

**BAT SPECIES DIVERSITY AND DISTRIBUTION IN A DISTURBED
REGIME AT THE LAKE BOGORIA NATIONAL RESERVE, KENYA**

BY

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REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
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JULY, 2015

DECLARATION

Declaration by the candidate

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DEDICATION

To God Almighty who has always guided me throughout my entire life. To my beloved wife Florence Kimuli. I am grateful for her love, care and encouragement that she gave to me. I am also grateful to my parents, for their moral support. God bless them all.

ABSTRACT

Rapid population growth in many parts of Kenya, has led to increased demand for land for agriculture and settlement. This invariably leads to loss, degradation and fragmentation of forests and other natural habitats. While many studies have assessed impacts of habitat loss on many wildlife species, especially the megafauna, little is known of its impact on small mammals). In Kenya's Rift Valley, human impacts on bat species diversity and distribution have not been evaluated. Using standard mist nets and the Baun-Blanguet method in the sampling protocol, this study assessed bat species diversity and distribution along a gradient of human disturbance among different vegetation types in and around Lake Bogoria National Reserve. The study was conducted from November, 2012 to July, 2013. Cluster analysis and Detrended Correspondence Analysis (DCA) grouped the vegetation into two broad categories on the basis of cover-abundance estimates. The assemblages were: *Acacia* woodland/*Acacia-Commiphora* woodland and riverine vegetation. Two hundred and thirty three bats representing eleven genera in seven families were recorded. These were: *Epomophorus minimus*, *Rhinolophus landeri*, *Hipposideros caffer*, *Cardioderma cor*, *Lavia frons*, *Nycteris hispida*, *Chaerephon pumilus*, *Mops condylurus*, *Neoromicia capensis*, *Scotoecus hirundo* and *Scotophilus dinganii*. Species richness estimators indicated sampling was exhaustive: the abundance-based Cover Estimate mean was 11.34 ± 0.42 while the Jack 1 mean was 11.94 ± 0.94 . Species richness ($S = 10$) and diversity ($D = 5.72$) were highest in the *Acacia* woodland while the more homogenous farmlands recorded the lowest species richness ($S = 5$) and diversity ($D = 1.94$). No significant differences were exhibited in interaction of bat diversity and plant diversity among the four vegetation formation ($r = 0.52$, $P = 0.658$, $n = 16$). One way ANOVA ($F = 0.34$, $df = 15$, $P = 0.81$) showed no significant differences in relative bat abundance in the four vegetation types. The low species richness and increased dominance of a few generalist species on farmlands may be indicative of different levels of disturbance, including historical grazing by cattle and vegetation clearance that may have resulted in a relatively homogenous habitat. Future studies should focus on use of state-of-the-art equipment, especially acoustic monitoring, in combination with mist netting to provide more accurate and unbiased surveys. This information will strengthen the scientific basis for the management of the Lake Bogoria National Reserve and other related savanna habitats in Kenya.

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LIST OF ACRONYMS

| | |
|---------------|------------------------------------|
| A-C | <i>Acacia-Commiphora</i> woodland |
| ACE | Abundance-based Coverage Estimates |
| A-W | <i>Acacia</i> woodland |
| DCA | Detrended Correspondence Analysis |
| FAO | Food and Agricultural Organization |
| F-L | Farmlands |
| GPS | Geographical Positioning System |
| Jack 1 | Jackknife 1 mean |
| LBNR | Lake Bogoria National Reserve |
| R-V | Riverine Vegetation |

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

One of the most universal features of global biodiversity is the variability of species richness across different regions. Nearly 6000 species of mammals currently exist on earth and more than 1300 species of these are of the order Chiroptera (bats) (Reeder *et al.*, 2007; Gorresen and Willig, 2004; Simmons, 2010; Mantilla-Meluk, 2008; Buden *et al.*, 2013; Moratelli and Wilson, 2013; Weibull *et al.*, 2013). Bats are the second most diverse group of mammals worldwide comprising two suborders: Megachiroptera restricted to Old World tropics of Africa and Asia, and Microchiroptera, composed largely of insectivorous bats (Mickleburgh *et al.* 2002; Sampaio *et al.*, 2003; Korine and Pinshow, 2004; Simmons, 2005). Megachiroptera contains a single family, (Pteropodidae), 42 genera, and 184 species which are mainly comprised of frugivorous bats. Microchiroptera, on the other hand, consists of 17 families, 135 genera, and approximately 931 species (Hutson *et al.*, 2001). However, molecular phylogeny of the extant bat families categorizes the order Chiroptera into two suborders (Yinpterochiroptera and Yangochiroptera) and four super familial groups (Teeling *et al.*, 2005). As the only mammals capable of sustained flight with diversified foraging and dispersal capabilities, bats can exploit many ecological resources (Patterson *et al.*, 2003). Nevertheless, they remain poorly studied and misunderstood in most parts of the world. For most regions and most bat species, detailed data on species distribution are usually not available (Prendergast *et al.*, 1999; Bowker, 2000; Ottaviani *et al.*, 2004). Yet, knowledge about species richness and diversity is crucial for conservation and management of biodiversity (Margules and Pressey, 2000).

The uncertainty on the diversity of bats occurring within the territorial limits of many environments has been a matter of debate (Bates and Harrison, 1997; Walker and Molur, 2003; Wilson and Reeder, 2005; Mahmood-ul-Hassan *et al.*, 2009). This is because bats exhibit different adaptations to the environment (Mickeviciene and Mickevicius, 2001; Patterson *et al.*, 2003). These unique adaptations allow bats to exploit different ecological niches (from terrestrial to arboreal). Nonetheless, the highest diversity of bats is found in tropical forests, especially in Africa, Asia and South America (Eisenberg and Redford, 1999; Willig *et al.*, 2003). Bats also exhibit high vulnerability to habitat loss, modification and fragmentation, which are currently rampant in many parts of the tropical world (Yom-Tov and Kadmon, 1998; Ashok and Kalu, 2004; Gorresen and Willig, 2004; Davy *et al.*, 2007; Presley *et al.*, 2009), making it difficult to predict bats species diversity based on past studies.

In Africa, public perceptions of biodiversity are dominated by charismatic megafauna, overshadowing an appreciation of less conspicuous fauna that may have equal or even greater overall importance. Bats perform vital ecological services, including many with consequences for agriculture, forestry, and public health (Simmons and Conway, 2003; Hutson *et al.*, 2009; Kunz *et al.*, 2011). Sub-Saharan Africa is home to over 20% of the world's bats and Kenya has about 108 species (Patterson and Webala, 2012), more than twice the number found in the United States and Canada. Unfortunately, bats are severely threatened from habitat loss due to human disturbance in critical cave roosts and through the destruction of forests from charcoal production, conversion to agricultural lands and settlement and illegal logging (Webala *et al.*, 2010).

In Kenya, bats represent about 25% of Kenya's mammal species and constitute a major

r component of Kenya's biodiversity (Patterson and Webala, 2012). Yet, little is known about the taxonomy and distribution of the more than 108 species of Kenyan bats (and most African bats), let alone their responses to habitat loss. Previous bat studies in Kenya were limited to Meru National Park (Webala *et al.*, 2004), and Lake Turkana (Webala *et al.*, 2009). Other available information is found in checklists and museum voucher specimens where information on taxonomy and geographic distribution can be inferred. Therefore, it is clear that limited work on Kenyan bats has been conducted, but enough to reveal that Kenya harbours one of Africa's richest bat faunas (Patterson and Webala, 2012). Given Kenya's high bat diversity, it is imperative that more studies on their occurrence and distribution in other areas, including protected ones are documented.

Lake Bogoria National Reserve (LBNR) is situated in a semi-arid region of Kenya with a savannah type of vegetation and currently protected (Johansson and Svensson, 2002). The Reserve is subject to pressure from human activities including, plant harvesting for medicine, firewood, charcoal burning, timber harvesting, and honey harvesting. Such a disturbed habitat invariably leads to loss of roost sites and foraging areas that are critical for bats, which may eventually affect population size and species distributions (Timpone *et al.*, 2010). The responsiveness of bat communities to human disturbance over short periods of time may permit researchers to monitor environmental health and faunal diversity. No study has hitherto investigated possible impacts of such modified habitats at Lake Bogoria National Reserve on bat species diversity and distribution. The goal of this study was to compare bat species richness and diversity in three vegetation communities and farmlands with differing levels of human disturbance at Kenya's Bogoria National Reserve.

1.2 Problem Statement

Knowledge about the geographical distribution of species is crucial for conservation and management of biodiversity (Margules and Pressey, 2000). Yet, for most regions and most taxa, detailed data on species distribution are usually not available and collecting such data is costly and labor intensive (Bowker, 2000; Ottaviani *et al.*, 2004). In Africa, only Madagascar (Monadjem *et al.*, 2010) and South Africa (Jacobs *et al.*, 2006) has witnessed a comparable level of active research leading to discovery of new cryptic species. In East Africa, few studies on bat assemblages have been conducted (e.g. Webala *et al.*, 2004, 2006,). Therefore, like many parts of Africa, the synthesis and understanding of East African bats has lagged behind the rest of the World.

The Lake Bogoria National Reserve (LBNR) is a delicate ecosystem and has not been spared from problems facing rangelands in other parts of the country. Human population growth and increased poverty have contributed to encroachment and extensive conversion of natural habitats for crop production. Harvesting of trees to build homes and animal enclosures, as well as charcoal burning to enhance human livelihoods is prevalent in the area. This often results in over-harvesting and destruction of the natural vegetation both around and in the reserve. Furthermore, overgrazing by both livestock and wild herbivores, a situation exacerbated by occasional droughts denudes the area of any vegetation. Yet, no study has investigated impacts of such disturbed regimes on different elements of biodiversity, including bats in the area. Using bats as a focal group, this study investigated impacts of human-induced habitat modifications on the diversity, abundance and distribution patterns of bats at LBNR.

1.3 Justification

The LBNR ecosystem was selected for this study because it is one of the protected areas in Kenya with diverse habitats some of which can be considered as ecologically fragile. The ecosystem in the area also contains rare and endemic plant and animal species. Human activities in such a fragile ecosystem can be destructive or may alter the attributes of some of its habitats. Yet such habitats may serve special functions such as breeding, roosting or feeding sites for fauna, including bats.

Studies of the distribution, species diversity and richness of any wildlife provide critical baseline data that can be compared with future datasets to help determine how and why changes occurred over space and time (Timpone *et al.*, 2011). There is also a need to gain more understanding on taxonomic variation in the least studied mammalian species that help in formulating management measures against any adverse ecological changes. In addition, results may help protected area management institutions to understand more on ecological processes going on in the environment.

1.4 Objectives of the study

1.4.1 General objective

The goal of this study was to investigate effects of habitat disturbance on diversity, abundance and distribution of bats at Lake Bogoria National Reserve.

1.4.2 Specific objectives

- i.** To identify bat species composition and diversity at the Lake Bogoria National Reserve.
- ii.** To compare bat species richness and diversity, and abundance in four vegetation types with differing levels of human disturbance in and around Lake Bogoria

National Reserve.

- iii. To determine associations between the heterogeneity of bat ensembles with plant species assemblages.

1.5 Hypothesis

- i. Habitat disturbance may not significantly alter bat species richness and diversity, abundance and their distribution patterns.

CHAPTER TWO

LITERATURE REVIEW

2.1 Why bats?

After rodents, bats (Chiroptera) are the second largest group of mammals on earth (Simmons, 2005). Furthermore, bats are one of the most diverse (taxonomically and ecologically) groups of living mammals (Patterson *et al.*, 2003), and can form some of the largest aggregations and thus may be among some of the most abundant groups of mammals in terms of individual numbers. They are distributed worldwide, with the exception of a few isolated islands, in the arctic and antarctic regions (Medellin *et al.*, 2000; Hutson *et al.*, 2001).

The taxonomy of bats for many decades has not been stable. Recent studies show that changes have occurred to some genera, leading to alteration of names of some species. Bats are one of the most important components of mammalian biodiversity in both tropical and temperate regions (Hutson *et al.*, 2001; Simmons, 2005). Moreover, the tremendous trophic diversity of bats makes them useful surrogates, reflecting the status of sympatric plant and insect populations (Jones *et al.*, 2009). The low reproductive rates and relatively long infant dependency of bats mean that population take a long time to recover from decline (Jones *et al.*, 2009). Coupled with the correct application of a few sampling techniques that can evaluate inventory completeness, bat populations can be monitored as effective ecological indicators (Patterson *et al.*, 2003; Monadjem *et al.*, 2010).

2.2 Role of bats in ecosystems

Bats are important in terms of their ecological and economic roles because they

exploit a wide array of ecological niches (Patterson *et al.*, 2003). This is essential in assessing ecosystem health.

2.2.1 Control of insect populations

Efforts to curb the widespread and indiscriminate use of chemical pesticides include the promotion of biological controls. An estimated 99% of potential crop pests are limited by natural ecosystems of which some fraction can be attributed to predation by bats (Naylor and Ehrlich, 1997). Bats are predators of a number of economically important insects including cucumber beetles, potato beetles, corn earh etc, which are important agricultural pests (Cleveland *et al.*, 2006; Kalka *et al.*, 2008). It is estimated that about 70% of all bat species worldwide feed on crop damaging nocturnal insects, providing a strong case for bats as biological agents of pest control (Hackett *et al.*, 2013). Globally, the value of pest control ecosystem service ranges between \$54 billion and \$1 trillion, an estimate that includes reductions in both crop losses due to pests and direct/indirect costs of pesticide use (Naylor and Ehrlich, 1997). This means that bats boost the world economy and food supplies by controlling insect populations naturally. (Kunz *et al.*, 2011) reviewed the ecosystem services provided by bats, concluding that insectivorous bats potentially exercise a top down control of arthropods in both natural and agricultural ecosystems. Colonies of cave-roosting insectivorous bats can contain millions of individuals; guano deposits, which are important as fertilizer, are indicators of the high biomass of insects that bats consume. A recent study suggested that loss of bats in North America could lead to agricultural losses estimated at more than \$3.7 billion/year (Boyles *et al.*, 2011) in crop damage from insects. Bats also help in control of mosquitoes that serve as vectors of human diseases. It is estimated that Individuals of some bat species can capture from 500 to 1,000 mosqui-

toes in a single hour, and large colonies can consume tremendous quantities (Tuttle, 2006), thereby reducing the threat of disease. For example, a Florida colony of 30,000 southeastern bats consumes 50 tons of insects annually, including over 15 tons of mosquitoes, and from 77.4% to 84.6% of little brown bats living in the northern U.S. and Canada eat mosquitoes. Because mosquitoes do not take evasive action, and are exceptionally easy to capture, bats may prefer them over larger prey (Tuttle, 2006). It is impossible in most cases, either chemically or naturally, to completely eliminate mosquitoes, though their numbers can be substantially reduced (Facione *et al.*, 1991). Corresponding studies on the food habits of African bats on African insects have not yet been conducted (Taylor *et al.*, 2013)

2.2.2 Seed dispersers

Seed dispersal by bats has been identified as a key dispersal mechanism for many tropical trees and shrubs (Medellin and Gaona 1999). The agility of bats, as an intrinsic feature allows them to cover a greater distance, visiting different habitats and sites in a single night, and defecate in flight. Through seed dispersal, bats influence the structure of the vegetation of plant species they consume and disperse (Bianconi *et al.*, 2007). For instance many important tropical fruits, such as wild bananas, avocados, figs and mangoes, are dispersed mostly by bats. Hence regeneration of African forests depends largely on frugivorous bats of the family Pteropodidae (Medellin and Gaona 1999; FAO, 2011).

2.2.3 Pollinators

From deserts to rainforests, nectar-feeding bats are critical pollinators for a wide variety of plants of great economic and ecological value (Neuweiler, 2000). About 528 spe

cies in 67 families and 28 orders of angiosperms worldwide are pollinated by bats (Fleming *et al.*, 2009). In North American deserts, giant cacti and agave depend on bats for pollination, while tropical bats pollinate incredible numbers of plants. The Old World bats *Rousettus aegyptiacus*, *Epomophorus wahlbergi* and *Eidolon helvum* pollinate flowers of the baobab tree, an economically important species of the East African savannah. It is so critical to the survival of so many wildlife species that it is often called the "African Tree of Life." Yet it depends almost exclusively on bats for pollination. Without bats, the "African Tree of Life" could die out, threatening one of our planet's richest ecosystems (Jones *et al.*, 2009; FAO, 2011).

Most flowering plants cannot produce seeds and fruit without pollination. This process also improves the genetic diversity of cross-pollinated plants. Bats that drink the sweet nectar inside flowers pick up a dusting of pollen and move it along to other flowers as they feed. A few of the commercial products that depend on bat pollinators for wild or cultivated varieties include: bananas, the silk-cotton tree, the fibre bark and seeds of which are economically important is pollinated by large number of bat species in Africa and South America (FAO, 2011).

2.3 Effects of anthropogenic pressure on bat ensembles

Vegetation patterns, dynamic processes and species diversity in the savannah biome are attributed to environmental heterogeneity (Fenton *et al.*, 1998). Such biomes are subject to disturbances both natural and anthropogenic (Turner *et al.*, 2003) and may lead to sudden or gradual, dramatic or subtle changes in ecosystems. Generally, it's accepted that the effects of anthropogenic pressure result in a loss of species richness through extreme habitat disturbance or fragmentation. Although the density of some

species may increase with certain types of land use, due to an increase in resource availability, these species are usually a remnant subset of native species (Shochat *et al.*, 2006).

One of the main concerns associated with anthropogenic pressure on ecological communities is the potential breakdown of community-assembly processes and mechanisms at each hierarchical level that can result from the novel, unstable environments presented by expanding urban areas and agricultural activities (Shochat *et al.*, 2006; Mlilo, 2011). Anthropogenic effects such as fire, wood cutting, agriculture and stock-farming are of grave concern as they contribute to extensive habitat disturbance and fragmentation (Golodets *et al.*, 2011).

In most parts of Africa's savannah woodland, livestock rearing is crucial to the livelihood of local people (Savadogo, 2007; Gandiwa, 2013). The few prevailing reserves are not strictly protected against human impact and are being utilized both legally and illegally by local people. Despite the enormous value of the resource, the vegetation structure and dynamics are adversely affected (Bakker *et al.*, 2006). Selective grazing, as well as heavy stocking rate, may alter floristic composition and result in a shift from long-lived perennials to annuals and forbs, with a concomitant decrease in production (Savadogo, 2007). Also, the canopy gaps created by the selective removal of trees may result in unfavourable thermal conditions and favour the growth of drought-tolerant species, thereby contributing to competitive exclusion processes (Savadogo, 2007). For example, competitive exclusion may be compounded as species that readily exploit the greater disturbance increase in abundance and finally dominate the community; out-competing less tolerant species resulting in their local extinction

(McKinney, 2002; Shochat *et al.*, 2006). Consequently, these disturbances lead to ecosystem degradation associated with habitat loss and decline in animal populations, hence affects human well-being by diminishing the supply of ecosystem services.

Understanding the degree to which species and communities are sensitive to habitat disturbance is fundamental to the establishment of effective conservation and management planning aimed at mitigating anthropogenic effects (Sampaio *et al.*, 2003). Studies focusing on relationships between specific organisms and their environment can provide a more valuable insight into ecosystem functioning. More importantly though, research aimed at the mechanistic processes that structure species assemblages should do so in the light of potential anthropogenic pressures so that alterations in community-assembly processes can be elucidated (Shochat *et al.*, 2006).

2.4 Habitat heterogeneity and species diversity

At multiple spatial scales, habitat diversity is associated with greater biodiversity. Moreover, diversity of taxa has been shown to have a positive relationship with habitat diversity (Jonsen and Fahrig, 1997). This is likely a result of an interaction between taxa and the positive influences of diverse habitats (Benton *et al.*, 2003). For example, high plant diversity may promote insect diversity which in turn may attract birds that prey on them (Benton *et al.*, 2003; Jonsen and Fahrig, 1997). High plant diversity can also facilitate co-occurrence of many volant species through spatial niche partitioning (Patterson *et al.*, 2003). Indeed, the habitat heterogeneity hypothesis predicts that higher species richness should result from greater habitat complexity. (Pierce, (2012) acknowledges that the two major facets of the habitat heterogeneity hypothesis are topographic variation and ecosystem diversity. They are not however;

mutually exclusive, and topographic heterogeneity is strongly correlated with ecosystem diversity (Pierce, 2012). Heterogeneous topography usually leads to an increase in species richness at a regional scale due to a multitude of habitats along a gradient of elevations. On the other hand, extreme variation in topography, such as the presence of cliffs, can facilitate local co-occurrence of ecologically and/or morphologically similar species (Saunders and Barclay, 1992).

While physiography is an important factor in ecosystem diversity, ecosystems can also be separated on the basis of climate, soil and vegetation thus some landscapes can have low topographic variation but maintain relatively high ecosystem diversity (Lapin and Barnes, 1995). Greater ecosystem diversity in a given area results in a higher number of niches being available per unit space through an increase in resource availability. It follows then that the structural complexity of a habitat should provide a strong basis on which to predict species diversity. Greater structural complexity, in the form of plant biomass, can provide greater protection from predators as well as more habitable space and food resources (Weibull *et al.*, 2000) and is thus likely to result in increased species richness. At the landscape scale in sub-saharan Africa, species richness of the majority of mammals is predominantly related to woody plant species richness (Fenton *et al.*, 1998). This relationship has been attributed to the fact that high plant species richness increases structural complexity potentially providing more available niches (Bakker *et al.*, 2006). At local scales too, mammal species richness has been associated with structural complexity of vegetation and percentage plant cover in Kenya (Webala *et al.*, 2004). Importantly, the mammal-plant species richness associations are usually most prevalent in small-medium bodied species that utilize resources which are distributed in three-dimensional space. More-

over, the abilities of such species to disperse and forage in three-dimensional space increase the likelihood for spatial niche partitioning in habitats with high structural complexity (Kingston *et al.*, 2000).

2.5 Habitat selection by bats

The selection of habitat by bats depends on many different factors such as foraging resources, availability of roosts, and potential predators (Russo *et al.*, 2005; Lesiski *et al.*, 2007). Often habitats are not optimal and therefore the selection is based on a trade-off between costs and benefits. For example, open habitat might provide the best foraging opportunity, while denser habitats provide shelter against predators. Furthermore, studies on the relationship between bat species richness, abundance and habitat area have generally shown that most bat species use different habitats without any very specific requirements. This is because flight permits bats to move considerable distances quickly and efficiently, giving them access to a variety of habitats to meet their requirements for food and roosts (Loayza and Loisele, 2009). It means that roosts and food need not be in the same immediate area, and for instance, some species of bats that forage along the edges of forest habitat may benefit from the disruption of wood-lands (Fenton *et al.*, 1998), therefore habitat selection is more critical.

CHAPTER THREE

MATERIAL AND METHODS

3.1 Study area

3.1.1 Location and topography

Lake Bogoria National Reserve ($0^{\circ}15'N$ $36^{\circ}06'E$) is located within Kenya's Great Rift Valley (Figure 3.1). Bogoria lies in rocky escarpments that rise to the east and west, reaching over 1500m above sea level.

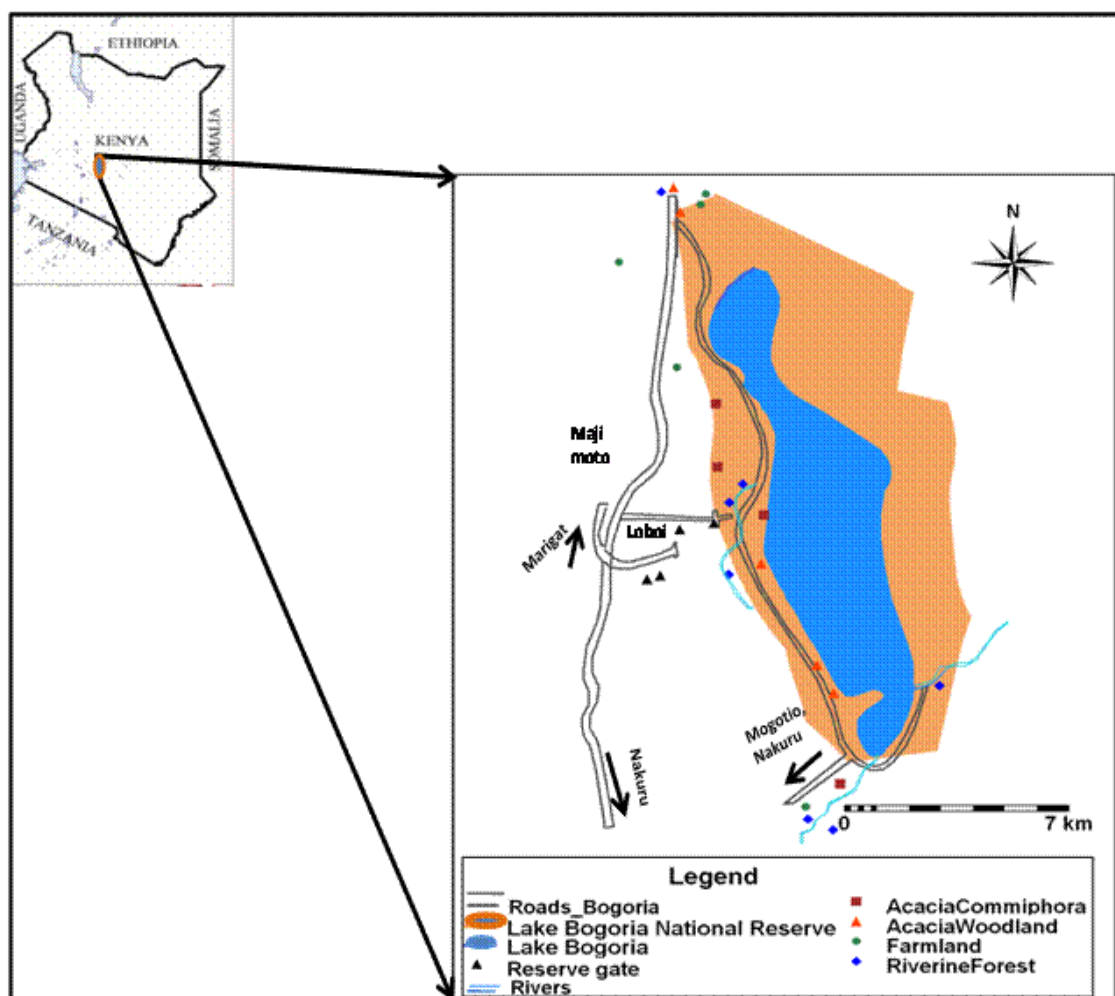


Figure 3.1: Location of the study area and sampling sites at LBNR and adjacent farm land. Inset is a map of Kenya showing the location of Lake Bogoria National Reserve (Source: Author, 2013)

The topography of the area is characterized by rugged hills, rocky outcrops, deep valleys and incised gullies some over 3m deep and cut into fine textured soil. The soils are alluvial, ranging from silt clay to loam.

3.1.2 Climate

Within the reserve and adjacent areas, the climatic conditions are harsh with temperatures at the Lake ranging from 18°C to 39°C with a daily mean of 25°C (Ashley *et al.*, 2002). Rainfall is erratic and highly localized. The yearly average for the foot hills varies between 1000 to 1500mm, and for lowlands between 300 to 700mm annually, with most of the rain falling from May to August and in light showers during November and December. The combination of weather variables and physiographic location give the lake basin a hot, semi-arid climate (De Groot *et al.*, 1992).

3.1.3 Vegetation

The natural vegetation is dominated by trees and shrubs and naturally-vegetated grassland with some *Acacia* dominated thorn bush but this gradually changes to deciduous and semi deciduous bush land with a number of common tree species such as: *Acacia tortilis*, and *A. mellifera* and common genera such as *Commiphora*, *Terminalia* and *Combretum*. The riverine vegetation is dominated by *Ficus sycomorus*, *F. capensis* mixed with some *Acacia* and *Terminalia* tree species. Due to sustained grazing by livestock, the association has been reduced to stands of about 2m above ground. Grazing practices may have contributed to encroachment of *Acacia nubica* and *A. ruficiens* including the invasive *Prosopis* species which have become thick and impenetrable in some places and have suppressed growth of grass and most ephemeral herbaceous species (Marangu *et al.*, 2008). Therefore, based on plant species dominance, the sites were classified into three vegetative formations: *Acacia* woodland (Plate 3.2a), *Acacia-Commiphora* woodland (Plate 3.2b), and riverine forest (Plate

3.2c). This represented the majority of habitats found at LBNR. In contrast, the adjoining areas of the Reserve are dominated by agrosystems such as banana plantations (Plate 3.2d), including pawpaw, maize and vegetable farms).

*a**b**c**d*

Plates 3.1: Vegetation types at LBNR. a. *Acacia* woodland; b. *Acacia-Commiphora* woodland; c. Riverine Vegetation; d. Agro-systems

(Source: Author, 2013)

3.2 Field methods

3.2.1 Bat surveys

The bat survey was conducted between November, 2012 to July, 2013. Four study sites were selected on the basis of accessibility in each vegetative formation within the Reserve and in areas adjacent to the reserve. The study area was mapped using a GPS (Global Positioning System). Four study sites were identified in each of the three

vegetation types including farmland as well. At each site, six mist nets were deployed for four consecutive nights across potential flyways (dry beds, forest tracks and gaps) to maximize bat captures. Nets were opened at 18.30h and monitored at intervals of 15 minutes until 23.30h to avoid injuries and/or to reduce cases of bat predation in the nets. Sampling was done systematically between and within habitats. Nights with full moon or bright moon light were avoided due to potential reduced capture rate resulting from lunar phobia by many bats (Kunz *et al.* 1996; Simmons and Voss, 1998; Lang *et al.*, 2004).

Morphometric measurements were taken of each captured specimen, and these included total length (including tail), head-and-body length (excluding tail), tail length, hind foot length, forearm length, ear length and tragus length, all to the nearest millimeter (Webala *et al.*, 2004). Data collected from each specimen included species, age (juvenile, subadult, and adult), sex, mass, and reproductive condition. Female reproductive condition was determined by palpating the abdomen and inspecting the mammae, and age-class determined by examining the degree of epiphyseal-diaphyseal fusion (Racey, 1988).

Bats were identified using available taxonomic nomenclature (e.g, Patterson and Webala, 2012). However, because it was not possible to accurately identify all species in the field, a few individuals of each species were collected and retained as museum vouchers to document captured species and to permit further identification at the National Museums of Kenya.

3.2.2 Vegetation surveys

A transect was established in each of the three vegetative formations. Along each transect, ten sampling plots, each 20 m x10 m, were randomly selected giving 30 sampling plots for the entire Lake Bogoria National Reserve. Using the Modified Baun-Blanquet Cover/Abundance Scale, each woody plant species (shrubs and trees) in each plot was assigned a cover/abundance rating (Causton, 2002).

Table 3.1: Modified Baun-Blanquet Cover Abundance Rating Scale

| Rating | Percentage Ground Cover |
|--------|-------------------------|
| 1 | <1 |
| 2 | 1 to 5 |
| 3 | 6 to 25 |
| 4 | 26 to 50 |
| 5 | 51 to 75 |
| 6 | 76 to 100 |

3.3 Data Analyses

To determine similarities in vegetation (species presence/absence, abundance) at all localities, cluster analysis and Detrended correspondence analysis (DCA) were applied. A correlation analysis was then used to assess any association between heterogeneity of bat assemblages with identified plant species assemblages and calculated as:

$$r = \frac{SS_{XY}}{\sqrt{(SS_{XX})(SS_{YY})}} \quad (\text{Lehman, 2005})$$

Where; r- The correlation coefficient (r)

SS_{YY} - The sum of squares for variable Y

SS_{XX} - The sum of squares for variable X

SS_{XY} - Finally, the sum of the cross-products (SS_{XY})

Bat species diversity for the different vegetation formations was computed using the modified inverse of Simpson-Yule diversity of concentration, C, for equally abundant species, and calculated as:

$$D = 1 / (\sum p_i^2) \text{ (Webala et al., 2006)}$$

Where D = Simpson's Diversity Index

p_i is the proportional abundance of the i th species, given by $p_i = n_i / N$, $i = 1, 2, 3 \dots S$. S = species richness which equals to the total number of species in a community. N = total number of individuals.

Evenness of each assemblage was calculated using indices derived from the reciprocal Simpson index ($E_{1/D}$), where evenness is expressed as a number between 0 (only one species present) and 1 (all species equally abundant). Estimates of species richness at all study sites were based on capture data using two models (Jackknife 1 and ACE from the program EstimateS 9.0 (Colwell, 2005). All indices were corrected for sampling bias using the jackknife technique (Magurran, 2004) and confidence intervals (CI) were computed accordingly. Equations which were used in EstimateS to estimate species richness are given below.

1. The first order Jackknife estimator (Jack 1): is an estimator based both on the number of species occurring in only one sample and on the total number of quadrats.

$$S_{\text{jack1}} = S_{\text{obs}} + Q_1 \left(\frac{m-1}{m} \right)$$

Where; S_{jack1} = the expected species number based on Jack 1 estimator

S_{obs} = the number of species observed in the all pooled samples

Q_1 = the frequency of unique (species that occur in one sample only)

m = total number of samples.

2. Abundance-based Coverage Estimator (ACE) of species richness: Is advantageous because abundant and rare species, including the singletons are represented.

$$S_{\text{ace}} = S_{\text{abund}} + \frac{S_{\text{rare}}}{C_{\text{ace}}} + \frac{F_1}{C_{\text{ace}}} \gamma_{\text{ace}}^2 \quad C_{\text{ace}} = 1 - \frac{F_1}{N_{\text{rare}}} \quad \text{and}$$

$$N_{\text{rare}} = \sum_{i=1}^{10} iF_i$$

$$\gamma_{\text{ace}}^2 = \max \left[\frac{S_{\text{rare}}}{C_{\text{ace}}} \frac{\sum_{i=1}^{10} i(i-1)F_i}{(N_{\text{rare}})(N_{\text{rare}} - 1)} - 1, 0 \right]$$

Where S_{ace} = expected species number based on abundance-based coverage estimator

S_{abund} = number of abundant species (each with more than 10 individuals)

when all samples are pooled.

S_{rare} = number of rare species (each with 10 or fewer individuals) when all

when all samples are pooled

C_{ace} = sample abundance coverage estimator

N_{rare} = total number of individuals in rare species

F_1 = the number of singletons

γ_{ace}^2 = estimated coefficient of variation of the F_i for rare species 2_{ace}

Sampling efficiency was also calculated as: number of species estimated (ACE mean + Jack 1 mean)/2. Sampling efficiency = (Species observed x 100/Species estimated).

Bat abundance in the four broad vegetation types was determined using single factor

ANOVA. To assess the completeness of the survey, and standardize the comparisons of different inventories of species, an accumulation curve of the number of bat species against sampling sites was plotted.

CHAPTER FOUR

RESULTS

4.1 Vegetation structure

Field determinations of the principal plants using a standard field guide (Agnew and Agnew, 1994) recorded 52 plant species. A cover/abundance rating (Baun-Blanquet) was recorded for plant species identified in 30 plots; 10 each, for *Acacia* woodland, *Acacia-Commiphora* woodland and the Riverine vegetation. Two plant species assemblages were identified according to their floristic similarity using both cluster analysis and Detrended Correspondence Analysis. While Riverine Vegetation (node 1) grouped separately, *Acacia* woodland grouped together with *Acacia-Commiphora* woodland (node 2) (Figures. 4.1 and 4.2). Indeed heterogeneity (D) indices within these assemblages were 2.58, 2.96 and 2.91 respectively.

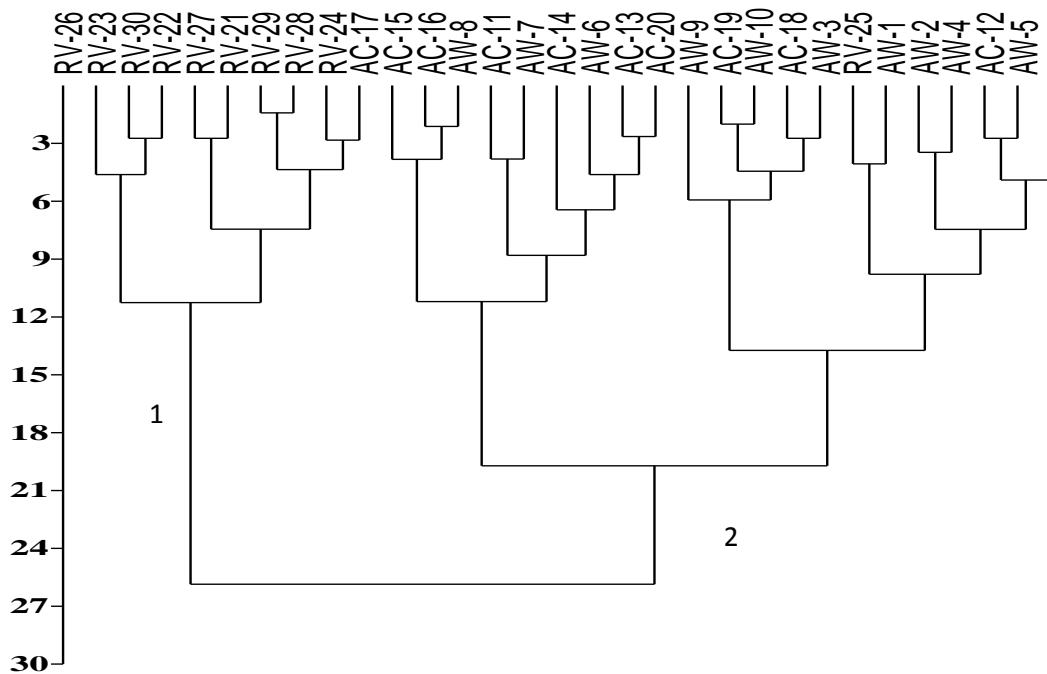


Figure 4.1: Dendrogram of species assemblages of vegetation (y-axis represents the dissimilarity level while the x-axis represents the assemblages. Node 1 represents Riverine Vegetation; node 2 *Acacia* woodland/*Acacia-Commiphora* woodland)

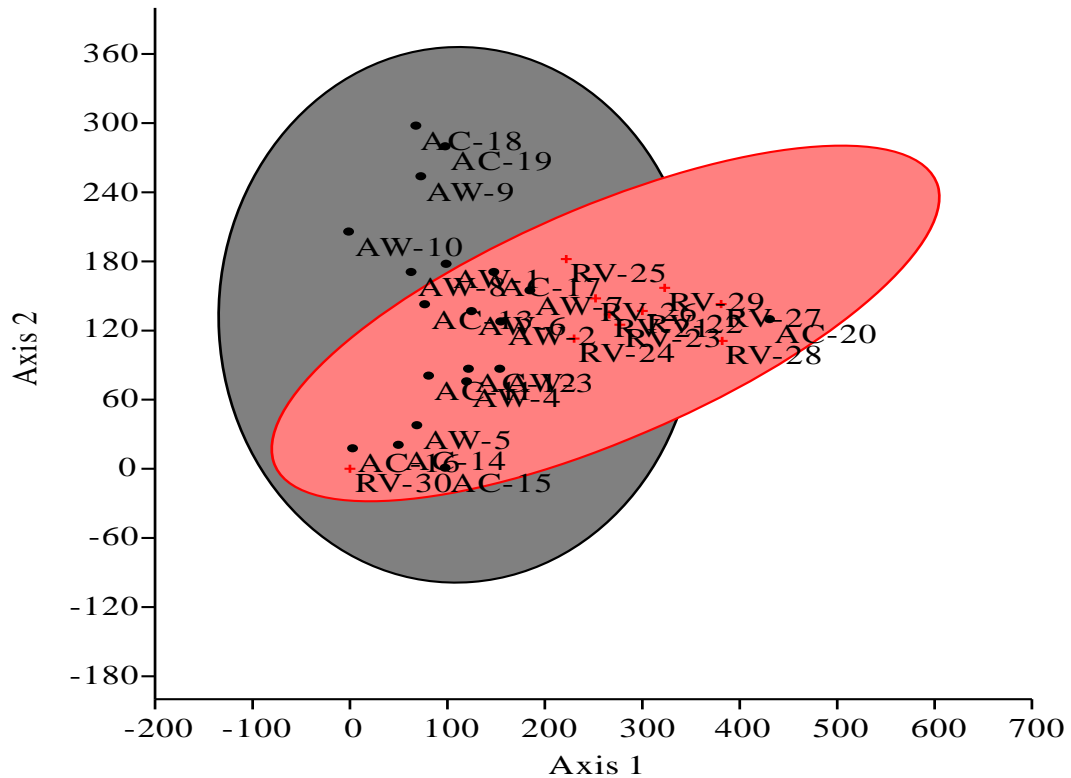


Figure 4.2: De-trended Correspondence Analysis (DCA) ordination diagram from the three vegetation formations: *Acacia* woodland (AW), *Acacia-Commiphora* woodland (AC) and Riverine Vegetation (RV).

4.2 Bat species records

Two hundred and thirty-three bats comprising 11 species from seven families (Table 4.2) were recorded during 64 trapping nights in three vegetation types within Lake Bogoria National Reserve and on adjacent farms. Bats were identified based on their external measurements (i.e. their morphometrics). The range of morphometrics and mass for different sexes for each species are shown in Table 4.1, with other detailed information on the different species indicated below (Plates 4.2 a-k).

Family *Pteropodidae*. *Epomophorus minimus* (Claesen and De Vree 1991): Specimens examined were 77 from all vegetation communities and farmlands.



Plate 4.2a: *Epomophorus minimus* (East African Epauletted Fruit Bat)

(Source: Author, 2012)

Epomophorus minimus is sometimes confused with *Epomophorus minor*, which was synonymised with *E. labiutus* (Patterson and Webala, 2012). It is a common species in East Africa and has been recorded from dry and arid savanna habitats. Large in size with brownish colour on the top body part and white patches under the belly. It is possible that this species has a specialized diet to persist in its arid habitat. There appear to be no major threats to this species. It is locally threatened in parts of its range by deforestation of its habitat for timber and firewood (IUCN, 2014).

Family *Rhinolophidae*. *Rhinolophus landeri* (Martin, 1838): Specimens examined were 2 from *Acacia* woodland.



Plate 4.2b: *Rhinolophus landeri* (Lander's horseshoe bat)

(Source: Paul Webala, 2012)

This species has been widely reported from much of sub-Saharan Africa, including Kenya. It has been recorded from low altitudes in coastal Kenya to high altitudes of 2000 m above sea level at Mt Elgon National Park (Patterson and Webala, 2012). This species is rather common locally with colonies can consist of hundreds of individuals. This species is generally associated with both savanna and gallery forest habitats. It has also been found in lowland, sparsely wooded transition areas, riverine forest, dense thorn shrub and tropical moist forest. Populations roost in caves, mine area and in crevices amongst piles of boulders. It has also been found roosting in a baobab tree, water wells and buildings (IUCN 2014).

Family *Hipposideridae*. *Hipposideros caffer* (Sundevall, 1846): Only 1 specimen examined from *Acacia-Commiphora* woodland.



Plate 4.2c: *Hipposideros caffer* (Common African leaf-nosed bat)

(Source: Paul Webala, 2013)

This is a medium-sized insectivorous bat with a horseshoe-shaped nose leaf and has two colour phases in adulthood? The color varies from grey-brown to golden-yellow; the ears are large and pointy; the nose-leaf is horseshoe-shaped. This species has a wide range, encompassing much of sub-Saharan Africa. It is a savanna-dwelling species and inhabits a variety of roost types including caves, hollow trees, and abandoned buildings. It often roosts in groups of thousands of individuals, is very common, and is not of special conservation concern.

Family *Megadermatidae*. *Cardioderma cor* (Peters, 1872): Specimens examined were 106 from the three vegetation communities and the farmlands.



Plate 4.2d: *Cardioderma cor* (Heart-nosed Bat)

(Source: Author, 2012)

Although there is little overall information on the abundance of this species, up to 81 bats have been found roosting in a hollow baobab tree. Have typically been recorded from lowland savanna, shrubland, and the coastal strip, and in some instances may be observed in river valleys. It roosts alone, or in small numbers, in caves, hollow trees and abandoned buildings. The species has been recorded from protected areas in Kenya (e.g. Tsavo West National Park) and is likely to be present in protected areas in some other East African countries. There appear to be no major threats to this species, however, further studies are needed into the impact of disturbance on roosting sites (IUCN, 2014).

Family *Megadermatidae*. *Lavia frons* (E. Geoffrey 1810): Specimens examined were 12 from three vegetation communities.



Plate 4.2e: *Lavia frons* (Yellow-winged Bat)

(Source: Author, 2013)

Although there is little information on the abundance of this species, it is probably uncommon. This species is widespread in riparian habitats in low lying acacia woodland, thorn scrubland and savanna. It is generally associated with open habitats and is probably absent from undisturbed rainforest. It usually roosts as individual animals in tree hollows, but has been recorded roosting in buildings. Other than studies into the possible effects of human activity on population dynamics of this bat, and additional research into the range of this species, no conservation measures are currently needed for this widespread species (IUCN, 2014).

Family *Nycteridae*. *Nycteris hispida* (Schreber, 1775): Specimens examined were 5 from *Acacia* woodland, riverine vegetation and farmland.



Plate 4.2f: *Nycteris hispida* (Hairy Slit-faced Bat)

(Source: Author, 2012)

The pelage colour is very variable, but dark beige and dark brown are the most common color tints. The dominance of these dark tones is mainly due to its common occurrence in the forests. This species has a wide range, encompassing much of sub-Saharan Africa, with the exception of the Horn of Africa and parts of southern Africa. This species has been recorded from a wide variety of habitats, ranging from lowland tropical moist forest, into moist savannah, dry savannah, papyrus swamps and marsh. Colonies range in size from individual and pairs of to up to 20 bats and roost in hollow trees, dense bushes, caves, holes in termite colonies and similar habitats. It is locally threatened in parts of its range by habitat loss, largely through the conversion of forest to agricultural use (IUCN, 2014).

Family *Molossidae*. *Chaerephon pumilus* (Cretzschmar, 1830-1831): Specimens examined were 13 from all three vegetation communities.



Plate 4.2g: *Chaerephon pumilus* (Little free-tailed bat)

(Source: Paul, Webala, 2013)

Shows extensive variation in colour pattern, size and echolocation across its wide distributional range with a light-winged form in north-eastern Africa and a dark form in southern Africa (Jacobs, *et al.*, 2004). The colonies of this species range from a few animals (between 5 and 20) to hundreds of individuals. Although the species appears to prefer forest or savanna woodlands outside built-up areas, its presence in built-up areas is determined solely by the availability of suitable roofs and buildings for roosting. In homes they are a nuisance due to the odour smell from their defecate especially on the ceiling board and may cause damage. In some parts, it is threatened from persecution as a pest, especially since it roosts in buildings (IUCN 2014).

Family *Molossidae*. *Mops condylurus* (A. Smith, 1833) Specimens examined were 4 from all three vegetation communities within the Reserve.



Plate 4.2h: *Mops condylurus* (Angolan Free-tailed Bat)

(Source: Author, 2012)

The bat species has dark charcoal-coloured fur above and a pale white or cream below which may extend more towards the chin. This species is larger in size, however, and the mouth is broader. Also, when in-flight the wing membranes may appear lighter in colour. They have wrinkly lips and forwardly ears. This bat is widely distributed over much of sub-Saharan Africa. They roost in crevices in rocks and many other crevice-like spaces, but very commonly they are found in high numbers in the roofs of houses or buildings, and therefore possibly threatened by general persecution (IUCN, 2014).

Family Vespertilionidae. *Neoromicia capensis* (A. Smith, 1829): Specimens examined were 2 from *Acacia* woodland and *Acacia-Commiphora* woodland.



Plate 4.2i: *Neoromicia capensis* (Cape serotine)

(Source: Author, 2013)

Neoromicia capensis probably represents a complex of several similar species. Further studies are needed to clarify the taxonomic status of populations currently allocated to this species. This lowland species is widespread over much of sub-Saharan Africa and typically inhabits lowland tropical moist forest, tropical dry forest, and dry and moist savanna. It has also been recorded from more arid areas, grassland, bush veld and *Acacia* woodland and roost under the bark of trees and similar vegetation, between cracks in walls and under the roofs of houses both thatched and corrugated iron or tiled. There is no direct conservation measures currently needed for this species as a whole (IUCN, 2014).

Family Vespertilionidae. *Scotoecus hirundo* (de Winton, 1899): Specimens examined were 5 from the *Acacia* woodland, the riverine vegetation and the farmlands.



Plate 4.2j: *Scotoecus hirundo* (Dark-winged lesser House Bat)

(Source: Author, 2012)

This widespread African species has been reported as scattered records from West Africa to East Africa. It is very rarely recorded, and information is available on the population abundance or size of this species. While the threats to this species are not well known, it is presumed not to have any major threats in view of the species wide distribution in habitats that are not rapidly declining throughout much of its recorded range (IUCN, 2014).

Family Vespertilionidae. *Scotophilus dinganii* (A. Smith, 1833): Specimens examined were 5 from *Acacia* Woodland, riverine vegetation and the farmlands.



Plate 4.2k: *Scotophilus dinganii* (Yellow-bellied House Bat, African Yellow Bat)

(Source: Paul Webala, 2013)

This species is identified by its distinct yellow color under the belly. The species has been recorded from both dry and moist savanna habitats with unknown population trends. It roosts in hollow trees, roofs and other dark places in houses. Although they may roost singly, groups of 20 to 30 bats are not uncommon. While *Scotoecus hirundo* species are known mainly from isolated records from a large area, the rest of bat species are presumed to be stable and large in population. They are listed as Least Concern in view of their wide distribution, and because they are unlikely to be declining fast enough to qualify for listing in a more threatened category (IUCN, 2014).

Ten species were recorded in *Acacia* woodland, six in *Acacia-Commiphora* woodland, seven in riverine vegetation and five on farmlands (Table 4.2).

Table 4.1: Range of morphometric measurements and mass of specimens collected from LBNR for both males and females (n= number of specimens, FA= forearm length, TTL= total length, TL= tail length, RHF= right hind foot length, EL= ear-length, Tr= Tragus length and WT= weight of specimen)

| Family | Species | n | | FA | TTL | TL | RHF | EL | Tr | WT |
|-------------------------|-----------------------------|------------|---|-----------|------------|-----------|------------|-----------|-----------|-----------|
| Pteropodidae | <i>Epomophorus minimus</i> | 77 | M | 54-63 | 86-117 | - | 18-19.5 | 18-20 | - | 23-44 |
| | | | F | 54-64 | 83-106.5 | - | 18-19 | 18-20 | - | 21-40 |
| Rhinolophidae | <i>Rhinolophus landeri</i> | 2 | M | 44-45 | 71-77 | 24-27 | 9-10 | 17-18 | 7-8 | 6-8 |
| Hipposideridae | <i>Hipposideros caffer</i> | 1 | F | 50 | 84 | 36 | 8 | 17 | - | 8 |
| Megadermatidae | <i>Cardioderma cor</i> | 106 | M | 53-57 | 63-80 | - | 18-21 | 35-38 | 17-20 | 18-34 |
| | | | F | 53-60 | 67-80 | - | 18-21 | 35-39 | 17-20 | 21-37 |
| | <i>Lavia frons</i> | 12 | M | 57-61 | 63-73 | - | 16-19 | 36-39 | 26-27.5 | 18-28 |
| | | | F | 57-64 | 63-71 | - | 17-18.5 | 35-38 | 26.5-27 | 18.5-25 |
| Nycteridae | <i>Nycteris hispida</i> | 5 | M | 43-44 | 35-51 | 30 | 9-10 | 28 | 5-6 | 6-8 |
| | | | F | 43-45 | 49.5-50 | 31 | 10 | 28-29 | 5-8 | 8-9 |
| Molossidae | <i>Chaerephon pumilus</i> | 13 | M | 30-46 | 78-113 | 31-42 | 7-13 | 15.5-16 | 1-3 | 9-22 |
| | | | F | 37-47 | 79-111 | 31-40 | 9-13 | 15-17.5 | 1-3 | 9-23 |
| | <i>Mops condylurus</i> | 4 | M | 33 | 88 | 36 | 8 | 6 | - | 7 |
| Vespertilionidae | <i>Neoromecia capensis</i> | 2 | M | 33 | 79 | 34 | 8 | 4 | - | 3.5 |
| | | | F | 31 | 82 | 30.5 | 7 | 7 | - | 3.5 |
| | <i>Scotoecus hirundo</i> | 6 | M | 32-33 | 87-90 | 28-36 | 7-8 | 5-6 | - | 4-9 |
| | <i>Scotophilus dinganii</i> | 5 | M | 51-52 | 126-127 | 54 | 9 | 7 | 2.5 | 22-23 |
| | | 233 | F | 53-56 | 129-131 | 54 | 7-12 | 7-9 | 2 | 17-22 |

Table 4.2: Distribution and proportional abundance of bats in four broad vegetation formations at Lake Bogoria National Reserve, November, 2012 -July, 2013.

| Family | Species | <i>Acacia</i> Woodland | <i>Acacia-</i> <i>Commiphora</i> woodland | Riverine Vegeta- tion | Farmlands | Total |
|------------------|-------------------------------------|---------------------------|---|--------------------------|--------------|------------|
| Pteropodidae | <i>Epomophorus minimus</i> | 7 | 8 | 35 | 27 | 77 |
| Rhinolophidae | <i>Rhinolophus landeri</i> | 2 | 0 | 0 | 0 | 2 |
| Hipposideridae | <i>Hipposideros caffer</i> | 0 | 1 | 0 | 0 | 1 |
| Megadermatidae | <i>Lavia frons</i> | 5 | 3 | 4 | 0 | 12 |
| | <i>Cardioderma cor</i> | 13 | 26 | 10 | 57 | 106 |
| Nycteridae | <i>Nycteris hispida</i> | 1 | 0 | 3 | 1 | 5 |
| Molossidae | <i>Chaerephon pumilus</i> | 10 | 1 | 2 | 0 | 13 |
| | <i>Mops condylurus</i> | 4 | 0 | 0 | 0 | 4 |
| Vespertilionidae | <i>Neoromicia capensis</i> | 1 | 1 | 0 | 0 | 2 |
| | <i>Scotoecus hirundo</i> | 1 | 0 | 3 | 2 | 6 |
| | <i>Scotophilus dinganii</i> | 2 | 0 | 2 | 1 | 5 |
| | Total (individuals) | 46 | 40 | 59 | 88 | 233 |
| | Observed species richness(S) | 10 | 6 | 7 | 5 | 11 |
| | D | 5.27 | 2.13 | 2.55 | 1.94 | |
| | Evenness (E_1) | 0.847 | 0.597 | 0.678 | 0.517 | |

4.3 Bat species richness and diversity

Although with the lowest numbers of captures, Acacia Woodland recorded the highest bat species diversity and evenness. In contrast, farmlands recorded the lowest species richness diversity and evenness but with highest number of captures of only two generalist species, *Epomophorus minimus* and *Cardioderma cor* (Table 4.2).

The species accumulation curve for all sampled sites combined did not reach an asymptote but leveled off (Figure 4.3)

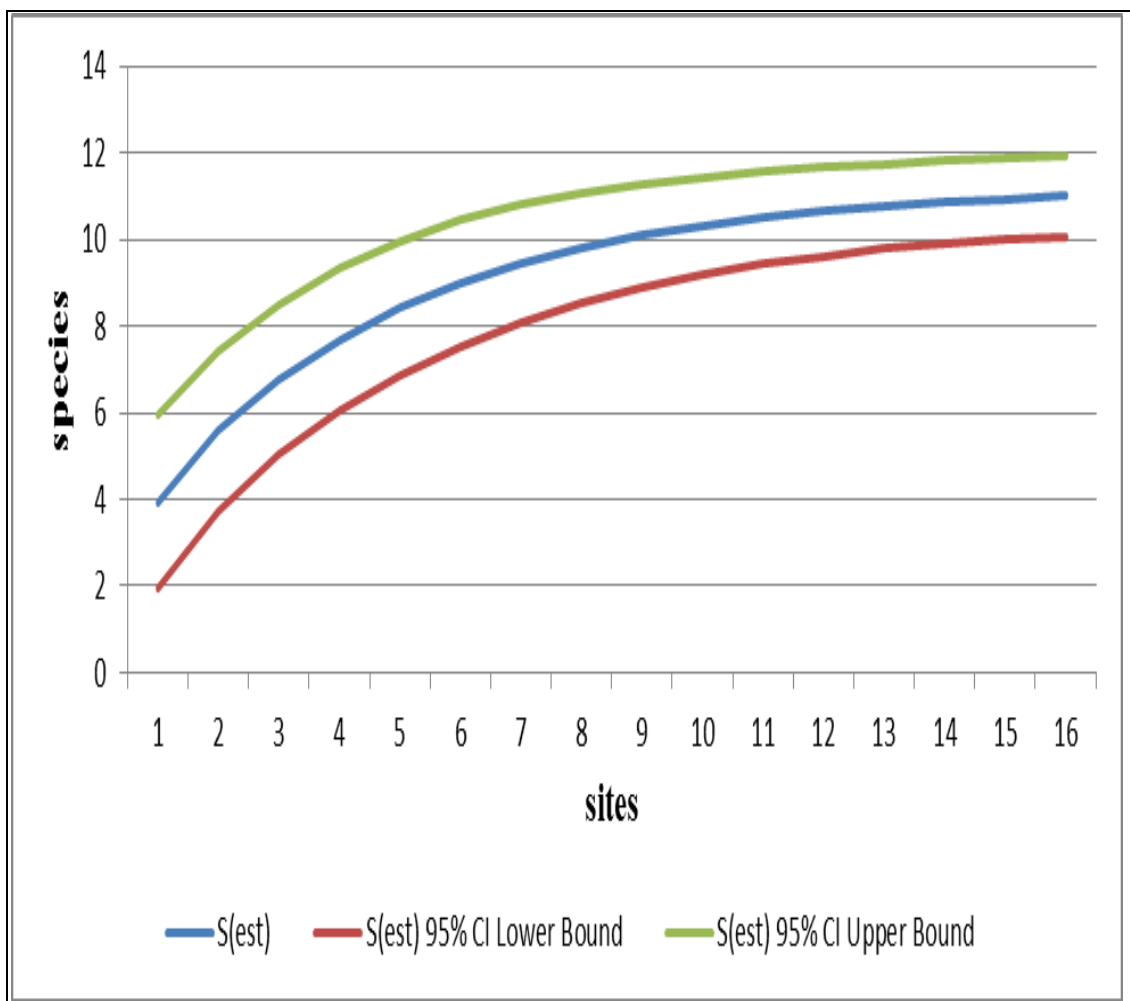


Figure 4. 3: Species accumulation rate for bats at the LBNR, November, 2012 to July, 2013.

4.4 Association between bat species and plant species assemblages

Analysis of plant species diversity for the three vegetation formations within LBNR showed that Acacia Woodland had the highest diversity and Riverine vegetation recorded the least (Table 4.4). Most species of bats were associated more with *Acacia* woodland ($D = 5.27$, node 2 of (Figure. 4.1) and *Acacia-Commiphora* woodland ($D = 2.13$, node 2) rather than with Riverine Vegetation ($D = 2.55$, node 1). However, the association indicated no significant difference ($r = 0.17$, $n=16$, $p = 0.5 > 0.05$) between the vegetation formations. Differences in bat abundance among the four vegetation formation was not significant (one way ANOVA, $F= 0.32$, $df=15$, $p = 0.81$).

Table 4.4: Relationship between bat and plant species diversity

| Vegetation Type | <u>Bat Species</u> Diversity (D) | <u>Plant Species</u> Diversity (D) |
|--------------------------------------|--|--|
| <i>Acacia</i> woodland | 5.27 | 2.58 |
| <i>Acacia-Commiphora</i> Woodland | 2.13 | 2.96 |
| Riverine vegetation | 2.55 | 2.91 |
| Farmland | 1.94 | 0.27 |

CHAPTER FIVE

DISCUSSION

Two broad plant species assemblages were identified within Lake Bogoria National Reserve by cluster analysis and Detrended Correspondence Analysis in this study. These were Riverine vegetation and *Acacia* woodland. However, from preliminary observations, the latter was comprised of sections where plants of the genus *Acacia* were dominant and others consisted of a mixture of both *Acacia* and *Commiphora* plants. Results of the bat species richness and diversity at Lake Bogoria National Reserve are discussed following this broad vegetation classification, namely; *Acacia* woodland, *Acacia-Commiphora* woodland and riverine vegetation.

Eleven bat species belonging to 7 families were confirmed to occur at Lake Bogoria National Reserve, representing the first record of bats in the area. These were: *Epomophorus minimus*, *Rhinolophus landeri*, *Hipposideros caffer*, *Cardioderma cor*, *Lavia frons*, *Nycteris hispida*, *Chaerephon pumilus*, *Mops condylurus*, *Neoromicia capensis*, *Scotoecus hirundo* and *Scotophilus dinganii*.

A species accumulation curve of the number of bat species plotted against number of capture sites did not only reach an asymptote but also levelled off, suggesting that the species recorded approaches the actual number trappable by this method (Colwell *et al.*, 2004). Statistical estimations of total bat species richness based on Jackknife1 mean and Abundance-based Cover Estimate means (ACE) were close to the actual number of species recorded in this study at Lake Bogoria National Reserve, suggesting that the sampling was adequate for species trappable using ground-based nets in this savannah ecosystem.

It is worth noting, however, that the bat species recorded in this study represent only species captured while flying up to 3m above ground because mist nets were deployed at ground level. Sub-canopy and canopy bats or even high fliers that forage beyond the canopy may not be adequately represented because they flew above ground-level mist nets (Kalko, 1997; Simmons and Voss, 1998; Meyer *et al.*, 2011). Furthermore, an important assumption used in many studies, utilizing mist nets, is that all bats have the same likelihood of capture. The reality, though, is that not all bat species have the same probability of being trapped due to their plasticity in behaviour among species (e.g, Schnitzler and Kalko, 2001). Mist nets are known to be biased against species, such as emballonurids, some hipposiderids and vespertilionids that are adept at detecting and avoiding mist nets (Kunz *et al.*, 1996; Gannon and Willig, 1998; Kuenzi and Morrison, 1998; O'Farrell and Gannon, 1999; MacSwiney *et al.*, 2008). Other species may be commuting from roosting sites outside the trapping area and might be expected to be more common at sites nearer to the roosts. Therefore, the combination of methods, including acoustic sampling using bat detectors, use of harp traps and trapping at or near roost sites (O'Farrell and Gannon, 1999), could have provided a more complete characterisation of the species assemblage at Lake Bogoria National Reserve (Meyer *et al.*, 2011).

For some species, however, apparent rarity may truly reflect low population densities (Kingston *et al.*, 2003), possibly related to specific roosting or habitat requirements. This study indicated that *Hipposideros caffer*, *Rhinolophus landeri* and *Neoromicia capensis* were rare, both spatially and numerically. This may be an artifact of sampling bias where patchily distributed species may appear rare if sampling fails (Kingston *et al.*, 2003), or may also be indicative of relative levels of anthropogenic distur-

bances among vegetation communities and/or sites. For bats, disturbance may limit the availability of suitable roosting and foraging sites. However, depending on size, flight mobility allows bats to utilize a mosaic of habitats for foraging, making abundant and optimal roost sites key for the survival of bats in an area (Brigham and Fenton, 1986; Vonhof and Barclay, 1996). Different bat species roost in different structures but common roosts include caves, tree hollows, under tree bark, in tree foliage, rock crevices, among others (Kunz, 1982). Firewood harvesting and charcoal burning, as well as vegetation clearing and fragmentation, typically leads to a reduction in numbers of large live and standing dead trees (Gibbons *et al.*, 2008). At Lake Bogoria National Reserve, this situation is manifested in the loss of older trees with hollows and defoliating bark, which may threaten the survival and persistence of bats and other vertebrate wildlife dependent on such resources for roosting.

Differences in bat species richness and diversity at Lake Bogoria National Reserve were quite evident, perhaps reflecting differential level of human disturbance in the area. The *Acacia* woodland recorded the highest number of species, evenness and diversity. This can be attributed to higher habitat variability that allowed more foraging and roosting sites (Hackett *et al.*, 2013). Conversely, farmlands recorded the least number of species, evenness and diversity. The farms were less diverse in terms of habitats and plant species, with only a few isolated trees among crop monocultures such as bananas and maize, providing few roosting sites near suitable foraging sites (Hackett *et al.*, 2013). Single factor ANOVA revealed that there was no significant difference in bat abundance ($P > 0.05$) among the four vegetation types. But observable differences indicated that *Cardioderma cor* and *Epomophorus minimus* were the most abundant and ubiquitous species, occurring at all of the four vegetation for-

mations. Both species are generalists, adapted to a wide range of environmental circumstances and food sources (Mickleburgh *et al.*, 2008), and neither is adept at avoiding mist nets. *C. cor* is known to roost alone, or in small numbers, in caves, hollow trees and abandoned buildings (Vaughan, 1976; Csada, 1996), and exploits a wide range of food items ranging from small vertebrates such as bats and frogs to moths, beetles and even centipedes and scorpions (Vaughan, 1976). Similarly, *E. minimus* is distributed widely in dry savanna habitats and feeds on a wide variety of fruits (Mickleburgh *et al.*, 2008). *E. minimus* was abundant on the farmlands but also in the Riverine Vegetation probably because of the availability of fruiting trees, especially of the genus *Ficus*, which allowed large populations to persist in the area (Francis, 2008). These two generalist bat species may be more prevalent in modified habitats as they usually are more common and are less likely to be affected by habitat disturbance or are more likely to re-colonize after a disturbance (Hansson, 1991). The ecosystem at Lake Bogoria National Reserve was skewed in favour of these common generalists, with other species appearing rare because they were sampled in ‘marginal’ habitats in contrast to their optimal habitats (Basset *et al.*, 1991). *Nycteris hispida*, *Scotoecus hirundo* and *Scotophilus dinganii* were also found distributed widely in all vegetation formations including farmlands although in small numbers. The presence of these species in vegetation formations may be explained by the availability of roost sites and food sources. However, frequency of occurrence of some species like *Hipposideros caffer*, *Rhinolophus landeri* and *Neoromicia capensis* documented in *Acacia–Commiphora* woodland and *Acacia* woodland respectively, was low with one or two individuals. Clutter-specialist species (e.g. rhinolophids and hipposiderids) are, however, generally more sensitive to habitat disturbance (Kingston *et al.*, 2003). Even though some species such as *H. caffer* and *S. dinganii* are known to utilize roosts in

man-made structures, their susceptibility to landscape fragmentation could explain their rarity or even few numbers in some vegetation types of the LBNR. This may be attributed to historical grazing pressure (up until the late 2000^s) LBNR experienced through livestock farming. Such activities often results in dense clumps of woody vegetation through bush encroachment among other anthropogenic disturbances. However, a more comprehensive consideration of problems related to sampling rare, elusive and nocturnal animals is warranted (Thompson 2004) before arriving at an incontrovertible conclusion.

This study also showed that more heterogeneous vegetation formations with higher plant species diversity supported higher bat species diversity. For instance, *Acacia* woodland, with highest plant species diversity, also recorded highest bat diversity compared to the other vegetation types. In generally, however, there was no significant difference in the overall species, abundance and distribution patterns in the entire LBNR, suggesting that despite differing disturbance levels, bats can persist in such modified habitats. These findings corroborate with other studies where bat many species, and particularly generalists, can persist in disturbed landscapes (Aguirre *et al.* 2003; Schulze *et al.*, 2000). This apparent tolerance to human-driven habitat disturbance is explained by the ability of bats to cross habitat boundaries and to fly over open areas to reach resources that are patchy in space and time (Montiel *et al.* 2006). Conversely, other taxa such as primates and understory birds (Bierregaard and Stouffer 1997), rodents (Qian *e al.*, 2009) and insects(Weibull *et al.*, 2000) whose diversity and composition is determined by potential structural heterogeneity.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study demonstrated that there were no substantial differences in species richness, diversity and abundance across the four vegetation formations at Lake Bogoria National Reserve. The presence of only a few generalist species on the farmlands may be an indication of habitat disturbance, where key bat resources such as cavity bearing trees are removed, leading to loss of suitable roosting sites near foraging sites (Fenton, 1997). While the more generalist species colonized all habitat types including farms, specialised species exhibited characteristics of rarity in space and abundance. Such species are likely to be more affected by environmental perturbations, especially those driven anthropologically (Webala *et al.*, 2004). Disturbances such as vegetation clearance, charcoal burning, cattle grazing and firewood collection are likely to have deleterious impacts on the roosting and foraging sites of bats, and as well as other fauna utilizing such ecosystems.

6.2 Recommendations

This study may not have yielded a comprehensive bat species assemblage at Lake Bogoria National Reserve because only ground mist-netting was employed. Future studies are advised to use sub-canopy and canopy mist-netting, acoustic sampling, radio-tracking of bats to their roost locations, and the use of harp traps at or near identified roost sites, to provide more accurate and unbiased surveys. The explanation given in this study to determine disturbance based on observable differences of bat species is rather basic and only gave a rough idea. Further research should measure disturbance gradient by determining canopy height, canopy openness, charcoal kilns

and tree stumps in order to give more meaningful differences in structural complexity and composition of vegetation. This may help reveal the direct effects of human disturbance on bats and other vertebrates.

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