 bats captured carrying young bats. Breeding males and females (lactating, pregnant, or with young) of *R. aegyptiacus*, *E. wahlbergi* and *C.cor* were captured in all seasons. However, largest numbers of breeding *R. aegyptiacus* (143) were captured in short rainy season, while with those of *E. wahlbergi* (85) and *C.cor* (33) were trapped in the dry season.

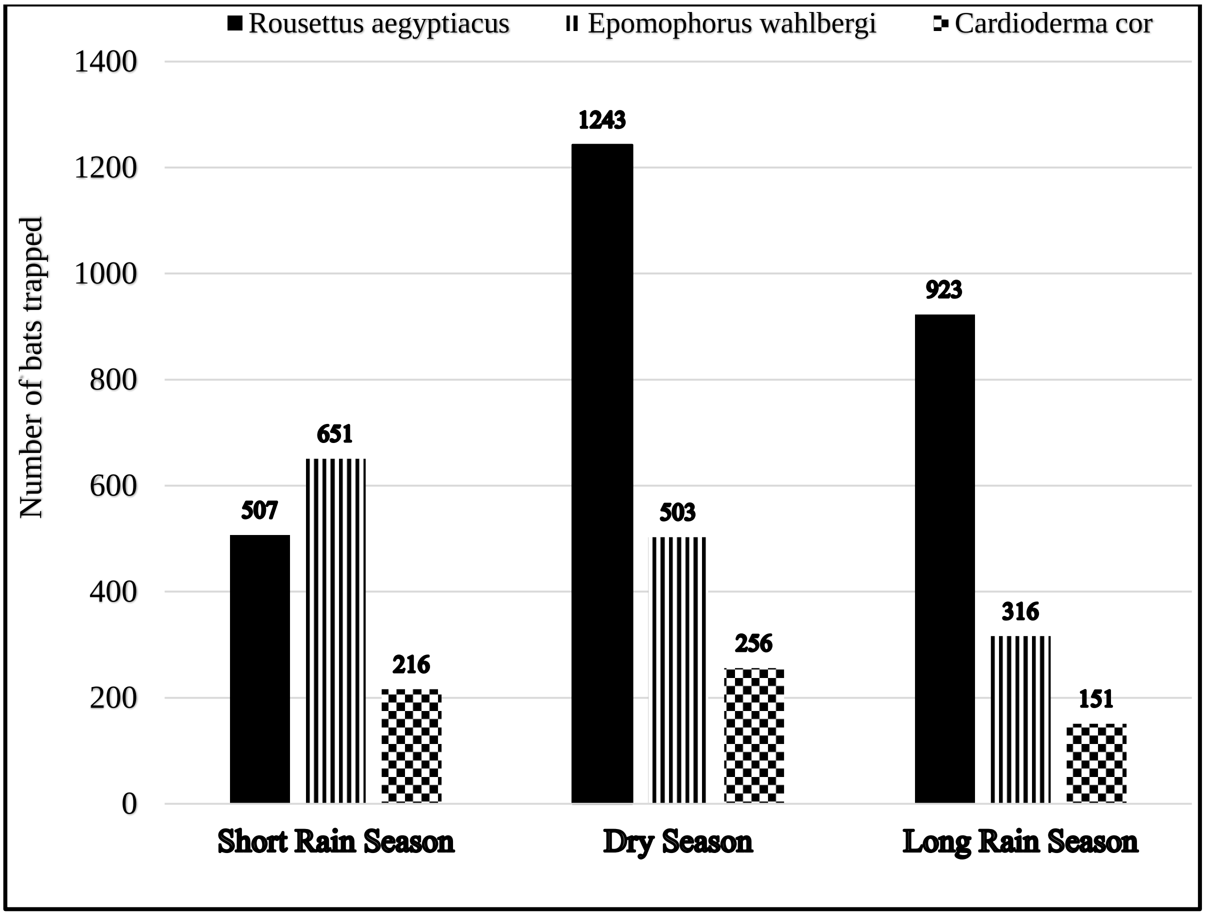

Figure 14. Number of individual bats of three bat species captured in different seasons

4.4 Discussion

The current study shows that bats were more common in farmland than in ASF. Studies of bats along disturbance gradient tend to give variable results. Results of the present study are similar with the findings of Struebig *et al*. (2013), who reported that heavily degraded and logged forests in Borneo had limited effects on bat species richness. However, the agricultural areas around Lake Bogoria National Reserve (Wechuli *et al*. (2016) and Meru National Park (Webala *et al*, 2004) in Kenya, had low bat species richness and abundance than the interior of the two protected areas. In the current study, fruits bats were commonly found in the farmland than in ASF. This was consistent with observation of Luskin (2010), in Fiji where the mean foraging density of frugivorous Pacific Flying Fox (*Pteropus tonganus*) in farmland was four times higher than in the forests. The presence of many cultivated orchard trees in the farmland may have contributed to large captures of fruit bats in the farmland.

The availability of roost sites influences the distribution and abundance of bats (Fenton and Rautenbach, 1986). There was only one active bat roost found in ASF, which was occupied by few individuals of *N. thebaica*. Many other roosts may have existed in ASF, but were difficult to locate, probably because of the high structural complexity of the forest vegetation. However, the farmland had 13 roosts, which collectively provided roosting habitat for 13 different bat species. Limestone cave roosts such as Alibaba and Kaboga in the farmland, had multiple species and in large numbers. In addition, some man-made structures in the farmland were also used by some bats for roosting. For instance, more than 100 individuals of *C. afra* roosted in one abandoned house in the farmland. The dry region of the western Madagascar has more species of bats than the humid east because of high density of limestone karst roosts (caves) in that region (Eger and Mitchell, 2003; Goodman *et al*., 2005). Therefore, the many man-made infrastructures as well as other natural roosts, supported a large number of bats, which probably hugely contributed to high captures in the farmland. However, the future of the roosts in the farmland for sustaining bats was uncertain, because they occurred on private land, where they could easily be destroyed or converted to other land uses incompatible to bat conservation. Furthermore, there were no specific measures implemented by any organisation, which were directed at the conservation of bats and or their roosts in the study area.

In conclusion, the farmland was richer in bat species, and bats were more abundant in it than in ASF. In addition, more bat roosts were found in the farmland than in ASF. Although the farmland outside the interior of ASF was extremely degraded, different bat species occurred in it and for some species, especially the fruit bats in large numbers. Thus, the farmland in the eastern part of ASF, is a vital habitat for bats conservation. It is therefore, important to enhance bat investigations in agro-ecosystems in Africa, in order to comprehend the roles of this ecosystem in the survival and management of bats habitats in the continent.

CHAPTER FIVE: BAT ACTIVITY IN ARABUKO-SOKOKE FOREST AND ADJACENT FARMLAND

ABSTRACT

Bats spend the day in roosts, and emerge after sunset into the airspace to forage or commute to suitable drinking areas. Bat activity was investigated in ASF and adjacent farmland, in order to understand how bats used the two study sites. Activity of bats was monitored with mist-nets (fruit and insectivorous individual bats captures) and acoustic (count of insectivorous bats echolocation calls (passes) methods. The mean number of individual bats captured using mist-nets hourly in the farmland was (425.3 ± 95.1, N=10), while in ASF it was (88.4 ± 11.2, N=10). There was a significant difference between the medians of bats captured in mist-nets hourly in both study sites (U=9.5: p <0.0025, Mann-Whitney U-Test). In total 14,727 insectivorous bat passes were counted, including 10,552 in the farmland and 4,175 in ASF. The mean number of counted bat passes nightly in the farmland (152.9 ± 13.2) was significantly higher than in ASF (60.5 ± 4.6) df = 68, t = -8.671, P <0.05, N = 69). The activity pattern of mist-netted bats and detector monitored insectivorous bats peaked after sunset (1900-2000hr), plunged to lowest level past midnight (0100hr-0200hrs), then slightly increased at dawn (0400hr-0500hr). Individuals of captured *R. aegyptiacus, E. wahlbergi* and *C. cor* were active throughout the night. Although, the farmland was very disturbed than the interior of ASF, bats actively used this habitat for either foraging or commuting. This underlines the importance of farmland habitat around ASF for conservation of bats, and the need to conduct more research in agricultural areas in Africa.

5.1 Introduction

Wild animals may coexist in the same area, if they forage in different types of habitats (Arlettaz, 1999), feed on diverse food items (Arlettaz *et al*., 1997), or be active on different times of the day or night (Bonaccorso *et al*., 2006). Bats spend the day time in roosts and disperse in the evening mainly to forage (Eckert, 1982). Insectivorous bats use echolocation to navigate, orientate and forage at night (Griffin, 1958). In contrast, fruit bats have superb nocturnal vision for navigation, and an extremely developed sense of smell to locate food (Happold and Happold, 2013). Fruit and insectivorous bats activity can be documented directly with mist-nets captures (Kunz and Brock, 1975). The number of individual captures of bats can be used as a surrogate for bat activity, under the assumption that higher flight activity of bats leads to higher capture rates (Aguiar and Marinho-Filho, 2004). Thus, an area where many individuals of bats are captured at any given time, may possibly indicate a habitat which is preferred by bats to forage or commute to other areas.

The activity of insectivorous bats, which uses echolocation to find their way in the environment, can also be documented indirectly with ultrasonic detectors (Hayes *et al*., 2009). The activity is counted in insectivorous bats echolocation calls, also known as 'passes'. A bat 'pass' is a signal of an echolocating bat picked by an ultrasonic detector (Fenton *et al*., 1998) and translated to sound audible to human ear (< 20 kHz). An area where many bat passes are counted at any given time, may indicate a habitat selected by insectivorous bats for foraging or commuting to other areas. Furthermore, areas of high bat activity indicate areas that are important to bats or others they use heavily (Adams *et al*., 2015), and such information can be used to identify priority areas for bat conservation (Estrada *et al*., 2004). In this chapter the activity of insectivorous and fruits bats was investigated in ASF and the adjacent farmland. Since, the two study sites were adjoined, and bats are very mobile, it was predicted that the ASF and the farmland would have the same pattern of bat activity.

5.2 Materials and Methods

5.2.1 Bat activity surveys

Mist-nets erected at 3M above ground were used to monitor bat activity in 69 different sampling stations in ASF and in the farmland. For each individual bat trapped and extracted from the net, the time it was found in the net, as well as the species and its sex were recorded. Insectivorous bat activity was monitored in the same 69 bat mist-netting stations. This was done by use of Pettersson D240x ultrasound detector (manufactured by Pettersson Elektronik ABTM Company, Uppsala-Sweden (whttp://www.batsound.com/) tuned to heterodyne mode (Estrada *et al*., 2004). The detector was always tuned to 33 kHz in all 69 stations. Fruit bats do not echolocate, except *R. aegyptiacus* whose echolocation frequency range from 10-20 kHz (Happold and Happold, 2013). Therefore, no fruit bat activity was monitored using the detector because the 33 kHz frequency setting used was way above that of *R. aegyptiacus*. However, by setting the detector at 33 kHz, it was possible to detect the presence of different species of insectivorous bats whose echolocation calls ranges between 25-41 kHz, because the detector has a bandwidth of 8 kHz (Musila *et al.* 2018a). Bat passes were counted for 10-minute each hour, by walking along a transect of 400 m where the mist-nets were erected. Bat passes were counted by an observer walking on foot with the detector held in one hand (Estrada *et al*., 2004). The numbers of passes was recorded using a tally counter. No sampling was done during nights of heavy rainfall. Stations in the farmland and in ASF were investigated alternately; with one night used in a station in forest surveys followed by a station in the farmland. Although the bat passes could not be identified to species, bat species such as *S. trujilloi, N. thebaica, C. afra,* Schlieffen's Twilight Bat (*Nycticeinops schlieffeni*), *S. hirundo,* Cape Pipistrelle (*Neoromicia capensis*), *N. tenuipinnis,* Mauritian Tomb Bat (*Taphozous mauritianus*), *P. rueppellii,* Little Free-tailed Bat (*Chaerephon pumilus*) and *N. rendalli* whose echolocation range is 25-41 kHz (Monadjem *et al*., 2010) most likely accounted for most of the counted passes. These bat species were captured throughout the mist-netting sampling in ASF and in the farmland (Table 2, 3).

5.2.2 Data analysis

To analyse bat capture data for activity patterns, the data in different vegetation types in ASF and farmland was pooled together, because in some vegetation types especially in ASF, it was not sufficient to infer about the activity of bats. The individual captures of each bat species were pooled into 1-h intervals (e.g., all bats captured from 1900 to 2000h) Presley *et al*., 2009), which cumulatively resulted in patterns of activity in each hour of all bats captured at each study site (ASF, farmland). Bat capture data were organized in MS excel program. Non-parametric two sample Mann-Whitney U-Test was used to test for differences in the sampled medians of captured bats each hour in ASF and farmland.

To investigate seasonal changes in bat activity, data for November 2015 (short rain season), February (dry season) and June (long rain season) 2016 were used because the sampling effort was uniform among seasons (Table 1). Means of the total number of bats captured in each hour in each season were calculated, and the differences in the sampled medians was tested using non-parametric Kruskal-Wallis Test. To understand pattern of bat activity among female and male bats, the segments of data collected for five hours (1900-2300hrs) were selected, because its sampling effort was consistent throughout the six visits undertaken in the study area (Table 1). In addition, data were only analysed for three species (*R. aegyptiacus, E.wahlbergi* (fruit bats) and *C. cor* (insectivorous bat), whose numbers were 20 or more individuals captured each hour in the entire survey. The mean number of total captures per hour of females and males of the three species in the five-hour duration was calculated, and the differences between sexes tested using non-parametric two sample Mann-Whitney U-Test.

Insectivorous bat activity was estimated as the number of bat passes counted (Russo and Jones, 2003) in each habitat and hour. Independent samples t-test was used to tested for differences in the mean number of bat passes between farmland and ASF, after log transforming the passes count data because it was not uniformly distributed. Kruskal-Wallis test was used to test for sampled medians of bat passes in three different vegetation types in ASF and farmland. To compare seasonal changes and hourly trends in bat activity, I used 11 hours (1900-0500hr) data for surveys in November 2015 (short rain season), February 2016 (dry) and November 2016 (long rain seasons) because the sampling effort was the same (Table 4.1). All statistical tests for means and parametric tests for capture and acoustic data were undertaken using PAST program (Hammer *et al.*, 2001). Statistical differences were considered to be significant at $P<0.05$.

5.3 Results

5.3.1 Activity patterns of mist-netted bats

A total of 5,137 bats were captured in the six surveys, including 884 individuals in ASF (Appindex 4) and 4,253 in the farmland (Appindex 5). The mean number of bats captured in mist-nets each hour in the farmland was 425.3 ± 95.1, N=10, and in ASF it was 88.4 ± 11.2, N=10. There was a significant difference between the medians of captured bats each hour in ASF and farmland (Mann-Whitney U-Test, U=9.5: $p < 0.0025$). The cumulative bat activity in both study sites, as well as in the farmland peaked after sunset from seven to eight in the evening, maintained a stable decrease to midnight, plunged to lowest activity from one to two in the morning, and then slightly increased between three to four at dawn (Fig. 5.15). The interior of ASF had a different pattern; activity had a very small peak at midnight, after maintaining a fairly uniform activity from seven to eleven, gradually declined to lowest activity from one to two, and then experienced very slight and gradual increase in between three to four at dawn (Fig. 15).

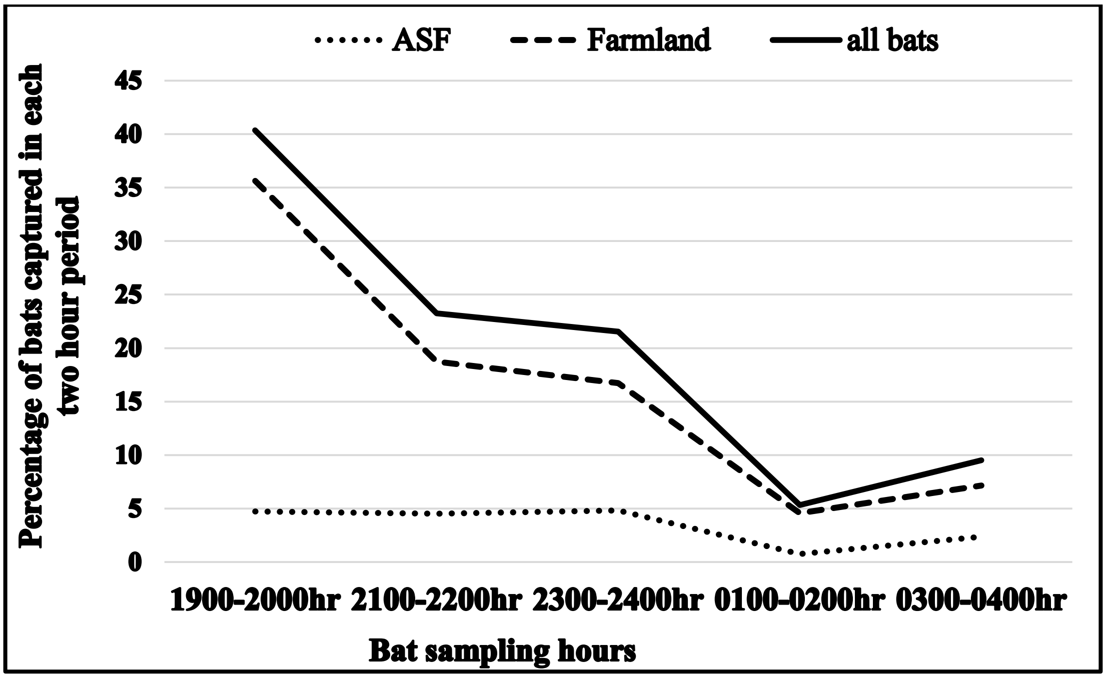

Figure 15. The percentage number bats captured each two hours and their pattern of activity in ASF and farmland

5.3.2 Insectivorous bat activity in ASF and farmland

A total of 1,056 individuals of insectivorous bats were captured; including 901 in the farmland and 155 in ASF. The mean number of captured insectivorous bats each hour in the farmland was 90.1 ± 33.7, N=10, while in ASF it was 15.5 ± 6.2, N=10. There was a significant difference between the medians of captured insectivorous bats hourly in both habitats (Mann-Whitney U-Test, U=10: p <0.0028). Insectivorous bat activity in the farmland peaked at seven in the evening, steeply declined from seven to nine, stabilized between nine to midnight, declined again to lowest activity at one, and then gradually again increased from two to four in morning. In ASF peak bat activity was at seven in evening, followed by a steady decline to no bat captures at two, and slightly low activity at dawn at four in the morning (Fig. 16). In ASF no species of insectivorous bat was captured each hour throughout the eleven hours of monitoring. In the farmland, individuals of *C. cor* were active overnight with individuals of this species captured each hour.

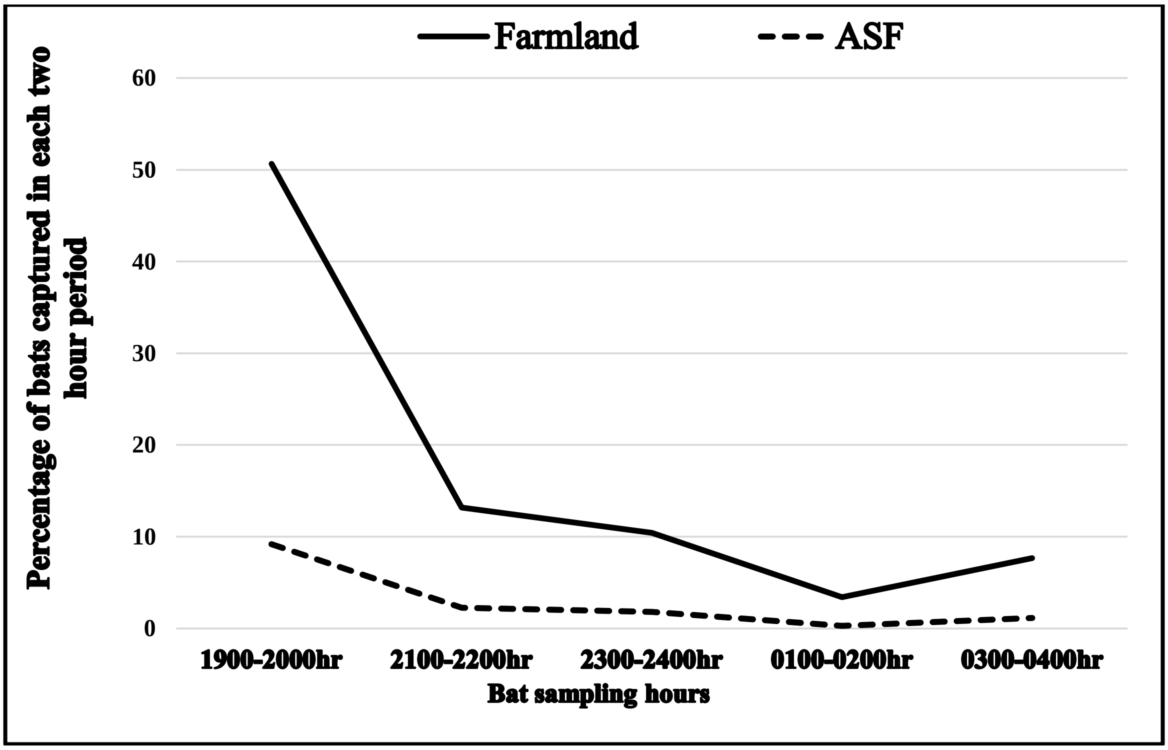

Figure 16. The percentage number of insectivorous bats captured each two hours and their pattern of activity in ASF and farmland

5.3.3 Fruit bats in ASF and farmland

A total of 4,081 individuals of fruit bats were captured; including 3,352 in the farmland and 729 in the interior of ASF. The mean number of fruit bats captured each hour in the farmland was 335.2 ± 67.1, N=10, and in ASF was 72.9 ± 14.8, N=10. There was a significant difference between the medians of captured fruit bats per hour in both study sites (Mann-Whitney U-Test, U=11: $p < 0.0036$). Fruit bats activity in the farmland were more active from seven in the evening, sharply declined to one in the morning, then followed by a slight activity increase from three to four at dawn (Fig. 17). The interior of ASF had a different pattern; with the highest peak activity being at midnight, and the lowest past midnight between one to two in the morning (Fig. 17). The individuals of *R. aegyptiacus* and *E. wahlbergi* bats influenced the pattern of bat activity in ASF and farmland, by being active overnight with many individuals of these species captured each hour throughout the night.

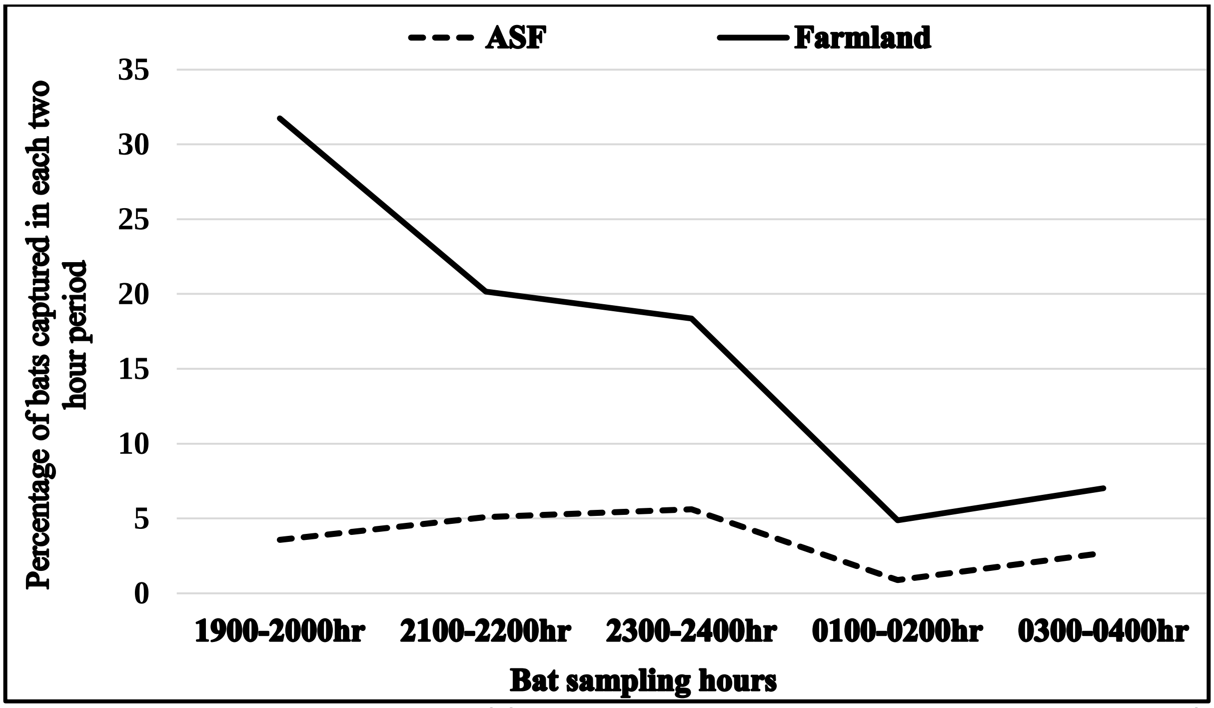

Figure 17. The percentage number of fruit bats captured each two hours and their pattern of activity in ASF and farmland

5.3.4 Seasonal changes in captured bats activity

A total of 2,391 bats were captured in three sampling seasons. This number is less than 5,137 bats reported earlier, because the analysis for this section used data for November 2015 (short rain season), February 2016 (dry season) and June 2016 (long rain season) sampling seasons. This was done because the sampling effort was uniform among seasons (Table 1). Of 2,391 bats, 809 were captured in the short rainy season in November 2015, 919 in the dry season in February 2016, and 663 in the long rain season in June 2016. The mean number of bats captured each hour in the dry season was (91.9 ± 9.6, N=10), short rainy season (80.9 ± 18.6, N=10) and long rainy season (66.3 ± 12.2, N=10). There was no significant difference in the sample medians of captured bats among different seasons (Kruskal-Wallis Test, H=3.698, df=9, p>0.05, N =10). The mean number of the individuals of insectivorous bats, fruits bats, *C. cor* and *E. wahlbergi* captured in each season was the same (Table 5). However, the mean number of individuals of *R. aegyptiacus* captured hourly among season was not the same (Table 5).

Table 5. Kruskal-Wallis test results of the medians of insectivorous and fruits bats; *R. aegyptiacus*, *E. wahlbergi* and *C. cor* captured each hour in different seasons.

	Variables	**N**	**Dry season**	**Short rain season**	**Long rain season**	**H**	**P**	**Result**
1	Insectivorous bats	10	13.5 ± 3.1	20.1 ± 6.4	11.1 ± 4.9	4.131	0.1268	NS
2	Fruit bats	10	78.4 ± 8.6	55.2 ± 9.1	60.8 ± 12.3	4.849	0.089	NS
3	*R. aegyptiacus*	10	46.1 ± 4.2	29 ± 4.7	39.1 ± 7.8	6.155	0.046	S
4	*E. wahlbergi*	10	32.3 ± 5.1	30.8 ± 7.2	16.1 ± 2.4	7.256	0.2656	NS
5	*C. cor*	10	10 ± 1.8	10.3 ± 2.7	6.6 ± 2.8	4.412	0.11	NS

Legend: N-number of samples, H-Kruskal-Wallis test statistics, p-p value, NS-Not significant, S-significant.

5.3.5 Activity among female and male bats

A total of 3,289 bats were captured for five hours (1900-2300hr) in the entire survey both in ASF and farmland. These include 1874 individuals of *R. aegyptiacus*, 994 *E. wahlbergi* and

421 *C. cor*. Of the 3,289 bats, 53.3% were females and 46.7% were males. There was no significant differences between the medians of captured bats between sexes (Table 6).

Table 6. Mann-Whitney test results of the median of bats of different sexes captured each hour in the study area

	Bats analysed	N	Males	Females	U	P	Result
1.	All bats	5	307.4 ± 46.1	350.4 ± 41.1	10	0.675	NS
2.	*R. aegyptiacus*	5	165.0 ± 26.7	209.8 ± 18.7	5	0.143	NS
3.	*E. wahlbergi*	5	92.8 ± 16.8	106.0 ± 15.8	9.5	0.600	NS
4.	*C. cor*	5	49.4 ± 15.1	34.4 ± 11.9	8.5	0.463	NS

Legend: N-number of samples, U- Mann-Whitney test statistics, p-p value, NS-Not significant

5.4 Insectivorous bat activity monitored with detector

5.4.1 Overall activity of insectivorous bats

In total 14,727 echolocation bat calls (passes) were counted including 71.7% in the farmland and 28.3% in ASF. The mean number of insectivorous bat passes counted nightly in the farmland was significantly larger (152.9 ± 13.2, N = 69) than in ASF (60.5 ± 4.6, N = 69) (t = -8.67, P <0.05, df = 68). In the farmland, the bat activity in coconut farms was slightly higher (156.3 ± 24.8, N = 23), than in mango (153.3 ± 19.2, N = 23) and mixed fruit tree (148.2 ± 24.9, N = 23 (Fig. 18) farms. However, there was no significant difference in the activity of insectivorous bats in the three vegetation types in the farmland (Kruskal-Wallis test, H = 0.3869, df = 22, P = 0.82, N =23). In ASF the highest bat insectivorous bat activity was recorded in *Brachystegia* woodland (65.2 ± 7.2, N = 23), followed by mixed forest (64.9 ± 9.7, N = 23) and *Cynometra* forest (51.5 ± 6.9, N = 23 (Fig. 18). However, the activity of insectivorous bats in the three vegetation types in ASF was the same (Kruskal-Wallis test, H=2.419, df =22, P = 0.2983, N =23).

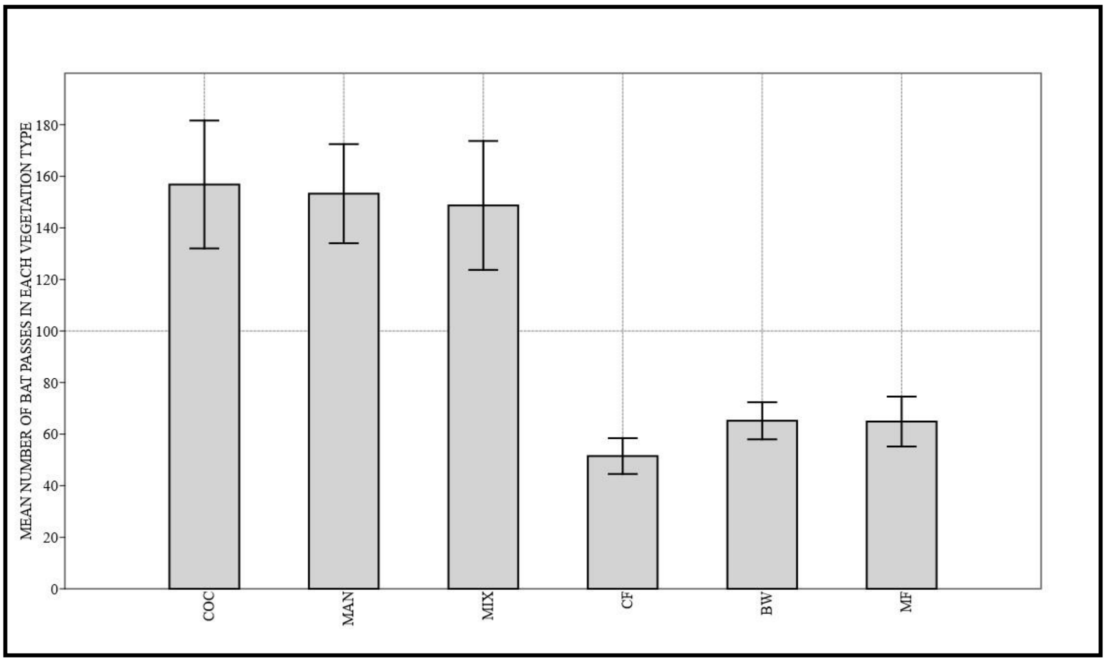

Figure 18. The mean number of bat passes recorded in each vegetation type in the farmland (COC-Coconut, MAN-Mango, MIX-Mixed farms) and in ASF (CF-*Cynometra* forest, BW-*Brachystegia* woodland, MF-Mixed forest (Error bars are standard errors).

5.4.2 Hourly trend in insectivorous bat activity

The mean insectivorous bat activity per hour in the farmland was highest at 1900hr (30.3 ± 6.6, N=36) and lowest at 0100hr (8.4 ± 1.3, N=36). In ASF, the mean bat activity per hour was highest at 1900hr (14.6 ± 1.9, N=36) and lowest at midnight (000hr (4.1 ± 0.7, N=36). In general bat activity pattern in both ASF and farmland peaked at 1900hr after the sunset, sharply declined to the lowest level in between 00hr-0100hr and maintained a gradual increase from 0200hr in the morning, to another lower peak at 0500hr at dawn (Fig. 5.19-20).

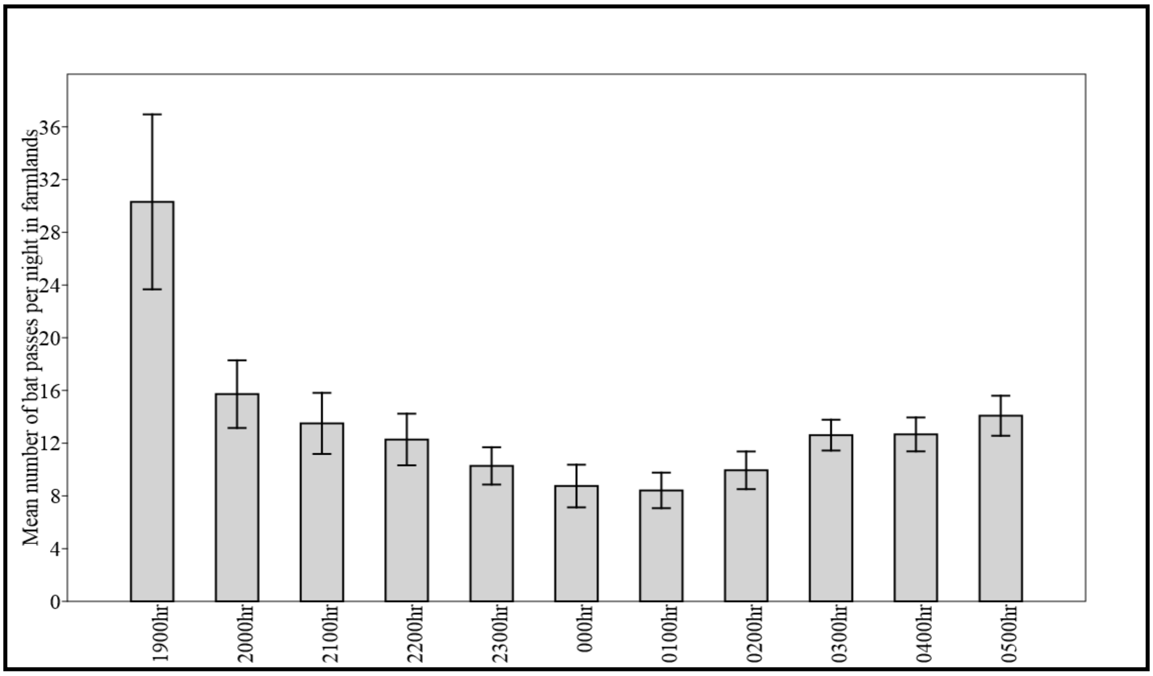

Figure 19. The mean number of bat passes per night in farmland from 1900h to 0500h (Error bars are standard errors).

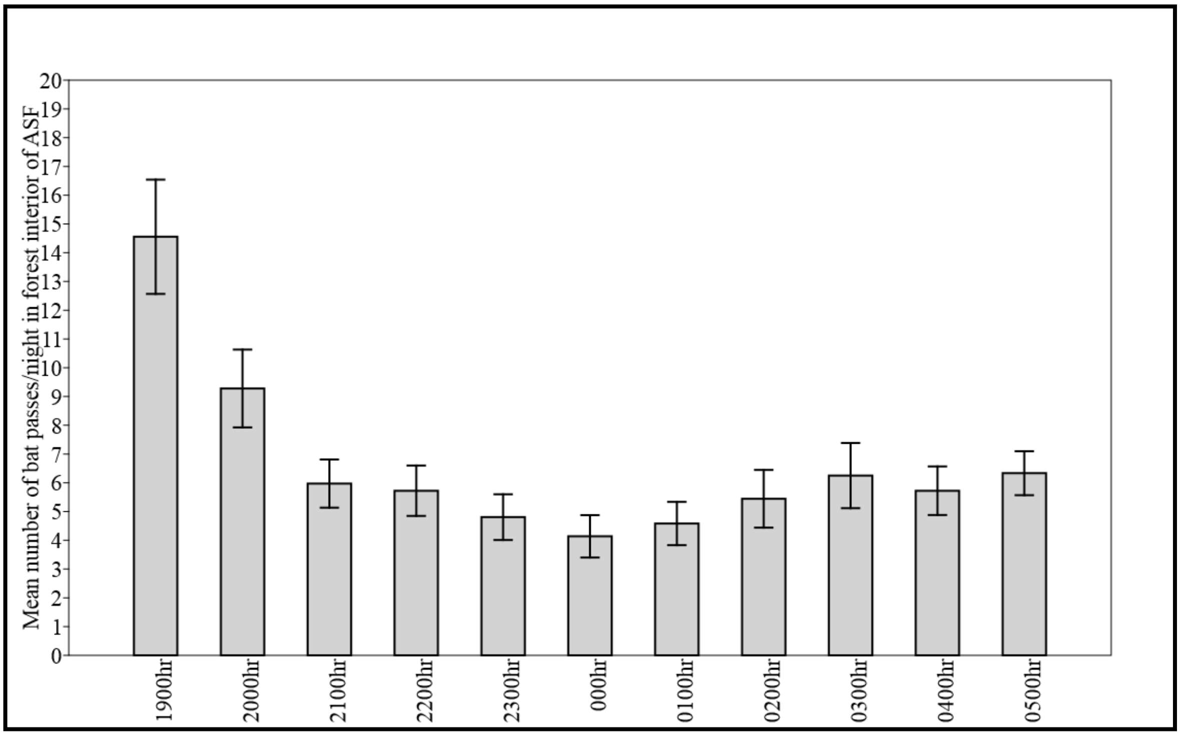

Figure 20. The mean number of bat passes per night in ASF from 1900hr to 0500h (Error bars are standard errors).

5.5 Discussion

Agricultural areas around protected areas provide important habitats for bats. The activity of mist-netted bats, as well as insectivorous bats monitored with a detector was higher in farmland than in the interior of ASF. This probably, indicate that the farmland in the eastern part of ASF, was a suitable foraging and commuting habitat for bats. These findings are similar to those of Estrada *et al*. (2004), in Los Tuxtlas, Veracruz-Mexico, where higher bat activity was recorded in agricultural areas, than in the continuous tropical rain forest habitat in the same area. The abundance of bats in a sampling station, their ease of capture with mist-nets, or detection of insectivorous bats with acoustic methods, can influence their activity in a given study area. In the current study, some bats were common and were frequently captured in the farmland and the forest, while others were uncommon with few individuals of each species recorded. The most common species increased the activity of bats, especially in the farmland. For instance, although individuals of *R. aegyptiacus* and *E. wahlbergi* occurred in both habitats, 65% of all captured fruit bats were found in the farmland. Furthermore, the large numbers of individuals of *C. cor* (604) captured in the farmland also hugely contributed to higher insectivorous bat activity in this habitat.

Although high levels of insectivorous bat activity in farmland may possibly point to areas that are important to bats and those heavily used (Adams *et al*., 2015), these results should be interpreted with caution. Even though bat calls could not be identified to species, 11 insectivorous bat species confirmed to occur in ASF and farmland through mist-netting sampling, have echolocation calls frequencies ranging from 25-41 kHz (Musila *et al*., 2018a). The use of one frequency setting (33 kHz) throughout the 69 stations, also reduced the number of passes which could be counted in a sampling station. This is because some bat species especially those of genera hipposideros and rhinolophus call at higher frequencies (Webala *et al*., 2019a), and their presence would not be detected by the detector frequency setting used.

The number of bat passes counted is possibly correlated to the number of individuals present (Wickramasinghe *et al*., 2003). However, it is impossible to enumerate the exact number of individual bats that are found in one station, since a detector can record the same individual more than once (Frick, 2013). However, this limitation was mitigated by ensuring that insectivorous bat activity was monitored by an observer constatntly in motion walking for 10 minutes. Insectivorous bats also modify their echolocation calls throughout their flight based on the habitat structure and activity (foraging or commuting). In a cluttered environment like inside ASF, some bats emit quieter echolocation calls, which consequently reduce their detection rates (Schnitzler and Kalko, 2001). The result is a false absence, with present individuals of a bat species being undetected (MacKenzie, 2005), and consequently counting a reduced number of passes.

Bat activity both in ASF and farmland showed the same pattern, it peaked after sunset, sharply declined to lowest level after midnight, and then had a smaller peak at dawn. The activity of many bat species peak during the first hour after sunset (Meyer *et al*., 2004). At Barro Colorado Island, Panama Lang *et al*. (2006), recorded no bat flight activity at all between 2300h and 0200h. Bats in the study area roost for about 12 hours (600am-1800pm) during the day without feeding. It is therefore, possible that in the evening there was a simultaneous emergence of many individuals of different bat species from their roosts to maximize on their feeding bout, hence the high activity at twilight. The lowest bat activity in both habitats was recorded in between 0100-0200am. Bats break their foraging activity and rest in their roosts at night (Kunz *et al*., 1995). The period of lowest bat activity in the study area, may suggest return of bats to their roosts for temporary break from their foraging or commuting activities. Female bats with young left behind in the roosts are more likely to return in the middle of the night to feed their young. However, from the current study it was impossible to determine how frequently bats returned to their roosts each night. Therefore, future studies, can use telemetry method to shed more light on how often roosts in the study area were used by bats.

The activity of all species of bats combined, insectivorous and fruit bats captured in the study area in three different sampling seasons was similar. Fruit bats that forage on fruits available throughout the year are captured repeatedly, while species feeding on ephemeral resources are found occasionally (Bumrungsri *et al*., 2007). Individuals of *R. aegyptiacus* and *E. wahlbergi* were recorded throughout the different seasons, probably suggesting that the study area had an abundant supply of fruit resources, which could sustain the fruit bats high energy demands. The activity of individuals of *R. aegyptiacus*, *E. wahlbergi* and *C. cor* between different sexes was same in our study area. Kunz *et al*. (1995) noted that due to high energetic demands of pregnant and lactating female bats, they use more time feeding than male bats or others in non-reproductive condition. Some other studies have also shown that males of several fruit bats species travel shorter distance than females to forage (Winkelman, 2000), suggesting reduced activity and may be rate of capture of males. The data analysed for seasonal changes in bat activity and between sexes relied on a total of 24 sites sampled in ASF and farmland in each season. The data may have been insufficient to make clear conclusions, which may explain the contrarily results from what has been reported in the past, both for seasonal changes in activity by bats of different sexes. Future studies should therefore, sample more stations in the study area and for a longer period in each season, so as to have sufficient data and make plausible conclusions.

In conclusion, the farmland had higher fruit and insectivorous bat activity than in ASF. Bat activity peaked after sunset, experienced a low increase at midnight, and then plunged to lowest activity in between 01:00-02:00hr, followed by a slight increase at dawn. Human-modified habitats, consisting of agricultural areas and human settlements, are the largest and rapidly expanding ecosystems in the world. The farmland around ASF, had completely lost the coastal indigenous vegetation found in ASF, but bats were using the habitat for foraging and commuting. Therefore, there is a need to work with land owners around ASF, to maintain the vegetation structure of their farms, in order to ensure they continue to support bats currently using the farmland habitat in the long run.

CHAPTER SIX: DIVERSITY OF INVERTEBRATE PREY IN ARABUKO-SOKOKE FOREST AND ADJACENT FARMLAND

ABSTRACT

The primary food of insectivorous bats is invertebrates, especially insects. This study investigated invertebrate prey abundance in ASF and adjacent farmland, in order to understand its availability to foraging insectivorous bats found in the two study sites. Invertebrate prey were sampled by use of solar powered lights, which attracted air-borne invertebrates to a suspended white cloth sheet, for four hours each night in 12 different stations each in ASF and farmland. A total of 6,557 individuals of invertebrates were captured: 52% in the farmland and 48% in ASF. The order Hymenoptera (ants, bees, wasps and sawflies) was the most abundant (38.1%), followed by Coleoptera (beetles (28.1%) and Lepidoptera (moths (15.7%). The farmland had the largest number of Hymenopterans and Coleopterans, while the largest number of Lepidopterans and of bigger sizes occurred in ASF than in the farmland. The Shannon-Weiner index of diversity was higher in ASF (1.72 ± 0.1) than in the farmland (1.41 ± 0.1). The mean number of invertebrate prey captured each night in the farmland was (260.5 ± 52.9, N=12), and in ASF (200.3 ± 36.4, N=12), but with no significant difference between the medians of captured invertebrates in both study sites (Mann-Whitney U-Test, U=61: P>0.544). In conclusion, the farmland and forest had similar invertebrate prey abundance. This study, highlight the importance of agricultural landscapes, which have been ignored in many biodiversity surveys, in providing invertebrate prey items to insectivorous bats especially in the study area.

6.1 Introduction

Measures of vegetation structure are important habitat variables which can serve to explain the distribution pattern of species (MacKenzie *et al*., 2006), especially for insectivorous bats (Loeb and O'Keefe 2006). However, habitat variables exclusively are insufficient to fully understand animals' distribution patterns and relationships (Morrison, 2001). Hence, there is need to investigate resources associated with the habitat where animals are found (Morrison, 2001). For insectivorous bats, the primary resource is invertebrate prey (Ford *et al*., 2005). Understanding the links between foraging insectivorous bats and prey availability has been recognized as an important research area, particularly within forested landscapes (Lacki *et al*., 2007). Furthermore, the activity of insectivorous bats is influenced by the density of invertebrate prey, as well as vegetation characteristics (Scanlon and Petit, 2008). Although dense vegetation structure may increase the abundance of invertebrates, which can consequently intensify foraging activity by insectivorous bats (Bender *et al*., 2015), the effects of vegetation structure may largely be independent of the abundance of invertebrate (Adams *et al*., 2009).

In this chapter the diversity and abundance of insectivorous bats invertebrate prey was investigated in ASF and the adjacent farmland. The results of bat studies, in six different sampling expeditions both in ASF and farmland (November 2014 to June 2016, showed that there was a higher insectivorous bat activity and bat captures in the farmland than in ASF (see also chapter 4-5). As a result, it was predicted that the farmland would have higher abundance of invertebrate prey than the interior of ASF.

6.2 Materials and Methods

6.2.1 Invertebrate prey sampling

Invertebrate prey sampling was undertaken once in November-December 2016, and not simultaneously with bats mist-netting and activity sampling, because of the high bat activity and large captures of insectivorous bats in the farmland than in ASF throughout the six different sampling expeditions (Table 7). Hence, it was assumed that the high abundance of captured insectivorous bats and activity in farmland in each season, reflected the existence of higher invertebrate prey abundance. Many invertebrates that are active at night such as different species of moths and beetles are attracted by light (Nag and Nath, 1991). Light traps have been extensively used to survey invertebrate species that are active at night (Holyoak *et al*., 1997). In this study four solar powered light traps (Sanyal *et al*., 2013). The lights erected at least 70m from each other, were used to attract air-borne nocturnal invertebrates. The solar lights (DP Light DP-6005A) http://en.dpled.com (Fig. 21), had an inbuilt sealed lead acid battery, which attained a wide range of voltage (110-240 V, or 50/60 Hz). The battery when charged with a panel (9V/3.5 W), from 0800-1600 hr during days of full sunlight, would keep one bulb very bright without fading for more than six hours.

Table 7. Total bat insectivorous echolocation calls (passes) and insectivorous bats captures in six different bat sampling expeditions in the interior of ASF and in the farmland

	Survey Dates/Trip	Sampling Season	Farmland Total Passes/Trip	ASF Forest Total Passes/Trip	Farmland Bat capture/Trip	ASF Forest Bat capture/Trip
1	Nov-14	Short rain season	1775	231	161	17
2	Feb-15	Dry season	2420	862	197	52
3	Jun-15	Long rain season	1808	461	140	31
4	Nov-15	Short rain season	2103	603	190	21
5	Feb-16	Dry season	1437	871	120	15
6	Jun-16	Long rain season	1009	1147	92	7
	TOTAL		**10,552**	**4,175**	**900**	**143**

Note: Insectivorous bats were not monitored with acoustic method in November 2016 survey, the reason the results are not included in this table

Figure 21. Solar DP Light DP-6005A used to attract nocturnal invertebrate prey

Inside ASF the light traps were fixed at the centre of a nylon string tied to two trees across the road, at a height of 1.5m from the ground. In the farmland, light traps were tied at the centre of a string tied to two selected nearby trees. A white cotton cloth sheet (c. 2m long by 1.5m wide), was erected using other strings facing the direction of the light source at a distance of 1 m away from the light source (Fig. 22). The cloth sheet provided a landing surface to attracted invertebrates (Fry and Waring, 2001), with the lowest part of the cloth from the ground being 30 cm, while the top part being 1.5m. A transparent plastic sheet was also spread under the suspended cloth sheet to enable easier detection of invertebrates in flight which struck the cloth sheet and fell on the ground (Fig. 22). The light traps were operated for four hours (1900-2300hr) each night (Fig. 23), in four different trapping stations each in *Cynometra* and mixed forests, *Brachystegia* woodland in ASF, and in the mango, coconut and mixed trees dominated farms. The light traps were checked twice each hour, with moths being killed in chloroform vapour in glass jar (Sanyal *et al*., 2013) and later preserved in plastic containers with toilet nappies placed in between specimens to prevent damage of moth's delicate wings. Other invertebrates were collected in plastic jars and stored in 70% ethanol, with a sample of each hour (Wolbert *et al*., 2014) in each vegetation type kept in a separate container, to determine their abundance throughout the trapping operation.

Figure 22. Set up of solar light trap, with white cloth screen and plastic sheet on the ground

Figure 23. Solar light trap in operation at night attracting invertebrate prey (black dots)

The moths of each trapping station in each vegetation type were stored together without separating captures into hours. The larger moths were killed and kept in plastic zip bags. Only invertebrates measuring 5-40mm in body length were collected, since small sized insects may not be detected by foraging insectivorous bats (Anthony and Kunz, 1977), while others bigger than this size would unlikely be consumed (Barclay, 1985). Invertebrate prey larger than 30mm by width were not collected, since they were considered too large for the largest resident insectivorous bat, Striped Leaf-nosed Bat (*Macronycteris vittata*) recorded in and outside ASF. Invertebrate prey sampling was conducted alternately, with one night in the forest, followed by the next in the farmland to distribute sampling bias between ASF and farmland vegetation types. Multiple trap types are recommended for a comprehensive sampling of invertebrates in an area, even for just one taxon (Aguiar and Santos, 2010). However, this approach is difficult to implement in most surveys, since it is time consuming and expensive (Russo *et al*., 2011).

6.2.2 Data analysis

Invertebrate prey were counted and identified to taxonomic order using specimen samples collected from ASF in the past and deposited with Entomology Section of NMK. Shannon-Wiener index was used to calculate the species diversity of invertebrates (Shannon and Weaver, 1963). The sizes of invertebrate were estimated by measuring their lengths (to the nearest 0.25mm) with a ruler from the head (excluding antennae) to the tip of the abdomen (without inclusion of cerci) (Coleman and Barclay, 2013). The invertebrates were grouped into four main size categories: 5-10mm, 11-21mm, 22-32mm, >33mm; and counted for each vegetation type in ASF and farmland. Mann-Whitney U-test was used to test for differences in sample medians of invertebrates captured in each night in the farmland and in ASF. To estimate the changes in invertebrate prey activity with night time, the number of invertebrates excluding moths captured in each hour from 1900-2300hr were counted. Moths were excluded from this analysis, because the information on the number of individuals captured each hour, in the 12 different sampling stations in ASF and farmland had not been recorded throughout the trapping operation. All statistical analyses were undertaken using PAST program (Hammer *et al*., 2001).

6.3 Results

6.3.1 Invertebrates diversity

In total 6,557 individuals of invertebrate prey were captured, including 52% in the farmland and 48% in ASF. The order Hymenoptera (ants, bees, wasps and sawflies) was the most abundant (38.1%), followed by order Coleoptera (beetles) 28.1% and Lepidoptera (moths) 15.7%) Tables 8-9, Appindex 6). Many individuals of Hymenopterans and Coleopterans were recorded in the farmland than in ASF (Table 8). There were more individuals of Lepidopterans and of bigger sizes in ASF than in the farmland (Table 9). The Shannon-Weiner index of diversity was higher in ASF than in the farmland. The mean number of invertebrate prey captured each night in the farmland was 260.5 ± 52.9, and in ASF 200.3 ± 36.4. There was no significant difference between the median abundance of invertebrate prey captured per night in both study sites (Mann-Whitney U-Test, U=61: p >0.544).

Table 8. Diversity and abundance of invertebrate prey in three habitat types in the farmland.

	INVERTEBRATES ORDERS	MIXFo	BRA	CYNO	ASF Total
1	Hymenoptera (Ants, bees, wasps and sawflies)	131	537	376	**1044**
2	Coleoptera (Beetles)	120	357	158	**635**
3	Hemiptera (Bugs, aphids and cicadas)	79	73	41	**193**
4	Blattodea (Cockroaches and termites)	68	108	62	**238**
5	Diptera (Flies and mosquitoes)	27	91	25	**143**
6	Orthoptera (Grasshoppers, crickets, katydids)	32	38	29	**99**
7	Mantodea (Praying mantids)	5	21	7	**33**
7	Neuroptera (Net winged invertebrate)	3	11	4	**18**
8	Odonata (Dragonflies and damselflies)	0	1	0	**1**
10	Lepidoptera (Moths)	159	280	325	**764**
Abundance		**624**	**1517**	**1027**	**3168**
Shannon_H		**1.85 ± 0.09**	**1.72 ± 0.08**	**1.57 ± 0.11**	**1.72 ±0.05**

Legend: MIXFo- Mixed forest, BRA-*Brachystegia* woodland, and CYNO-*Cynometra* forest.

Table 9. Diversity and abundance of invertebrate prey in three habitat types in the ASF.

	Invertebrates Orders	MAN	COC	MIXFa	Farmland Total
1	Hymenoptera (Ants, bees, wasps and sawflies)	1157	202	93	**1452**
2	Coleoptera (Beetles)	414	247	547	**1208**
3	Hemiptera (Bugs, aphids and cicadas)	39	42	23	**104**
4	Blattodea (Cockroaches and termites)	122	10	18	**150**
5	Diptera (Flies and mosquitoes)	39	12	14	**65**
6	Orthoptera (Grasshoppers, crickets, katydids)	47	42	33	**122**
7	Mantodea (Praying mantids)	1	7	1	**9**
7	Neuroptera (Net winged invertebrate)	8	4	3	**15**
8	Odonata (Dragonflies and damselflies)	1	0	0	**1**
10	Lepidoptera (Moths)	135	46	82	**263**
Abundance		**1963**	**612**	**814**	**3389**
Shannon_H		**1.27 ±0.94**	**1.52 ± 0.15**	**1.16 ± 0.16**	**1.41 ± 0.06**

Legend: MAN-Mango farms, COC-Coconut farms, MIXFa-Mixed farms

6.3.2 Invertebrate sizes and hourly activity pattern

About 68% of captured invertebrates were of small size (5-10mm), followed by those of 11-21mm (29%) Table 10). The largest number of individuals of invertebrate prey both in ASF and in the farmland were captured at 1900hr; in forest they declined sharply to 2000hr, while activity in farmland remained in a relatively stable decline, with activity in both habitats gradually declining to 2300hr (Fig. 24).

Table 10. A summary of the counts of invertebrates of different sizes sampled in the farmland and ASF

	5-10mm	11-21mm	22-32mm	sizes >33	Total
Total (Farmland and ASF)	3440	1869	167	54	5530
Total (Farmland and ASF)	994	30	3	0	1027
Total (Farmland and ASF)	**4434**	**1899**	**170**	**54**	**6557**
Percentage (%)	**67.6**	**29.0**	**2.6**	**0.8**	**100.0**

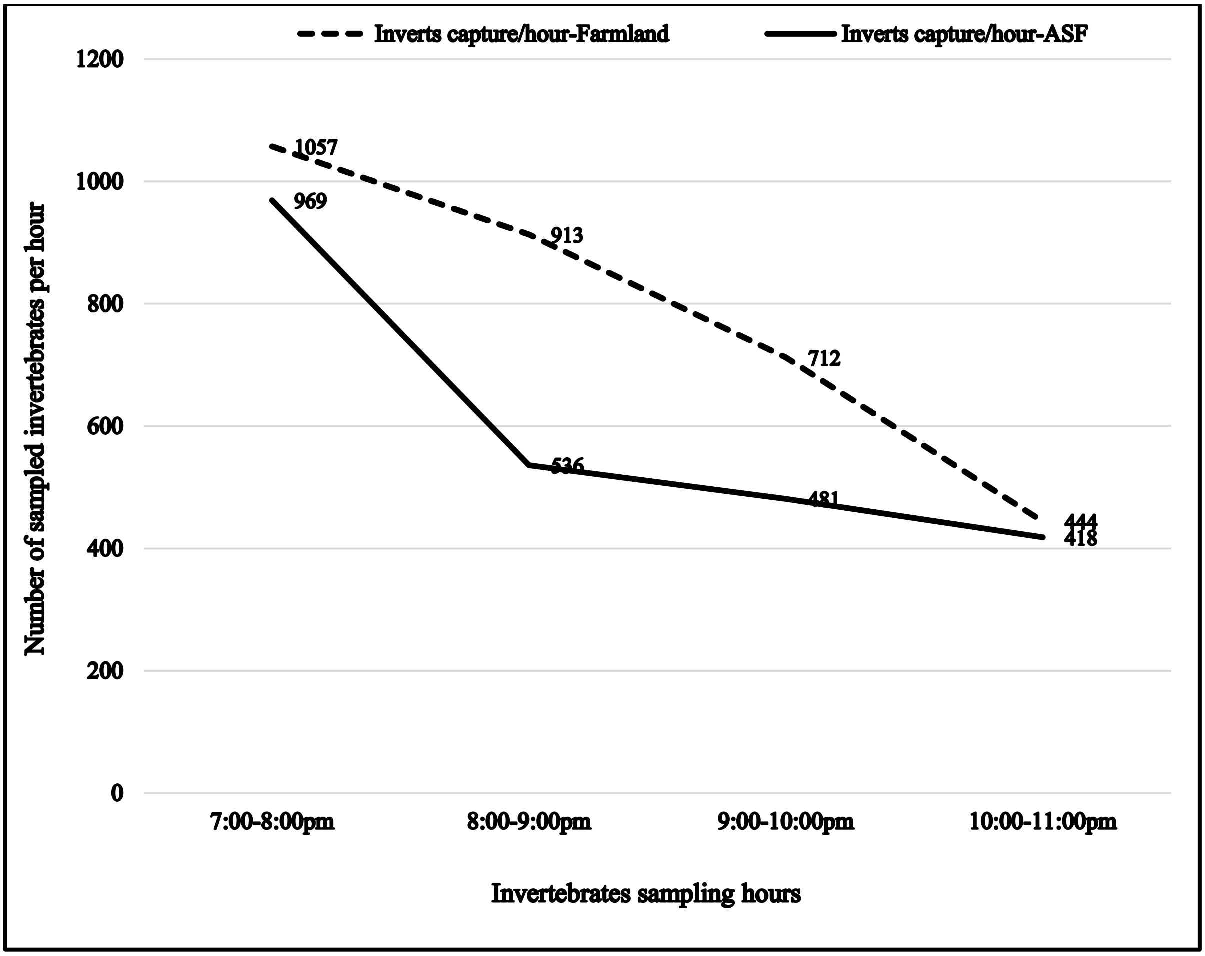

Figure 24. The hourly trend in the capture of invertebrate prey (excluding moths) sampled in ASF and in the farmland.

6.4 Discussion

This study investigated invertebrate prey species richness, diversity and abundance in ASF which is relatively intact, and surrounding farmland which has lost indigenous coastal forest vegetation. Results showed that the ASF and farmland had the same invertebrate abundance, but species diversity was higher in ASF than in the farmland. Moths were more abundant and of bigger sizes in ASF than in the farmland. Moths abundance has been shown to decline with agriculatural intensification (Wickramasinghe *et al*., 2004), mainly because relatively undisturbed habitat such as ASF, provide sheltered environments (Merckx *et al*., 2008) as compared to the more open and disturbed farmland outside this forest. The representatives of different invertebrate orders were captured in large numbers in both study sites, but with individuals of Hymenopterans, Coleopterans and Orthopterans being more abundant in the farmland than in ASF. Similar results were recorded by Khadijah *et al*. (2013), at Kota Damansara Community Forest Reserve in Malaysia.

Hymenoptera is one of the four largest orders of invertebrates, the other three being Coleoptera, Lepidoptera and Diptera (Mason and Huber, 1993), and perhaps this explains the high abundance of individuals these orders recorded in this study. The most common groups of invertebrate prey eaten by insectivorous bats are Coleoptera, Lepidoptera, Diptera, Hymenoptera and Isoptera (Pavey *et al.*, 2001), which were also captured in large numbers in both study sites. However, more individuals of Lepidopteran, Dipterans and Blattodea occurred in ASF than in the farmland. Thus, although ASF had low captures of insectivorous bats and activity than the farmland (Chapter 4-5), the invertebrate composition which are prey items for these bats were abundant inside ASF.

A number of vegetation structure related factors may determine the abundance and composition of invertebrates sampled in a location. For instance, understorey vegetation structure can affect the capture of invertebrates sampled with light traps. Understorey openness may increase the effectiveness of light-trapping radius, especially for nocturnal invertebrates (Beck *et al*., 2010). For example, inside ASF, the light source was visible in a small area due to the obstructions created by the thick understorey vegetation cover. Thus, a small area of ASF was sampled, the radius immediately near the source of light. Nevertheless, in an open habitat, as was the case of farmland in this study, the light source was detectable from further distance, which probably attracted invertebrate prey from a large trapping radius. In addition, canopy openness has also been shown to strongly affect beetle assemblages (Hosaka *et al*., 2014), but not moths (Wirooks, 2005). Therefore, although cluttered (thick) habitats which are less disturbed have high invertebrate densities (Kalcounis and Brigham, 1995), the obstruction of trapping light source by canopy vegetation may have reduced light detection by aerial insects, and hence reduced the overall abundance of captured invertebrates in ASF. This may possibly suggest that, although results of this study showed that, the ASF and farmland had the same abundance of invertebrates, the insects may be more abundant inside ASF. Invertebrate prey activity peaked at 1900hrs and declined to the lowest level at 2300hr in the farmland and as well as in ASF. Insectivorous bats capture and activity in and around ASF was high immediately after dawn from 1900-2000hrs and lowest past midnight (Chapter 5), probaly suggesting that insectiverous bats sychronized their foraging activity with invertebrate prey abundance and activity.

In conclusion, the farmland was very disturbed and would be expected to have reduced abundance of invertebarte prey (Chung *et al*., 2004). However, this habitat had the same invertebarte prey abundance with the relatively undisturbed ASF, probally suggesting that both study sites provided suitable foraging areas for the existing insectivorous bat species. Nonetheless, in order to have a comprehensive understanding of invertebrate assemblages in both study sites, there is need to use a combination of invertebrate sampling methods in future studies (Aguiar and Santos, 2010). This is because the effectiveness of invertebrates prey sampling using light traps varies between taxa (Bowden, 1982), and light traps sample only invertebrate taxa attracted to light (Webala *et al*., 2011). In addition, there is need to assess the types of insect prey items eaten by different insectivorous bat species found in the study area, by collecting and analysing their faecal samples for fragments of invertebrates which they feed on (Fukui *et al*., 2000).

CHAPTER SEVEN: INFLUENCE OF HABITAT STRUCTURE AND FRUIT TREES DISTRIBUTION ON BATS ABUNDANCE IN ARABUKO-SOKOKE FOREST AND ADJACENT FARMLAND

ABSTRACT

This study investigated habitat structure and fruit trees resources in ASF and nearby farmland, and their roles in the distribution and abundance of bats in the two study sites. Point-centred Quarter (PCQ) method was used to assess vegetation structure in each of the three different vegetation types in ASF (*Cynometra* and mixed forest, *Brachystegia* woodland) and farmland (mango, coconut or mixed farms). Understorey vegetation cover was assessed by use of checkerboard of 25 squares painted in white and red. Canopy cover was assessed by use of paper cylinder (diameter 4.5cm and 10cm long). Overall the farmland was cultivated with orchards of exotic fruit trees dominated coconut (54%), mango (31%), cashew nut (11%) and neem (3%) trees. The ASF was predominantly covered by four indigenous trees; *Brachystegia spiciformis* (30%), *Cynometra webberi* (30%), *Manikara sansibarensis* (18%) and *Hymenaea verrucosa* (11%). The largest number of trees producing fruits (mangos, guavas and cashew nuts) eaten by fruit bats occured in the farmland (385) than in ASF (166). The % understory cover at ASF (38.2 ± 1.9) was signficantly more closed than that of the farmland (5.8 ± 2.3) t (208) = 16.634; $P < 0.05$). The % canopy cover at ASF (48.2 ± 1.4) was signficantly thicker than that of the farmland (29.3 ± 2.9) t (208) = 5.6887; $P < 0.05$). The abundance of fruit producing trees in the farmland attracted many individuals of fruit bats into this habitat, while the cluttered nature of the interior of ASF, inhibited bats use of this habitat. The farmland trees around ASF should be maintained in this habitat, because of their vital role in enhancing the survival of bats in the study area.

7.1 Introduction

The tropical forest provide vital resources such as fruits, pollen and leaves which support fruit bats, and also a wide variety of invertebrates consumed by insectivorous bats. In addition, the forest structure and management influences its suitability for use by bats (Entwistle *et al*., 1996). For example, the amount of spatial complexity in the environment, or vegetation clutter (Fenton, 1990), influence the selection of foraging areas by insectivorous bats (Humes *et al*., 1999). Small bats have a more manoeuvrable flight, and forage in cluttered airspaces (Norberg and Rayner, 1987), whereas larger bats with higher wing loadings are less manoeuvrable, and forage in the open areas (Fenton 1990; Brigham *et al*., 1997). Dense vegetation also obscure calls from insectivorous bats (Patriquin *et al*., 2003) which is a major limitation of bat acoustic studies on activity and habitat use.

The differences in habitat structure between the ASF and farmland, could influence the availability of resources used by bats. For example, resource availability (e.g. fruit trees) in the forest and the agricultural areas can shape bats composition (Hodgkison *et al*., 2004). The study investigated vegetation structure in ASF and in the farmland and its influence in structuring bat communities found in them, by assessments of 1). The abundance of fruit tree species which produced suitable fruits that could be eaten by foraging fruit bats, and 2). Canopy and understorey vegetation cover in ASF and in the farmland, which could enhance or inhibit bats habitat use of the two study sites.

7.2 Materials and Methods

7.2.1 Assessments of tree species and their characteristics

Tree characteristics in both study sites was assessed using the Point-centred Quarter method (PCQ) Cottam and Curtis, 1956), a plotless technique which uses a number of randomly selected points covering an area under vegetation investigation (Cottam *et al*., 1953). In ASF and in the farmland vegetation sampling transects were laid in the same general areas where bats surveys had been previously sampled as done by Estrada *et al*. (2006). The PCQ points in ASF were selected following forest roads through *Cynometra* forest, *Brachystegia* woodland and mixed forests where bats had been sampled. In the farmland, transects were laid parallel to each other at interval of 50M from the longest orientation of the mango, coconut or mixed farms, especially for sampled farms which were at most 4ha.

In ASF, a random PCQ point selected to start sampling trees, was about 200M from the nearest vegetation of different type. In the farmland, the random starting PCQ point was selected 5M from the boundary with the neighbouring farm. A minimum distance of 30M interval from each point was used, so as not to sample same trees in two adjacent PCQ points. The area around each sampling point was divided into four 90^0 quadrants (Mueller-Dombois *et al*., 2008; BirdLife International, 2012). Any tree species of >20cm DBH, nearest to the centre of PCQ point was located, identified to species and recorded in each of four quadrants (Fig. 25). The distance from the centre of the PCQ point to that tree, its DBH and crown diameter were recorded. The trees crown diameter were measured with the assumption that the crown was circular. A ruler was used to measure the DBH of trees. The distance to nearest selected trees in each quadrant, their crown diameter, and distance between PCQ points were estimated by pacing. Smaller trees (<19cm) were not sampled because they were less likely to be used by bats (Ragusa-Netto and Santos, 2014), in the same way big trees would be selected by foliage and hollow roosting bats. In the case of trees with multiple living trunk, all trunks were evaluated (Ruschel *et al*., 2007) and DBH recorded as one trunk. Dead trees in any quadrant were not included in the assessments. In each of the three vegetation types (*Cynometra* (70) and mixed forest (70), *Brachystegia* woodland (70) in ASF and in farmland (mango (70), coconut (70) or mixed (70) farms), 70 PCQ points were used to sample vegetation structure. Thus, in total 210 PCQ points were used to assess vegetation structure and tree characteristics each in the ASF and the farmland.

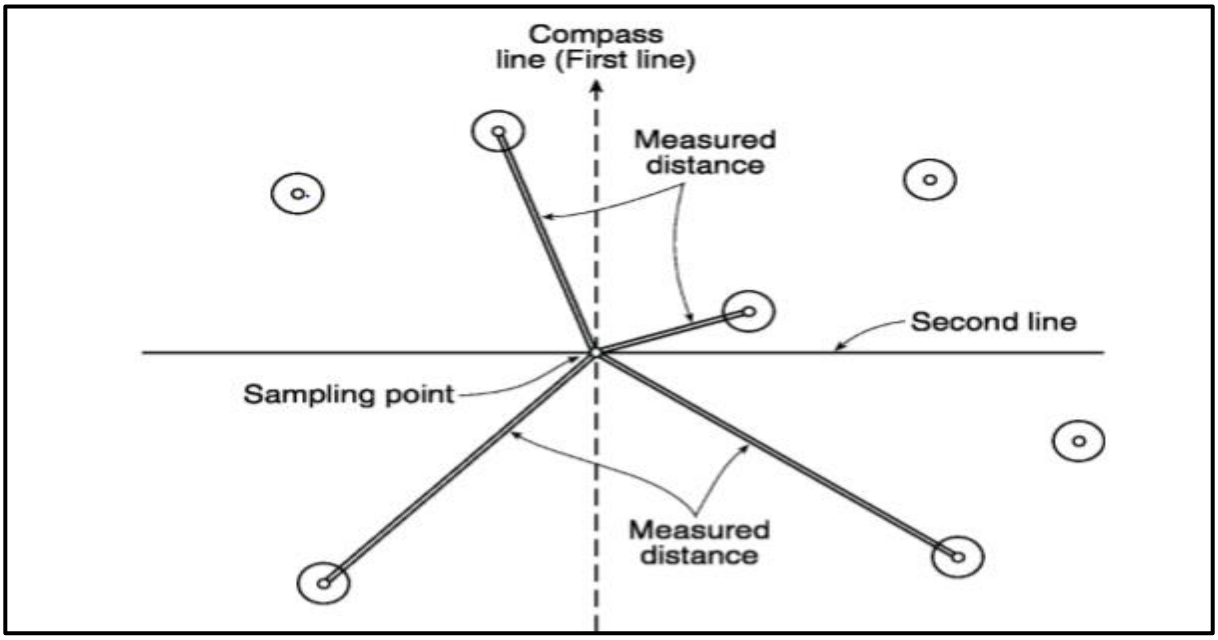

Figure 25. Point-centred Quarter Method (PCQ) method diagram (Mueller-Dombois *et al*., 2008)

7.2.2 Assessments of understory and canopy vegetation cover

The understory/undergrowth vegetation cover was assessed by use of cover boards (Nudds, 1977). These boards vary in dimensions but are generally narrow panels with bands of alternating colours (checkerboard pattern), which are modified to researcher's requirements. A board of plywood painted in red and white patterns of 25 squares, each measuring 10cm by 10cm (Fig. 26 A-D) assessed understory vegetation cover around each PCQ point (Higgins *et al*., 1996). The cover board was held by an assistant in the north and south directions of the compass at each sampling PCQ point, at a height of 1.5M above the ground and 5M away from the centre of each point. To estimate the understory vegetation cover, the total number of squares covered by more than 50% by tree branches and leaves were counted by one observer at each distance (Fig. 26 A-D) Pacifici *et al*., 2008).

A. 21 squares are >50% obscured by vegetation. Highly cluttered/thick understorey cover

B. 20 squares >50% obscured by vegetation- Highly cluttered/thick understorey cover

C. One square are >50% obscured by vegetation- Not cluttered/very open understorey cover

D. No square is >50% obscured by vegetation- Not cluttered/very open understorey cover

Figure 26 A-D. A wooden board of plywood checkerboard painted in red and white patterns of 25 squares for assessing understorey vegetation cover.

The % canopy cover was assessed with a paper cylinder (diameter 4.5cm and 10cm long) Fanshawe, 1993). The cylinder was used as a sighting tube to assess canopy cover at each PCQ point by use of naked eye (Rautiainen *et al*. 2005; Korhonen *et al*., 2006). To estimate the % canopy cover at any given PCQ point, the cylinder was held pointing directly above, and the percentage of the open space of the cylinder obstructed by tree branches and leaves estimated. Dead plant matter were not included in canopy cover estimates at a sampling point (Korhonen *et al*., 2006). Two canopy cover readings were taken at each PCQ point; one at the centre of each PCQ and another 5M away, always on the northern direction of the compass. To reduce the errors in assessment of the canopy cover at each point, the paper cylinder was always held vertically (Jennings *et al*., 1999). To minimise observation bias, the count of the number of squares, as well as the estimation of percentage canopy and understorey cover, were all assessed by one person throughout the vegetation sampling exercise.

7.2.3 Data analysis

The Point-Centred Quarter (PCQ) data was organized in excel program and used the same to summarize and analyse various tree characteristics at ASF and farmland following formulas described by (Mitchell, 2007). The Mean distance between trees, was calculated by the sum of the nearest neighbour distances in the quarters surveyed divided by the number of quarters. The absolute density of an individual species is number of trees of that species that are expected to occur in an area the size of one hectare (Mitchell, 2007). The absolute density, which is the number of trees per unit area in one hectare was calculated using a method provided by Cottam *et al*. (1953) and Morisita (1954). The % of the total number of tree observations of that species is the relative density of each tree species. The cover or dominance of an individual tree was measured by its basal area or cross-sectional area, with the absolute cover or dominance of each species being expressed as its basal area per hectare. The relative cover or relative dominance for a particular species was defined as the absolute cover for that species divided by the total cover times 100 to express the result as a percentage (Cottam and Curtis, 1956). The importance value of a tree species was calculated as the sum of relative density + relative cover + relative frequency (Mitchell, 2007). To find out trees which produced fruits eaten by fruit bats from the collected tree data, the type of fruits produced by all tree species found in ASF and farmland in this study, were checked in '*Kenya trees, shrubs and lianas*' a plant book published by Beentje (1994). The selected fruiting trees targeted by foraging frugivorous bats from the sampled trees in ASF and farmland, were those documented by Beentje (1994) to produce small, big, wild or cultivated fruits, which when ripe are soft and edible. This is because fruit bats teeth are not strong enough to crack hard small or big seeds or nuts; however they target ripe and soft fruits (Happold and Happold, 2013). All trees from the sampled tree data in ASF and farmland documented by Beentje (1994) to produce hard small or big fruits or nuts when ripe were not considered as potential food resource of fruit bats.

Other habitat structure data, such as understorey, canopy and crown cover, and DBH and were organized in excel. The data was checked for normality and analysed using one-way ANOVA for habitat structure differences in ASF and farmland. If the p-value corresponding to the F-statistic of one-way ANOVA was lower than 0.05, it indicated that, one or more habitat variable were significantly different. Thus the, Tukey HSD post-hoc tests was done to identify which of the pairs of variable were significantly different from each other. All analysis was done using program PAST Hammer *et al*., 2001).

7.3 Results

7.3.1 Tree species in the farmland and ASF

A total of 840 individual trees (of >20cm DBH), of eight different species were found in 210 PCQ points assessed in the farmland. These trees included mango, cashew nut, coconut, neem, casuarina, guava, *Gmelia arborea* and citrus spp (lemon) trees (Fig. 27). No indigenous tree was recorded in the 210 PCQ points in the farmland. The commonest tree found in the farmland was coconut, represented by 54% of all trees followed by mango (31%), cashew nut (11%) and neem (4%) trees, with the other trees being very few in numbers (Appindex 7). In mango farms sampled, mango trees were the most dominant and represented 71% of all trees, followed by coconut trees (19.6%). In the sampled coconut farms, coconut trees were the most dominant represented by 89% of all trees, followed by mangos (3.9%). The most dominant tree in the sampled mixed farms was coconut represented by 53% of all trees, followed by cashew nuts 23% and mango 19%.

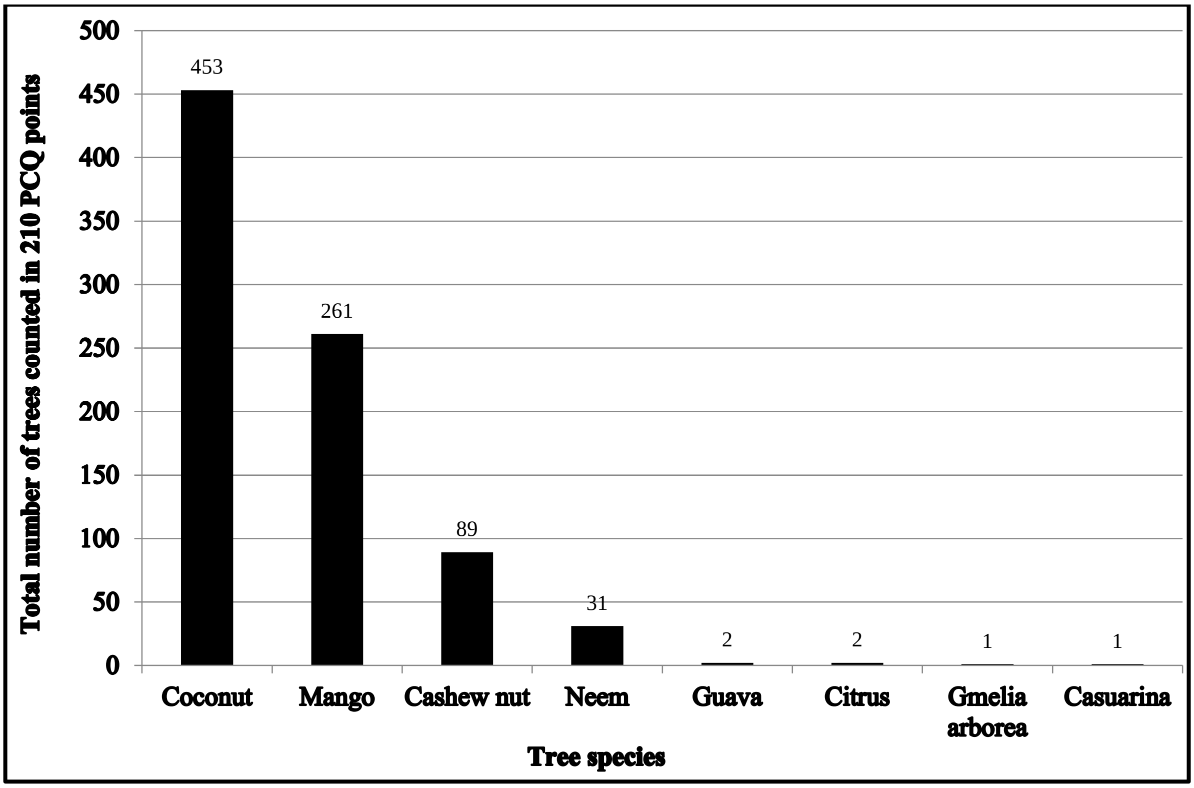

Figure 27. Total number of individuals of diverse tree species found in 210 PCQ points in the farmland

In total 840 individual trees (of >20cm DBH), of 20 different species occurred in the 210 PCQ points assessed in the interior of ASF. The commonest trees found in ASF were *B. spiciformis* represented by 30% of all trees, followed by *C. webberi* (29%), *Manikara sansibarensis* (18%) and *Hymenaea verrucosa* (11%) with other trees being very few (Fig. 28). No exotic and cultivated tree was recorded in the 210 PCQ points inside ASF (Appindex 8). In *Cynometra* forest, *C. webberi* tree was the most dominant represented by 87% of all trees, followed by *B. huillensis* (5%). In the *Brachystegia* woodland, *B. spiciformis* tree was the most dominant represented by 89% of all trees, followed by *H. verrucosa* (5%). The mixed forest was dominated by *M. sansibarensis* trees represented by 53.6%, followed by *H. verrucosa* (28%) and *Afzelia quanzensis* trees (10%).

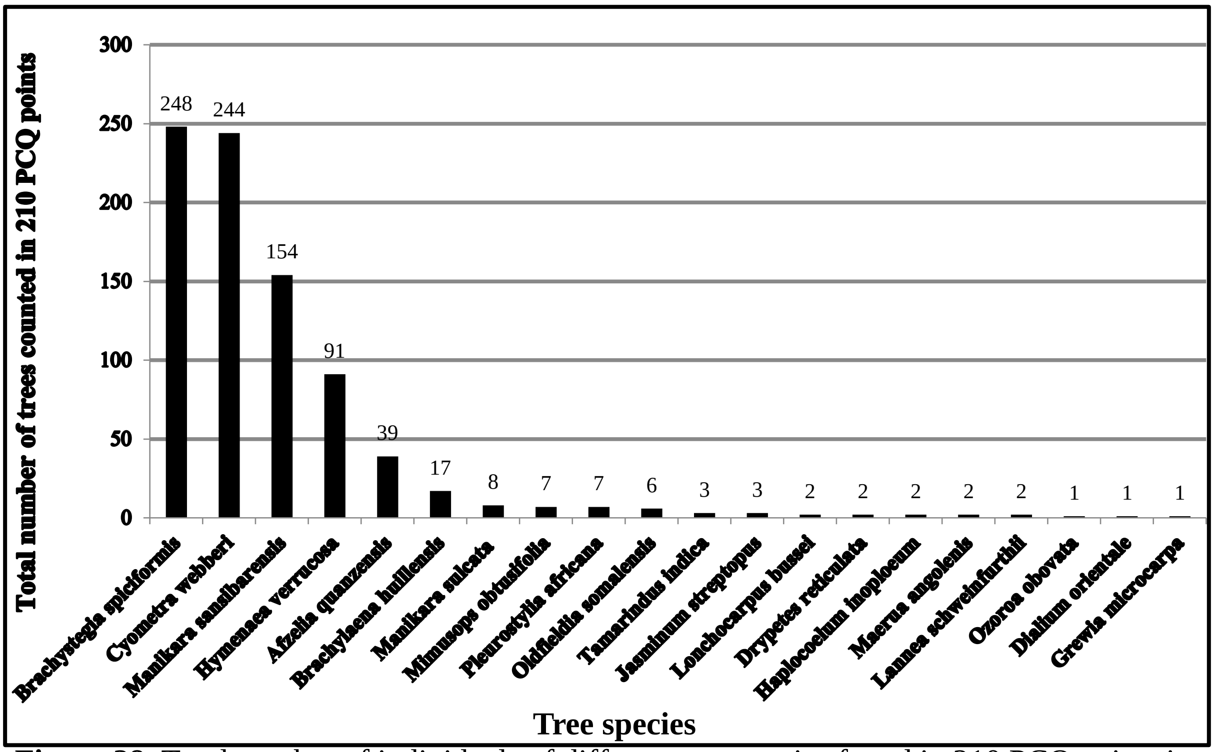

Figure 28. Total number of individuals of different tree species found in 210 PCQ points in the interior of ASF.

7.3.2 Fruits trees found in the farmland and at ASF

Of 840 individual trees found in the farmland 210 PCQ points, 456 (54%) including coconut, casuarina and citrus trees do not produce fruits which would be eaten by fruit bats. The remaining 384 (46%), which include cashew nuts, neem and mangos produce soft fruits when ripe which could be consumed by fruit bats (Appindex 7). Out of 840 individual trees in ASF 210 PCQ points 674 trees (80%) do not produce fruits which would be eaten by fruit bats, while 166 trees (20%) in the same habitat including *M. sansibarensis, Mimusops obtusifolia, Lannea schweinfurthii, Haplocoelum inoploeum* and *Dialium orientale* (Appindex 8)produces edible fruits which potentially are eaten by fruit bats.

7.3.3 Tree characteristics in the farmland and ASF

The mean distance between trees in the farmland was 9.5M, while in ASF it was 10.95M. The absolute density in the farmland was 111/ha and in ASF 84/ha. In the farmland, the coconut trees had the highest density per hectare (60), followed by mango (34) and cashew nut (12) (Appindex 9). In ASF *B. spiciformis* had the highest density of of trees per ha (25), followed by *C. webberi* (24) and *M. sansibarensis* (15) Appindex 10). The coconut trees in the farmland had the highest (54%) relative density of all trees recorded in the farmland, followed by mango (31%). In ASF *B. spiciformis* and *C. webberi* had highest relative density (30% and 29% respectively). In the farmland the mango trees had the largest total basal area per ha (m^2/ha) 26.3), followed by cashew nut (4.1) and coconut (3.8 (Appindex 11), while in ASF it was *B. spiciformis* (7.2), followed by *C. webberi* (1.8), and *M. sansibarensis* (1.3) Appindex 12).

Mango trees in the farmland had the highest (75%) relative cover (relative dominance) of a species, followed by cashew nut (12%) and coconut (11%). In ASF *B. spiciformis* had the highest (54%) relative cover of a species, followed by *C. webberi* (14%) and *Afzelia quanzensis* (11%). The mango tree had the highest (30%) relative frequency of a species in the farmland followed by cashew nut (12%), while in ASF *B. spiciformis* and *C. webberi* had the same relative frequency (20%). The tree species in the farmland with the highest important value of a species was mango (136), followed by coconut (112) and cashew nut (39 (Appindex

13); while in ASF it was *B. spiciformis* (102) followed by *C. webberi* (62) and *M. sansibarensis* (46) Appindex 14).

7.3.4 Habitat structure in the farmland and ASF

There was a significant difference in the mean distances among trees in the six different vegetation types in the two study sites (One-Way ANOVA [F (5, 1674) = 27.39, $p < 0.05$]. Trees in *Brachystegia* woodland (BRA) in ASF were the most spaced (14.4m ±0.8) than in the other vegetation types in the two study sites. In the farmland trees in coconut farms (COC) were the least spaced (7.5m ±0.3) Fig. 29). Note MAN (mango farms), COC (coconut farms), MIXFa (mixed exotic trees in farmland) BRA (*Brachystegia* woodland), MIXFo (mixed indigenous tree forest in ASF) and CYNO (*Cynometra* forest).

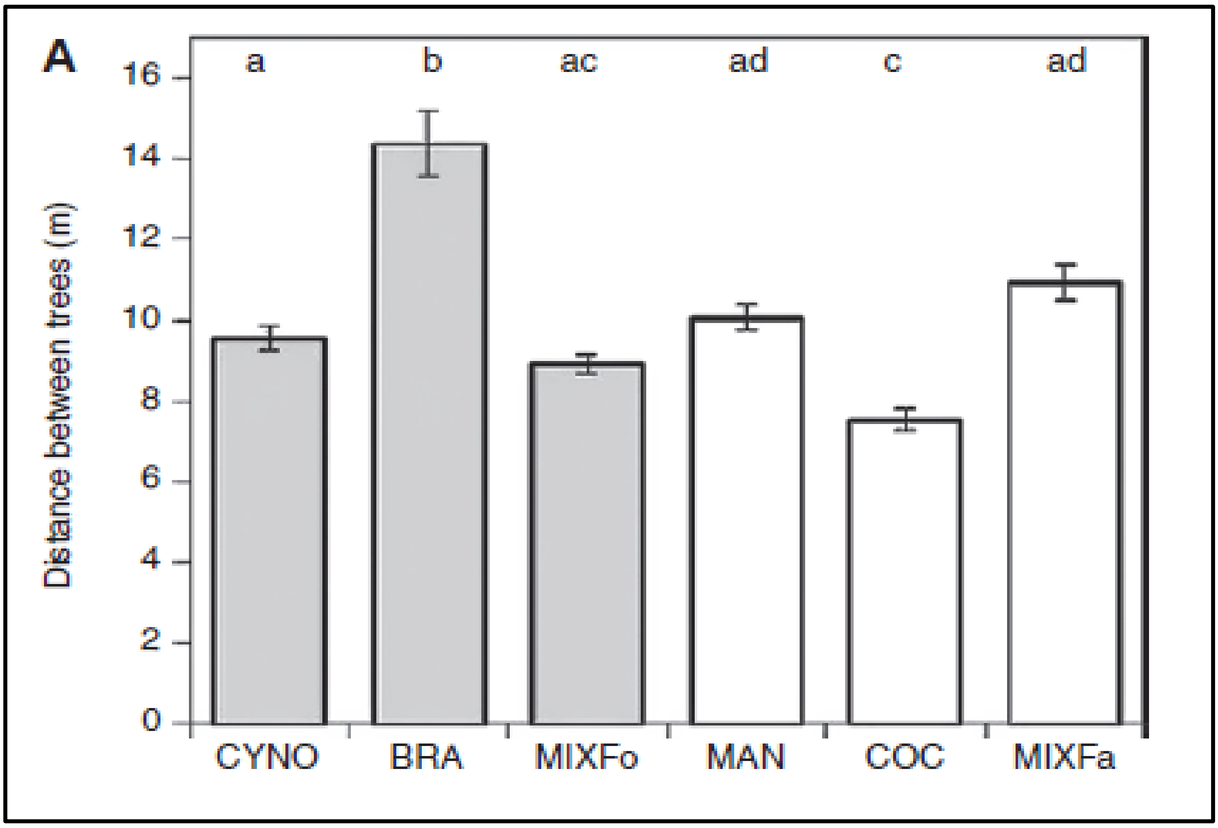

Figure 29: Mean values (±SD) of distance between trees (m) N=280) in ASF vegetation types (shaded) and farmland (unshaded). Different single letters (eg, a,b,c) indicate significant difference in distance between trees among vegetation types, while combined different letters (eg ac) indicate significant differences in distance between trees in two vegetation types.

There was a significant difference in the mean DBH of trees in the six different vegetation types in the two study sites (One-Way ANOVA [$F (5, 1674) = 115.68$, $p < 0.05$]. Trees in mango farms (MAN) had the largest DBH (76.3cm ± 2.7) followed by those in *Brachystegia* woodland (BRA) 53.5cm ± 1.6) in ASF (Fig. 30). Some of the old *B. spiciformis* trees had large hollows which some species of insectivorous bats would likely roosts in (Fig. 31).

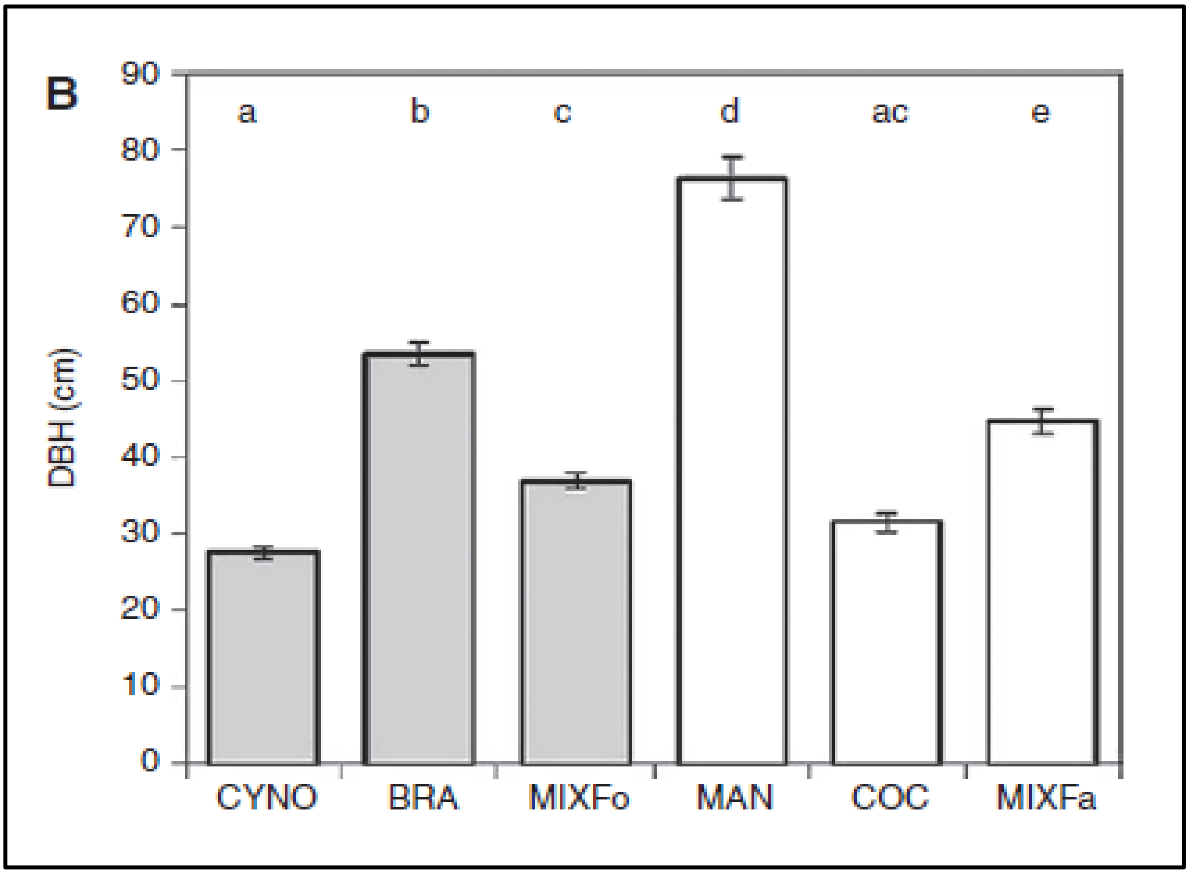

Figure 30. Mean values (±SD) of Diameter at Breast Height (DBH (cm) N=280) in ASF vegetation types (shaded) and farmland (unshaded). Single letters (e.g. a) indicate significant difference in DBH among vegetation types, while two different letters (e.g. ac) indicate significant differences in DBH between the two vegetation types.

	
M. sansibarensis trees with big hollows	*B. spiciformis* with big hollows

Figure 31. Old large and hollowed *B. spiciformis* and *M. sansibarensis* trees in ASF which could likely be used a roosts by some insectivorous bats.

There was a significant difference in the mean percentage vegetation canopy cover in the six different vegetation types in the two study sites (One-Way ANOVA [$F (5, 414) = 16.41$, $p < 0.05$]. In the farmland the most closed canopy was in the mango farms (MAN) followed by coconut farms. In ASF the canopy of *Brachystegia* woodland (BRA) and mixed forest (MIXFo) was the most closed (Fig. 32). The canopy cover among *Brachystegia* woodland (BRA), mixed forest (MIXFo) and mango farms (MAN) was the same, while that of *Cynometra f*orest in ASF was the most open among all the vegetation types in the two study sites (Fig. 32).

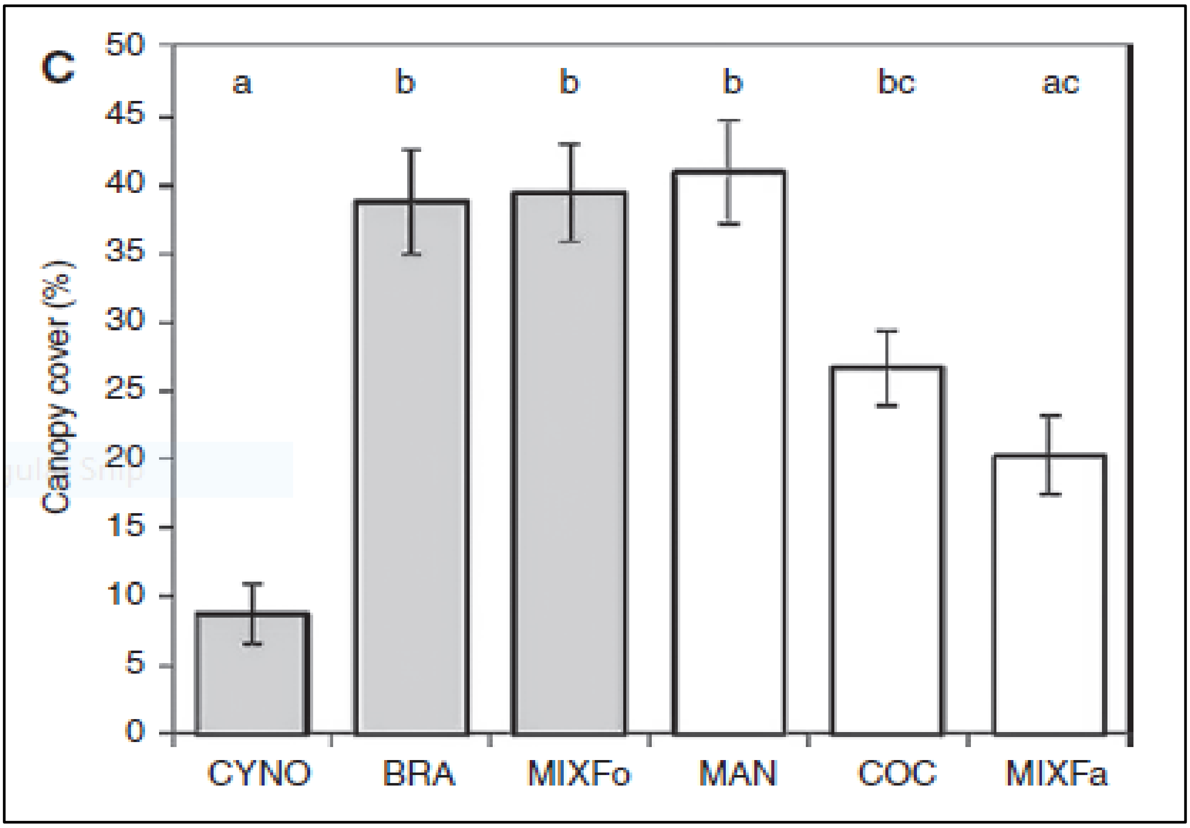

Figure 32. Mean values (±SD) of % canopy cover (N=70) in ASF vegetation types (shaded) and farmland (unshaded). Same single letters (e.g. b) indicate no significant difference in canopy cover among the three vegetation types, while two letters (e.g. bc) indicate significant differences in canopy cover between vegetation types.

There was a significant difference in the mean percentage understorey/undergrowth vegetation cover in the six different vegetation types in the two study sites (One-Way ANOVA [F (5, 414) = 61.59, $p < 0.05$]. The % understorey cover among the three vegetation types (MAN, COC, MIXFa) in the farmland was the same. In ASF, the thickest understorey was in *Cynometra* forest (CYNO), while *Brachystegia* woodland (BRA) and mixed forest (MIXFo) had the same percentage understorey cover (Fig. 33).

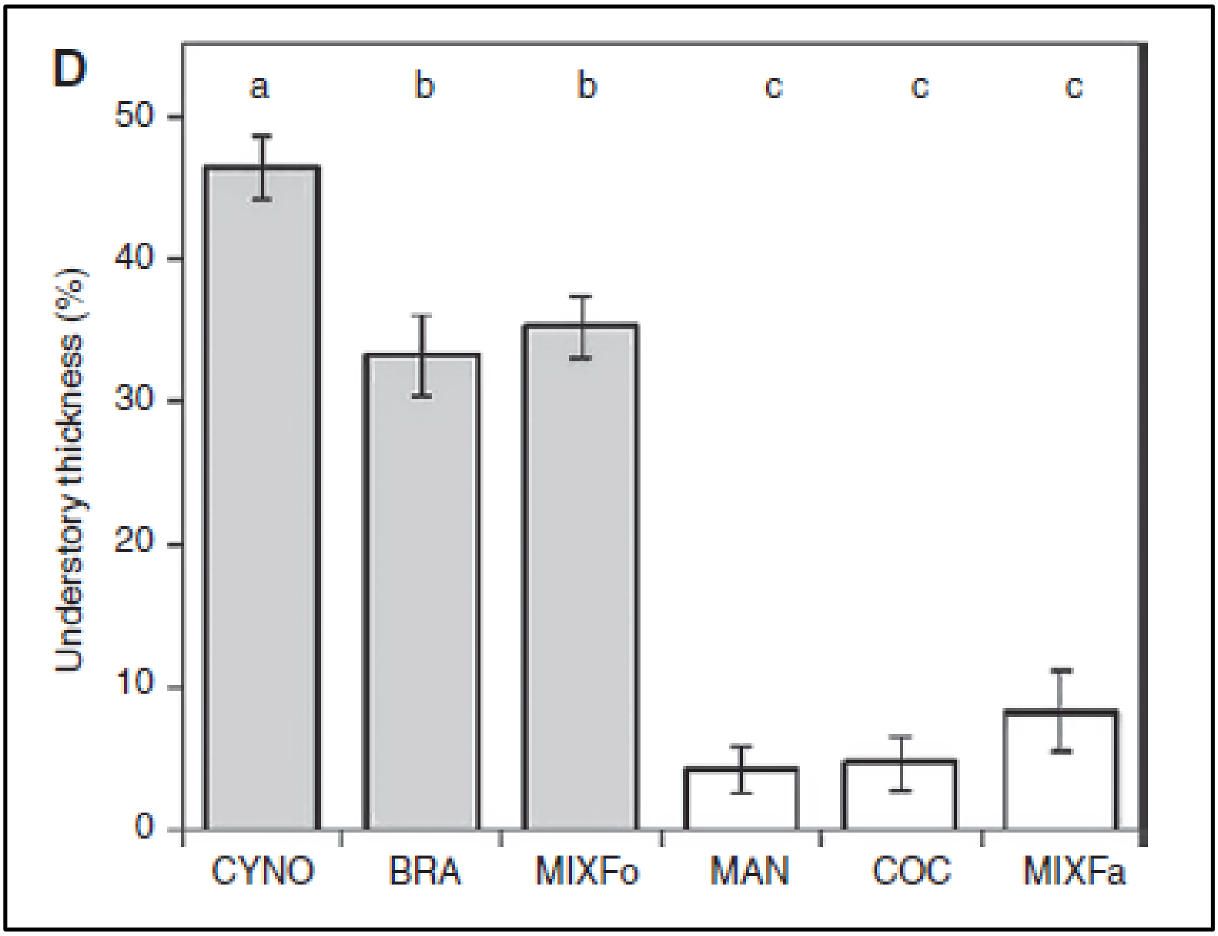

Figure 33. Mean values (±SD) of % understorey cover (N=70) in ASF vegetation types (shaded) and farmland (unshaded). Same single letters (eg, b and c) indicate no significant difference in understory thickness among vegetation types.

There was a significant difference in the mean crown diameter of trees in the six different vegetation types in the two study sites (One-Way ANOVA [$F (5, 1674) = 215.73$, $p < 0.05$]. The crown diameter of trees in *Brachystegia* woodland (BRA) was the largest (18.4m ±0.4), followed by those of mixed forest (MIXFo) and mango farms (MAN). The crown diameter of trees in mixed forest (MIXFo) and mango farms (MAN) was the same (Fig. 34). The large crown diameter of mango trees in the farmland, and the nature of these trees of being evergreen throughout provided a suitable roosting habitat for some fruit bat species (Fig. 35-36).

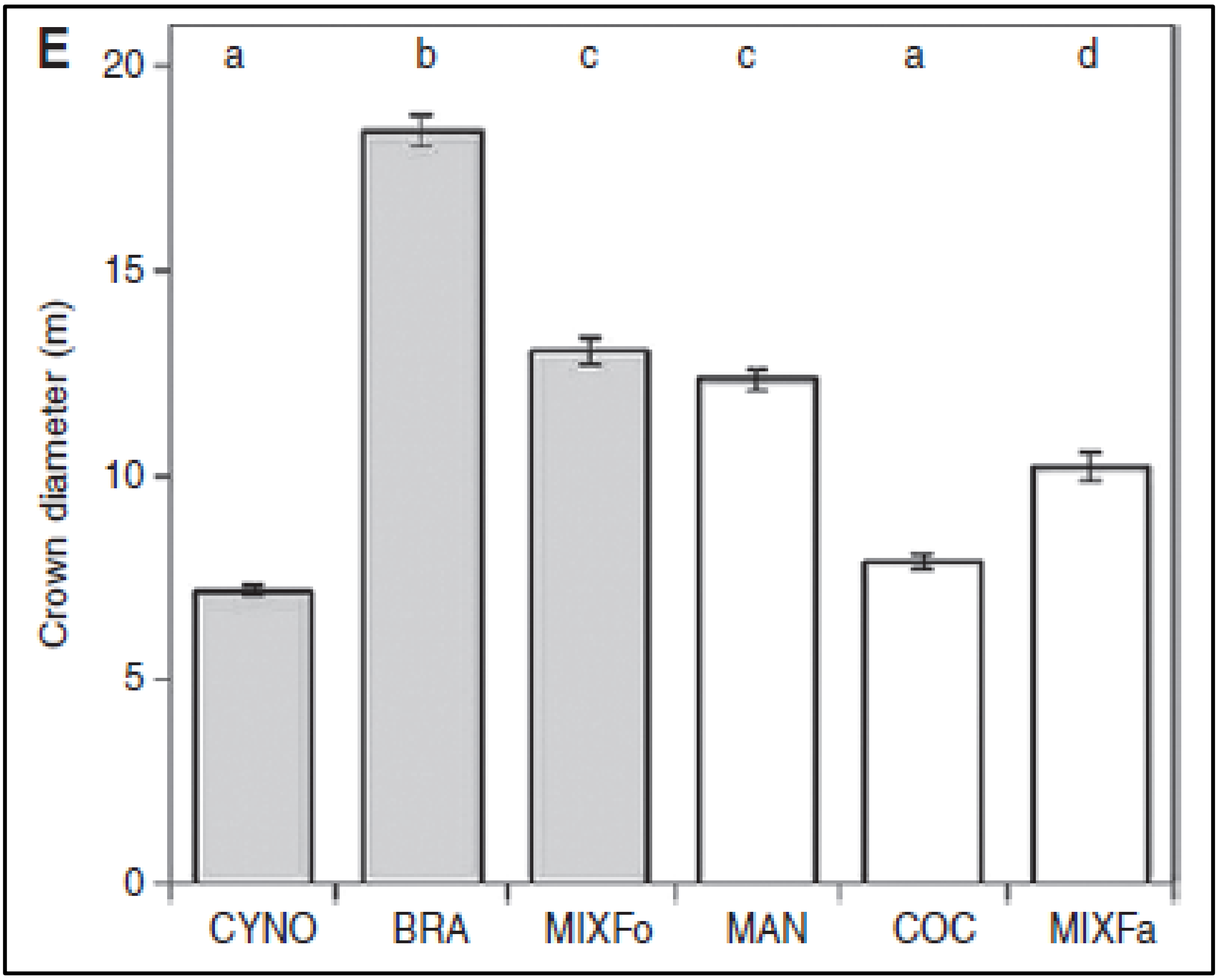

Figure 34. Mean values (±SD) crown diameter (m) N=280) in ASF vegetation types (shaded) and farmland (unshaded). Same single letters (eg, a or c) indicate no significant difference in crown diameter between the two vegetation types.

Figure 35. Mango trees in the farmland with large crown diameter which remain evergreen annually and the dense crown provided suitable roosts for foliage roosting bats

Figure 36. Individuals of *E. wahlbergi* roosting in the foliage of mango and cashew nut trees at Gede market

When the habitat structure variables were compared between the ASF and the farmland, they were found to be signficantly different (Table 11). The DBH of trees was significantly larger in the farmland than in ASF (*t* (838) = 6.8934; *P* = 0.0001). The percentage understory and canopy cover in ASF was more closed in ASF than in the farmland (Table 11).

Table 11. Comparison of different habitat structure variables between ASF and farmland. Means (±S.E.) and student *t*-tests with associated probabilities. Significant results at *P* = 0.05 are shown in bold.

	Comparison: Habitat Structure ASF And Farmland			
Vegetation Types	**ASF**	**FARM LAND**	**t-test**	***P***
1. Distance between trees (m) N=840)	10.9±0.3	9.5±0.2	5.0391	**<0.05**
2. DBH (cm) N= 840)	39.4±0.8	50.9±1.3	6.8934	**<0.05**
3. % Canopy cover (N = 210)	42.8±1.4	29.3±1.9	5.6887	**<0.05**
4. % Understory thickness (N= 210)	38.2±1.9	5.8±2.3	16.634	**<0.05**
5. Crown diameter (m) (N = 840)	12.9±0.2	10.2±0.2	9.016	**<0.05**

7.4 Discussion

In this chapter the vegetation structure in ASF and farmland were studied, in order to undestand how the habitat structure and forest resources influenced the distribution and habitat use by bats. No single indigenous tree typical of coastal forests in Kenya was found in the 210 PCQ points assesed in the farmland, but this habitat was dominated by exotic orchard of trees. In addition, no single exotic tree occurred in the 210 PCQ points assesed in ASF. The current study recorded the same indigenous dominant tree species recorded in the three broad vegetation types in ASF by Robertson and Luke (1993), suggesting this forest is still relatively in good habitat condition. The marked changes in habitat structure between ASF and farmland, has dramaticaly affected the distribution of many wildlife species probably bats included, but particularly more the globally threatened species found in this forest (Bennun and Njoroge, 1999).

The farmers around ASF cultivated exotic trees as sources of fruits which were consumed at household level or were sold to provide additional income to families. Some of these trees were also sources of timber for locals. Because of the immense livelihoods benefits derived by the farmers, the trees were densely planted (9.5 m ± 0.2, from each other) as compared to those inside ASF (10.9 m ± 0.3). The farmland trees were of bigger sizes (50.9m ± 1.3 DBH) than those in ASF (39.4 m ± 0.8). This suggests that the farmland trees trees had been cultivated for many years, the reason some like mangos had attained very big mean girths (76.3m ± 2.7), much bigger in size than the largest *B. spiciformis* trees (53.5 m ± 1.6) in ASF. Some of the big and old *B. spiciformis* and *M. sansibarensis* trees in ASF had large hollows (Fig. 31) which potentially could be used by some insectivorous bats for roosting, although this was not verified during the current study. In addition, trees like mango (Fig. 35), cashew nut, coconut and neem remained evergreen annually, and could provide potential roosting habitat especially for the foliage roosting bats (Fig. 36). The presence of the large density of trees in the farmland probably enhanced this habitat use by bats. For example, bat activity and captures (Chapter 4-5) was higher in the farmland than in ASF. This observation is consistent with other bat studies elsewhere. For example, the activity of foraging bats was often higher near trees in open areas in Australian forests (Law and Chidel, 2002). Furthermore, agricultural landscapes which incorporate large trees on farms have limited effects on bat activity and abundance (Williams-Guillén *et al*., 2016).

In the farmland, probably to increase the production of fruits by trees, as well as other crops, much of the undergrowth in the cultivated farms was cleared to enable easy access and possibly to reduce water and nutrients competition among growing plants. Thus, the understorey and canopy cover in the farmland was more open than inside ASF. Some studies have shown that thick vegetation or clutter decreases the number and species of bats that use a habitat (Bobrowiec *et al*., 2014). In a thick forest habitat like ASF, with very few accessible roads, there were very few bats flight paths, which essentially meant there were limited foraging areas below the canopy. For instance, many individuals of *N. thebaica* a clutter tolerant species, were captured in the farmland (40) than in ASF (14), probably suggesting the less obstructed nature of farmland, may have provided a more preferred foraging habitat than ASF interior. Hence, the dense clutter in ASF, may have inhibited bat use of this habitat, and probably explains the low capture of all bats and activity recorded for this habitat (Chapters 4-5).

In addition, dense understorey clutter also affect the accessibility of insects prey by below the canopy foraging bats (Rainho *et al*., 2010). Although farmland and ASF had the same abundance of invertebrates (Chapter 6), the dense understorey and canopy cover may have prevented their accessibility by foraging insectivorous bats in ASF. Contrary, the farmland had many bats flyways and due to its openness, the habitat could possibly enable many bats to forage or fly at lower level, and be easily captured in mist-nets.

The farmland had the largest number of trees (46%) which produces fruits which are eaten by fruit bats as compared to the interior of ASF (20%). The neems, guavas, mangos and cashew nuts cultivated in the farmland produces soft fruits when ripe and are consumed by frugivorous bats (Korine *et al*., 1994). The largest number of individuals of fruit bats in the farmland were captured in mango farms (1288, Table 3), while in ASF it was in mixed forest (382, Table 2). The fruit trees in ASF including *M. sansibarensis*, *M. obtusifolia*, *L. schweinfurthii*, *H. inoploeum* and *D. orientale*, produce tiny fruits characterised by soft pulp after they ripen (Beentje, 1994), and are thus likely to be consumed by frugivorous bats. The mixed forest was dominated by *M. sansibarensis* (150 trees), probably suggesting that the fruit bats were attracted to fruits produced by this tree. Sixty five percent of all bats documented in this study were frugivorous bats which occurred in the farmland and only 17% in ASF. The main fruit bat species captured in the study area were *R. aegyptiacus* and *E. wahlbergi*. Individuals of *R. aegyptiacus* and *E. wahlbergi* consume many different types of ripe cultivated fruits trees including those of neem, mango, cashew nuts and guava (Ayensu, 1974). Most likely, because of the tiny sizes of the wild forest fruits in ASF, when compared with the large commercial fruits produced in farmland, the former fruits were probably exploited less by foraging bats. Hence, the huge abundance of edible fruits cultivated in the farmland, may be the most likely reasonable explanation for the large quantities of frugivorous bats captured in this site.

To conclude, the farmland habitat lacked all indigenous tree species found inside ASF. This indicates a complete conversion of the original natural forest in this area into agroecosystem. The dominant trees that characterised the three broad vegetation types in ASF in the past, were recorded in large numbers, suggesting that the ASF is still relatively intact, and in good habitat condition to sustain endemic, globally threatened and common wildlife species. The farmland was covered in actively cultivated exotic trees which probably provided useful habitat to bats for roosting and foraging. The understorey and canopy of the farmland were more open than in ASF. In addition, the farmland had many cultivated fruit trees, which provided fruit resources to frugivorous bats dominant in this habitat. Therefore, to enhance the conservation of bats in the study area in the long run, there is a need to work with local farmers, to ensure proper management and continued cultivation of trees (neem, mango, cashew nuts, coconut and guavas) in their farms.

CHAPTER EIGHT: HUMAN-BAT INTERACTIONS AROUND ARABUKO-SOKOKE FOREST

ABSTRACT

Human beings are the main drivers of flora and flauna extinctions worldwide. In this study local people attitudes and perceptions were examined, in order to understand how their actions might influence bats survival in the study area. A semi-structured questionnaire was used to investigate knowledge, attitudes and perceptions about bats by 394 local people surrounding ASF. Beliefs to unfounded mythologies were dominant among local people and these myths were connected with low acceptance of bats. The attitudes of the elderly and more educated respondents were more positive toward bats than those of the youths and illiterate people. Females believed myths about bats more than males. The males around ASF had more antagonistic behaviour toward bats as compared to females. About one-third of respondents killed individuals of bats upon encounter or damaged their roosts; and a comparable number associated bats with no benefits to humans. Many people around ASF implicated bats in the damage of cultivated fruits such as mangos, cashew nuts and guavas. To counteract the low appreciation of bats common among locals around ASF, there is a need to intensify bat awareness among school going youths, in order to positively influence their attitudes toward bats.

8.1 Introduction

The theory of how people behaves hypothesizes that attitudes, subjective customs, and observed behaviour, regulates people behavioural objectives (Ajzen and Fishbein, 1980). Attitude is the manner an individual reasons or acts about something (Eagly and Chaiken, 1993). Subjective customs are pressures which emanate from a society where one lives or is born, which guide choices made by individuals, especially what they choose to do at any given time (Ajzen, 1991). Perceived behaviour control refers to person's perception of the likelihood of behaving or acting in a certain way (Azjen, 1991). Bats as well as rats, microbes, spiders and reptiles (snakes), are the major animals which recurrently have been reported to cause fear to human (Robins and Regier, 1991). Bats are feared because they are associated with diseases and parasites (Rego *et al*., 2015), and also due to negative myths, publicity and misrepresentation of facts disseminated to the general public about them (Mayen, 2003). Animals which are adversely perceived and are dreaded by people, face persistent attack from people using an assortment of approaches (Prokop and Fančovičová, 2012). Therefore, it is imperative to document information on human-bat interactions, in order to comprehend the most appropriate approaches to use to involve people in the conservation of bats as well as their habitats.

The knowledge, perceptions and attitudes toward bats among individuals of Mijikenda tribe that live nearby ASF were investigated. The Mijikenda tribe is a Bantu speaking people, which lives mainly along the Kenyan coast that primarily consists of nine different sub-tribes. The nine sub-tribes are Duruma, Ribe, Rabai, Chonyi, Digo, Kambe, Kauma, Giriama and Jibana). Though information about attitudes and perceptions about bats among 44 tribes in Kenya, haven't been documented, this traditional information can provide fundamental insights in the preparation of a comprehensive national bat conservation plan. Like all tribes in the world, the Mijikendas, have cultural beliefs about bats which may affect their survival both positively or negatively (Musila et al. 2018b). Because more knowledge (Bjerke *et al*., 2003) and better education positively influences human attitudes towards animals (Kleiven *et al*., 2004), it was hypothesized that literate respondents around ASF would be more appreciative of bats than illiterate people. Human females have more negative attitudes towards animals that are known to be a threat to people than males (Ceríaco, 2012), hence it was also predicted that female respondents in this study would be less appreciative of bats and have more negative beliefs about them than their male counterparts.

8.2 Materials and Methods

8.2.1 Study area

This study was undertaken in villages in Gede and Watamu sub-locations, on the eastern part of ASF (Fig. 37). Because one of the main interest of this study was to investigate how local peoples' knowledge, attitude and perception about bats varied among people living near proximity to bat roosts and those living far away, there was a need to locate bat caves around ASF, before socioeconomic surveys were conducted. During pilot surveys three limestone bat caves were located in the eastern part of ASF, at Jimba village, south east of Gede market, in Watamu-sub location. The caves were visited during reconnaissance period and were confirmed to be used by roosting bats. The caves were Panga Yambo (A), Ali Baba /Makuruhu (B) and Kaboga (C) Fig. 37). Makuruhu cave, also known as Alibaba, was the largest coral cave around Gede, with high ceiling as well as smaller chambers and four openings. It was located on a private land, which was rocky and difficult to exploit for crops cultivation. However, most large trees and other plants around the cave had been cleared and burned, but some trees and bushes remained near the cave openings. The cave had two separate sections each with more than one entrance. One section was used for cultural activities and worship by the local people and had few or no bats remaining. The other opening had many bats, and was avoided by local people. About a million bat individuals of six different species occurred in this cave including large breeding colonies of *H. caffer* and *C. afra*. Other abundant species in the cave were *T. afer, T. hildegardeae, M. minor,* and *M. cf. inflatus*. Panga Yambo was small coral cave, with a single entrance and three chambers, located in a private piece of land used for crop farming and human settlement (one family). Much of the natural vegetation around the cave had been removed and replaced with exotic farmland trees including mango, cashew nut, neem and coconut. The cave had a breeding colony of *C. cor*, consisting of approximately 100 individual bats. Kaboga cave was a medium-sized coral cave, with three sections, each with a separate entrance. One chamber had high roof and with many bats; two chambers were smaller and had few bats. There was an estimated 5000 individuals of bats in the cave including *H. caffer, M. vittata, T. afer, C.cor, Coleura afra, T. hildegardeae M. cf. inflatus* and *M. minor.* The cave was located in the middle of a private farm with extensive human activities, including an active limestone quarry. Most of the natural vegetation around it had been removed. The position of each cave was geo-referenced, for use in the estimation of the distance from each cave and each household where respondents to be interviewed were going to be sampled. Interviews were also undertaken 4km from these caves at near Gede town in

Gede Sub-location. Detailed description of human settlements, habitat and farming activities around the caves is the same as provided in Chapter 3.

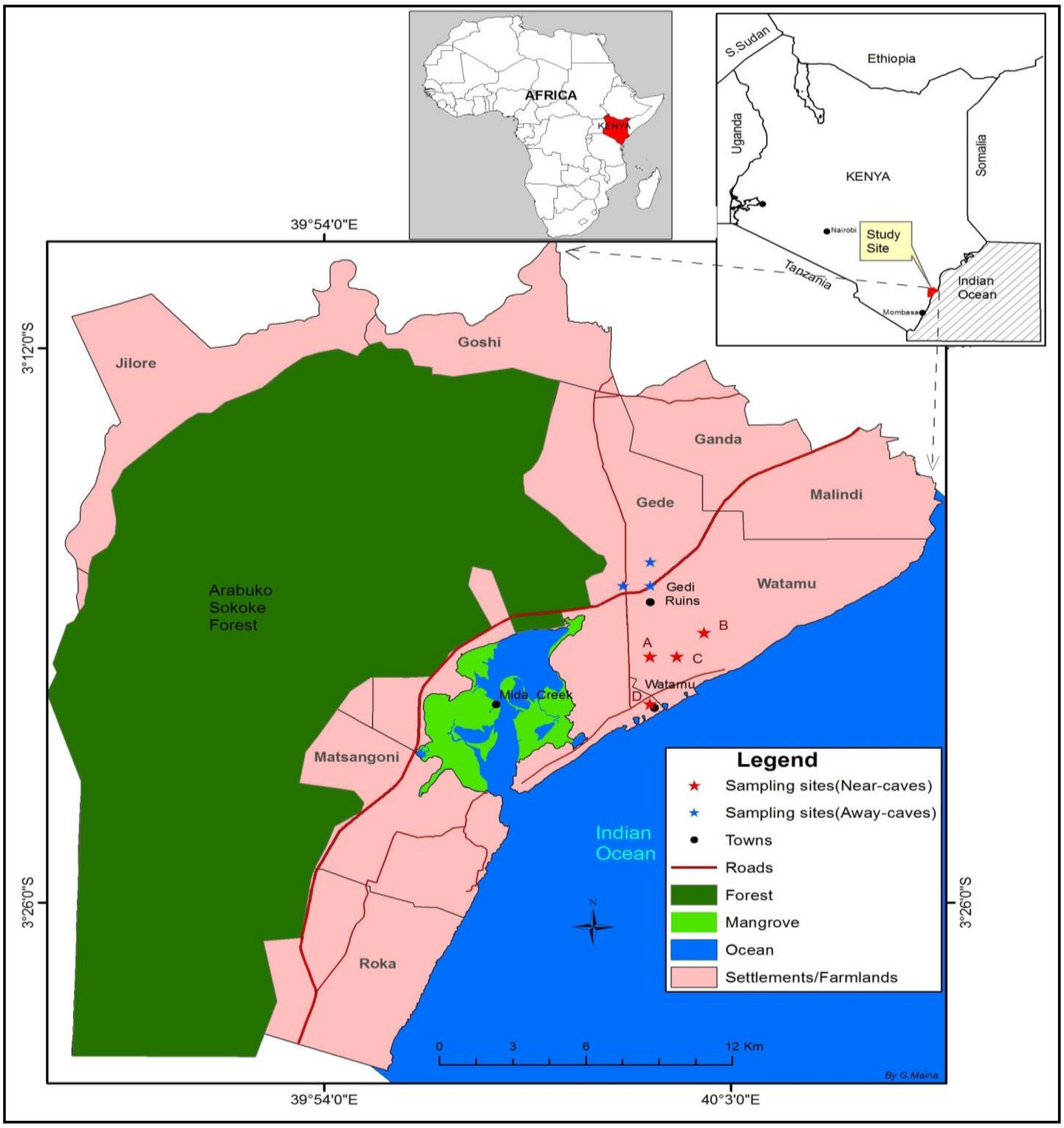

Figure 37. Map of ASF showing areas around Gede and Watamu sub-locations where bat-human interactions studies were undertaken. Points A-C were areas around caves and blue stars were areas 4km away from caves.

8.2.2 Selection of the respondents and interview procedure

Purposive sampling, a non-probability sampling technique in which the characteristics of the sample to be involved in the study or study sites to be assessed are defined by the researcher (Tongco 2007; Black, 2010; Quinn *et al*., 2014), was used in selection of study sites and respondents in this study. Purposive sampling is widely used in socioeconomic studies

(Campbell 1955; Godambe 1982; McDonald *et al*. 2003; Li *et al*. 2006, Prance 2004; Garcia 2006; Dolisca *et al*. 2007). Purposive sampling was appropriate for the current study, because there was need to compare knowledge, attitude and perception about bats among people living near the proximity to selected limestone caves and those that lived far away.

Before the start of interviews, the local government administration (chiefs, sub-chiefs), were visited and elucidated about the procedures of the planned socioeconomic surveys. The government administration was provided with copies of letters authorizing the study, as well as copies of prepared questionnaires used in data collection. The procedures of conducting the socioeconomic survey were explained to them, as well as areas or villages to be visited. This was done because of the heightened security situation along the Kenyan coast, and government led Nyumba Kumi initiative, which was being implemented to control cases of terrorist insecurity since 2013. Semi-structured questionnaires were first developed in English (Appindex 15), then translated into Swahili (Appindex 16), the chief dialect used by majority of the local people around ASF. The questionnaire was pre-tested by interviewing 50 people in the study area prior to the actual data collection (Musila *et al*. 2018b).

Purposive sampling has potential biases (Quinn *et al*., 2014), which can be minimised by collecting data in a systematic sampling manner (Bourdeau, 1953), and also by describing steps used in selection of respondents in detail, in order to ensure that the procedures can be repeated in future studies (Tongco, 2007; Quinn *et al*., 2014). Biases can also be mitigated by use of maximum variation sampling technique, which relies on choosing participants with human population features likely to influence respondent views about a subject under investigation (Brikci and Green, 2007; Tongco, 2007). These variable in the current study included gender (males, females) and age (youths and adults) of the respondents as well as distance from the roosts. Almost an equal number of adults and youths of both gender were interviewed in this study, in order to get views from the age groups representative of the population. A youth in this study was a respondent aged below 8-20yrs, and an adult a person above 21yrs.

A team of three people, accompanied by a native who spoke Giriama and Swahili visited households. Respondents were sampled by walking along paths or roads in the villages and selecting respondents from the third household from the first or the last visited. This was done to ensure a systematic method of selecting respondents from households was applied around the bat roosts away from them. The research team was introduced in each household by a local guide. If adult members of the family were available, the purpose of the research team visit was explained to them, if not available the household was skipped. Thereafter, a request to participate in the interview was sought from adult members of the household available. If permission was granted, two members of the household of dissimilar gender or age category were selected for interview.

To get the information from the respondents; questions in the questionnaire were read by an interviewer, and answers provided by each interviewee were used to fill each individual questionnaire. An interview with one respondent lasted about 15 minutes. Respondents were asked about their Mijikenda sub-tribe, their education background and number of family members. To document what respondents knew about bats and how they interacted with them, they were asked about names given to bats in their local dialect, the last time they had sighted an individual bat, known bat roosts in the village which were actively being used by many bats, cultural beliefs held about bats, whether bats were beneficial or harmful to people. To document how local people reacted to bats which roosted in their households, respondents were provided with five different choices to choose one option. These choices included I). I killed many bats, 2). I killed at least one bat, 3). I destroyed roosts to chase bats away, 4). I did nothing, and 5). I contacted responsible officer. To investigate how peoples' knowledge, perceptions and attitudes changed with distant from bat roosts (caves), 190 people were interviewed among people living adjacent (at most 1km away each cave) to the three caves in Jimba, Gongoni, Kanani, Mnanzini, Bikahanga, Adam B and Panga Yambo villages in Watamu sub-location. Out of the 190 respondents, 93 were females (47 adults, 46 youths) and 97 males (49 adults, 48 youths). In addition, 204 people were interviewed 4KM away from the three caves at Mkenge, Mabuani, Kizingo, Msabaha, Baraka Chembe and Gede villages in Gede sub-location. These included 102 females (51 adults, 51 youths) and 102 males (51 adults, 51youths).

8.2.3 Measures for attitudes toward bats

The attitudes towards bats by local people around ASF were investigated by use of 5-point Likert-type scale semi-structured questionnaire, prepared in the same way to attitudes towards animals by Kellert (1996). The questionnaire was divided into five categories (domains) for investigating attitudes (myths, negativistic, scientistic, ecologistic and knowledge) (Prokop *et al*., 2009). Each category was accompanied by a number of listed questions for assessing attitudes towards bats. Nine negativistic questions measured respondents shunning of bats due to abhorrence or anxiety such as; "bats destroy fruits in our farm". Four scientistic questions measured concern in the natural history of bats such as; "I would like to know more about bats". A total of eight knowledge questions asked simple facts about natural science of bats, by use of questions which were easy to understand by people who lack experience in bat science such as: "bats lay eggs". Nine ecologistic questions investigated local people awareness about the role played by bats in the environment such as; "Bats help in seed dispersal". Seven myths questions investigated the levels of respondents' belief of cultural myths existing in their community about bats such as; "bats are ghosts". Each question was scored by selection of one option from a set of five choices that were rated on a Likert type scale from one; strongly disagree, rather disagree, undecided, rather agree to strongly agree Before the interviewees started answering the questions asked by the interviewer, they were enlightened about the meaning of selecting one of the five provided multiple choices (strongly disagree, rather disagree, undecided, rather agree and strongly agree), for each question posed to them.

8.2.4 Data analysis

Data were organized in excel and summarized, especially for information on respondents demographic characteristics including age, size of household, education level, names of bats in mother tongue, myths, benefits and effects of bats on people. To analyse attitude data rated on likert scale the reliabilities of each attitude domains (categories) were checked and were found to be low (Cronbach α averaged (0.36-0.7). The scores of knowledge domain had a very low reliability (α = 0.18) Nunnaly, 1978). To increase reliability scores of different domains factor analysis was used with Varimax rotation on attitude data. Varimax rotation is a statistical method used at one level of factor analysis to try to clarify the association among variables under investigation (Forina *et al*., 1989). Barletts test of sphericity (χ^2 = 2463.5) and Kaiser-Meyer-Olkin measure of sampling adequacy (0.72) yielded to significant results ($p < 0.001$) indicating that it was appropriateto run factor analysis. A total of 14 factors that explained 64.5 % of variance of results were derived. Factor loadings which had less than 0.3, as well as domains associated with less than three items were removed from further analysis. This further analysis resulted into a reduced number of items under each domain, but the reliability of most domains was highly improved (scientistic domain, α = 0.72; negativistic domain, α = 0.5; ecologistic domain, α = 0.67 and myths, α = 0.68). However, the reliability of the knowledge domain did not improve. Thus, data on this domain was not included in further statistical analyses. To test how attitude of different remaining domains were influenced by independent predictors, multiple linear regression analysed the data in the same way done by Kalteborn *et al*. (2006). Independent variables included in the analysis were: sex, age of respondents, total number of people found in each household, the presence of individuals of bats in different household farms, stages in the education of each respondent, the last time a bat was seen and the distance of each household to bat roosts (caves).

The data on the observation of bats with time were combined into two categories of observations; one in which respondents reported to have seen an individual bat within a week (last seven days), and two, respondents who had not seen an individual of a bat in the last seven days. For the analysis the dependent variabe was always one domain of attitudes using the same method used by Kaltenborn *et al*. (2006). The analysis produced a number of various multiple regression models. To achieve normality of the data the dependent variables were Box-Cox transformed. To investigate behaviour toward bats among respondents, only data from individuals from households who reported the presence of bats on their farms (N = 352) were used in analysis. This was because respondents who did not report bats roosting in their farms (42 of them), could not answer this question, since the provided choices in the questionnaire (I. I killed many bats, 2). I killed at least one bat, 3). I destroyed roosts to chase bats away, 4). I did nothing, 5) I contacted responsible officer, were not applicable to them. Ordinal regression was performed to identify variables associated with respondents behaviour towards bats (dependent variable), with independent variables being sex, age, total number of household members, education level attained by each respodent, the last time a bat was seen, distance to each bat roost (caves) and four domains of attitudes as described above. All statistical analysis were made in Statistica (StatsSoft, 2007).

8.3. Results

8.3.1. Socioeconomic characteristics of respondents

A total 394 people were interviewed in the eastern part of the ASF. Their age, household sizes, and distance from the roosts are summarized below (Table 12). Among the 394 respondents there were five different tribes represented. These include Bajuni, Swahili, Taita and Sanya and six sub-tribes of Mijikenda (Giriamas, Durumas, Chonyis, Digos, Kaumas and Rabais). Ninety four percent (371) of respondents were of Giriama sub-tribe, with the rest of the other tribes and Mijikenda sub-tribes represented by very few individuals. Majority of the respondents had attained primary education (66%), followed by high school (19%), 10% uneducated and very few with college or university education.

Table 12. Summary results of respondents' age, household sizes and distances from near and away from roosts (caves).

	Demographic features	Range	Mean
1	Age	8-80 years	27 years. SD = 16.0, N = 394)
2	Household sizes	1-25 people	M=9.0 people, SD = 6.0, N = 394
3	Distance to households near roosts (caves)	100-1000M	644.0M (SD = 194.0, N = 190)
4	Distance to households away from roosts (caves)	3-5km	4189.0M (SD = 504.0, N = 204).

8.3.2. General knowledge about bats by local people around ASF

The main bat roosts reported by majority of respondents included trees (54%) and natural caves (24%). An additional 16% of those interviewed did not know where bats roosted (Fig. 38). Popo is the Swahili name for a bat. The vernacular names given to a bat were Kanundu, Nundu, Ndema, Mpopo and Popo. Seventy one percent of the respondents, of Giriama sub-tribe called bat in their mother tongue Ndema. Other vernacular names used by Giriamas were

Kanundu (18%) and Nundu (10%). The name Ndema mainly was used in reference to big bats, particularly individuals of frugivorous bats, which were not known by the locals to roost in man-made structures. The names Nundu and kanundu were interchangeably used to refer to small bats; especially the insectivorous bats which were known by the local people to sporadically enter into living houses at night.

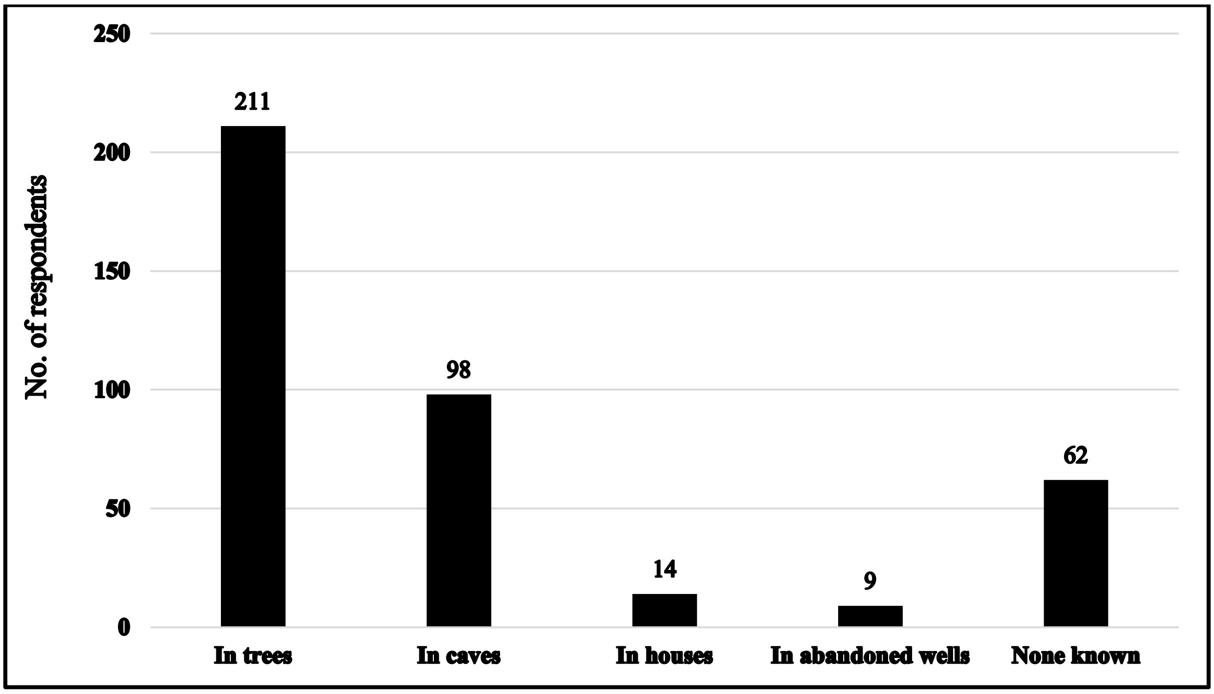

Figure 38. Bat roosting areas reported by respondents around ASF

8.3.3. Traditional myths about bats

A number of negative myths about bats were reported by local people around ASF. Bats were mainly associated with witchcraft and witches, harmed people, and were dirty and a nuisance. Many local people (61%) claimed that bats were agents of fiend, and that magicians could use them to bewitch people, while 25% of the respondents did not know any cultural beliefs associated with bats (Fig. 39). Bats particularly the insectivorous bats (Kanundu/Nundu), were the ones known to be used by the sorcerers to bewitch people. This was assumed to happen when witches sent the bats into people's houses. Respondents reported that even though bats occasionally entered their houses, it was their behaviour inside the houses, which indicated whether they came to harm the family or not. For example, they said that if an insectivorous bat entered a house quietly, flew around inside the house without making any noise and departed, that type of bat was a harmless and a good bat that was a blessing to the household. However, if an insectivorous bat entered into the house frequently, and each time it immediately started making noise, which sounded like Ziz, Ziz, Ziz, Ziz, it was a sign of bad omen, and misfortunes like death in the family could happen thereafter.

Some locals narrated how some members of the local community had died or faced misfortunes, after a bat entered their houses regularly while making noise. Local people also believed that when one opened the stomach of a bat, a young bat was found, which was followed by finding a young bat if the inside of the young bat was opened; and this pattern was reported to replicate itself, in the subsequent opening of the stomach of any next young bat. This implied that countless number of young could be retrieved from any bat if its stomach was opened. Bats were also a nuisance to local people because of their droppings which were scattered on the floor of the houses, when they frequently roosted in the one place inside the house or on trees near houses.

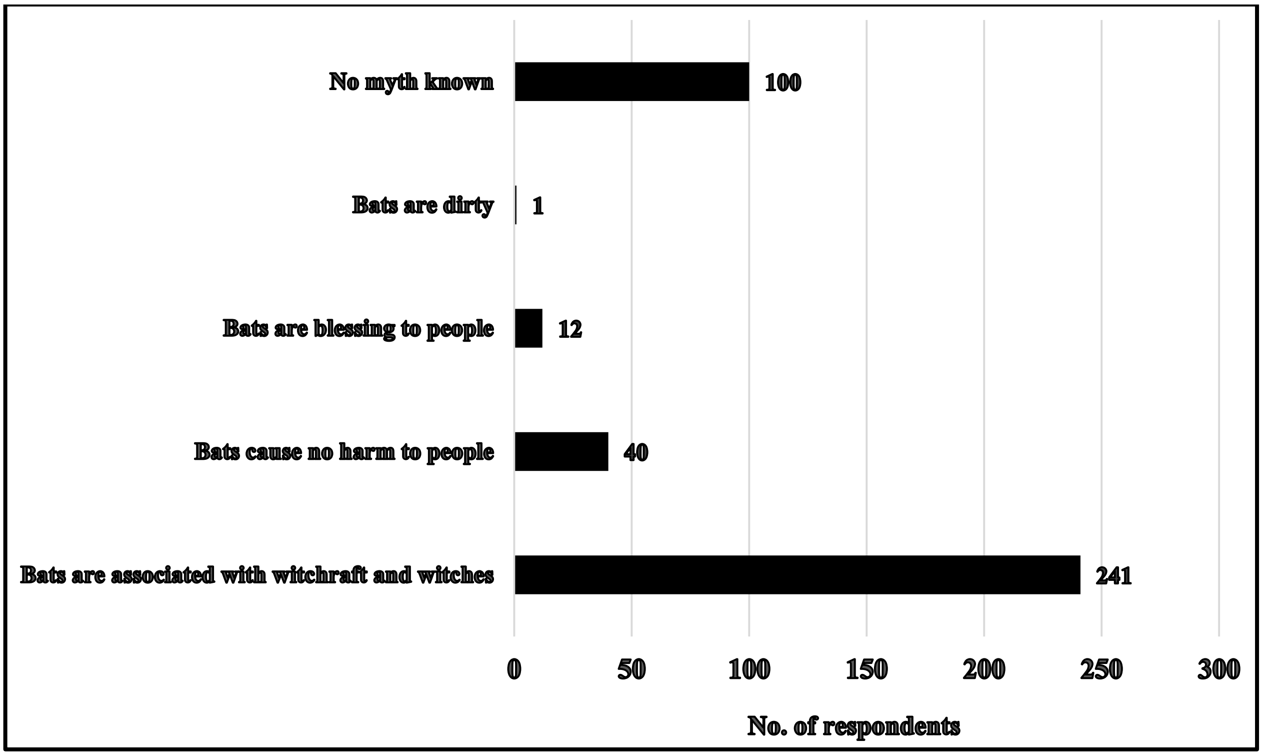

Figure 39. Different types of traditional myths associated with bats by local people around ASF

8.3.4. The value of bats to people around ASF

Bats were reported to be beneficial to local people around ASF in eight different ways (Fig. 40). About 36% of respondents reported that bats had no value to people, while 64% reported that bats were beneficial in different ways. Thirty percent of the respondents stated that bats were valuable, because they brought seeds and fruits to their household farms, while 19 associated bats with seed dispersal to environment. Six percent of the respondents said that bats made fruits drop from trees, while the remaining 9% of the respondents said that bats were beneficial in other six minor ways (Fig. 40).The seeds or fruit fragments reported by local people to be brought to their farms by bats included mangos, cashew nuts, neems, guavas, pawpaws (*Carica papaya*) sugar-apples (*Annona squamosa*) and bananas (*Musa* spp). The main fruit fragments and seeds brought by bats to individual farms were cashew nuts (57%) and guavas (19%). The cashew nut seeds deposited under the trees in the individual farms by bats were collected by children in the morning, roasted in open fires, eaten by them or stored for sale at Gede market, one of the main towns around ASF.

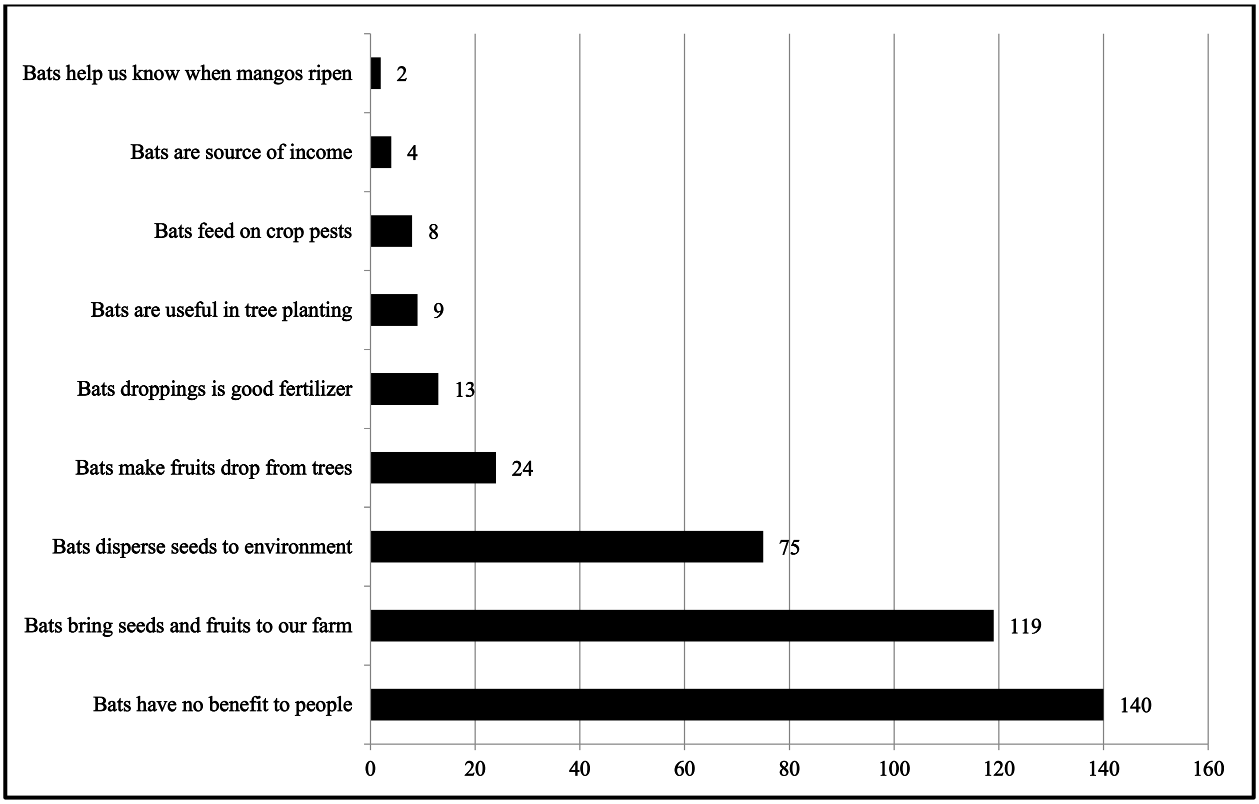

Figure 40. The range of benefits of bats to local people around ASF

Bats were reported as seed dispersing agents because they picked fruits from one tree or farm, and carried it, and ate it from a different tree or farm. In the process of eating the fruit pulp, the incompletely eaten fruits or seeds dropped (Fig. 41) to the ground from the eating perches, where they potentially would germinate and grow into trees. Fruits or seeds of cashew nut were reported by local people to be dispersed by bats overnight, because the local children collected nuts of this tree, under other trees available in their farms, such as mango, neem, coconut or Casuarina. Respondents reported that children even collected cashew nut seeds under other trees, in some farms without a single cashew nut tree. About 5-20 seeds were reported as the number of seeds which could be found scattered on the ground under one tree overnight. The locals also reported that they collected seeds and fruit fragments dropped by foraging bats, from same selected trees, that were used as feeding perches for years. In addition, bats in some natural caves provided some income to a few households, especially when tourists and researchers paid some money to family members before being allowed to explore caves located in their land.

Figure 41. Dispersal of cashew nut by fruit bats around ASF. Cashew nut ripe fruit pulp and nut on the tree ready for harvest (1); *E. wahlbergi* caught in a mist net in farmland around ASF transporting a cashew nut fruit to a feeding perch and (2); Sweet soft fruit pulp of cashew nuts half eaten by foraging fruits bats dropped under trees (3).

8.3.5 Negative effects of bats to local people

There were four main negative effects of bats to people reported by respondents. These were damaging of farmer's fruits, nuisance to people, bats infected people with diseases and carried fruits from one farmer's farm to another. Majority of respondents (66%) associated bats with damaging of fruits cultivated by local farmers (Fig. 42-43), while a few of the respondents (18%) reported bats that did not effects people in anyway. Bats were reported to damage fruits, when they ripped off their skin cover and sucked fluids in them, ate the fruit partially or in other cases the whole fruit was completely eaten (Fig. 43). This made fruits unusable by people for eating or sale as a source of income. The main fruit types reported to be destroyed by bats were mango, cashew nut, guava, pawpaw, sugar apple and bananas. The fruits reported most damaged were mangos (42%), guavas (18%) and cashew nuts (18%). Bat droppings, especially those from roosts near the proximity to households, were implicated in the spreads of diseases to local people which were not disclosed.

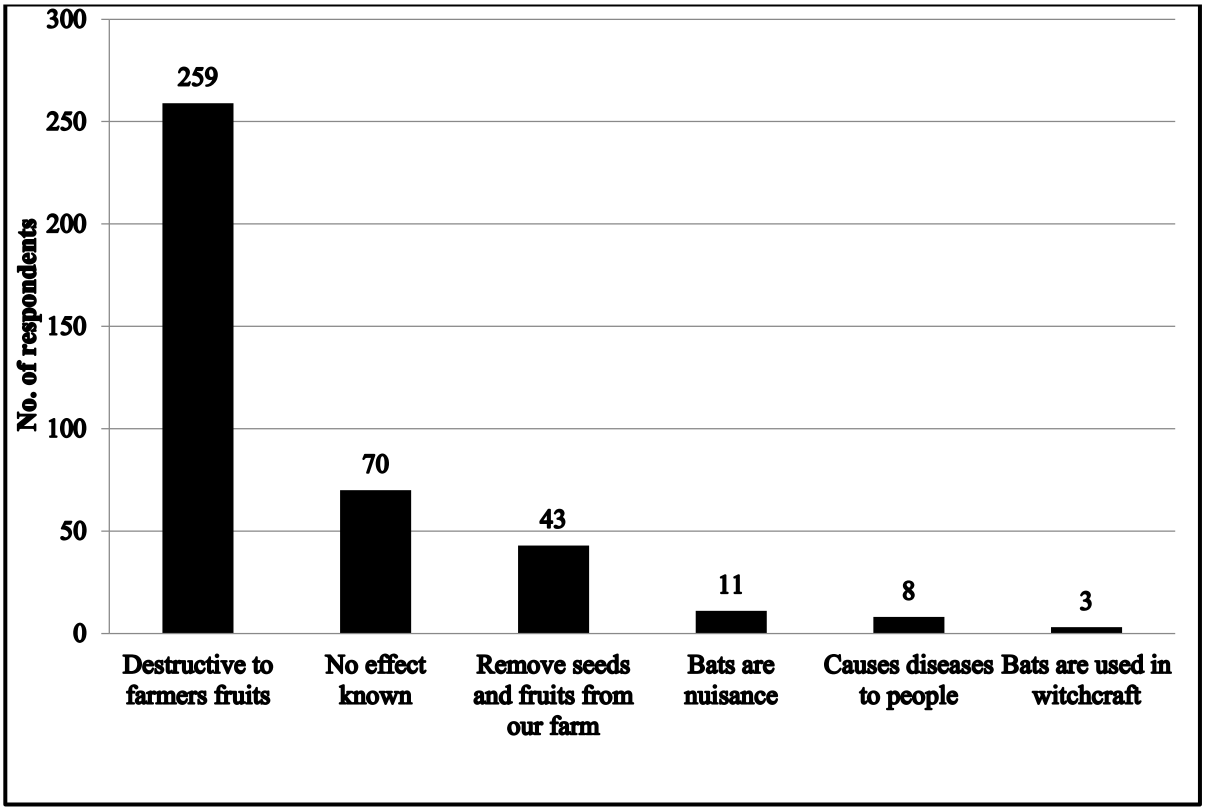

Figure 42. The negative effects of bats to local people around ASF

Figure 43. Damage to mango fruits by bats on farms around ASF, which starts by scratches on the surface of mangoes to open the yellow pulp which is the main food of these bats.

8.3.6 Attitudes towards bats among local people around ASF

Attitudes on scientistic domain

The mean value of the interest in biology of bats (scientistic domain) was 3.92 (SE = 0.03), meaning that in this domain the respondents manifested a positive attitude towards bats. The multiple regression model was significant ($R^2 = 0.06$, $F(5,387) = 4.9$ $p < 0.001$, Table 13). Of the five variables which were entered into the regression model, only three were significantly associated with scientistic attitudes. Households with many people held more positive attitude about bats than those those with few members. In addition, local people with higher levels of education held more positive scientistic attitude about bats than those who were illiterate. People who reported encounters with bats within seven days held more more positive scientistic attitudes toward bats. Even though data on the presence of bats on individual farms and sex differences contributed to the regresseion model, their contributions were insignificant.

Table 13. The results of multiple regression on the scientistic domain. The distance to bat roosts and age of the respondents were removed from the regression model (N=394)

	B	SE of β	t	*P*
Intercept			0.41	0.68
Day bat/s last seen	0.11	0.05	2.18	0.03*
Level of education	0.12	0.05	2.36	0.02*
No. of household members	0.1	0.05	1.99	0.05*
Bats presence in the farm	-0.07	0.05	-1.50	0.13NS
Gender	0.07	0.05	1.46	0.14NS

Legend: * significant, NS-not significant

Attitudes on negativistic domain

The mean value of the negativistic (fear, avoidance and dislike of bats) domain was 3.07 (SE = 0.03), meaning than in this domain many respondents held neutral attitudes rather than extremely positive (mean value ≥ 4; 3.8 % of respondents) or extremely negative attitudes (mean value ≤ 2; 1.8 % of respondents). Multiple regression analysis resulted in a significant model (R^2 = 0.08, F (5,387) = 7.2 $p < 0.0001$, Table 14). The elderly people held more positive attitudes toward bats than youths. In addition the female respondents held more negative attitudes to bats than males. Although the number of individuals in households and encounter with bats contributed to the regreession model the variables did not significantly influence the negative attitudes toward bats.

Table 14. The results of multiple regression on the negativistic domain. The distance to bat roosts and levels of education of the respondents were removed from the regression model (N = 394).

	β	SE of β	t	*P*
Intercept			3.14	0.00
Age	-0.21	0.05	-4.18	0.00*
Gender	-0.18	0.05	-3.50	0.00*
No of people in household	0.07	0.05	1.39	0.17NS
Bat lastly seen	-0.07	0.05	-1.33	0.18NS

Legend: * significant, NS-not significant

Attitudes on ecologistic domain

The mean value of the ecologistic (concern for the role of bats in nature) domain was 3.52 (SE = 0.03), meaning that in this domain the local people manifested slightly positive attitudes toward bats. The model on ecologistic domain was significant (R^2 = 0.1, F (4,388) = 14.131 $p < 0.0001$, Table 15). The old and highly educated people around ASF had more positive ecologistic attitudes towards bats. Although gender differences of the respondents, as well as encounters with bats contributed to the model, their results was a non-significant association with ecologistic attitudes.

Table 15. Results of multiple regression on the ecologistic domain. The number of individuals in household, distance to bat roosts as well as the presence of bats in the farms were removed from the regression model (N = 394).

	β	SE of β	t	*P*
Intercept			-1.27	0.21
Age	0.34	0.05	6.86	0.00*
Education level	0.15	0.05	3.07	0.00*
Bat lastly seen	0.07	0.05	1.47	0.14NS
Gender	0.06	0.05	1.25	0.21NS

Legend: * significant, NS-not significant

Attitudes on myths domain

The mean value of the myths (acceptance of traditional beliefs) domain was 2.83 (SE = 0.03). This means that some few respondents believed in myths (mean value ≥ 4; 2.5% of respondents compared with 10% of respondents with a mean value ≤ 2). The model for the myths domain was significant ($R^2 = 0.10$, $F(5,387) = 9.0$, $p < 0.0001$, Table 16). The female respondents held more belifes in traditional forklores about bats than males. Furthermore, more literate and the elderly people had few untrue beliefs about bats. The respondents living nearer to bat roosts held more myths about about bats than those living away, even though this association was only marginally significant.

Table 16. Results of multiple regression on the myths domain. The number of individuals in a household, the last time bats were observed and as well as presence of bat in farms were removed from the regression model (N = 394).

	β	SE of β	t	*P*
Intercept			3.86	0.00
Gender	-0.24	0.07	-3.48	0.00*
Education level	-0.31	0.07	-4.37	0.00*
Age	-0.14	0.07	-2.04	0.04*
Cave distance	0.12	0.07	1.78	0.08NS

Legend: * significant, NS-not significant

Behaviour of individuals towards bats in their farms

Majority of respondents (73%) had sighted individuals of bats in the last two days (Fig. 44). The mean score was 3.58 (SE=0.04). Few number of respondents (11%) killed many individuals of bats or at least one when they occured in their farms. About 18% of the respondents destroyed areas where bats roosted, so as to drive them away. Many respondents (70 %) did not do anything to bats which occurred in their farms. Very few of people interviewed (1%) contacted responsible officers about the presence of bats in their farms. The males manifested very hostile behavior to bats than females (estimate = 1.21, $p < 0.0001$). Recent encounters with bats by individuals interviewed were associated with positive behavior towards bats (estimate = -0.75, $p = 0.02$). The associations between age of individual respondents, number of individuals in households, education level and behavior towards bats were not significant (all $p > 0.05$).

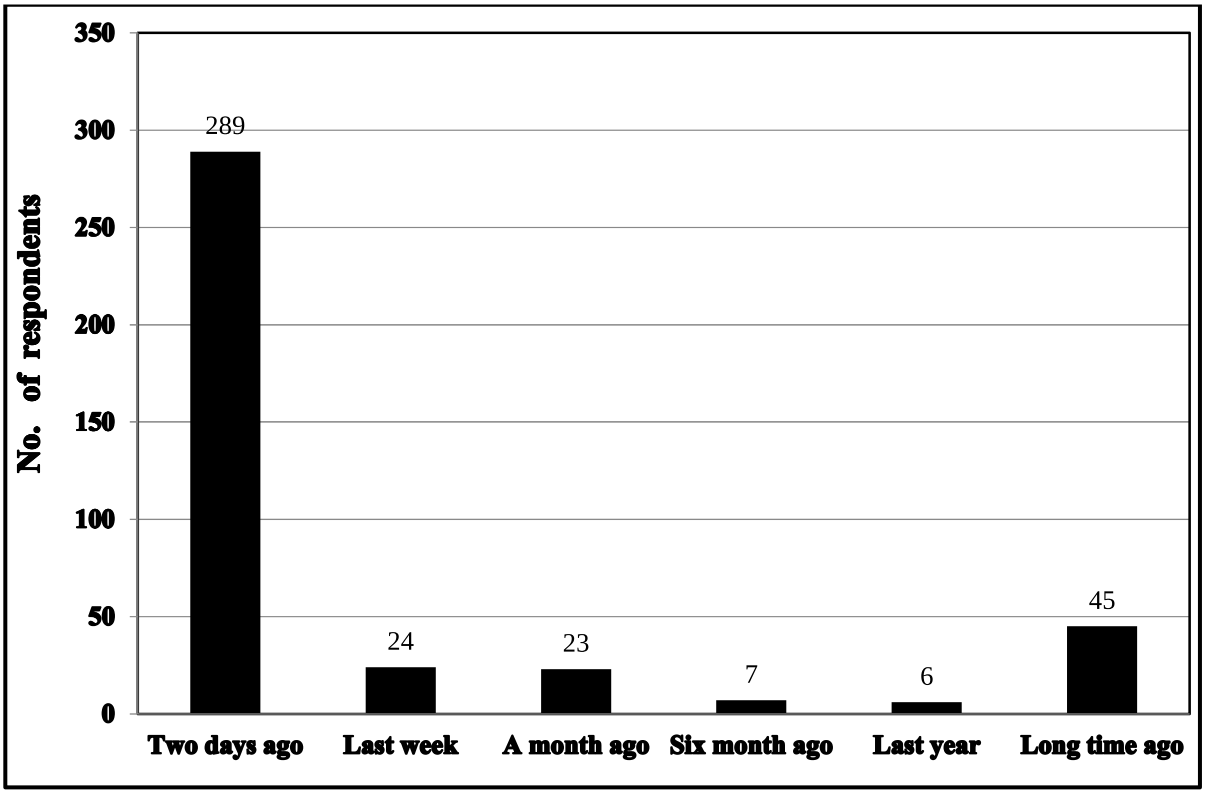

Figure 44: The number of respondents around ASF who saw a bat at different times

8.4 Discussion

This study investigated perceptions, knowledge and attitudes about bats by local people who live around ASF. This forest is of special concern because around it there are some limestone coral bat roosts (caves) in the farmland, which are actively used by bats for roosting. Many people living around ASF had observed individuals of bats in the environment in the last two days, probably suggesting that bats were very common around ASF, and people interacted with them frequently. Bats also occurred in man-made structures in close proximity to people, almost with daily interactions with them. Hence, how people reacted towards bats they encountered, may determine whether they survive in the long run or not.

The fear generated due to encounter with events or even animals, like bats, most of the time generates numerous mythologies that are more or less appreciated by affected people (Prokop and Kubiatko, 2014). The current study confirmed this observation, because many respondents (61 %) claimed that bats were agents of the evil spirits, which could potentially be used by witches to inflict harm to people. Most encounters with individuals of bats and detections are generally at a distance and transitory (Sexton and Stewart 2007). Furthermore, most of the close encounters with bats takes place in a negative or dreadful setting, such as sources of annoyance in human dwellings (Voigt *et al*., 2016). The brief encounters and limited understanding about bats, may be the reason many people around ASF viewed them negatively. Beliefs of untrue folklores are predominantly hostile, because they can lead to development of negative attitudes among people (Alves *et al*., 2014), and also sometimes fuel deliberate killing of animals (Dickman, 2010). Indeed, beliefs of untrue legends in current research were pointedly associated with deliberate harassments of individual bats, as well as destruction of their roosts.

The more information one has about a subject, as well as advanced levels of learning influences the development of a positive attitudes towards animals by humans (Røskaft *et al*., 2003), and enhances wildlife species conservation efforts (Kideghesho *et al*., 2007). In particular, local people with advanced education in this study had more encouraging scientistic and ecologistic attitudes towards bats. In Kenya, learners are exposed to the studies about the environment for about 12 years, from primary to secondary school. This probably, improves their understanding and appreciation about plants and animals' interrelationships, and thus improves their perception about wildlife. The age of an individual is also possibly associated with better knowledge (Randler *et al*., 2007), and thus, the elderly around ASF had more positive attitudes about bats. The old persons have interacted with natural world for a lengthier period of time than young people. Consequently, some of the untrue folklores or misrepresentation about bats learned by the old people in their infancy, may have been invalidated by their extensive period of exposure to bats in their long life. Thus, the initial negative attitudes, which the elderly respondents had acquired when they were young may have been improved to a positive acceptance of bats with passing of age. For instance, the elderly in Portugal had less negative attitudes towards frogs and reptiles, as compared to youths (Ceríaco, 2012).

The respondents who lived near caves actively used by bats, had more myths about bats. This may have arisen from frequent interaction with bats, as they emerged from the caves to forage in the evening or during their return to caves to roost at dawn. Females had more negative attitudes and believed more false folklores about bats than males. However, males had more hostile behaviour towards bats than females. Some studies have shown that females habitually harbour more negative attitudes toward, ostracised wild animals and carnivores compared to males (Almeida *et al*., 2014). These sex differences in their reaction to detested animals, probably arises from stronger evasion to carnivorous animals (Røskaft *et al*., 2003) and infection cues (Prokop *et al*., 2010), since females are more susceptible to attacks (Treves and Naughon-Treves, 1999) and innately want to defend their offsprings from pathogens (Prokop and Fančovičová, 2016). Furthermore, males habitually perpetrate harm and persecution to animal than females (Pagani *et al*., 2007), which might explain the reason males in this study were more intolerant to bats.

Less than half of the people interviewed (36%) did not see any value of bats to human or by extension to the improvement of their environment. Furthermore, a substantial (66%) number of the respondents implicated bats with the damage of fruits cultivated by farmers. Nevertheless, although the locals reported that bats damaged their fruits, the quantities lost by bats compared to that used by local people may be marginal but highly overestimated. Individuals of *R. aegyptiacus*, an abundant frugivorous bat around ASF, forages on numerous fruits cultivated by farmers, and is labelled as a crop pest in some regions, but its impact on the overall crop harvest has been generally overrated (Korine *et al*., 1999). In Israel and Cyprus for example, conflict with farmers has led to the implementation of control measures, which have drastically reduced the population size of this species (Hadjisterkotis, 2006).Therefore, it would also be important to assess the quantities of fruits lost to bats around ASF, so as to consider possibilities of implementing appropriate methods of controlling bat losses.

About 64% of respondents around ASF reported that bats were valuable to people, because they supported essential ecosystem service of dispersing the seeds of cashew nuts and guavas to their farms. In order to encourage local people to be tolerant to bat existences in the study area, it would be important to emphasize the value of bats in bringing cashew nut seeds into their farms. Cashew nut nuts were very valuable around ASF, because they were consumed by local people. Furthermore, it would be important to quantify the amount of the seeds of cashew nuts dispersed by frugivorous bats in the study area, in order to evaluate the financial influence of the frugivorous bats to welfare of local people around ASF.

In conclusion, majority of the people living around ASF manifested impartial or marginally positive attitudes towards bats. More educated and older people had positive scientistic and ecologistic attitudes toward bats. Efforts to decrease the numerous conservation threats to bats eventually hinge on altering peoples' behaviour (Clayton and Myers, 2015). However, bat knowledge is commonly low (Sheherazade and Tsang, 2015) and is associated with low attitudes toward bats (Prokop *et al*., 2009). Hence, there is need to increase bat conservation awareness around ASF, among population segments who are currently unappreciative of bats existence, especially by targeting youths. This is because, when adult conservationists are queried about the source of their obligation to defend the natural world, they recurrently recount positive familiarities with environment in their childhood (Wells and Lekies, 2006). This can be done by conducting bat awareness in boarding schools and colleges around ASF in the evening (1600pm-0900pm), by catching bats using mist-nets, displaying them to learners, and responding to queries raised by students and elucidating the details of ecology and biology of bats. These awareness sessions would help to demystify the lives of bats and their relationship with people, and probably change the negative attitudes the youths have about bats.

CHAPTER NINE: SUMMARY OF FINDINGS, GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

9.1 Summary of findings

This study investigated factors which influenced bat community structure and their activity in ASF and adjacent farmland, as well as bat-human interactions around this forest. The summary of findings of each chapter are as follows: in chapter four; Bat diversity and abundance in ASF and farmland, were investigated in order to document distribution of bat species in both habitats. The farmland was richer (25) in bat species richness than ASF (19), but the forest interior had higher bat diversity (H'= 1.48 ± 0.2) than the farmland (1.33 ± 0.1). Bats were also more abundant in the farmland (4327) than in ASF (890). Of the 14 roosts actively used by bats, 13 occurred in the farmland.

In chapter five, bat activity in ASF and adjacent farmland were investigated by use of mist-net captures and acoustics methods, to understand the patterns of bat activity and their use of both habitats. The farmland had a higher activity (425.3 ± 95.1, N=10) of captured bats per hour than the forest interior (88.4 ± 11.2, N=10). For insectivorous bats, a total of 14,727 bat echolocation calls (passes) were counted including 10,552 in the farmland and 4,175 in ASF. The farmland had a higher activity of insectivorous bats per night (152.9 ± 13.2) than in ASF (60.5 ± 4.6). The activity pattern of mist-nets and acoustic monitored bats, peaked after sunset (1900-2000hr), plunged to lowest level past midnight (0100hr-0200hrs), then slightly increased at dawn (0400hr-0500hr).

In chapter six, solar powered light traps were used to investigate invertebrate prey abundance in ASF and adjacent farmland, in order to understand their availability and accessibility to foraging insectivorous bats found in both habitats. Of 6,557 individuals of invertebrate prey captured: 52% occurred in the farmland and 48% in ASF. Although the farmland had slightly higher abundance (260.5 ± 52.9, N=12) of invertebrate prey, than the ASF (200.3 ± 36.4, N=12), there was no significant difference in the abundance of prey between the two sites.

In Chapter seven, Point-Centred Quarter method was used to describe the habitat structure and fruit trees resources in ASF and the farmland, and its roles in influencing the distribution and abundance of bats in both study sites. The farmland was dominated by orchard of actively cultivated exotic trees (coconut (54%), mango (31%) and cashew nut (11%), while the forest was dominated by indigenous trees (*B. spiciformis* (30%), *C. webberi* (29%) and *M. sansibarensis* (18%). The farmland had the largest number of fruit trees (385) producing large fruits that are eaten by foraging frugivorous bats, while the forest had 166 native trees which produces small sized fruits. The farmland had larger trees (mean DBH 50.9cm ± 1.3) than those in ASF (39.4cm ± 0.8). The percentage canopy and understory cover of the interior of ASF interior was more closed than that of the farmland.

In chapter eight, knowledge, attitudes and perceptions towards bats by local people living in the eastern part of ASF were investigated using structured questionnaires. The purpose of this investigation was to understand how people's actions could affect the survival of bats in the study arean in the long run. The elderly and people with advanced education, had more positive attitudes towards bats than the young and uneducated people. Females had more negative attitudes towards and believed more to untrue folklores about bats than males, while males manifested a more antagonistic behaviour towards bats than females. About one-third of respondents aggressively killed individuals of bats or damaged their roosts; and a comparable number also reported that bats had no value to people. Although the locals recounted that bats were valuable in the dispersal of cashew nut seeds, majority of them also associated bats with the damage of mangos and cashew nuts fruits cultivated by the farmers.

9.2 General discussion

In this study, farmland around ASF had more bat species than the forest interior. In addition, bats were more abundant in the farmland than in the interior of ASF. The responses of bat species to habitat disturbance is unclear: abundances of some species may increase, decrease, or remain unaffected (Aguirre *et al*., 2003; Willig *et al*., 2007). The findings of this study are consistent with Heer *et al*. (2015), who found high diversity of bats in intensively used rubber-cacao plantation in Brazil despite the shortage of resources for bats. In addition, highly degraded forests that had been logged many times in Borneo had little effects on bat species richness (Struebig *et al*., 2013). However, the results of the current study contrasts those of Webala *et al*. (2019b), who recorded low bat species richness and abundance at Malava forests, which was more disturbed, than in the interior of less disturbed and well conserved Buyangu forest fragment of Kakamega forest. However, due to the use of ground level mist-nets, and the ability of echolocating bats to detect the presence of these nets and avoid them (Kunz and Kurta, 1988; Murray *et al*., 1999; Ratcliffe *et al*., 2005), the forest interior bat assemblage may have been undersampled.

The activity of insectivorous and mist-netted bats (insectivorous and fruits bats) was higher in the farmland than in the interior of the forest (ASF). This suggests that the farmland was highly used by bats for either flying or foraging. In Los Tuxtlas, in south-eastern Veracruz, Mexico, Estrada *et al*. (2004), recorded a higher bat activity in agricultural and human settled areas than in interior of continuous forest in tropical rain forest habitats in this area. These differences in bats assemblage and their activity patterns between the forest and the adjacent farmland were possibly as a result of the marked differences in habitat structure and availability of important resources (e.g. roosts, and fruit producing trees abundance, accessibility to insectivorous prey) used by bats. A total of 13 active bat roosts were found in the farmland. The availability of roosts in the farmland may also have contributed to higher species richness and abundance in the farmland. Many of these roosts harbored large large bat colonies of multi-species (e.g. Alibaba cave >million bats). The simulatenous flight of these bats from their roosts at nightfall might have increased their capture rates and activity in the farmland landscape.

The vegetation structure between adjacent farmland and forest interior was strickingly different from each other. The percentage canopy and understory vegetation cover inside the forest was more closed than that of the adjacent farmland. Thus individuals of bats had less access to the forest floor, than the forest canopy. On the other hand the farmland landscape was more open, and potentially provided many unhindered foraging and flying spaces. Vegetation thickness (clutter) at ground level strongly influences bats abundance and species composition (Marciente *et al*., 2015). It can also make foraging more complicated and increase the energetic coast of flight (Aldridge and Rautenbach, 1987). This may explain the low abundance and activity of bats inside ASF as opposed to the farmland. In addition, the farmland had the largest number of trees producing fruits with soft pulp that are eaten by frugivorous bats than the forest. The availability of food influences the distribution and abundance of bats (Bernard and Fenton, 2003). The large numbers of fruit producing trees (mangos, cashew nuts, neem) in the farmland, is the most reasonable explanation for the numerous number of frugivorous bats that were found in this habitat. Frugivorous bats are directly reliant on the geographical distribution of fruit producing plant species (Marciente *et al*., 2015). Furthermore, farmland landscape around ASF, was not bare but had many actively cultivated trees which provided suitable foraging and roosting habitat for the bats. The biodiversity found in agricultural areas is critically enriched by the existence of trees (Fischer *et al*., 2010). For example, foraging activity of bats is often higher near trees in open areas and along the edges (Lumsden and Bennet, 2005).

Although the farmland had more insectivorous bat species (20 in farmland, 16 in ASF) and in higher abundance (930 in farmland, 157 in ASF), the two habitats had similar invertebrate prey abundance. Studies on effects of habitat disturbance on invertebrate abundance generate mixed results in different types of habitat; in some resulting into decline, or no negative effect at all. This study is consistent with the findings of Hovorka (1996) in southern Arizona, who found cattle overgrazing on the vegetation, had no effects on the abundance of flying insects. However, invertebrate densities tend to be high in cluttered habitats (Kalcounis and Brigham (1995), and forest disturbance affects the composition of invertebrates (Bank *et al*., 2010). Nonetheless, in a cluttered habitat like in the interior of ASF, although invertebrates may be abundant, it is difficult for insectivorous bats to identify and capture them (Rainho *et al*., 2010; Müller *et al*., 2012), possibly the reason there was higher insectivorous bat activity in the farmland, which was more open, and may have facilitated foraging activity of bats.

The elderly and more educated people around ASF had more positive attitudes toward bats than young and unschooled people. Studies have shown than educated people manifest more positive attitudes toward animals (Kellert, 1980), and are likely to participate in conservation efforts to save wildlife species (Kidegesho *et al*., 2007). The females around the study area had more negative attitudes toward and more beliefs to cultural myths about bats than males, while males showed more aggressive behaviour toward bats than females. The findings of the current study are consisted with findings of Almeida *et al*. (2014), in Portugal who found that female children had more negative attitudes toward animals than males. Some studies have frequently shown that males are the main perpetrators of animal abuse than females (Flynn, 1999; Pagani *et al*., 2007). To change the attitudes toward bats among youths; illiterate, females and male segment of population around ASF, there is need for sustained bat education awareness. Even though, changing human behaviour is difficult (Zint *et al*., 2002), and wildlife education awareness need to be undertaken for a long period of time, Bogner (1998) reported that even a short out-door learning experience can have a positive influence on the future environmental attitude of children.

9.3 Conclusion

Results of bat diversity study showed that; the farmland was richer in bat species richess than the interior of ASF. In addition, fruit and insectivorous bats were more common in the farmland than in the ASF. Thus, the finding of this section of study resulted in rejection of the null hypothesis initially stated as; the interior of ASF and farmland would have the same bat species richness, because bats are highly mobile.

Results of bat activity study showed that; activity of mist-nettted and accoustic monitored bats was higher in the farmland than in the interior of ASF. Bats were more active immediately after nightfall, activity declined to lowest between 1.00-2.00am, followed by a slight increase at dawn (4.00-5.00am). This pattern of activity was the same in the interior of ASF and in the farmland. These findings resulted in acceptance of null hypothesis of this section of the study stated as; the farmland and interior of ASF would have the same pattern of bat activity.

Results of habitat structure and fruit trees resources showed that; the interior of ASF was dominated by indigenous trees typical of the coastal forest, while the farmland was covered in actively cultivated exotic trees. Many trees producing fruits which are eaten by fruit bats occurred in the farmland (385) than in the ASF (166). The understorey and canopy cover was higher in ASF than in the farmland. These differences in habitat structure and fruit tree producing plants influenced the abundance of bat species in ASF (19 spp, and 890 bat captures) and in the farmland (25 spp, and 4327 bat captures). These findings resulted in the rejection of the null hypothesis of this section of the study stated as; highly cluttered habitats and those with higher abundance of fruit trees resources would have similar bat species diversity and abundance.

Results of insectivorous bats prey abundance study showed that; prey abundance was the same in both in ASF (3168 invertebrates) and in the farmland (3381). These results, supported the stated null hypothesis of this section of the study.

Results of human-bat interactions study around ASF showed that; the aged had more positive attitudes toward bats than young people. In addition the females held more negative attitudes to bats than males. These findings resulted in the rejection of the null hypothesis of this section of the study initially stated as; there are would be no differences in the attitudes and perceptions about bats between gender and age groups of local people in the study area.

To conclude, although the farmland habitat around ASF was highly degraded than the well protected forest, it was still heavily used by bats, which emphasises the value of this ignored habitat in biodiversity surveys for conservation of bats, especially in the study area. Thus, there is a need to work with local people around ASF, to encourage them to maintain the current habitat conditions of their cultivated farms, in order for them to continue to support bat populations in the long run. The local people around ASF had negative attitudes towards bats and their roosts. This can be mitigated by enhancing bat conservation education among local people around ASF.

9.4 Recommendations

Further study

Further research is recommended in the following areas with a view to increasing our understanding of bat biodiversity in and around ASF;

1. *Mapping of echolocation calls of insectivorous bat species*: the current study used Patterson heterodyne D240 detector to monitor bat activity, but it was not possible to identify the call to species. Therefore, there is a need to map the calls of the insectivorous bat species using a either Pettersson D500x or SM4BAT bat detectors, which allows for identification of bats using calls, and also would improve our understanding of which bat species uses which habitat type.

2. *Movement ecology of bat*s: There is need to attach transmitters to some insectivorous and fruit bat species in the study area. This would improve our understanding about foraging areas and range of some species, whether they switch roosts at night, and types of roosts they use habitually.

3. *Seed dispersal and assessment of damage of cultivated fruits by fruit bats*: About 57 % of 394 respondents reported that fruits bats in the study area were useful in dispersals of cashew nuts and guava seeds. Moreover, 66% of the people interviewed associated frugivorous bats in the damage of fruits cultivated by farmer. A follow-up study is required to assess the diversity of seeds dispersed, their quantities, and by which bats, as well as quantify the amount of mangos damaged by fruit bats compared to that harvested and eaten locally or sold by landowners.

4. *Monitor population trends of fruit bats*: There was high fluctuation in seasonal abundance of fruit bats in each month surveyed, with farmland having high abundance throughout the sampling period than the forest interior. The factors driving these fluctuations were unclear but are suspected to be influenced by either local fruit abundance or local migration. There is need to monitor population fluctuations of fruit bats around ASF and investigate factors which influence their population turnover annually.

Conservation actions

The following recommendations to enhance the conservation of habitat and species would ensure that bats are able to survive in and around ASF in the long run;

1. *Establish a functioning coconut, mango and cashew nut trees sales and value chain*: The farmland around ASF were dominated by mango, cashew nut and coconut trees which were the main sources of income and food to owners. The farmers depended on middle men, who exploited them with low prices, since there was no organised marketing chain dealing with the buying and sale of these fruits. As results many fruit trees were not properly taken care of; were growing in fallow land infested with weeds, some were aging and others were in the process of slow death in other farms, supposedly due to the minimal economic benefits derived from the trees. Failure to establish an organized functioning fruits sale and value chain may eventually lead to loss of many cultivated trees or lack of interests to cultivate new trees, which will be a loss of essential habitat which sustain large population and species of bats around ASF.

2. *Enhance bat conservation awareness and protection of bat roosts*: The eastern part of ASF had many bat roosts, especially the large coral limestone caves which had multiple bat species. However, these roosts occurred in private land and were highly

prone to destruction. Thus, there is need to work with the local land owners, and local wildlife conservation organizations like AROCHA Kenya and Kenya Wildlife Service to manage these roosts, and promote their protection by local people nd the government. More awareness is also required especially to illiterate, adult males, youths and females in order to improve their understanding about the value of bats to the environment, in order reduce their fear toward them which fuel persecution of these animals.

Management and policy actions

To enhance the long term conservation of bats in Kenya, and improve the livelihood of communities around ASF and coastal areas in generals the following policy managements actions are recommended;

1. *Develop policy to map, protect and conserve bat roosts*: Kenya has a large network of wildlife conservation areas, but none of these areas was set aside principally to conserve bats biodiversity. Many bat roosts (caves) that occur outside the protected host large assemblages of bat species, yet they are not protected by law. Therefore, there is need to develop policy guidelines on bats conservation in Kenya, by first mapping roosts, their conservation status and implementation of active management strategy. This will help save the currently remaining bat caves, as well as ensure that they will not be converted to other land uses which are incompatible to bat conservation.

2. *Develop policy to enhance the farming of coconut, mango and cashew trees*: Like coffee and tea in central and western Kenya, coconut, mango and cashew trees are cash crops, which if well managed can improve the economic status of coastal people in

Kenya. However, there is need for a government policy framework as well as an injection of capital to enhance the production and sale of these fruit tree crops. This policy would improve the income of local farmers, and planting of new trees and improved care of the existing trees. The existence of these trees in the farmland, would continue to provide vegetation cover for bat roosts as well as fruit resources to frugivorous bats.

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APPINDICES

Appendix 1. Voucher specimens of different bat species collected at ASF and in farmland and deposited with Mammalogy Section lab-National Museums of Kenya (NMK).

NO.	GENUS	NMK CAT. NO.	LOCATION	DATE	SEX	AGE	FOREARM	WEIGHT	EAR
1	*Pipistrellus rueppellii*	191002	Arabuko Sokoke Forest	21/11/2014	F	Adult	30	5	
	Pipistrellus rueppellii	190985	Arabuko Sokoke Forest	21/11/2014	M	Adult	30	4	
	Pipistrellus rueppellii	190961	Arabuko Sokoke Forest	11/02/2014	F	Adult	30	5.5	
2	*Nycteris thebaica*	190982	Arabuko Sokoke Forest	11/04/2015	M	Adult	50	12	
	Nycteris thebaica	190938	Arabuko Sokoke Forest	26/11/2014	M	Adult	44	8	
	Nycteris thebaica	191086	Arabuko Sokoke Forest	03/03/2014			43.4	7.5	
3	*Rousettus aegyptiacus*	191046	Arabuko Sokoke Forest	29/11/2014			100		
	Rousettus aegyptiacus	191051	Arabuko Sokoke Forest	29/11/2014			95		
4	*Scotoecus hirundo*	190980	Arabuko Sokoke Forest	03/06/2014			33.6	9	
	Scotoecus hirundo	190971	Arabuko Sokoke Forest	13/04/2014	M	Adult	37		
5	*Macronycteris vittata*	191045	Nguwas Farm Gede	11/12/2016	M	Adult	101	96	
	Macronycteris vittata	191060	Nguwas Farm Gede	11/12/2016	F	Adult	89	55	
	Macronycteris vittata	191087	Arabuko Sokoke Forest	03/06/2014	F	Adult	86	62	
6	*Epomophorus wahlbergi*	191003	Arabuko Sokoke Forest	03/03/2014	F	Adult	72		
	Epomophorus wahlbergi	191939	Arabuko Sokoke Forest	03/03/2014	F	Adult	72.5		
	Epomophorus wahlbergi	191026	Arabuko Sokoke Forest	12/03/2014	F	Adult	72		
7	*Scotophilus trujilloi*	191000	Arabuko Sokoke Forest	11/02/2014	F	Adult	55	27	
	Scotophilus trujilloi	191091	Arabuko Sokoke Forest	12/09/2014	M	Adult	54	29	
8	*Rhinolophus deckenii*	190986	Arabuko Sokoke Forest	03/04/2014	F	Adult	54	21	
	Rhinolophus deckenii	191089	Arabuko Sokoke Forest	28/11/2014			57	19.5	
	Rhinolophus deckenii	191083	Arabuko Sokoke Forest	11/02/2015	F	Adult	53	17	
9	*Nycticeinops schlieffeni*	190945	Arabuko Sokoke Forest	11/02/2015	F	Adult	34	6	
10	*Miniopterus minor*	191052	Kaboga Cave Gede	11/12/2016	F	Adult	40	6.5	9
	Miniopterus minor	191044	Kaboga Cave Gede	11/12/2016	M	Adult	40	7	9
11	*Miniopterus cf inflatus*	191056	Kaboga Cave Gede	11/12/2016	F	Adult	41	6.5	9
12	*Coleura afra*	191071	Kaboga Cave Gede	11/12/2016	F	Adult	53	12	12
	Coleura afra	191074	Kaboga Cave Gede	11/12/2016		Adult	49	11	14
13	*Neoromicia rendalli*	190978	Mangrove edge	18/11/2015			34	6	
14	*Hipposideros caffer*	190954	Arabuko Sokoke Forest	12/03/2014	F	Adult	53		
	Hipposideros caffer	190962	Alibaba Cave Gede	03/05/2013	M	Adult	47.9		
	Hipposideros caffer	191085	Arabuko Sokoke Forest	12/03/2014	M	Adult	54		
15	*Chaerephon pumilus*	191034	Arabuko Sokoke Forest	11/02/2015	F	Adult	53	22	
	Chaerephon pumilus	190970	Arabuko Sokoke Forest	12/09/2014	M	Adult	39	10	
16	*Cardioderma cor*	191053	Arabuko Sokoke Forest	11/02/2015	M	Adult	54	26	
17	*Taphozous mauritianus*	190981	Arabuko Sokoke Forest	12/08/2014	M	Adult	61	25	
18	*Neoromicia nana*	191009	Arabuko Sokoke Forest	22/11/2014			30		30
	Neoromicia nana	190996	Arabuko Sokoke Forest	03/03/2014	M	Adult	26		3.5
19	*Neoromicia capensis*	190973	Arabuko Sokoke Forest	27/11/2014		Adult	34	8	
	Neoromicia capensis	190958	Arabuko Sokoke Forest	01/02/2014	F	Adult	33	11	
20	*Triaenops afer*	191041	Alikiba Cave Gede	03/04/2014		Adult	86.1	65	
	Triaenops afer	190953	Alikiba Cave Gede	03/05/2014	M	Adult	50.6		
21	*Mimetillus moloneyi*	191070	Arabuko Sokoke Forest	15/02/2015	M	Adult	30	10	
	Mimetillus moloneyi	190984	Arabuko Sokoke Forest	15/02/2015	M	Adult	30	8	

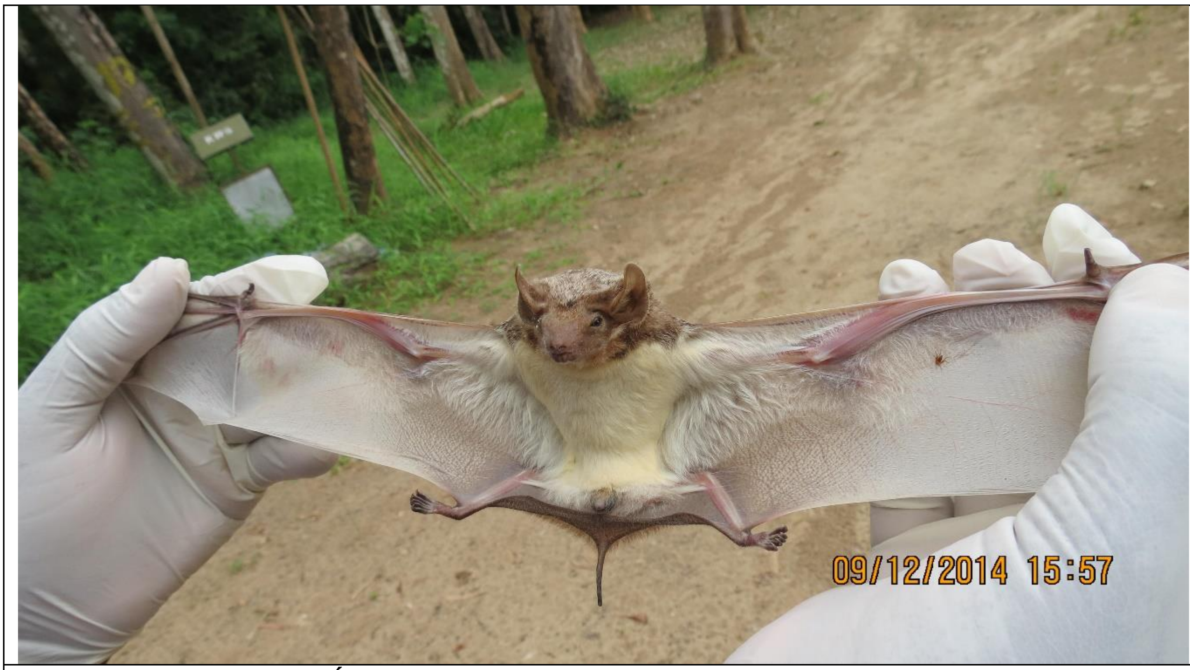
NOTE- Vouchers of *Neoromicia tenuipinnis, Otomops harrisoni* and *Eidolon helvum* were not collected

Appendix 2. Some species bat photos recorded in the farmland and the interior of ASF

Triaenops afer Dobson, 1871. African Trident Bat captured in the farmland and ASF

Coleura afra (Peters, 1852) African Sheath-tailed bat captured in the farmland and ASF

Macronycteris vittata (Peters, 1852) Striped Leaf-nosed Bat captured in the farmland and ASF



Taphozous mauritianus É. Geoffroy, 1818 Mauritian Tomb Bat captured in the farmland and ASF

Nycteris thebaica É. Geoffroy, 1818 Egyptian Slit-faced Bat captured in the farmland and ASF

Scotophilus trujilloi Brooks and Bickham, 2014 Trujillo's House Bat captured in the farmland and ASF

Chaerephon pumilus (Cretzschmar, 1830–1831). English: Little Free-tailed Bat captured in the farmland and ASF

Cardioderma cor (Peters, 1872) Heart-nosed Bat captured in the farmland and ASF

Rhinolophus deckenii Peters, 1868 Decken's Horseshoe Bat captured in the farmland and ASF

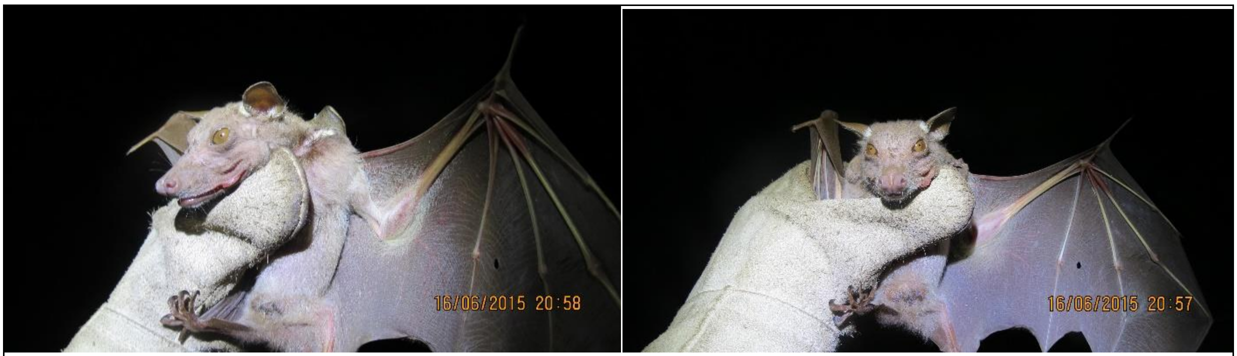
Nycticeinops schlieffeni (Peters, 1859) Schlieffen's Twilight Bat captured in the farmland and ASF

Otomops harrisoni Ralph, Richards, Taylor, Napier and Lamb, 2015 Harrison's Giant Mastiff Bat only captured in the farmland

Mimetillus moloneyi (Thomas, 1891) Moloney's Mimic Bat only captured in the ASF

Miniopterus minor Peters, 1867 Least Long-fingered Bat captured in the farmland and ASF

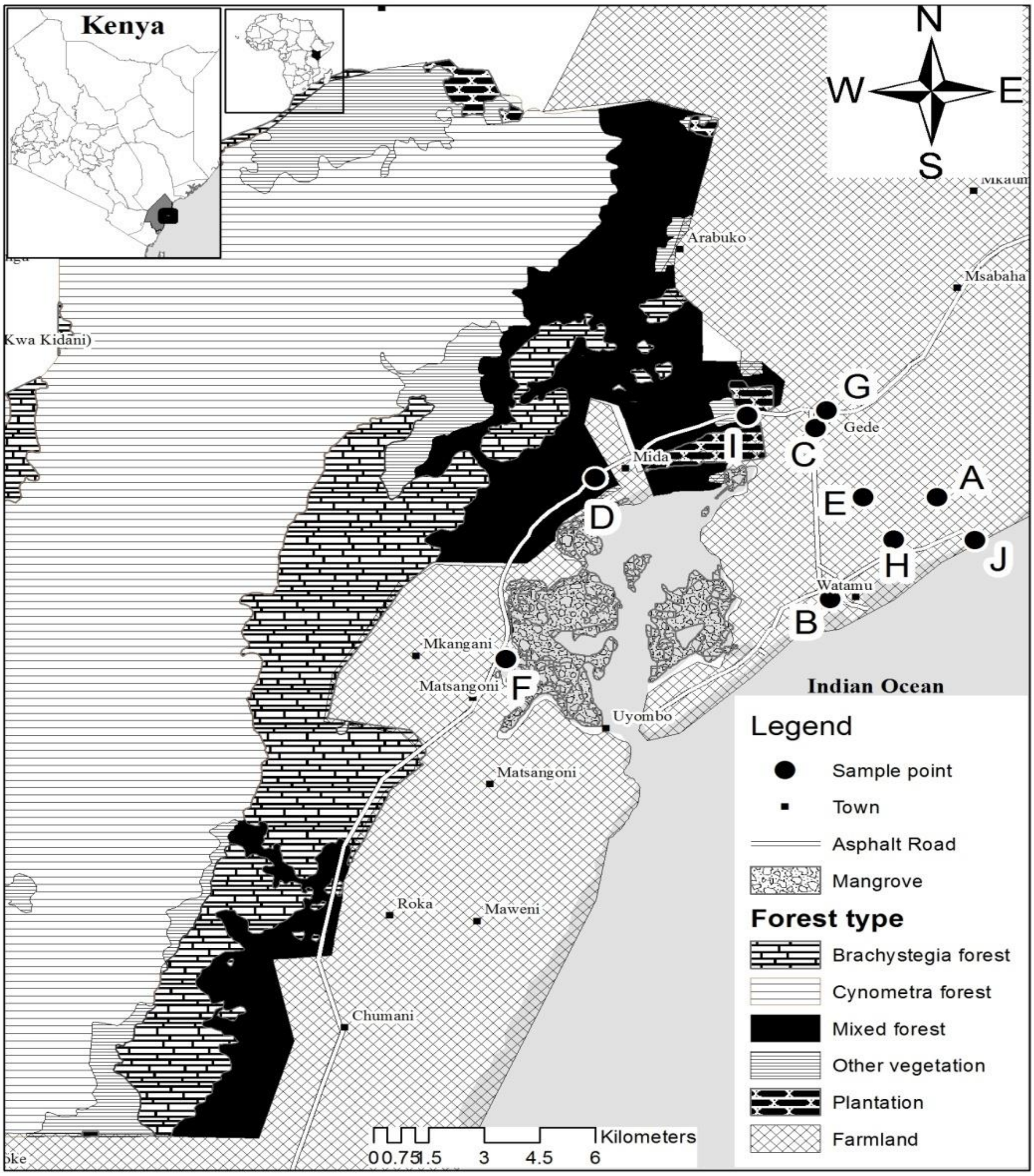
Rousettus aegyptiacus (É. Geoffroy, 1810) Egyptian Rousette breeding condition captured in the farmland and ASF



Epomophorus wahlbergi (Sundevall, 1846). Wahlberg's Epauletted Fruit Ba captured in the farmland and ASF

Hipposideros caffer (Sundevall, 1846) Sundevall's Leaf-nosed Bat colony roost at Alibaba/Makuruhu limestone roost in the farmland; species captured in both study sites

Appendix 3. Location of some bat roosts in ASF and farmland



Legend: Ali Baba/Makuruhu cave (A); Watamu Police Station cave (B), Gede Market Tree Roost (C), Lion cave (D), Panga Yambo (E), Uyombo cave (F), Borehole Roost (G); Kaboga Cave (H), Latrine Roost (I) and Kanani Cave (J).

Appendix 4. Bat species and total number of captures each hour in the interior of ASF

	Genus	Species	Bat group	1900 hr	2000 hr	2100 hr	2200 hr	2300 hr	2400 hr	0100 hr	0200 hr	0300 hr	0400 hr	Total/ Species
1	*Epomophorus*	*wahlbergi*	Fruit bat	28	72	58	46	34	55	15	13	17	76	**414**
2	*Roussetus*	*aegyptiacus*	Fruit bat	5	41	67	36	50	90	6	2	10	7	**314**
3	*Eidolon*	*helvum*	Fruit bat			1								**1**
4	*Neoromicia*	*nana*	Insect bat	13	3	1		1						**18**
5	*Macronycteris*	*vittata*	Insect bat	15	1	1			1				2	**20**
6	*Miniopterus*	*minor*	Insect bat	1	6	2	1		4			1	4	**19**
7	*Nycteris*	*thebaica*	Insect bat	4	3	2	3	2						**14**
8	*Hipposideros*	*cafer*	Insect bat	3	4	1	3		1				1	**13**
9	*Coleura*	*afra*	Insect bat	1	7	2	1		4			1	1	**17**
10	*Nycticeinops*	*schlieffeni*	Insect bat	11		1		1						**13**
11	*Rhinolophus*	*deckenii*	Insect bat		5	2	1	2						**10**
12	*Scotophilus*	*trujilloi*	Insect bat	4	1		1	1		2			1	**10**
13	*Neoromicia*	*capensis*	Insect bat	4			1							**5**
14	*Pipistrellus*	*rueppellii*	Insect bat	4	1									**5**
15	*Chaerophon*	*pumilus*	Insect bat	3										**3**
16	*Mimetillus*	*moloneyi*	Insect bat	2									1	**3**
17	*Miniopterus*	*cf inflatus*	Insect bat			1				1				**2**
18	*Cardioderma*	*cor*	Insect bat		1			1						**2**
19	*Taphozous*	*mauritianius*	Insect bat						1					**1**
	Total /hour			**98**	**145**	**139**	**93**	**92**	**156**	**24**	**15**	**29**	**93**	**884**

Appendix 5. Bat species and total number of captures each hour in the farmland

	Genus	Species	Bat group	1900 hr	2000 hr	2100 hr	2200 hr	2300 hr	2400 hr	0100 hr	0200 hr	0300 hr	0400 hr	Total/ species
1	*Roussetus*	*aegyptiacus*	Fruit bat	338	498	313	281	254	311	45	87	69	132	**2328**
2	*Epomophorus*	*wahlbergi*	Fruit bat	273	184	113	114	85	99	36	31	29	56	**1020**
3	*Eidolon*	*helvum*	Fruit bat	1	1	1	1							**4**
4	*Cardioderma*	*cor*	Insect bat	183	143	72	32	44	53	14	14	17	32	**604**
5	*Scotophilus*	*trujilloi*	Insect bat	35	3	2	1				4	5	1	**51**
6	*Nycteris*	*thebaica*	Insect bat	16	4	6	5	2	3	1			3	**40**
7	*Macronycteris*	*vittata*	Insect bat	16	5	1	4		1		1		8	**36**
8	*Hipposideros*	*cafer*	Insect bat	15	2	3	1							**21**
9	*Coleura*	*afra*	Insect bat	17	1	2			1		1		1	**23**
10	*Rhinolophus*	*deckenii*	Insect bat	14	5	2	1	1					5	**28**
11	*Nycticeinops*	*schlieffeni*	Insect bat	16	3									**19**
12	*Miniopterus*	*minor*	Insect bat	13	2									**15**
13	*Neoromicia*	*nana*	Insect bat	9		1	1					1		**12**
14	*Otomops*	*harrisoni*	Insect bat	2			2	1	1		1	2	2	**11**
15	*Scotoecus*	*hirundo*	Insect bat	10										**10**
16	*Neoromicia*	*tenuipinnis*	Insect bat	5					1					**6**
17	*Neoromicia*	*capensis*	Insect bat	4	1			1						**6**
18	*Taphozous*	*mauritianius*	Insect bat			2			1			1	2	**6**
19	*Pipistrellus*	*ruepellii*	Insect bat	4										**4**
20	*Triaenops*	*afer*	Insect bat	5										**5**
21	*Chaerephon*	*pumilus*	Insect bat	1			1							**2**
22	*Neoromicia*	*rendalli*	Insect bat	1										**1**
23	*Miniopterus*	*cf inflatus*	Insect bat									1		**1**
	Total/hour			**978**	**852**	**518**	**444**	**388**	**471**	**96**	**139**	**125**	**242**	**4253**

Appendix 6. Orders of different invertebrates excluding Order Lepidoptera (moths) trapped in different vegetation types in ASF (Cynometra forest (CYN) Brachystegia forest (BRA), mixed forest in ASF (MIXFo), and farmland (mango farmfarms (MAN), coconut farmfarms (COC), and mixed farmfarms (MIXFa).

ORDERS	Families	MAN	COC	MIXFa	FARM	MIXFo	BRA	CYN	ASF	ASF+Farm
Blattodea	Blattellidae	29	3	4	**36**	5	17	2	**24**	**60**
	Blattidae	10	5	11	**26**	56	52	14	**122**	**148**
	Euthyrrhaphidae	67		3	**70**	6	33	2	**41**	**111**
	Termitidae	16	2	0	**18**	1	6	44	**51**	**69**
Order Total		**122**	**10**	**18**	**150**	**68**	**108**	**62**	**238**	**388**
Coleoptera	Alleculidae	2	0	1	**3**	7	1	3	**11**	**14**
	Bostrychidae		4		**4**	1			**1**	**5**
	Brenithidae	4	5	0	**9**	1	2	0	**3**	**12**
	Bruchidae	19	10	3	**32**		9		**9**	**41**
	Buprestidae	0	2	0	**2**	3	0	0	**3**	**5**
	Cantharidae				**0**	1	1		**2**	**2**
	Carabidae	49	9	8	**66**	13	5	2	**20**	**86**
	Cerambycidae	5	4	2	**11**	7	18	17	**42**	**53**
	Chrysomelidae	21	25	31	**77**	16	153	28	**197**	**274**
	Cleridae				**0**			1	**1**	**1**
	Coccinelidae	24			**24**				**0**	**24**
	Curculionidae				**0**	1		2	**3**	**3**
	Elateridae	63	23	29	**115**	10	2	4	**16**	**131**
	Erotylidae	17	4		**21**	1	27	52	**80**	**101**
	Hybosoridae	4	11	1	**16**				**0**	**16**
	Lymexilidae			1	**1**			2	**2**	**3**
	Meloidae	1	2	0	**3**	0	0	2	**2**	**5**
	Mordellidae			2	**2**				**0**	**2**
	Paussidae	4	2	11	**17**	0	0	0	**0**	**17**
	Rhynchophoridae	10	1		**11**				**0**	**11**
	Scarabaeidae	104	84	340	**528**	17	50	36	**103**	**631**
	Staphylinidae	2			**2**	20	49	3	**72**	**74**
	Tenebrionidae	85	58	119	**262**	19	40	6	**65**	**327**
	Trogidae				**0**	1			**1**	**1**
Order Total		**414**	**244**	**548**	**1206**	**118**	**357**	**158**	**633**	**1839**
Diptera	Asilidae	14	2	5	**21**	7	26	14	**47**	**68**
	Calliphoridae	1			**1**				**0**	**1**
	Muscidae	20	9	7	**36**	20	60	5	**85**	**121**
	Sarcophagidae	2	1	2	**5**		3		**3**	**8**
	Tabanidae	1			**1**		1	1	**2**	**3**
	Tephritidae	1			**1**		1	4	**5**	**6**
Order Total		**39**	**12**	**14**	**65**	**27**	**91**	**24**	**142**	**207**
Hemiptera	Cercopidae	7	15	2	**24**	46	17	22	**85**	**109**
	Coreidae	4	2	0	**6**	0	0	0	**0**	**6**
	Cydnidae	6	2		**8**				**0**	**8**
	Lygaeidae	8	14	15	**37**	3	31	7	**41**	**78**
	Pentatomidae	7	2	1	**10**	3	0	0	**3**	**13**
	Reduviidae	7	7	5	**19**	27	25	12	**64**	**83**
Order Total		**39**	**42**	**23**	**104**	**79**	**73**	**41**	**193**	**297**
Hymenoptera	Apidae		1		**1**				**0**	**1**
	Braconidae			1	**1**				**0**	**1**
	Eumenidae	1			**1**				**0**	**1**
	Formicidae	1154	201	92	**1447**	130	540	373	**1043**	**2490**
	Mutilidae				**0**	1			**1**	**1**
	Pompilidae	1			**1**				**0**	**1**
	Scoliidae	1			**1**				**0**	**1**
Order Total		**1157**	**202**	**93**	**1452**	**131**	**540**	**373**	**1044**	**2496**
Mantodea	Mantidae	1	7	1	**9**	5	21	7	**33**	**42**
Neuroptera	Ascalephidae		1	1	**2**				**0**	**2**
	Myrmeleontidae	0	3	2	**13**	3	11	4	**18**	**31**
Order Total		**0**	**4**	**3**	**15**	**3**	**11**	**4**	**18**	**33**
Odonata	Libellulidae	1			**1**		1		**1**	**2**
Orthoptera	Acrididae	32	36	17	**85**	14	6	4	**24**	**109**
	Gryllacridae	2	3		**5**	1	1	8	**10**	**15**
	Gryllidae	7	4	4	**15**	5	10	7	**22**	**37**
	Pyrgomophidae			10	**10**				**0**	**10**
	Tettigonidae	6	2	2	**10**	12	21	10	**43**	**53**
Order Total		**47**	**45**	**33**	**125**	**32**	**38**	**29**	**99**	**224**
TOTALS	**ALL SITES**	**1828**	**566**	**733**	**3127**	**463**	**1240**	**698**	**2401**	**5528**

Appendix 7. Diversity of trees in different vegetation types in the farmland

	Types of trees in farmland	Trees in mango farms	% Trees in mango farms	Coconut farms	% Trees in coconut farm	mixed farms	% Trees In mixed farms	Farmland trees totals	% Trees in farmland
1	Coconut	55	19.6	250	89.3	148	52.9	453	53.9
2	Mango	198	70.7	11	3.9	52	18.6	261	31.07
3	Cashew nut	8	2.9	16	5.7	65	23.2	89	10.59
4	Neem	15	5.4	3	1.1	13	4.6	31	3.69
5	Guava	1	0.4		0.0	1	0.4	2	0.24
6	Casuarina	1	0.4		0.0		0	1	0.12
7	Citrus	2	0.7		0.0		0	2	0.24
8	Gmelia arborea		0		0.0	1	0.4	1	0.12
	TOTAL	**280**	**100**	**280**	**100.0**	**280**	**100**	**840**	**100**

Appendix 8. Diversity of trees in different vegetation types at ASF

	Tree species	No. trees Mixed forest	% of trees in mixed	No. trees in Cynometra forest	% of trees in Cynometra forest	No. of trees in *Brachystegia* woodland	% of trees in *Brachystegia* woodland	ASF tree totals	% Trees at ASF
1	*Brachystegia spiciformis*		0.0		0	248	88.6	248	30
2	*Cyometra webberi*		0.0	244	87.1		0.0	244	29
3	*Manikara sansibarensis*	150	53.6		0.0	4	1.4	154	18
4	*Hymenaea verrucosa*	77	27.5		0.0	14	5.0	91	11
5	*Afzelia quanzensis*	27	9.6		0.0	12	4.3	39	5
6	*Brachylaena huillensis*	2	0.7	15	5.4		0.0	17	2
7	*Manikara sulcata*		0.0	8	2.9		0.0	8	1
8	*Mimusops obtusifolia*	7	2.5		0.0		0.0	7	1
9	*Pleurostylia africana*	7	2.5		0.0		0.0	7	1
10	*Oldfieldia somalensis*		0.0	6	2.1		0.0	6	1
11	*Tamarindus indica*	3	1.1		0.0		0.0	3	0
12	*Jasminum streptopus*		0.0	3	1.1		0.0	3	0
13	*Lonchocarpus bussei*	2	0.7		0.0		0.0	2	0
14	*Drypetes reticulata*	2	0.7		0.0		0.0	2	0
15	*Haplocoelum inoploeum*		0.0	2	0.7		0.0	2	0
16	*Maerua angolenis*		0.0	2	0.7		0.0	2	0
17	*Lannea schweinfurthii*		0.0		0.0	2	0.7	2	0
18	*Ozoroa obovata*	1	0.4		0.0		0.0	1	0
19	*Dialium orientale*	1	0.4		0.0		0.0	1	0
20	*Grewia microcarpa*	1	0.4		0.0		0.0	1	0
	TOTALS	**280**	**100.0**	**280**	**100**	**280**	**100.0**	**840**	**100**

Appendix 9. Number of each tree species per ha in the farmland

	Tree species	Species in each quarter	Frequency/Quarter	Overall trees/ha	Tree species /ha	Potential for fruit bat food
1	Coconut	453	0.539285714	111	60	
2	Mango	261	0.310714286	111	34	Fruit edible
3	Cashew nut	89	0.105952381	111	12	Fruit edible
4	Neem	31	0.036904762	111	4	Fruit edible
5	Citrus	2	0.002380952	111	0	
6	Guava	2	0.002380952	111	0	Fruit edible
7	Gmelia arborea	1	0.001190476	111	0	Fruit edible
8	Casuarina	1	0.001190476	111	0	
	TOTALS	**840**	**1**		**111**	

Appendix 10. Number of each tree species per ha in the interior of ASF

	Tree species	Total tree species in each quarter	Frequency/Quarter	Overall trees/ha	Tree species /ha	Potential for fruit bat food
1	*Brachystegia spiciformis*	248	0.30	84	25	
2	*Cyometra webberi*	244	0.29	84	24	
3	*Manikara sansibarensis*	154	0.18	84	15	Fruit edible
4	*Hymenaea verrucosa*	91	0.11	84	9	
5	*Afzelia quanzensis*	39	0.05	84	4	
6	*Brachylaena huillensis*	17	0.02	84	2	
7	*Manikara sulcata*	8	0.01	84	1	
8	*Mimusops obtusifolia*	7	0.01	84	1	Fruit edible
9	*Pleurostylia africana*	7	0.01	84	1	
10	*Oldfieldia somalensis*	6	0.01	84	1	
11	*Tamarindus indica*	3	0.00	84	0	
12	*Jasminum streptopus*	3	0.00	84	0	
13	*Lannea schweinfurthii*	2	0.00	84	0	Fruit edible
14	*Lonchocarpus bussei*	2	0.00	84	0	
15	*Maerua angolenis*	2	0.00	84	0	
16	*Drypetes reticulata*	2	0.00	84	0	
17	*Haplocoelum inoploeum*	2	0.00	84	0	Fruit edible
18	*Dialium orientale*	1	0.00	84	0	Fruit edible
19	*Ozoroa obovata*	1	0.00	84	0	
20	*Grewia microcarpa*	1	0.00	84	0	
	TOTALS	**840**	**1.00**		**84**	

Appendix 11. The total tree basal area per hectare (m^2/ha) in the farmland.

	Tree species	Mean Basal Area	Tree species /ha	Total BA/ha (m^2/ha)
1	Mango	7728.655993	34	26.27743038
2	Cashew nut	3451.289727	12	4.141547673
3	Casuarina	4187.071429	0	0
4	Gmelia arborea	2828.571429	0	0
5	Neem	1785.193548	4	0.714077419
6	Citrus	1767.857143	0	0
7	Guava	1235.535714	0	0
8	Coconut	624.8319142	60	3.748991485
	Total Cover/ha			**34.88204695**

Appendix 12. The total tree basal area per hectare (m^2/ha) at ASF

	Tree species	Mean Basal Area	Tree species /ha	Total BA/ha (m^2/ha)
1	*Brachystegia spiciformis*	2889.3	25	7.2
2	*Cyometra webberi*	755.0	24	1.8
3	*Manikara sansibarensis*	896.2	15	1.3
4	*Hymenaea verrucosa*	1278.5	9	1.2
5	*Afzelia quanzensis*	3581.3	4	1.4
6	*Brachylaena huillensis*	505.4	2	0.1
7	*Manikara sulcata*	589.1	1	0.1
8	*Mimusops obtusifolia*	919.2	1	0.1
9	*Pleurostylia africana*	1002.3	1	0.1
10	*Oldfieldia somalensis*	868.1	1	0.1
11	*Tamarindus indica*	8835.6	0	0.0
12	*Jasminum streptopus*	913.2	0	0.0
13	*Lannea schweinfurthii*	12951.7	0	0.0
14	*Lonchocarpus bussei*	990.4	0	0.0
15	*Maerua angolenis*	2642.0	0	0.0
16	*Drypetes reticulata*	3055.6	0	0.0
17	*Haplocoelum inoploeum*	671.4	0	0.0
18	*Dialium orientale*	3319.6	0	0.0
19	*Ozoroa obovata*	2124.6	0	0.0
20	*Grewia microcarpa*	346.5	0	0.0
	TOTALS	**1671**	**84**	**13.4**

Appendix 13. The importance value of each tree species in the farmland

	Tree species	Relative Density of a Species	Relative Cover of a Species	Relative frequency	Importance
1	Mango	31	75	30	136
2	Coconut	54	11	47	112
3	Cashew nut	11	12	16	39
4	Neem	4	2	6	12
5	Citrus	0	0	1	1
6	Guava	0	0	1	1
7	Gmelia arborea	0	0	0	0
8	Casuarina	0	0	0	0
	TOTALS	100	100	100	300

Appendix 14. The importance value of each tree species in ASF

	Tree species	Relative Density of a Species	Relative Cover of a Species	Relative frequency of a species	importance value of a species
1	*Brachystegia spiciformis*	30	54	20	103
2	*Cyometra webberi*	29	14	20	62
3	*Manikara sansibarensis*	18	10	17	46
4	*Hymenaea verrucosa*	11	9	18	38
5	*Afzelia quanzensis*	5	11	9	24
6	*Brachylaena huillensis*	2	1	4	7
7	*Manikara sulcata*	1	0	2	3
8	*Mimusops obtusifolia*	1	1	2	3
9	*Pleurostylia africana*	1	1	2	4
10	*Oldfieldia somalensis*	1	1	2	3
11	*Tamarindus indica*	0	0	1	1
12	*Jasminum streptopus*	0	0	1	1
13	*Lannea schweinfurthii*	0	0	0	0
14	*Lonchocarpus bussei*	0	0	0	0
15	*Maerua angolenis*	0	0	1	1
16	*Drypetes reticulata*	0	0	1	1
17	*Haplocoelum inoploeum*	0	0	1	1
18	*Dialium orientale*	0	0	0	0
19	*Ozoroa obovata*	0	0	0	0
20	*Grewia microcarpa*	0	0	0	0
	TOTALS	**100**	**100**	**100**	**300**

Appendix 15: Bat attitude questionnaire (BAQ)-English version

BATS ATTITUDES SURVEYS AROUND CAVES IN ARABUKO-SOKOKE FOREST

READ HERE FIRST: The purpose of this questionnaire is to collect information about bats from local people around Arabuko Sokoke Forest purely for scientific research; therefore, we would like to obtain honest answers.

INSTRUCTIONS: TICK AS APPROPRIATE: Thank you for taking part in this interview- For more information contact: SIMON MUSILA: Mammalogy Section, National Museums of Kenya, P. O Box 40658, GPO 00100 Nairobi-Kenya. Email- smusila@museums.or.ke, Mobile-0727-093737 and 0735-476314.

SECTION 1-RESPONDENTS DEMOGRAPHIC INFORMATION

Sex: 1.Male [ ] 2. Female [ ] Distance from nearest bats cave…. Tribe/Language spoken: ...

How old are you (Yrs): ……………………How many children do you have?...………

Level of education: 1. None [ ] 2. Primary [ ] 3. Secondary [ ] 4. College[ ] 5. University [ ]

What is the name of bat in your mother tongue…………………when last did you see a bat……..

Name a place you know where many bats are found in large numbers……………………….……

What traditional beliefs exist in your community about bats…………………………………..

……………………………………………………………………………………………………

List all benefits which people get from bats……………

………………………………………….

……………………………………………………………………………...................………

……

List ways in which bats affect people or anything owned by people........…………………………

……………………………………………………………………………………………………

Have you ever had bats living in your compound (farm or house) Yes [ ] No [ ]

If YES what did you do to these bats?

1. I killed at least one [ ]
2. Killed very many of them [ ]
3. I destroyed their resting place in order to chase the bats away [ ]
4. I did nothing [ ]
5. I contacted responsible officer [ ]

SECTION 2-NEGATIVISTIC

1. **Are you afraid that bats can infect you with dangerous diseases?**
   1).Not at all[ ] 2).No[ ] 3).Undecided[ ] 4).Somehow they can[ ] 5).Extremely very much[ ]

2. **How much do you consider appearance of bats attractive to you?**
   1). Absolutely not attractive [ ] 2).Not attractive[ ] 3).Undecided[ ] 4).Attractive[ ]
   5). Extremely very attractive[ ]

3. I like holding a bat in my hand
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

4. **I cannot enter a cave where bats are found**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

5. **I can live in a house where bats are founds**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

6. **When I see a bat I ran away immediately**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

7. How much do you consider bats disgusting to you?
1). Absolutely not disgusting [ ] 2). Not disgusting[ ] 3).Undecided[ ] 4).Disgusting[ ]
5). Extremely very disgusting[ ]

8. **I can cut any tree down in our compound if it was occupied by bats**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

9. **Bats destroy fruits in our farm**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

SECTION 3-SCIENSTISTIC

1. **I would like to know more about bats**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

2. **We should learn more about bats in school**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

3. **I cannot understand how someone can be interested in bats**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

4. **I would like to join a bat trip/expedition and learn about bats**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

SECTION 4-ECOLOGISTIC

1. **Bats should be protected law**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

2. **Bats play a very important role to the environment**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

3. **Bats help in pollination of flowers**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

4. **Bats help in seed dispersal**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

5. **Bats help in insect pest control**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

6. Bats droppings are source of good fertilizer
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

7. Planting tress helps conserve bats species
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

8. Caves are very important for survival of bats
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

9. There is no problem even if we lose all bats species in Kenya
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

SECTION 5-KNOWLEDGE

1. **A bat is a bird**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

2. **Bats lay eggs**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

3. **Bats are only active during the night**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

4. **Bats build nets**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

5. **Bats live in houses**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

6. **Bats do not live in caves**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

7. **Bats live in trees/bushes**
1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

8. **Bats are blind and cannot see**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

SECTION 6-MYTHS

1. **Bats are ghosts (majini)**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

2. **When you see a bat in your house, it is send by your enemy to harm you**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

3. **If a bat urinates on someone he/she becomes impotent**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

4. **It is a sign of bad omen if bats start living in your new house before you move in**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

5. **A home where many bats are found it is a sign of riches/wealth**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

6. **Soup made from bats meat can heal stroke**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

7. **Body parts of bats are used by witchdoctors to cast spells to people**

1).Strongly disagree[ ] 2).Rather disagree[ ] 3).Undecided[ ] 4).Rather agree[ ] 5). Strongly agree [ ]

Appendix 16. Bat attitude questionnaire (BAQ)-Swahili version

UTAFITI WA POPO/BATS KATIKA PANGO ZINAZOZUNGUKA MSITU WA ARABUKO-SOKOKE FOREST-MALINDI

SOMA HAPA KWANZA: Nakushuru sana kwa kujitolea kushiriki katika utafiti wa popo, unaoshirikisha watu waoishi katika sehemu zinaozunguka msitu wa Arabuko Sokoke Forest. Nia ya haya maswali ni untafiti wa kisayansi, wa kujua maoni yako kuhusu popo. Kwa hivyo ninakuomba majibu yako yawe ya kweli iwezekanavyo.

MAELEKEZO: CHANGUA JIBU MOJA KATIKA KILA SEHEMU: Ukiwa na swali yeyote uliza: *Simon Musila*-Mammalogy Section, National Museums of Kenya, P. O Box 40658, GPO 00100 Nairobi-Kenya. *Barua pepe*: smusila@museums.or.ke; *Rununu*: Mobile-0727-093737 and 0735-476314.

SEHEMU-1 RESPONDENTS DEMOGRAPHIC INFORMATION
Gender: 1.Mume [ ] 2.Mke [ ] Umbali kutoka kwa pango ya popo iliyo karibu……..
Lugha ya mama:………………….
Wewe una umri gani (miaka)…………Nambari ya watoto wako…………………………………
Kisomo chako: 1. Sijasoma [ ] 2. Msingi [ ] 3. Sekondari [ ] 4. College[ ] 5. Chuo [ ]
Andika **njina la popo** kwa lugha ya mama…………………Ni lini uliona popo mwisho……………
Andika njina ya **mahali popo** wanapopatikana kwa wingi kijijini kwenu…..…………………..
Eleza mambo watu wa kabila yako wanoyoamini kuhusu popo…………………………………..
……
Andika **faida** wanadamu wanapata kutoka kwa popo ……………………………………………
…………………………………………………………………………………………………..
Andika **hasara** wanadamu wanapata kutoka kwa popo ………………….……………………….
……

Kuna wakati popo wameishi nyumbani ama shambani mwenu? Ndiyo [ ] La[ ]
Kama NDIYO hoa popo uliwafanyia nini?

1. Niliuwa popo mmoja [ ]
2. Niliuwa popo wengi sana [ ]
3. Niliaribu mahali walipokuwa wamekaa ili niwafukunzie mbali [ ]
4. Sikufanya chochote [ ]
5. Nilimwendea afisa ambaye anausika [ ]

SEHEMU-2-NEGATIVISTIC

1. **Wewe unaungopa ya kwamba popo anaweza kukuambukiza magonjwa hatari?**
   1). Nakataa kabisa hawezi[ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali kidogo [ ] 5). Nakubali anaweza Kabisa [ ]

2. **Ni kwa kiwango ngani unafafikiria vile popo anakaa ama ameumbwa anapendeza?**
   1). Hapendezi hata kidogo[ ] 2).Hapendezi[ ] 3).Sijui[ ] 4).Anapendeza kidogo[ ] 5). Anapendenza sana[ ]

3. **Napendelea kushika popo katika mkono wangu**

1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

4. **Siwezi nikaingia katika pango ambapo popo wanapatikana**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

5. **Siwezi kuishi katika nyumba ambayo popo wanapatikana**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

6. **Nikimouna popo mimi ukimbia mara moja**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

7. **Ni kwa kiwango ngani, wewe unafafikiria popo anachukiza?**
1). Achukizi hata kidogo [ ] 2). Achukizi[ ] 3).sijui[ ] 4).Anachukizi kidogo[ ] 5). AnaAchukizi sana[ ]

8. **Mimi naweza kukata mti wowote nyumbani kwetu ukifamiwa na popo**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

9. **Popo wanaharibu matunda katika shamba yetu**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

SEHEMU-3-SCIENTISTIC

1. **Mimi ningependa kufahamu/kujua mengi kuhusu popo**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

2. **Ingekuwa vyema kama tungesoma mengi kuhusu popo shuleni**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

4. **Siwezi nikaelewa vile mtu yeyote anawezwa kupendezwa na mambo ya popo**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

6. **Ningependelea kwenda safari ya kujifunza mambo ya popo**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

SEHEMU-4-ECOLOGISTIC

1. **Serikali inapaswa kumbuni sheria za kuhifadhi popo**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

2. **Popo ni mnyama wa maana katika mazingira yetu**

1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

3. Popo anachangia katika utengezaji wa matunda ya mwituni
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

4. Popo anachangia kutawanya mbegu za miti mwituni
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

5. **Popo anachangia kupunguza wadudu wabaya**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

6. **Mavi ya popo ni mbolea nzuri**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

7. **Upandaji miti unachangia uhifadhi wa aina nyingi za popo**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

8. **Mapango yana maana sana katika kuhifadhi popo**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

9. **Inchi yetu haitapoteza chochote aina wote wa popo wakiangamia**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

SEHEMU-5-KNOWLEDGE

1. Popo ni ndege
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

2. Popo hutaga mayai
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

3. Popo anatembea tu usiku
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

4. Popo anajenga kiota
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

5. Popo anaishi katika nyumba
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

6. **Popo hawaishi Katika mapango**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

7. **Popo wanaishi katika miti**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

8. **Popo ni kipovu hawezi akaona kwa macho**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

SEHEMU-6 MYTHS

1. **Popo ni jini**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

2. **Ukimuona popo kwa nyumba yako, ametumwa na adui wako akudhuru**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

3. **Popo akikukojolea utakuwa tasa**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

4. **Popo akifamia nyumba yako mpya kabla ujaanza kiutumia, ni ishara mambo mabaya**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

5. **Nyumba ambayo popo wengi wanapatika ni ishara ya kwamba ni matajiri**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

6. **Supu iliyotenezwa na nyama ya popo inatimbu kupooza**
1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

7. **Sehemu za mwili wa popo zinatumika na wachawi kuronga**
   1). Nakataa kabisa [ ] 2). Nakataa [ ] 3). Sijui [ ] 4). Nakubali [ ] 5). Nakubali Kabisa [ ]

Appendix 17. List of publications

Papers in peer-reviewed journals (3)

1. Musila, S., Gichuli, N., Castro-Arellano, I. and Rainho, I. 2019. Composition and diversity of bat assemblages at Arabuko-Sokoke Forest and the adjacent farmlands, Kenya. *Mammalia* (https://doi.org/10.1515/mammalia-2018-0117 Received July 4, 2018; accepted June 27, 201).

2. Musila, S. & Bogdanowicz, Wieslaw & Syingi, Robert & Zuhura, Aziza & Chylarecki, Przemysław & Rydell, Jens. 2019. No lunar phobia in insectivorous bats in Kenya. Mammalian Biology. 95. 10.1016/j.mambio.2019.03.002.

3. Musila, S., Pavol Prokop & Nathan Gichuki .2018. Knowledge and Perceptions of, and Attitudes to, Bats by People Living around Arabuko-Sokoke Forest, Malindi Kenya, Anthrozoös, 31:2, 247-262, DOI: 10.1080/08927936.2018.1434065