ABUNDANCE, DIVERSITY AND DISTRIBUTION OF SMALL MAMMALS IN OLOOLUA FOREST, NAIROBI, KENYA

BY:

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DECLARATION:

I hereby declare that the work herein reported to the best of my knowledge is my original work and has not been presented for the award of a degree in any other university.

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DEDICATION

This thesis is dedicated to my immediate family- my dear wife Rehema Nyaboke and our three beautiful girls: the calm Kierra Kerubo, the very active Kaylah Buyaki and the witty Nataniah Kang'ina. Your support and patience during the field work and the writing of this thesis was superb and is greatly appreciated.

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LIST OF ABBREVIATIONS

NMK	National Museums of Kenya
IPR	Institute of Primate Research
DBH	Diameter at Breast Height
PAST	Paleontological Statistics
SMSG	Small Mammals Specialist Group
IUCN	International Union for Conservation of Nature
CBD	Convention on Biological Diversity

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ABSTRACT

Nairobi's fast growth as an urban center has posed various negative challenges to fauna and flora. The future of small mammals is especially bleak considering their specific ecological needs which are easily affected by habitat alteration. The purpose of this study was to assess the abundance, distribution and diversity of small mammals in Oloolua forest; the seasonal variation in captures of small mammals; as well as the effect of habitat structure on the abundance and distribution of small mammals. Four habitats were sampled for 90 days during the dry and wet seasons of the year 2017. Rodents and shrews were captured using a mixture of traps, small carnivores were sampled using tomahawk cage traps whereas bats were captured using mist nets. The traps were placed randomly in transects that were systematically positioned in each habitat. A total of 217 small mammals belonging to three orders, Rodentia (43.78%), Soricomorpha (2.76%) and Chiroptera (53.46%) were captured. The diversity index of the small mammals was higher in disturbed habitats (Shannon_H'=1.594) than in the undisturbed habitats (Shannon_H'=1.477); and captures were less in the undisturbed habitats (101) as compared to those in the disturbed (116). A one-way analysis of variance on the abundances across the habitats yielded $F_{(3, 35)} = 0.5209$ $P > 0.05$ indicating that there was no significant difference in the abundance of small mammals among the four habitats sampled. Overall captures across the dry and wet seasons also showed no significant difference, $t(9) = -0.03939$ $P > 0.05$. There were significant differences in the results of each of the habitat variables studied even though they did not influence the abundance, diversity and distribution of small mammals across the habitats. This study confirms that small mammal abundance, diversity and distribution in Oloolua forest is uniform across all its habitats as had been hypothesized. It also highlights the importance that surveys of small mammals in urban green spaces have towards highlighting the effects of climate change on the dwindling yet very important urban ecosystems.

CHAPTER ONE: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Mammals have for a long period of time roamed the surface of the earth and have attracted interest from all corners- naturalists as well as the common man. Their elegance and beauty, their unique graceful nature, and even the secretive lifestyles of some species continue to amaze people. They play a critical role in the ecosystem acting as both predators and grazers and occupy several levels of food chains **(**Ray et al. 2005**).**

Domesticated mammals are a great source of meat, milk, hair, wool, hides, and even the provision of labour especially for peasant farmers and traders. Some mammals e.g. camels, donkeys, oxen, horses and buffaloes are used for providing transport. Oil and fat, ivory and other products are also obtained from mammals of various species.

Biomedical research has widely benefitted from mammals, such as guinea pigs, rodents, rabbits, monkeys as well as dogs which are used widely in scientific studies. They are at times hated by humans because of their role as pests of agricultural plants and produce. This is because they can cause a lot of damage on food crops either in the farms or in granaries and stores.

Mammals also act as carriers of diseases and disease causing organisms. Common diseases that are transmitted by mammals include trichinia, typhus, as well as bubonic plague. A common species well known in disease transmission is the rodent *Rattus spp* which on its own is known to transmit scrub Typhus, murine Typhus, Leptospirosis, Salmonellosis, Toxoplasmosis, Leishmaniasis and Chagas disease. This implies that small mammals are indeed important ecologically, economically and medically, and cannot be neglected without man suffering a great loss.

Globally the situation is not so good when it comes to mammalian conservation. Uncontrolled habitat loss and illegal harvesting of mammals have resulted in unprecedented declines of mammals globally (Hoffman *et al*., 2010). According to the IUCN (2008) report 25% of mammalian species are either extinct, facing extinction or highly threatened and there is every concern to document what is present currently even before any conservation measures can be enforced. Africa as a continent has had its share of struggles dealing with mammalian population declines and eastern Africa has experienced declines of more than 50% during the period 1970 to 2005. Kenya has also experienced population declines of large mammals in the past decade. What is not clear is the faunal diversity, distribution and natural history of small mammals (rodents, hares, otter shrews, elephant shrews, hedge hogs, shrews as well as bats) in Kenya. This necessitated a small mammal biodiversity survey in order to highlight their diversity and distribution which was the focus of this study.

1.2 Literature Review

1.2.1 Geographical distribution of small mammals

Small mammals are highly adaptive therefore enabling them to also be widely distributed (Scott *et al.,* 1987). Only scanty information is available on the distribution and diversity of small mammals in East Africa. This is attributable to their being cryptic, concealed and non-majestic according to Oguge *et al*., 2004. Depending on how various small mammal groups have co-evolved to date, clear-cut distribution patterns across the world are seen. Some species e.g. tree shrews are only found in some regions of south-East Asia; a good number of insectivores and rodents have more general distributions occurring almost everywhere in the world except the Antarctica. Shrews and hedgehogs are found in the Americas and Africa and in the latter, they co-exist very well with sengis (elephant shrews). (Small Mammal Specialist Group, n.d.).

1.2.2 Diversity of small mammals

Apart from fishes, small mammals are the most numerous and diverse group of vertebrate animals in the world. There are 2800 described species but they remain little studied and have received little attention in terms of conservation (Amori and Gippoliti, 2003). According to Schipper *et al.,* (2008), small mammals constitute close to two thirds of the global mammalian diversity. Even with these mind boggling statistics they continue to be neglected largely by conservationists and planners (Amori and Gippoliti, 2000). Kenya has a high diversity of small mammals and has been identified by IUCN's Small Mammal Specialist Group as key target for study and conservation of rodents and insectivores (Order Soricomorpha) in Africa, especially because of its unique and endemic species (Amori, *et al.,* 2012).

Small mammals' secretive and evasive behavior has greatly contributed to their being little studied and information on their abundance, diversity and distribution is very little in East Africa (Oguge *et al.,* 2004). In bat conservation, Kenya is recognized as an important country boasting of more than 100 species of bats (Patterson and Webala, 2012).

1.2.3 Ecological significance of small mammals

Small mammals have numerous ecological roles in the ecosystem the most crucial being that they act as indicator species (Scott *et al.,* 1987). They act as prey (Greenwood, 1982) or predator (Maxson and Oring, 1978) as well as seed dispersal agents (Fogel and Trappe, 1978). Their role in communicable diseases is also documented (Ross, 1983). Small mammals have been noted to promote the productivity of some plant species through inducing growth of shoots (Smirnov and Tokmakova, 1971) when they graze upon them. Taylor (1936) describes them as agents of range destruction. They have been blamed for destroying crops and lessening their ability to seed (Batzli and Pitelka, 1970) as well as overall crop failure (Gashweiler, 1970).

Small mammals significantly promote decomposition of plant material through their behaviour of not consuming all that they swallow (Scott *et al*., 1979) but go ahead and release it into the litter layer where the green matter decomposes faster than the brown (Grant and French, 1980). Another critical role that the small mammals play is the introduction into the soil of nitrogen (Taylor, 1935) and calcium through their droppings (Greene and Reynard, 1932).

Ecosystem dynamics is influenced by the carnivory behaviour of some small mammals who prey on some invertebrates e.g. the hymenopteran cocoons as was seen in a study by Obtrel *et al*., 1978. Bats and rodents provide reliable ecological feedback on impacts of forest management processes at regional levels (Kaminski *et al.*, 2007).

1.2.4 Diversity of habitats

Small mammals have been found and studied in forests (Oaten and Larsen, 2008; Sullivan and Sullivan, 2001), deserts (Valone and Brown, 1995) and in grasslands (Howe *et al.* 2002, Reed *et al.* 2007). An excess of 70% of all life on land is found in forests (FAO, 2010; Schmitt *et al*., 2009) that are found either in urban areas or in the rural set up. Rise in human population, climate change effects and unrealistically heightened forest product demands (UNEP, 2011; Slingenberg *et al*., 2009; DeFries *et al*., 2010) have caused forests now to be under so much pressure to provide for their fauna (Young *et al*., 2005). Many people think that urban areas are deprived of biodiversity and thereby should not attract conservation action. Conversely, a number of scholars highlight the fact that they indeed host quite a number of local and exotic species (Ives *et al.*, 2016). It is also known that urban areas harbour species that are of regional or global conservation concern, as well as a number of endemic species (Ives *et al.*, 2016). Because of the foregoing, more and more scholars are welcoming the ideology of urban ecology (Grimm *et al.,* 2013).

Godefroid (2001) points out that cities which have high quality green spaces are best placed to support the thriving of a number of wildlife species.

1.2.5 Factors influencing habitat choice

Vegetation cover has been documented to affect the distribution and the densities of a large array of small mammals (Ajayi and Tewe, 1978). For example, bats are affected by roost structure and its availability (Humphrey, 1975); temperature (Yom- Tov and Kadmon, 1998); precipitation (Yom- Tov and Kadmon, 1998); vegetation types and clutter (Peters *et al*., 2006). Rodents on their part have been shown to be affected by the presence of large mammals (Hoffman and Zeller, 2005); altitude (Mulungu *et al.*, 2008); vegetation type (Prakash and Singh, 2001); human disturbance (Liu *et al.*, 2008) and precipitation (Tadesse and Afework, 2008).

The extent to which habitat fragmentation occurs will affect forest structure thereby hindering species occurrence (Tews *et al.*, 2004). Some of these creatures may remain in their particular isolated patches where they most likely will occupy non-native vegetation, while others will occupy the extensive forest patches (Pardini *et al.*, 2005; Viveiros and Fernandez, 2004). Loss of habitats has clearly been noted to negatively impact species richness (Findlay and Houlahan, 1997), as well as the restricted distribution and abundance of organisms (Gibbs, 1998).

1.2.6 Adaptation for occupation of tropical forests

McKinney (2006) notes that a good number of species are able to persist and even thrive well in urban landscapes. This is despite the negative effects of urbanization, such as habitat fragmentation and loss, pollution as well as introduction of human induced stressors in the ecosystem (Grimm *et al.*, 2008). McKinney (2008) specifically points out that urbanization directly affects mammals, clearly seen in their abundance and diversity, as a possible consequence of habitat destruction and fragmentation. Animals may be extirpated in urban areas due to a lack of the necessary landscape features that they rely on (Gilbert, 1989; Haupt *et al.*, 2006)

Recent studies indicate that urban landscapes continue to offer great opportunities in the conservation of species that could otherwise be exterminated (Frankie and Ehler, 1978). In Kenya, urban green spaces like City park, Karura forest and Ngong forests have been shown to harbor many important species critical to the ecosystem (Nyambane *et al*., 2016). The critical role of urban green spaces and forests in promoting biodiversity conservation (Jones and Leather, 2012) has resulted in their continual appreciation resulting in their co-option into global action plans that directly touch on biodiversity conservation (Secretariat of the Convention on Biological Diversity, 2012). Following the 1992 Rio Earth Summit on CBD, urban areas have succeeded in eliciting focus towards biodiversity conservation (Cilliers *et al.*, 2004).

1.2.7 Habitat loss and its ecological effects on small mammals

Habitat disturbance irrespective of whether it is human or animal driven, is an important factor that can lead to changes in population density and community structure of small mammals especially rodent and shrews. There is growing concern over increased pressure from climate change (Hulme *et al*., 2001) as well as human activities like habitat change (Sinclair, 2008) on the East African ecosystems. As urban centers continue to grow and develop, biodiversity on the other hand continues to be adversely affected to the level of extirpation of many local species (Marzluff, 2001). Urbanization has tended to push the native species out replacing them with some exotic ones, inadvertently affecting the ecosystem biological distinctiveness through a process of where extinctions and invasions tend to propagate similarity of several locations over time (Blair, 2001). For many taxa, the general trend is that the population of nonnatives increases as one nears urban centers, whereas local species populations lower (Blair and Launer, 1997).

Loss of suitable habitat is a major setback on biodiversity conservation in general. Its adverse effects range from negative impact on species richness (Findlay and Houlahan, 1997), the restricted distribution and abundance of organisms (Gibbs, 1998), erosion of genetic diversity (Gibbs 2001), reduced population growth rate (Donovan and Flather, 2002), reduction of trophic chain length (Komonen *et al.,* 2000), alteration of species interaction (Taylor and Merriam, 1995), reduced breeding success (Kurkie *et al.,* 2000), restricted dispersal (With and Crist, 1995) and enhanced predation rate reduction (Hartley and Hunter, 1998). These are large and ecologically important effects, with serious consequences at national and regional levels.

With habitat loss, organisms settle in suboptimal habitats that would be less preferred (Hilbert *et al.,*1981) because of unavailability of food and other survival necessities. Small mammals can and indeed have provided reliable ecological feedback on impacts of forest management processes at regional levels (Kaminski *et al.,* 2007). Biodiversity research will generally include the exploration of a species' temporal as well as spatial distribution patterns (Zhou *et al.,* 2000).

1.2.8 Urbanization and its effect on small mammals

Developed countries have been noted to be have a downward trend when it comes to urbanization, whereas in developing countries which are known to be refuges of many biodiversity hotpots (Myers *et al.,* 2000), it seems to be declining. As urban centres continue to grow and develop, biodiversity on the other hand continues to be adversely affected sometimes even to the level of extirpation of various local species (Marzluff, 2001). It has been documented that the degree of fragmentation coupled with regeneration level collaborate to impact the structure of forests, thereby affecting species presence and distribution through influencing habitat suitability (Tews *et al*., 2004). Small mammals respond differently to fragmentation. There are those that remain in the isolated patches occupying non-native vegetation where there is forest transformation. Others will be limited to the expansive and interlinked forest stands (Pires *et al*., 2002).

1.2.9 Influence of habitat characteristics on small mammals

Habitat structure has been shown to affect small mammals' presence and populations in forest ecosystems (Lawlor, 2003). According to Greenberg *et al.* (2006), small mammals tend to prefer relatively more open forests which contain more food resources. This is greatly influenced by canopy cover. The implication is that forests with high canopy may tend to harbor lower abundances of small mammals.

Distribution as well as the density of small mammals is affected by vegetation cover (Ajayi and Tewe, 1978). Wiens (1989) purports that vegetation structure and its variation from place to place has an impact on animal distributions. What remains unclear nonetheless is the precise interconnection (Turner *et al.*, 2001).

Small mammal community structures can be studied via many approaches and one approach focuses on microhabitat usage assessment (Schoener, 1974). According to various studies this is because it is considered very important in niche differentiation (Yahner, 1982). Investigation into the microhabitat characteristics generates data that can be used to test whether there is any correlation between the environmental factors and the population patterns observed (Hamilton, 1974). Increased mortality as well as lowered small mammal abundances generally are connected with adverse weather conditions (Cheeseman, 1977). When the weather is adverse the small mammals have been reported to either change to habitats of lower quality (Gurskey, 2000) or change their reproductive physiology and behavior (Neal, 1984). Microhabitat studies also provide information that is very helpful in the designing of conservation management plans of other mammals as well.

Small mammals also emerge tops as the most numerous and diverse yet least known category of mammals. They are ubiquitous and often play a crucial role in maintaining the healthy functioning of ecosystems. Even with these facts, around 437 species of small mammals face extinction. IUCN's Small Mammals Specialist Group (SMSG) has as its main agenda ensuring that there is increased knowledge to all people concerning the world's 2800 small mammals, besides fronting and promoting serious conservation action. SMSG has noted that the top twenty threatened small mammals require urgent surveys so as to inform appropriate conservation action in a bid to prevent extirpation and possible extinction. The work must be cascaded down to the local scale so that the conservation knowledge can be used in forest management at the local level.

Biodiversity conservation suffers its greatest obstacle from lack of basic ecological data from urban and rural green spaces (Hong *et al.,* 2005). This calls for appropriate survey and documentation of what our urban forests harbor. This will then go a long way to inform appropriate conservation decisions of these invaluable forest fragments on private as well as public green spaces.

Small mammals living in forest fragments in Nairobi and other urban areas in Kenya, require research attention because of the imminent risks of transfer of zoonotic diseases to domestic animals and people. They will normally exhibit a grazing type of food chain where energy flows from the autotrophs that produce it, then to the herbivores, up to the carnivals or omnivores that consume the latter. Many small mammals, including shrews, mice, hyrax, squirrels, hedge hogs, mongooses, genets and bats, are known to be reservoirs of parasites and diseases that can have serious health effects on domestic animals and people (Jones *et al.*, 2008). Domestic animals and people can interact with small mammals through their movement into the forests in search of resources while the small mammals have the potential to invade human settlements. This study is intended to shed light on the relative abundance of small mammals in Oloolua forest, their distribution and species diversity as well as the relationship between the small mammals' community structure and habitat variables in the native and exotic forest types in the study area.

1.3 Problem Statement

With unprecedented increase in human population in the past decade, there is increased pressure to invade and utilize natural forests in ways that are ecologically detrimental. Natural forests in urban areas are getting more insularized because of human encroachment and transformation of the land to other uses, such as roads, housing estates, golf courses, cemetery and other uses. Oloolua forest lies on prime settlement land south of the city of Nairobi. The land is attractive to housing estate developers. The forest resources, including timber, fuel wood, wild honey, medicinal plants, and building stones are increasingly being exploited by people in the rapidly urbanizing peri-urban area of Rongai and Ngong. The biodiversity associated with the forest is seriously threatened with displacement and extirpation. There is also growing risk of wild fire, which threatens both plants and animal species, especially small mammals and reptiles. Habitat destruction could lead to the migration of small mammals into peoples' compounds and this increased interaction between wild animals and domestic animals as well as people from the surrounding settlements is likely to lead to enhanced transmission of zoonotic diseases. Small mammals are known to play an important role in the transmission of parasites and diseases from the wild animals to humans and domestic animals.

The threats described above apply to Oloolua forest. There are clear stands of natural and exotic forest in which changes brought about by human activities are visible. Quarrying for building stones, frequent wild fire and selective logging of wood have significantly affected forest size, vegetation structure and regeneration. The presence, abundance, diversity and distribution of small mammals can indicate changes in the structure of the forest ecosystem and its capacity to regenerate and provide essential ecological services to residents of Nairobi and neighbouring Kajiado county. This study was aimed at shedding light into these issues and provide data and information needed for effective management of Oloolua forest. Knowing the small mammal species present provides biological tools for long term monitoring of the health of the forest ecosystem.

1.4 Research Justification

The presence of small mammals in an area directly impacts the ecology of that area. Small mammals act as predators for ground nesting passerine birds as well as prey for higher level carnivores, such as mongoose, jackals and owls in the ecosystem. They are also major agents of change responsible for altering landscapes, especially the subterranean mole rats. Beavers tend to cut down trees to construct their own dams while the large cane rats manipulate wetland vegetation. Despite their important role in energy transfer and nutrient cycling in the aquatic and terrestrial ecosystems, small mammals have largely been neglected by conservation planners even though ample evidence existing indicates that they are facing serious human pressures. Due to their restricted distribution, they are likely to be negatively affected by climate change impacts which are also likely to be augmented by human activities in specific ecosystems. In urban forests, wild small mammals face the risk of displacement by human settlements and infrastructural development. The displaced animals may opt to find refuge in habitat patches, such as gardens and hedge rows within human settlements and hence increasing the chances of interaction with domestic animals and people. The consequence is the risk of transmission of zoonotic diseases to pets, livestock and people. Small mammals are better protected in their natural forest habitat but we can only conserve that which we know. The Kenyan Wildlife Conservation and Management Bill 2013 classifies 19 small mammal species as worthy of being conserved. This is because they are either vulnerable (15 species) or endangered (4 species). The fact that no comprehensive data and information exists on the small mammals in Oloolua forest formed the basis of conducting this research. This study sought to generate baseline data on the distribution and abundance of small mammals. This information is very key in judging the extent of climate change and its adverse impacts on the biodiversity of urban forests. The results of this study are key in increasing scientific knowledge, promoting conservation of small mammals as well as setting the stage for possible continuous ecological change monitoring in Kenya's urban forests.

1.5 Research Questions

1. What is the abundance, diversity and distribution of small mammals in Oloolua forest?
2. What is the seasonal variation in abundances of small mammals of Oloolua forest?
3. Does habitat structure affect the abundance and distribution of small mammals in the forest? If so, how?

1.6 General Objective

The general aim of this study was to assess the abundance and distribution of small mammals in Oloolua forest in Nairobi, Kenya.

1.7 Specific Objectives

1. To determine the abundance, diversity and distribution of small mammal species in Oloolua forest
2. To determine the seasonal variation in small mammal abundances in Oloolua forest

3. To determine the effect of habitat structure on small mammals in Oloolua forest

1.8 Research Hypotheses

1. There are no differences in the small mammals' abundance, diversity and distribution in different habitats, seasons and levels of disturbance in Oloolua forest.

CHAPTER TWO: STUDY AREA, MATERIALS AND METHODS

2.1 Study Area

This study was carried out in Oloolua forest reserve, that is in close proximity to a habited environ. There are several settlements and establishments around the forest. The vegetation in Oloolua is principally forest, characterized by continuous stands of trees that are ten or more meters tall and that have interlocking crowns; or woodland characterized by open stands of trees at least eight meters tall and having a canopy cover of 40% or more (Beentje, 1994).

2.1.1 Brief history and location of Oloolua forest

This research work was done in Oloolua forest while lies in the coordinates (S1º 22' 0.12", E 36 º 42' 0"). Oloolua forest lies about 20 kilometers to the south west of Nairobi town, in the posh suburb of Karen. The forest has distinct habitats of woodland forest, indigenous forest, the regenerating quarry and lastly the eucalyptus plantation forest. The four fall into two major classifications- less disturbed forest stand (indigenous and woodland) and the disturbed stand (quarry and eucalyptus habitats). The natural forest covers a total area of 479.6 hectares while the remainder is under poorly managed eucalyptus forest plantation.

The study area is encompassed by various locations, viz. Bulbul, Rongai township and Karen to the north, south and west respectively (Figure 1). These are all built settlements that make Oloolua forest an island. The population in the neighbouring locations is high, and anthropogenic activities especially in Gataka and Bulbul are intense. These includes farming, animal husbandry, and very many infrastructural developments. Active quarries in Gataka area are a common sight. The quarry habitat in the study area was brought about by intense stone quarrying that was in operation for several decades (Gatheru *et al*, 2000). Other threats the forest faces include pollution caused by dumping of solid waste from picnicking visitors and local people from the nearby settlements. Over-harvesting of forest products, including medicinal plants and firewood was also rampant. Livestock herders from the neighbouring Kajiado county graze their livestock in the forest, especially during the dry period.

Oloolua forest serves as an important habitat corridor linking the Nairobi National park and Ngong hills which are both critical wildlife coverts (Gatheru *et al.*, 2000). It happens that it is part of the once continuous northern belt composite of upland dry forest fragments. The six or so fragments making this one-time block all occur in the peri-urban centres within Nairobi and can confidently be regarded as important refuges of wild flora and fauna (Gatheru *et al.*, 2000).

2.1.2 Climate

Oloolua forest experiences a bi-modal distribution of annual rainfall with the long rains falling from March to June and the short rains fall from October to December. With rainfall ranging between 550 to 1000mm per annum, with most areas receiving below 600mm, and even this is unpredictable. The area can be said to be marginal since it enjoys below average quantities of rainfall. The mean monthly temperature ranges between 20ºC and 32ºC.

2.1.3 Vegetation types

Scholars who have worked in Oloolua forest in the past describe it as a dry upland forest composed of Croton stands (Lind and Morrison, 1974); or as a dry and intermediate forest (Trapnell and Brunt, 1987).

Pittosporum viridiflorum, Warbugia ugadensis and *Brachylaena huillensis* are species of medicinal significance which have been documented in the past, and noted to be decreasing in number. Only the latter (*Brachylaena huillensis*) was documented in the current research.

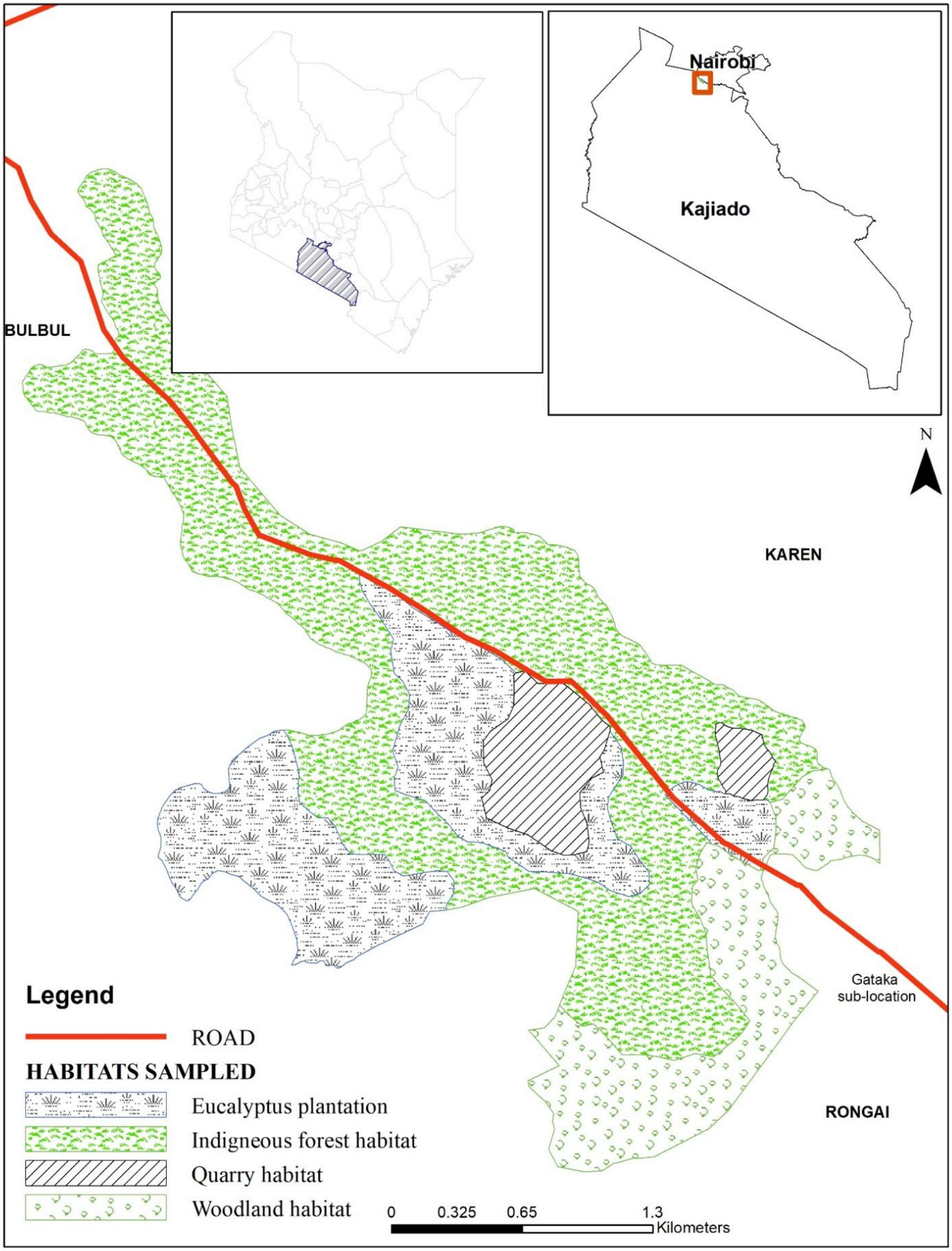

Figure 1: A map of the study area showing the distribution of different habitats.

2.1.4 Forest fauna

Previous work in the forest documents the presence of several species that are of global and local interest. These include leopards *(Panthera pardus),* buffaloes *(Syncerus caffer),* bushbucks *(Tragelaphus scriptus),* red forest duiker *(Cephalophus natalensis),* grey duiker *(Sylvicapra grimmia),* Dikdik *(Madoqua kirkii),* Warthog *(Phacochoerus aethiopicus),* bush pigs (*Potamochoerus lavartus),* Giraffes *(Giraffa camelopardalis tippelskirchi),* Spotted hyenas *(Crocuta crocuta),* Sykes monkey *(Cercopithecus albogularis),* Vervet monkey *(Cercopithecus aethiops)* and the Greater Galago *(Otelemur garnettii)* (Gatheru *et al.,* 2000).

2.2 Study design of small mammals

Stratified random sampling was applied in establishing four transects in the distinct and major vegetation types in the forest. A similar sampling protocol was used in each of the vegetation clusters so as to increase captures of small mammals that are represented in each cluster.

2.2.1 Rodents, shrews and small carnivores' sampling

A 100 m long transect was established in each vegetation type and was maintained throughout the sampling period. Trap stations were positioned at intervals of 10 m in the various habitats (Gurnell and Flowerdew, 1990). In each trapping station, different types of traps were used to increase animal captures (Smith *et al*., 1975). A mixture of 10 collapsible aluminium medium-sized Sherman traps, (H.B. Sherman Traps Inc., Tallahassee, Florida, USA) (Figure 2), 20 snap traps (Victor snaps measuring 17.5 × 8.5 and museum specials 14 × 7cm) (Figure 3), 5 pitfalls (5litre buckets buried in the ground such that the top of the bucket was flush with the ground) (Figure 4) and 1 live wire tomahawk (Figure 5) were used in each transect to facilitate sampling of rodents and shrews. Sherman traps were used to target smaller species of rodents as they have been shown to be more efficient with those species (Schittini *et al.* 2002), pitfalls for shrews

(Goodman *et al*.,2001), snap traps targeted larger species of rodents, whereas tomahawk mesh wire were used to target the largest rodents e.g. *Cricetomys ansorgei* and the small carnivores. A total of 36 traps were therefore placed in each 100 meter transect to facilitate capture of small mammals. Sherman and snap traps were baited using a mixture of peanuts and oats whereas tomahawks were baited with sardines (Rosatte *et al*., 2011).

Traps were checked twice a day, early in the morning (0730-0830 am) and in the evening (1730-1830 hours). Sampling of rodents, shrews and small carnivores was done for a total of 90 nights (45 in the dry and 45 in the wet season) in each transect. The term trap night is used to refer to one trap (or bucket) in operation for one 24-hour period i.e. 1900 hours to 1900 hours) to quantify sampling effort.

Opportunistic sightings were also employed and any species sighted was recorded and categorized in relation to the habitat where it was detected.

	A medium sized live Sherman trap, 23 × 9.5 × 8cm in size; best for trapping medium sized rodents.

Figure 2: Sherman trap set at the base of a tree in Oloolua forest, south of Nairobi

(a)	(b)

Figure 3: Figure 3(a) shows a trapped rodent in a museum special snap trap while Figure 3(b) shows a bird trapped accidentally by a victor trap while foraging on the ground.

A 5L bucket used for trapping the smallest of small mammals some as small as 5g in weight

Figure 4: Pitfall trap (bucket) with bait, leaf litter and a shrew trapped in it.

A Tomahawk trap, best for trapping small carnivores and the larger rodents like the giant pouched rat found in Oloolua

Figure 5: A Tomahawk cage trap used to capture large rodents and small carnivals

2.2.2 Bat survey

Sampling of bats followed a uniform protocol in each sampling site to capture bats (O'Farrell and Gannon, 1999): One mist net measuring (3×12m) (Figure 6) was erected in each habitat along observed bat flyways as well as forest trails used by wildlife (Kunz and Kurta, 1988). Nets were opened at 1900 hours and remained open for 9 hours each night for four consecutive nights (36 net hours per habitat) before being moved to a new location. This approach resulted in a total effort of 2160 net hours. In nights when there was downpour sampling still continued except for nights when it was too heavy a downpour and in the event that it continued pounding in excess of an hour. This would then necessitate a halting of the sampling which would later resume in case the rains subsided. Identification of bats involved identification using morphological characteristics as well as dentition differences. Standard identification keys were used to facilitate this process (Meester and Setzer, 1971) as well as relevant field guides (Kingdon, 2013; Monadjem *et al.*, 2010). Handling of captured animals was done following protocols stipulated and recommended by the American Society of Mammalogists (Sikes and Gannon, 2011).

Captured small mammals (rodents, shrews and bats) were identified following established taxonomic nomenclature (Kingdon, 2013), weighed, and the state of the vagina (closed or perforated) or the testes' position (scrotal or abdominal) noted so as to determine their breeding status. The following body measurements were then taken: head body length, tail, ear and hind foot length (and forearm length for bats). An ear notch was made on the left ear for ease of identification in the event a specimen was recaptured. A few species which could not be identified in the field were collected as voucher specimens and deposited with Mammalogy section of the National Museums of Kenya for further identification. The voucher specimens taken to the museum were preserved in 70% ethanol awaiting taxidermy and preparation as study skins and/or complete skeletal material for the Mammalogy and Osteology collections respectively.

(a)	**(b)**

Figure 6: Mist net set across the forest trail during the day with no capture (6a) and the same mist net at night with a captured bat (6b)

2.3 Assessment of habitat characteristics

Oloolua forest is a mosaic of four different forest stands of varying disturbance, succession and regeneration levels. The four habitats are indigenous forest, woodland, quarry and eucalyptus. The first two can be categorized as undisturbed stands and the other two as disturbed habitats. The regeneration and succession levels in the disturbed stands are however high.

Habitat characterization can be at the macro or micro level, each having great influence on the small mammals' abundance and distribution. A mixture of the two was used in assessing the habitat characteristics.

The habitat characteristics were sampled strategically and randomly in all vegetation categories. A modification of the protocol described by Kaminski *et al.* (2007) was used. Characteristics measured were both at the macrohabitat level (canopy cover, canopy height and diameter at breast height) as well as at the microhabitat level (% basal cover, leaf litter depth and rock outcrop density) that are known to influence small mammal distribution and abundance in a particular area. Characterization at the macrohabitat level was done through the use of three quadrats (10×20m) which were placed along the already established 100m long base transect, whereas at the microhabitat level a quadrat of size $1m^2$ was used.

2.3.1 Canopy cover

Canopy cover is defined as the proportion of forest floor covered by the vertical projection of tree crowns (Jennings *et al.*, 1999). Its relevance surfaces especially since it is considered a very useful indicator ecologically in a number of ways including estimating leaf area index (LAI), animal plant habitat discriminator, as well as forest floor assessment in terms of the amount of light reaching it as well as the prevalent microclimate (Lowman and Rinker, 2004).

In the current study, four digital photographic images of the canopy were taken at each sampling point. These were then transformed into black and white images, and analysed using the Gap Light Analyser Program as explained by Frazer *et al*., (1999) to help verify the proportions of no light penetration (black pixels) relative to light penetration (white pixels).

2.3.2 Canopy height

The canopy height exactly above each trap station was measured accurately using a digital height meter. The average of five height readings was taken as the final reading so as to have a more generalised value of the canopy height.

2.3.3 Tree size variation (Diameter at Breast Height)

The circumference at a height of 130 centimetres (breast height) of all woody species encountered within the marked quadrat along the transect was measured using a graduated tape and recorded to the nearest centimetre. All woody species that were buttressed had all their buttresses measured at the said height and the sum of the various circumferences recorded. These were thereafter converted to DBH by dividing by *pi* or a constant value of 3.14.

2.3.4 Percent basal cover

Percent basal cover was determined using a wire mesh quadrat measuring (1m*1m) and having 100 eyelets- each space representing 1%, a modification of the protocol described by Freitas *et al.,* (2002). The quadrat was placed on top of the trap position and all small squares having grass (not bare ground) or any other vegetation were counted and the total recorded as the cover.

2.3.5 Litter Depth

Litter depth specifically around the sampling station on a quadrat of 1m by 1m was measured using a wooden stick that was graduated to the nearest centimetre following a modification of a protocol described by Dalmagro and Vieira (2005). Leaf litter depth was taken at four random places on the wire mesh quadrat ($1m^2$) and the mean determined and recorded as the leaf litter depth. The random numbers were generated using a mobile phone application called Random UX and a reset done every time a station was completed.

2.3.6 Ground morphology

The ground morphology was assessed by determining the rock outcrop density of each plot along the transect. Rock outcrop density was determined by visually counting the presence of distinct rock outcrops occurring within each quadrat of 10*20 meters.

2.4 Data exploration and analyses

A decrease in trapping efficiency will most likely be caused by traps being sprung or disturbed, most likely by the targeted animals or by any other cause. This therefore calls for a correction since the overall trapping effort is reduced as each trap is sprung/disturbed.

The method described by Nelson and Clark (1973) was used to account for both sprung traps as well as those predated upon. The formula $CE = A \times 100/(TU - IS/2)$, where CE = catch per effort, A number of animals captured of the desired species, P - number of trapping intervals, I - length of trapping interval, N - number of traps, S - total traps sprung by all causes and $TU = P \times I \times N$ (number of trapping units).

Species richness was estimated as the number of species caught in each habitat type. Data was checked for normality of distribution and homogeneity of variances (Zuur *et al*., 2010) and wherever necessary log transformed to achieve normality (Axelsson *et al.*, 2011). Data that was collected in this study included number of species that were encountered in Oloolua forest, the abundance of the small mammals, and captures across the wet and dry seasons. All data on species that were not trapped using standard protocol was not subjected to any inferential data analysis. Relative abundance of species actually captured was calculated as the number of individuals captured for a particular species divided by the total number of individuals of all species captured.

Sex ratios were tested whether they differed from 1:1 through the application of a chi-square test. Analyses were performed using Paleontological Statistics PAST (version 3.1). Species diversity was determined using the Shannon-Weiner index given by the formula $H' = -\sum (P_i * \ln P_i)$ where H' is the diversity index; P_i is the proportion of representation by species *i* and ln is the natural logarithm.

A two tailed student's t-test was used to test if there was a significant statistical difference in the captures between the two seasons.

A one-way analysis of variance (ANOVA) was used to test for overall differences in captures amongst the four different habitats as well as differences in the habitat characteristics across the different habitats. Levels of significance (α) of all tests were determined at P=0.05.

CHAPTER THREE: RESULTS

3.1 The small mammal community of Oloolua forest

3.1.1 Species composition

The 90-day sampling exercise recorded a total of twelve small mammal species in Oloolua forest reserve. These 12 species comprised of nine from the standard trapping techniques and three from opportunistic surveys (Table 1). Those from standard trapping techniques belonged to three orders, viz. Rodentia- 42.78%; Soricomorpha- 2.76%; and Chiroptera- 53.46% (Figure 7). A total of 12,938 corrected trap nights (12960 total trap nights) and 2160 net hours realised 101 rodents and shrews and 116 bats (images of select taxa are presented in Figure 8) respectively. The mean trapping success was 0.781% for rodents and shrews, and 5.417% for bats.

Table 1: Species composition and taxa of individuals captured in Oloolua forest

Order	Family	Species	Common Name	No.
Rodentia	Sciuridae	*Paraxerus ochraceus*	Ochre bush squirrel	32
	Nesomyidae	*Cricetomys ansorgei*	Southern giant pouched rat	47
	Muridae	*Gerbilliscus boehmi*	Robust gerbil	6
		Lemniscomys striatus	Zebra mouse	7
		Mus spp	Common mouse	3
Soricomorpha	Soricidae	*Crocidura spp*	White toothed shrew	6
Chiroptera	Pteropodidae	*Epomophorus wahlbergi*	Epauletted fruit bat	108
	Nycteridae	*Nycteris thebaica*	Slit-faced bat	1
	Vespertilionidae	*Neoromicia nana*	Pipistrelle bat	7
Primates	Galagidae	*Otolemur garnetti kikuyuensis* *	Small eared galago	*
Carnivora	Herpestidae	*Herpestes sanguineus* *	Slender Mongoose	*
		Ichneumia albicauda *	White-tailed mongoose	*
Total				217

* :- represents individuals opportunistically encountered

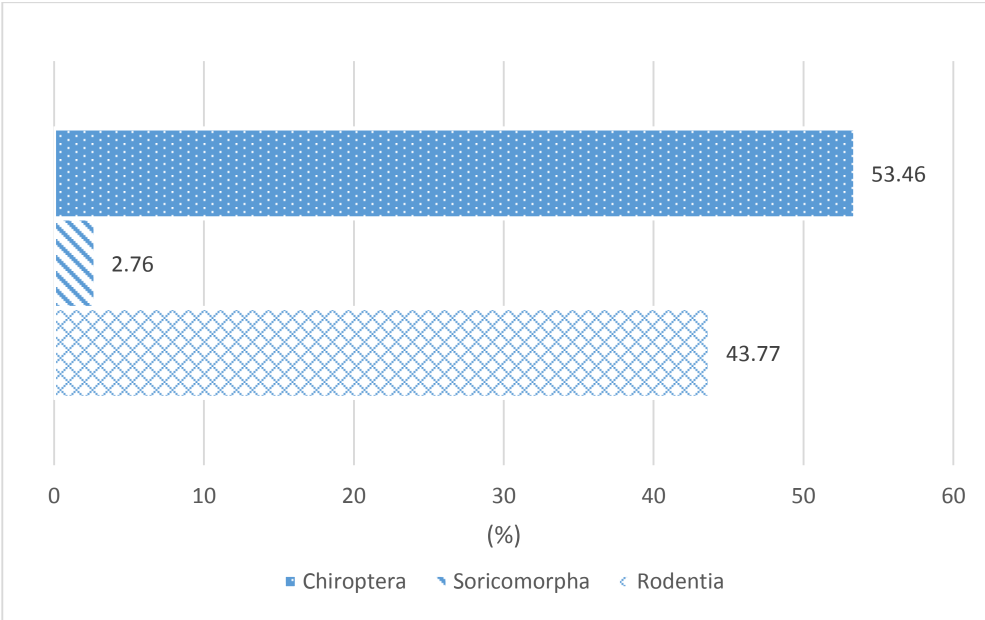

Figure 7: Percentage distribution of major orders of small mammals of Oloolua forest

Figure 8: Photographs of selected small mammals of Oloolua forest, Kenya

	Measurements: Head Body length (HB): 90–140mm. Tail length: 95–150mm. Weight: 18–70g.

Figure 8a: Zebra mouse *Lemniscomys striatus*

This is a mega-bat, inhabiting mainly forests and forest edges and preferring woodland and savannah areas, resident in Africa

Measurements: Head Body length (HB): 125-250mm; Weight: 40-120g

Figure 8b: Epauletted fruit bat *Epomophorus wahlbergi*

One of the most common and diverse shrews in Africa

Measurements: Head Body length (HB): 45–140mm. Tail length: 45–90mm. Weight: 11–40g.

Figure 8c: White toothed shrew *Crocidura spp*

	Very small bats that feed on insects. Measurements: Head body length (HB) 39–57mm; Forearm length (FA) 22–39mm; Weight (W) 3.5–10.5g. Note that the whole bat sits on the thumb of a human being

Figure 8d: Pipistrelle bat *Neoromicia nana*

3.1.2 Small mammal abundance and distribution across habitats

The most dominant volant (able to fly) species was *E. wahlbergi*, whereas amongst the non-volant, *C. ansorgei* was the most dominant. *L. striatus* was captured in the woodland and eucalyptus habitats, whereas *Mus spp* was captured in all other habitats except indigenous habitat. *N. thebaica* was exclusively captured in the indigenous habitat. It was also observed that four species were encountered in all the four habitats, viz. *P. ochraceous, C. ansorgei, Crocidura spp* and *E. wahlbergi.* Two pairs of species (*G. boehmi* and *Crocidura spp*; and *L. striatus* and *N. nana*) had equal abundances of six and seven respectively (Figure 9). The general distribution of the species was that 7 were encountered and recorded in two habitats (indigenous and eucalyptus), 5 were recorded in the quarry habitat, and 8 were found in the woodland region.

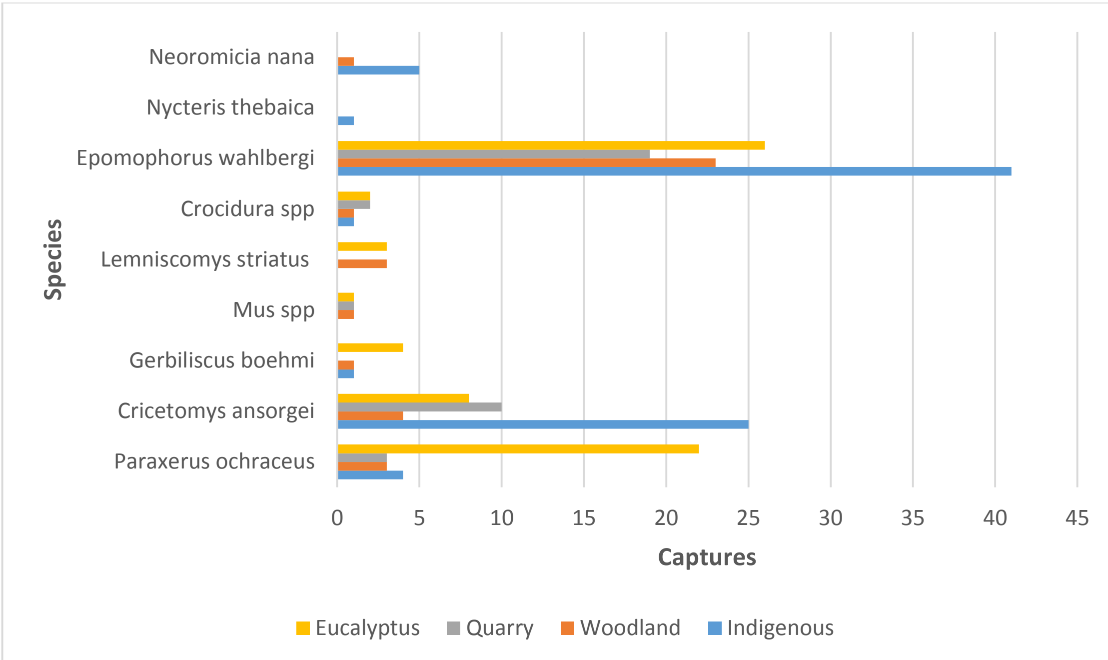

Figure 9: Frequency of occurrence of small mammal species in different habitats in Oloolua forest, Kenya

Across the habitats, the highest number of captures were made in indigenous forest which had a capture of 78, followed by eucalyptus 67, woodland 38 and lastly quarry 34 (Figure 10).

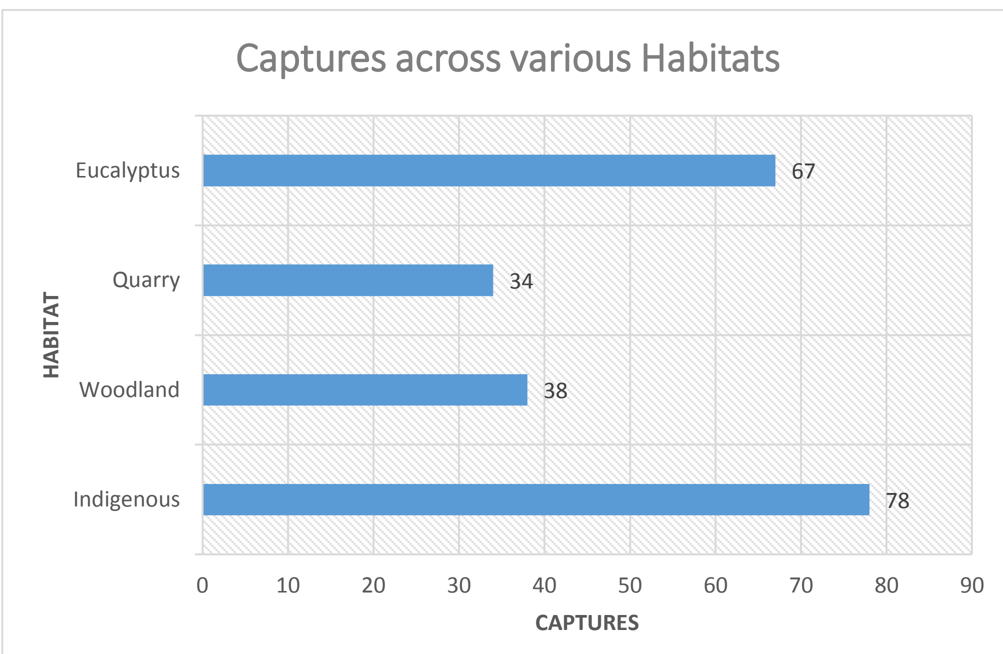

Figure 10: Captures across all the four habitats studied in Oloolua forest, Kenya

There was no significant difference between individuals captured in the four habitats during the sampling period given by an ANOVA result of $F_{(3, 35)} = 0.5209$ with $P > 0.05$. This therefore means that the apparent difference in the number of captures across the four habitats were not statistically significant.

3.1.3 Species diversity of the small mammals

When data from all the habitats was pooled to have just two groups (less disturbed and disturbed habitats), the Shannon Weiner species diversity was 1.477 and 1.594 respectively (Figure 11). The diversity index for the less disturbed habitats was lower than the diversity for the disturbed habitats.

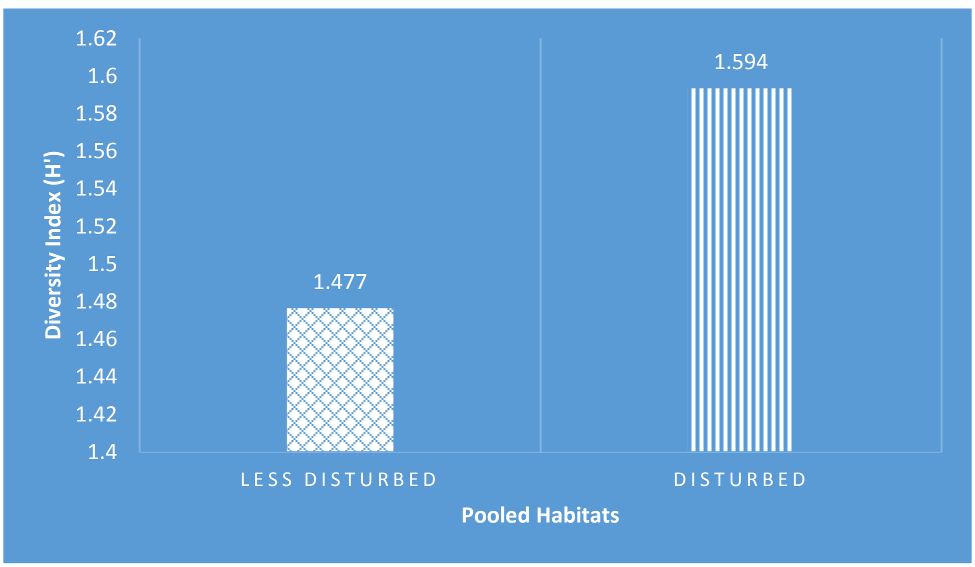

Figure 11: Diversity indices of small mammals for the pooled captures in pooled habitats

However, when the habitats were considered separately the diversity indices were 1.424, 1.697, 1.569 and 1.656 respectively for indigenous, woodland, quarry and eucalyptus habitats respectively (Figure 12). It was noted that the diversity index that was highest (1.697) was from a less disturbed habitat (woodland), and the lowest diversity index (1.424) was also from a less disturbed habitat (indigenous).

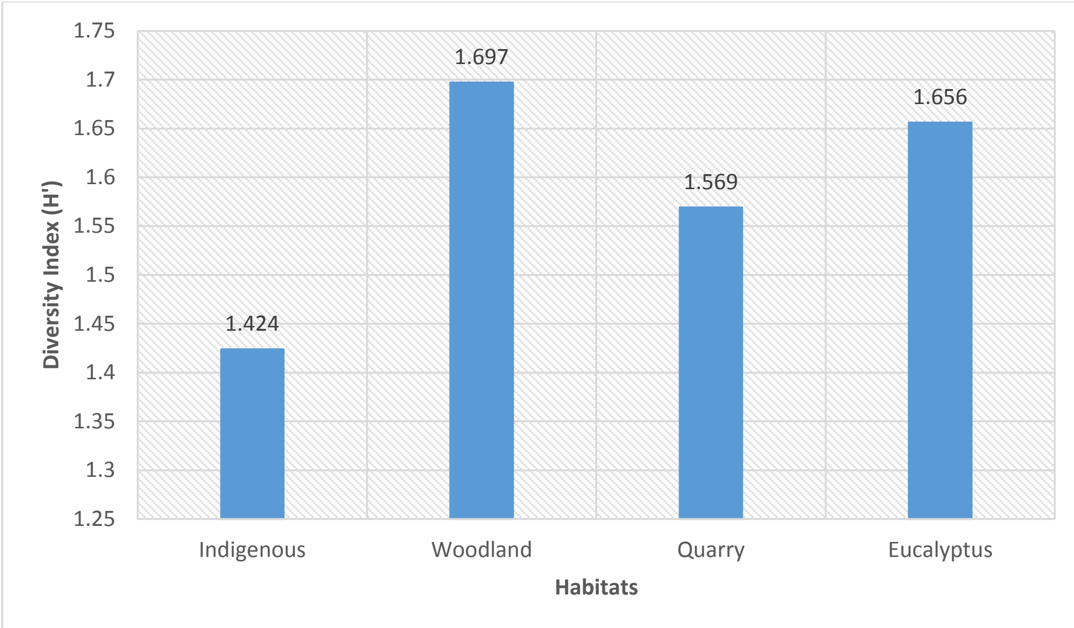

Figure 12: Diversity of small mammals in the four habitats in Oloolua forest

3.1.4 Age structure of small mammal populations in various habitats

Both adults and sub-adults specimens were captured in all habitats. The general trend was that in all habitats adults far out-numbered the sub-adults. (Figure 13). The higher number of adults may be attributed to the higher foraging/ flying power of adults as compared to the sub-adults.

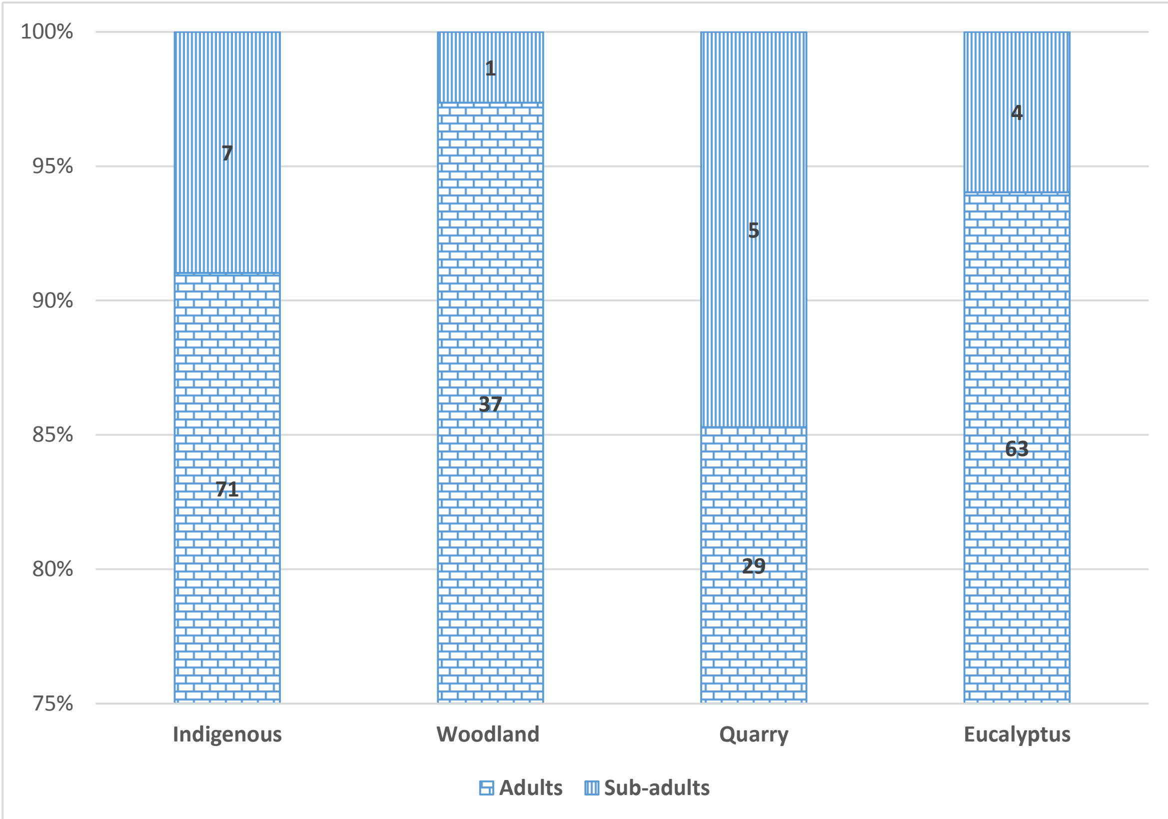

Figure 13: Age structure of captured small mammals in the study site

3.1.5 Sampling effort and trapping success of the survey

The sampling effort was spread evenly across habitats and throughout the entire sampling period, covering a total of 90 days for rodents and shrews, and 60 days for bats. A trap success of 0.433-1.269% (average of 0.7805) for rodents and shrews and 3.333-8.704% (an average of 5.3703%) for bats was realised during the trapping period (Table 2).

Table 2: Trapping success of small mammals in Oloolua forest, Kenya

Habitat	Captures: Rodents & Shrews	Corrected Trap nights	Trap success (%)	Captures: Bats	Net hours	Trap success (%)
Indigenous	31	3238	0.957	47	540	8.704
Woodland	14	3232	0.433	24	540	4.444
Quarry	15	3237	0.463	18	540	3.333
Eucalyptus	41	3231	1.269	27	540	5.000
Totals	101			116		
Average			0.7805			5.3703

3.1.6 Populations of major small mammal species captured in Oloolua forest

The population structures of three major small mammals; namely *C. ansorgei*, *P. ochraceus* and *E. wahlbergi* were examined in detail. The rest of the species had relatively low captures and hence their populations were not analyzed further.

3.1.6.1 Population structure of the rodent Cricetomys ansorgei

The small mammal *C. ansorgei* was the most populous amongst all captured non-volant small mammals making up 21.66% of total captured individuals, and 49.47% of those captured that were of its order. The giant pouched rats were the most widely dispersed of all rodents inhabiting all four habitats. Their abundances across the four habitats were 25, 4, 10, and 8 in the indigenous, woodland, quarry and eucalyptus habitats respectively. Of all captured individuals 38 were found to be adults whereas nine were sub-adults. Examination of their reproductive status indicated that 19.15% were breeding, 44.68% were non-breeding, 29.78% were lactating whereas 6.38% were pregnant (Figure 14). The sex ratio of the giant pouched rats for the dry and wet seasons did not differ significantly (χ^2 = 0.1525, d.f = 1, P> 0.05). This implies that there was no significant departure from the expected population sex ratio of 1:1 in both seasons.

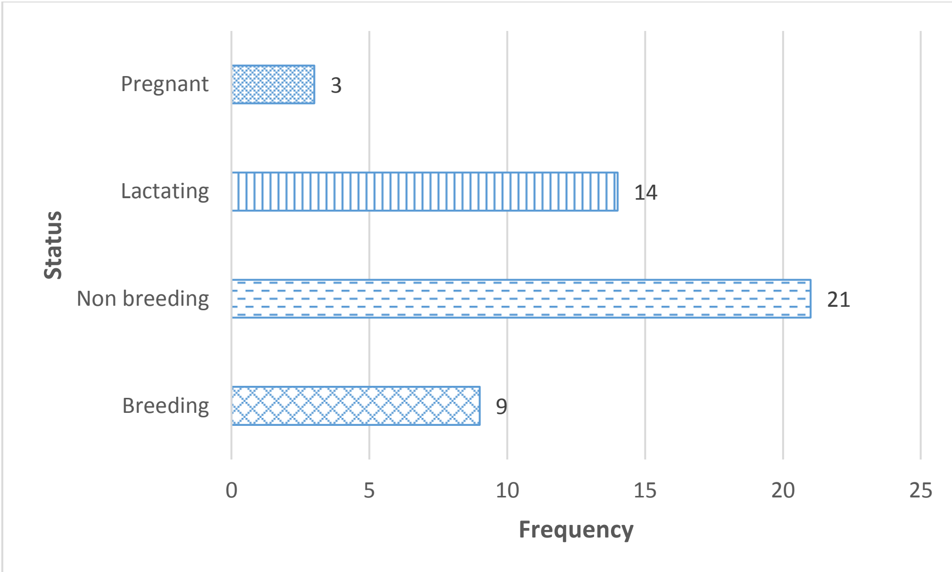

Figure 14: The reproductive status of the rodent *Cricetomys ansorgei* in Oloolua forest, Kenya

3.1.6.2 Population structure of the bat Epomophorus wahlbergi

The small mammal *E. wahlbergi* was the most populous amongst all captured volant small mammals, representing 49.77% of total captured individuals and 93.1% of captured individuals of its order. It belongs to the order Chiroptera and the family Pteropodidae. These epauletted fruit bats were the most widely dispersed of all chiropterans, inhabiting all four habitats. Their abundances across the four habitats were 41, 23, 19 and 26 in the indigenous, woodland, quarry and eucalyptus habitats respectively.

Of all captured individuals 102 (94.44 %) were found to be adults whereas six (5.56%) were sub-adults. Examination of their reproductive status indicated that 83.33% were non-breeding, 10.19% were lactating whereas 6.48% were pregnant (Figure 15).

The sex ratio of the epauletted fruit bats for the dry and wet seasons did not differ significantly ($\chi^2 = 0.0076$, d.f = 1, $P > 0.05$). This implies that there was no significant departure from the 1:1 sex ratio in both seasons.

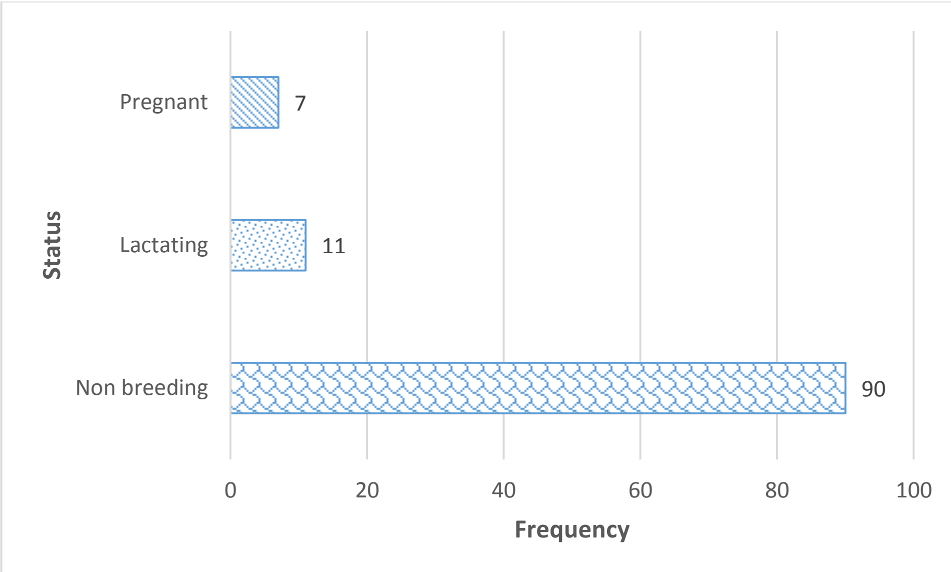

Figure 15: The reproductive status of the bat *Epomophorus wahlbergi*

3.1.6.3 Population structure of the rodent Paraxerus ochraceus

The small mammal *P. ochraceus* was the second most populous amongst all captured non-volant small mammals representing 14.75% of total captured individuals and 32.32% of all rodents captured. It belongs to the order Rodentia and the family Sciuridae. The ochre bush squirrels were also widely dispersed and inhabited all four habitats. Their abundances across the four habitats were 4, 3, 3 and 22 in the indigenous, woodland, quarry and eucalyptus habitats respectively.

All the 32 captured individuals were found to be adults. Examination of their reproductive status indicated that 12.5% were breeding, 78.13% were non-breeding, 6.25% were lactating whereas 3.12% were pregnant (Figure 16). The sex ratio of the ochre bush squirrels for the dry and wet seasons did not differ significantly ($\chi^2 = 0.0253$, d.f = 1, $P > 0.05$). This implies that there was no significant departure from the expected population sex ratio of 1:1 in both seasons.

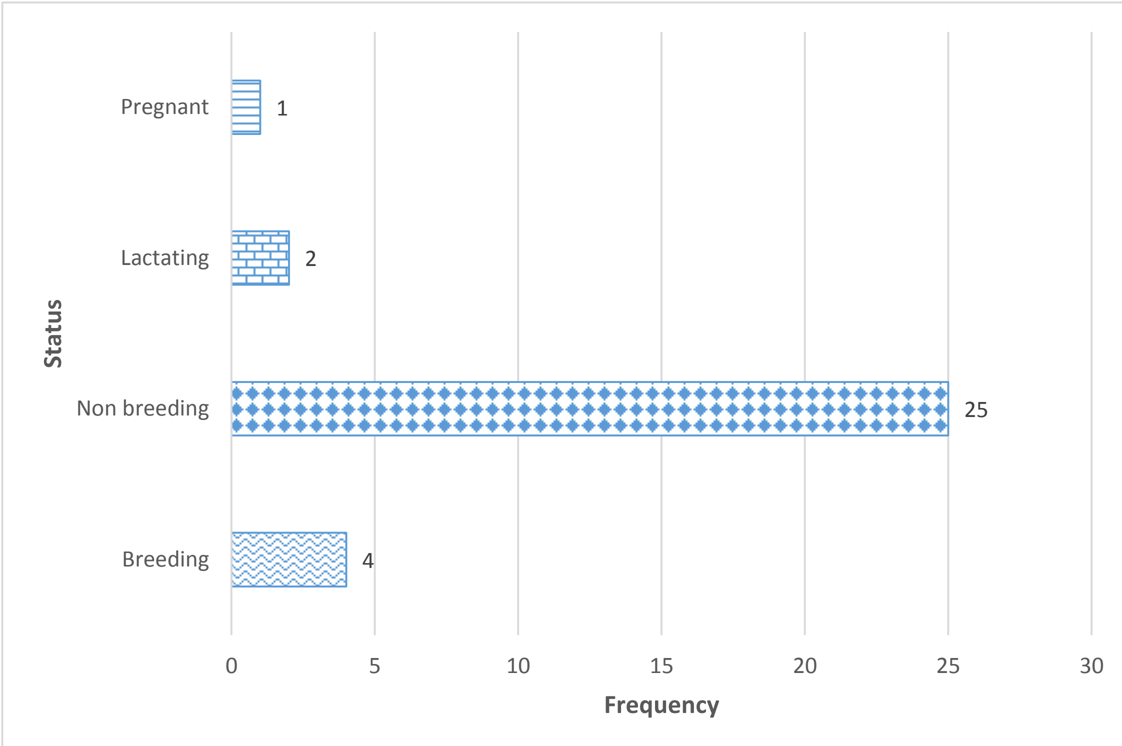

Figure 16: The reproductive status of the rodent *Paraxerus ochraceus* in Oloolua forest, Kenya.

3.2 Seasonal variation of small mammals abundance

It was noted that there were zero captures in both dry and wet seasons for several species: *Mus spp* and *L. striatus* in the indigenous habitat; *N. thebaica* in the woodland; *G. boehmi, N. thebaica* and *N. nana* in the quarry habitat; and both *N. thebaica* and *N. nana* in the eucalyptus habitats (Table 3). Those species which were captured only in the dry season are *P. ochraceus, G. boehmi, Crocidura spp, N. thebaica* and *N. nana* in the indigenous habitat; *Mus spp* and *Crocidura spp* in the woodland habitat and *Crocidura spp* in the eucalyptus habitat. Species not captured during the dry season but were captured during the wet season were *G. boehmi* (woodland habitat) and *Mus spp* (quarry and eucalyptus habitats).

A comparison of the means of captures of all species in the two seasons using a student's t test gave t (9) = -0.03939 with P= 0.96907 >0.05, indicating that there was no significant statistical difference between individuals captured in the two seasons.

Table 3: Seasonal variation of small mammal captures in Oloolua forest, Kenya

Species	Captured individuals across habitats and seasons								
	Less Disturbed				Disturbed				
	Indigenous		Woodland		Quarry		Eucalyptus		
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Totals
Paraxerus ochraceus	4	-	2	1	2	1	13	9	32
Cricetomys ansorgei	6	19	2	2	3	7	4	4	47
Gerbilliscus boehmi	1	-	-	1	-	-	2	2	6
Mus spp	-	-	1	-	-	1	-	1	3
Lemniscomys striatus	-	-	2	2	-	-	2	1	7
Crocidura spp	1	-	1	-	1	1	2	-	6
Epomophorus wahlbergi	31	10	6	16	10	8	4	23	108
Nycteris thebaica	1	-	-	-	-	-	-	-	1
Neoromicia nana	5	-	1	1	-	-	-	-	7
Totals	49	29	15	23	16	18	27	40	217

3.3 Structural habitat characteristics across small mammal habitats

Of the four habitats in the forest, the indigenous forest habitat is the largest in size and was characterised by *Vepris simplicifolia*, *Maytenus heterophylla* and *Elaeodendron buchananii* respectively. The woodland habitat was characterised by *Strychnos henningsii, Vepris simplicifolia* and *Ochna ovata* tree species. Quarry habitat, an old quarry that has undergone regeneration, was characterised by *Olea africana, Strychnos henningsii* and *Vepris simplicifolia.* The eucalyptus habitat was the narrowest as compared to the other three. One tree species (*Eucalyptus botryoides*) was very dominant understandably so because it is a plantation forest. The other two common tree species in the eucalyptus plantation habitat were *Olea africana* and *Croton megalocarpus.*

3.3.1 Canopy cover

Canopy cover ranged between 43% and 75% with the Eucalyptus habitat recording the highest. Woodland had the lowest canopy cover which measured 41.33% below that of the highest (Eucalyptus) habitat. The results indicate that the disturbed habitats had higher covers than the less disturbed habitats. The high canopy cover in the Eucalyptus stand may be attributed to the fact that it is a plantation and the trees are not naturally occurring. There are no paths crisscrossing the plantation thereby resulting in reduced human interference. Upon arcsine transformation, the cover values were tested for significance using one-way ANOVA. The results indicated that there was a significant difference in percent canopy cover among the four habitats ($F_{(3, 139)} = 34.38$ and $P < 0.05$).

Table 4: Summary of the habitat variables measured in Oloolua forest, Kenya

Parameters	Indigenous	Woodland	Quarry	Eucalyptus
% Canopy cover ±SE	51.14±3.05	44.43±2.44	61±1.45	75±1.94
Canopy height ±SE (m)	14.26±0.85	7.43±0.29	13.47±0.62	12.41±0.62
Diameter at breast height ±SE (cms)	21.8±1.77	29.9±2.09	25.06±2.60	24.02±1.37
% Basal cover ±SE	95.2±1.30	71±1.43	70±1.67	80.29±1.70
Leaf litter depth ±SE (cms)	1.10±0.11	0.99±0.07	1.00±0.11	2.06±0.13
Rock outcrop density ±SE	1.17±0.23	1.14±0.08	2.63±0.30	1.2±0.11

3.3.2 Canopy height

Canopy height ranged from between 7 and 15 meters with the Indigenous and Woodland habitats having the highest and lowest recorded heights. It was interesting to note that the regenerating old quarry had very tall trees that had exceeded those in the woodland habitat. The woodland trees may be subject to illegal harvesting from the adjacent *Gataka* informal settlement area. The canopy height values were tested for significance using ANOVA and results indicate there is a significant difference in percent canopy cover for the four habitats ($F_{(3, 139)} = 24.09$ and $P < 0.05$).

3.3.3 Tree size variation (DBH)

The size of trees (DBH) in the study area ranged between 20 and 30 centimeters. Highest DBHs were found in both the disturbed and the less disturbed habitats (Table 4). It was noted that several trees in the woodland were buttressed and this could have contributed to their diameters ending up to be higher than all the rest. It was observed that the tallest trees exhibited the smallest diameters. After arcsine transformation, the DBH values were tested for significance using one-way ANOVA. The results indicate that there was a significant difference in tree sizes (DBH) among the four habitats ($F_{(3, 199)} = 2.897$ and $P < 0.05$). circumference figures were divided by the constant *pi* to convert to DBH, viz., circumference/π.

3.3.4 Percent basal cover

Basal cover was generally high in all the habitats, 70% as the lowest and 95% as the highest (Table 4). The percent basal cover was not affected by whether the habitat was disturbed or less disturbed this being evidenced by the fact that the highest two covers were from the less disturbed and the disturbed habitats respectively. The percent basal cover values were arcsine transformed and then tested for significance using one-way ANOVA. Results indicated that there is a significant difference in percent basal cover among the four habitats ($F_{(3, 139)} = 58$ and $P < 0.05$).

3.3.5 Leaf litter depth

Leaf litter depths ranged between slightly less than one and slightly higher than two. The eucalyptus habitat had the highest leaf litter depth (2.06±0.13), followed by indigenous (1.10±0.11), quarry (1.00±0.11) and finally woodland habitat (0.99±0.07) as shown in Table 4.

The leaf litter depth values in the four habitats studied were tested for significance using one-way ANOVA and results indicated that there was a significant difference in leaf litter depth among the four habitats ($F_{(3, 139)} = 23.75$ and $P < 0.05$).

3.3.6 Ground morphology (Rock outcrop density)

Rock outcrop density ranged between 1 and 3, with the disturbed habitats having higher values than the less disturbed habitats. The ground in the old Quarry habitat had the highest density of rock outcrops, followed by the Eucalyptus habitat, Indigenous and lastly Woodland as shown in Table 4 above. The conspicuously higher density in the Quarry habitat is obviously because the habitat was previously highly exposed due to it being a stone harvesting habitat. The Eucalyptus stand also had a lot of manipulation done on it during the reclamation period.

The rock outcrop density (per square meter) values after arcsine transformation were tested for significance using one-way ANOVA. Results indicated that there was a significant difference in rock outcrop density among the four habitats ($F_{(3, 139)} = 13.38$ and $P < 0.05$).

3.4 Abundances and densities of trees in the various habitats

The abundances and densities of the top three most numerous (common) trees in the four habitats were recorded, and a checklist of all trees encountered in each habitat was also generated (Appendices 1-4). The trees were from various families, especially Rutaceae, Celastraceae, Loganiaceae, Oleaceae, Euphorbiaceae and Myrtaceae.

3.4.1 Abundances of the dominant trees in the various habitats

Indigenous, Woodland and Eucalyptus habitats each had three dominant tree species (Table 5). Although none of these dominant species was common in all the four habitats, one species (*Vepris simplicifolia*) was common in three habitats (Indigenous, Woodland and Quarry) at varying densities. The highest density for any species recorded was in the Indigenous habitat. The three overall most abundant tree species in the entire study area are *Vepris simplicifolia* (174), *Olea africana* (89) and *Strychnos henningsii* (77) (Table 5).

Table 5: Abundances of the common trees in Oloolua forest, Kenya

Species	Indigenous	Woodland	Quarry	Eucalyptus	Totals
Vepris simplicifolia	107	24	43	-	174
Maytenus heterophylla	26	-	-	-	26
Elaeodendron buchananii	24	-	-	-	24
Strychnos henningsii	-	32	45	-	77
Ochna ovata	-	21	-	-	21
Olea africana	-	-	85	4	89
Croton megalocarpus	-	-	19	2	21
Eucalyptus botryoides	-	-	-	24	24

3.4.2 Densities of the dominant trees in the various habitats

Densities of the common trees in the study site were expressed as number of trees per hectare per habitat. The densities of the common trees in the indigenous habitat are *Vepris simplicifolia* (1783.3), *Maytenus heterophylla* (433.3) and *Elaeodendron buchananii* (400). In the woodland habitat the frequencies are *Strychnos henningsii* (533.3), *Vepris simplicifolia* (400) and *Ochna ovata* (350). The quarry habitat had four trees that were common, viz. *Olea africana* (1416.7), *Strychnos henningsii* (750), *Vepris simplicifolia* (716.7) and *Croton megalocarpus* (316.7). Lastly, the eucalyptus habitat trees had the following frequencies: *Eucalyptus botryoides* (400), *Olea africana* (66.7) and *Croton megalocarpus* (33.3) (Table 6).

Table 6: Densities (per hectare) of common trees in the four habitats of Oloolua forest, Kenya

Species	Indigenous $(Ha)^{-1}$	Woodland $(Ha)^{-1}$	Quarry $(Ha)^{-1}$	Eucalyptus $(Ha)^{-1}$	Totals $(Ha)^{-1}$
Vepris simplicifolia	1783.3	400	716.7	-	2900
Maytenus heterophylla	433.3	-	-	-	433.3
Elaeodendron buchananii	400	-	-	-	400
Strychnos henningsii	-	533.3	750	-	1283.3
Ochna ovata	-	350	-	-	350
Olea africana	-	-	1416.7	66.7	1483.4
Croton megalocarpus	-	-	316.7	33.3	350
Eucalyptus botryoides	-	-	-	400	400

Key: - means the tree was either absent or did not qualify to be classified as dominant

3.5 Trends in small mammal captures

Comparison was made of the species captured in the current study and another study in the same site in 2010 to check whether species previously encountered were still present in the forest, as well as highlight the species encountered in the current study which had previously not been encountered. The results indicated that while in the former study 9 species of small mammals were recorded, the current study documented 12 species (Table 7). 4 species caught in the earlier study were not captured in the current study and these are: narrow footed woodland mouse (*Grammomys dolicheurus*), dormouse (*Graphiurus murinus*), cane rat (*Thryonomys swinderianus*), and hedgehog *Atelerix albiventris*. Species that I encountered and which were not encountered in the 2010 study are as follows: robust gerbil *G. boehmi*, zebra mice *Lemniscomys striatus*, common mouse *Mus spp*, white toothed shrew *Crocidura spp*, epauletted fruit bat *Epomophorus wahlbergi*, slit faced bat *Nycteris thebaika* and pipistrelle bat *Neoromicia nana*.

Table 7: Trends in small mammal captures in Oloolua forest during the year 2010 and 2017.

Item(s) of comparison	Previous study in 2010	Current study by Meroka (2017)
Number of species encountered	9	12
Number of species captured using standard methods	5	9
Number of individuals captured using standard methods	160	217
Orders encountered	Rodentia, Erinaceomorpha, Carnivora and Primates	Rodentia, Soricomorpha, Primates, Carnivora and Chiroptera
Families encountered	Oricetidae, Sciuridae, Muridae, Muscardinidae, Thryonomyidae,	Sciuridae, Nesomyidae, Muridae, Soricidae, Pteropodidae, Nycteridae, Vespertilionidae, Galagidae, Herpestidae
What is new compared to 2010 study		7 species: (3 bat species, 1 shrew and 3 rodents) *Epomophorus wahlbergi* *Neoromicia nana* *Nycteris thebaika* *Crocidura spp* *Lemniscomys striatus* *Mus spp* *Gerbiliscus spp*

CHAPTER FOUR: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

4.1 Discussion

4.1.1 Abundance, diversity and distribution of small mammals in Oloolua forest

Surveys of small mammals' abundance and distribution in urban forests have indicated that several species actually thrive well there. In north-western Ethiopia, a study in Arditsy forest, an urban forest, recorded 8 species of which 7 were rodents and 1 was an insectivore (Bantihun and Bekele, 2015). The same study revealed that the seven rodents were all from the Muridae family, and the one insectivore was a shrew of the Soricidae family. This is consistent with the current study too, in terms of the families' representation, where both Muridae and Soricidae were recorded. However, some bat families recorded in the current study were not within the scope of the Ethiopian study. Nevertheless, the number of species is relatively low compared to the results of Liu *et al.*, (2008) who realised 17 species of the order rodentia and 7 of insectivore in a study in the eastern part of the Wuling mountains in central China. This may be attributed to a longer sampling period (five years) and the fact that it was conducted in an evergreen forest ecosystems different from the dry upland forest at Oloolua. However, it is possible that this study may have under-estimated some rare species probably due to the length of the sampling period or the method(s) used. Further, chiropteran survey work in the forest ought to consider the use of harp traps which have been shown to be more efficient (Francis 1989); or a combination of all the methods which eliminates the challenge of each (Ochoa *et al*., 2000).

Nzui (1994), in a study of Ngong Hills forest (approximately 13 kilometres from Oloolua) obtained 8 species of rodents and shrews. Three of these species (*Mus spp*, *Lemniscomys striatus* and *Crocidura spp*) were also captured in my study. This may be attributable to the fact that these stands of forests were at one time connected in a large continuum of urban forests block. These have since been delinked due to human activities resulting in deforestation and habitat destruction.

Species diversities (Shannon Weiner Indices) comparison between less disturbed and disturbed habitats show that the disturbed habitats had a slightly higher figure. This is not strange as it is consistent with studies by Vera-Y-Conde and Rocha (2006) in an Atlantic rainforest of Ilha Grande in southeastern Brazil. One possible reason for higher diversities in the disturbed habitats of Oloolua could be the fact that many years have elapsed since the quarrying stopped in the area, and reclamation of the quarried area done. The long period of time has indeed allowed considerable vegetation regeneration to take place. The old quarry area is presently characterized by tall trees and does not bear large expanses of bare ground. This may advertently have assisted the small mammals to recolonize the habitats. It has been noted that previously disturbed but regenerating forests also exhibit high diversities of some small mammal species (Ricart *et al*., 2007). Studies have also indicated that intermediate disturbance levels often result in the highest species diversities (Grime, 1979). This is consistent with our findings where the disturbed habitats exhibited a higher species diversity as well.

The giant pouched rat (*Cricetomys ansorgei*) and Ochre Bush Squirrel (*Paraxerus ochraceus*) have also been encountered in other environs of Nairobi such as Kahawa area (Martin and Dickinson, 1985). The species that had the lowest abundance (*Nycteris thebaika*) seems to be a resource specialist, and its population seems to have declined as a response to urbanization (McKinney and Lockwood, 1999).

Generally, the captures were relatively low compared to those reported by studies done in comparable areas. Low trap success realized in the study area may be attributed to a number of factors. Disturbance from non-target species (birds and monkeys) and other animals like livestock, evidenced also by Bantihun and Bekele (2015) was evidenced in the current study. Disturbance from the latter sources was quite prevalent affecting the overall capture rates due to destruction of traps (Appendix 5) though replacement of the destroyed traps was done as soon as it was realised. There was a case of theft of traps but replacement of the stolen traps was done a day after realization. The low trap success may also have been due to disturbance and soil pollution caused by the increasing number of people visiting the reserve. This was evidenced by bottles of alcohol, soda and other rubbish strewn in several spots within the trail that probably would have led to high levels of toxic wastes entering the soil. The presence of a nature trail, several camping sites and a waterfall in the area has attracted visitors from Nairobi and other places in Kajiado County.

The higher abundance of bats in the less disturbed compared to that of the disturbed areas 68 and 50 respectively in our study has also been noted in Michigan (USA) and Poland, where it was noted that bats' species richness tends to be highest in the least altered areas and lessens as levels of urbanization increases (Kurta and Teramino, 1992). This implies that bats are sensitive to human disturbance and habitat alteration. It could also be attributed to availability of roost sites and variety of food resources in the less disturbed habitats. Undisturbed native tree dominated forests are known to provide higher diversities of fruit trees ensuring availability of fruits almost all year round (Opler *et al.,* 1980).

The abundance of two bat species viz, *Neoromicia nana* and *Nycteris thebaica,* was relatively low compared to that of *Epomophorus wahlbergi*. Merriam *et al.,* (1989) notes that populations that are isolated may end up realizing decreased genetic heterozygosity, and are highly likely to face extirpation (Fahrig and Merriam, 1985). According to Duvergé and Jones (2003), a number of species may exhibit habitat specificity which often restricts their abundance and distribution.

This may be the case with the two rare species aforementioned. What is not known is if these two species may have highly specific habitat requirements and still suffer from impeded migration ability to other favourable habitat patches (Laurance, 1994). The United Nations National Bat Survey notes that bats of the family Vespertilionidae (in our case the species *N. nana*) strongly avoid searching for food in habitats that have been altered through various anthropogenic activities including cultivation. Areas around the study site had farming being practiced by the locals, possibly impacting *N. nana* negatively. Loss of foraging habitats, reduction in its quality as well as fragmentation are rapidly becoming serious threats to bat assemblages. These have come about due to increased food demands to cater for the ever rising human population with the end results being fragmentation and habitat loss in a global scale (Vina and Cavelier, 1999).

Abdullahi (2010), working in the same study site, recorded 9 small mammal species. The lower species richness is probably due to the fact that he did not purpose to capture any volant species. On the contrary, our study focussed on both volant and non-volant species, giving a more exhaustive and complete small mammal diversity account. Possible absence of some species initially encountered in the current study could possibly be the effect of continued development in the forest through the erection of several new buildings in the past nine years since the earlier study. It may also be attributed to the difference in the sampling sites location, given that the forest is hundreds of hectares big.

Two species were captured in all the habitats in our study possibly due to structural homogenization, which is responsible for communities of small mammals that are characterised by generalists (Kelt *et al*., 2013). Kassen (2002) argues that heterogeneous ecosystems that are prone to anthropogenic disturbance will be dominated by habitat generalists. These two species

Cricetomys ansorgei and *Paraxerus ochraceus* behave like generalists since they do not exhibit any distinct habitat preference.

4.1.2 Seasonal variation in abundance of small mammals in Oloolua forest

It was noted that there was no significant statistical difference between individuals captured in the dry and wet seasons. It is more common for captures to be higher during the wet season but this was not the case in my study area. A possible reason may be availability of alternative food resources right in the individual species' natural habitats which may translate to lower than expected captures. With greater food availability during the wet season there is possibility of seasonal diet change by some species. Other studies have indicated that this seasonal availability of food may bring about reduced captures and trap success (Kronfeld-Schor and Dayan, 1999) as the small mammals disperse widely in the forest.

4.1.3 Effect of habitat structure on the abundance and distribution of small mammals in Oloolua forest

It was noted that there were significant differences in all habitat variables studied across the four habitats studied. Nevertheless, these differences did not influence the small mammal captures across the various habitats. This could probably have been due to the fact that each habitat had experienced some level of perturbation, and varying degrees of regeneration as well. This was contrary to other researchers' findings which indicate that the distribution of small mammals is lower in areas with reduced canopy cover due to increased predation risk (Kotler, 1997). It also is contrary to findings by Raoul *et al*. (2001) who states that the habitats that are under management tend to have lower abundances of small mammals due to a reduction of their preferred habitats (Eucalyptus habitat had the second highest small mammal captures in my study area).

4.2 Conclusions

The following conclusions can be drawn from the research work at Oloolua forest:

1. It was realized that small mammal abundance, diversity and distribution in Oloolua forest is uniform across habitats as had been hypothesized.
2. There is no difference in the seasonal abundances of small mammals in Oloolua forest.
3. Habitat structure did not influence the abundance, diversity and distribution of small mammals in Oloolua forest.

This study sets the stage for further research work in urban ecology as it relates to small mammals. Only the surface has been scratched, and so much more can be done to better understand the environmental health status of urban forests through the study of the invaluable bio-indicators that are rodents and bats. This should then inform conservationists as to what needs to be done so as not to lose our biodiversity, as well as mitigate against the harsh and harmful effects of climate change such as desertification and extirpation of wildlife species that have not been able to withstand the pressures of these changes.

4.3 Recommendations

4.3.1 Recommendations on current work and further research

As regards small mammals research in Oloolua I recommend that:

1. Sampling of small mammals in the un-sampled areas should be done to see if the trend realised in the current study will still hold.
2. Sampling of bats should be done using harps which are better at sampling the high flying bat species.
3. Further monitoring of small mammals should be done annually or biannually as may be feasible to check on the effect of the infrastructural developments in the vicinity as well

as climate change on species' presence, abundance and distribution.

4. A survey of the bigger carnivals (hyenas) and herbivores (buffaloes) should also be done as they too may influence the distribution of the small mammals.
5. Further research on the diet and other ecological attributes of bats present in Oloolua forest would go a long way in informing the forests management on what measures to put in place so as not to lose the bat community of Oloolua forest.
6. An assessment of the predator-prey dynamics within the forest also needs to be done as this may also affect small mammal populations.
7. Research as to why some species initially found in Oloolua are currently not traceable is also necessary.

4.3.2 Recommendations for conservation and management

For the conservation of small mammals in Oloolua forest reserve the following should be considered for enforcement:

1. Establishment of a public education program to sensitize those living and working around the forest on wildlife and how to peacefully coexist with the wildlife, as well as the value of maintaining habitat connectivity.
2. Promotion of the use of fences that are wildlife friendly but that can keep away wildlife from personal gardens and homes.
3. Discouraging the installation and use of artificial lights especially during the night on server roads in the forest reserve's neighbourhood so as not to interfere with bats' activities at night.
4. Seeking alternative routes for personal cars that drive through the forest's dust roads during periodic peak hours when there is heavy jam on the roads as this is detrimental to

small mammals' survival as well as movement.

5. Discouraging picnickers and other visitors to the forest from feeding the animals or even providing water to the wild animals.
6. All those who are camping within the forest should be instructed to take away their non-biodegradable wastes leaving behind only that which is biodegradable and safe to the environment. Possible commitment forms/agreements need to be enforced in relation to this as a prerequisite for being allowed to camp in the facility.
7. Construction of additional roads and other structural developments should not be prioritised at the expense of possible biodiversity loss.

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LIST OF APPENDICES

Appendix 1: Checklist of trees in the indigenous forest habitat in Oloolua forest, Kenya

Family	Species	Life-form
Apiaceae	*Heteromorpha arborescens*	Tree
Asteraceae	*Brachylaena huillensis*	Tree
Celastraceae	*Maytenus heterophylla*	Tree
	Elaeodendron buchananii	Tree
Euphorbiaceae	*Croton megalocarpus*	Tree
Loganiaceae	*Ochna ovate*	Tree
Malvaceae	*Afrocanthium keniensis*	Tree
Oleaceae	*Olea Africana*	Tree
Rutaceae	*Vepris simplicifolia*	Tree
	Calodendrum capense	Tree
	Clausena anisate	Tree

Appendix 2: Checklist of trees in the woodland habitat in Oloolua forest, Kenya

Family	Species	Life-form
Celastraceae	*Maytenus heterophylla*	Tree
Euphorbiaceae	*Croton megalocarpus*	Tree
Loganiaceae	*Ochna ovata*	Tree
	Strychnos henningsii	Tree
Malvaceae	*Afrocanthium keniensis*	Tree
	Dombeya burgessiae	Tree
	Grewia similis	Tree
Oleaceae	*Olea Africana*	Tree
Rutaceae	*Clausena anisate*	Tree
	Vepris simplicifolia	Tree

Appendix 3: Checklist of trees in the regenerating quarry habitat in Oloolua forest, Kenya

Family	Species	Life-form
Euphorbiaceae	*Croton megalocarpus*	Tree
Loganiaceae	*Ochna ovata*	Tree
	Strychnos henningsii	Tree
Malvaceae	*Afrocanthium keniensis*	Tree
	Dombeya burgessiae	Tree
	Grewia similis	Tree
Oleaceae	*Olea Africana*	Tree
Rutaceae	*Vepris simplicifolia*	Tree
Thymelaeaceae	*Gnidia subcordata*	Tree

Appendix 4: Checklist of trees in eucalyptus habitat in Oloolua forest, Kenya

Family	Species	Life-form
Anacardiaceae	Rhus natalensis	Tree
Ebeneceae	Euclea divinorum	Tree
Euphorbiaceae	*Croton megalocarpus*	Tree
Myrtaceae	*Eucalyptus botryoides*	Tree

Appendix 5: Sherman trap destroyed by humans in one of the transects in Oloolua forest

Appendix 6: Aerial view of the Indigenous forest within Oloolua forest, Kenya.