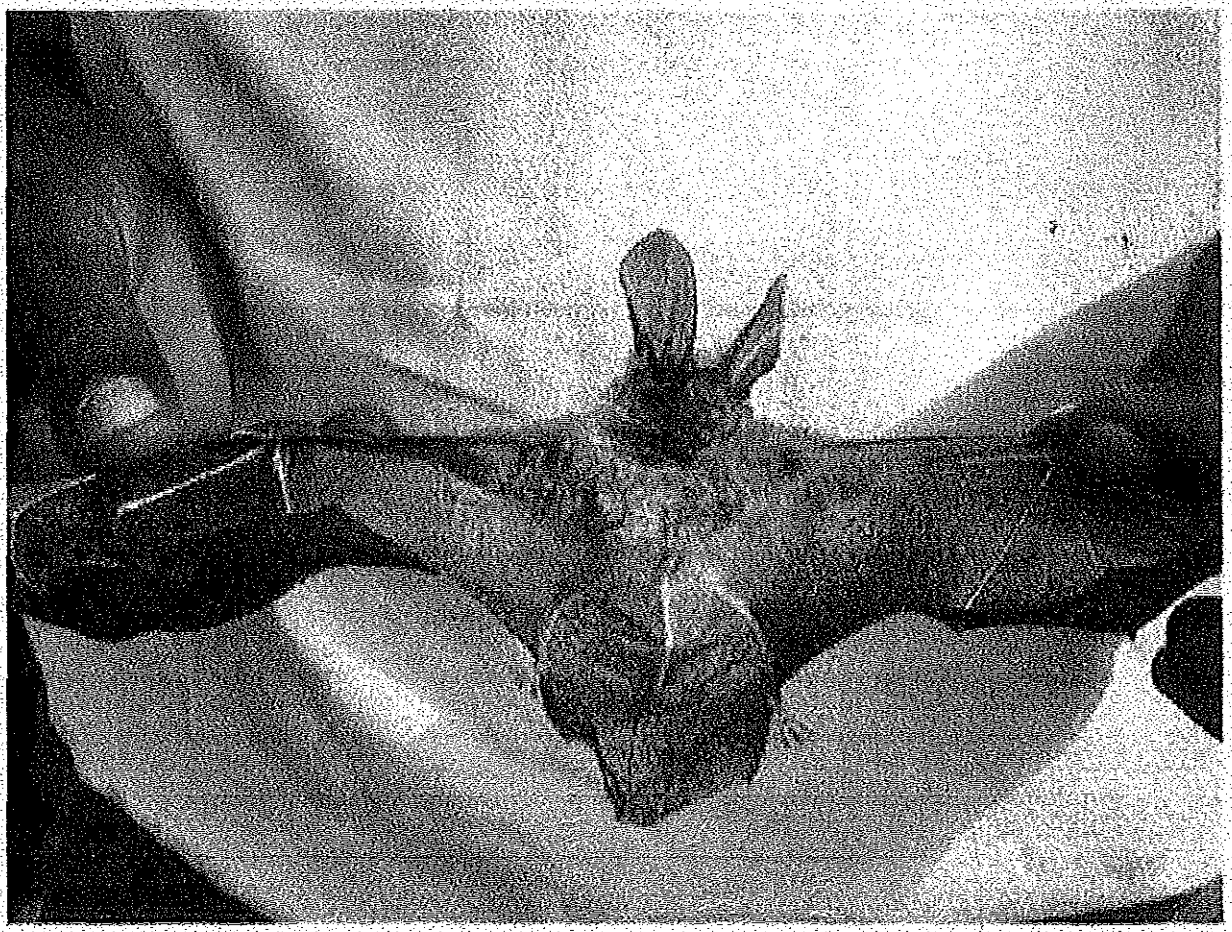
Addis Ababa University
School of Graduate Studies

A study of the diversity and distribution of Bats at Meru National park, Kenya



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Pual Waswa Webala

June 2001

Addis Ababa, Ethiopia

A STUDY OF DIVERSITY AND DISTRIBUTION OF BATS AT MERU NATIONAL PARK, KENYA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN DRYLAND BIODIVERSITY

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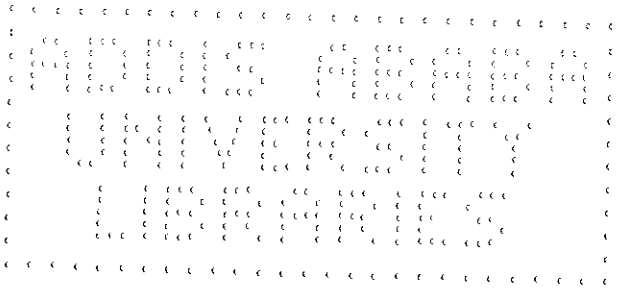
JUNE 2001

ADDIS ABABA, ETHIOPIA

Dedication

This thesis has been dedicated to my father, Elijah Wekesa Webala, my mother, Robai Webala and sister, Mary Webala who will always remain a source of strength and inspiration to me.



Acknowledgement

I obtained valuable cooperation and assistance from many people. I regret that only a few will be mentioned here. However, to all I extend my sincere thanks.

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TABLE OF CONTENTS

List of tables

List of figures

List of appendices

ABSTRACT

The present study was carried out in Meru National Park, Kenya and adjacent farms from September 2000 to February 2001. The diversity and distribution of bats based on vegetation disturbance and plant species cover/abundance were examined. Four hundred and ninety five (495) bats representing the families Pteropodidae (2 species), Megadermatidae (2 species), Vespertilionidae (4 species), Molossidae (3 species), Hipposideridae (2 species), Nycteridae (1 species) and Rhinolophidae (1 species) were recorded. Four species: --*Nycteris arge*, *Myotis welwitschii*, *Tadarida cistura* and *Tadarida acetabulosus* had not been previously recorded in eastern Kenya. Open *Acacia* woodland consisted of the highest proportion of bats (38%) and the farms consisted the least (8.9%). The species *Epomophorus labiatus*, *Epomophorus wahlbergi* and *Cardioderma cor* were captured in all the vegetation communities and on the farms. Both *Combretum* wooded grassland and *Acacia-Commiphora* bushland had the highest species richness (S = 9) while open *Acacia* woodland and the farms had 7 and 4 species respectively. Bat species diversity was highest in the *Combretum* wooded grassland (H' = 1.70 and D = 4.6) and least on the farms (H'= 0.955 and D = 1.99). Similarly, Shannon's evenness index was highest in the *Combretum wooded* grassland (E = 0.76) but least in the Open *Acacia* woodland (E = 0.52). Most species of bats were found to be mostly associated with *Combretum* wooded grassland and *Acacia-Commiphora* bushland and least with open *Acacia* woodland indicating probable disturbance in the open *Acacia* woodland relative to other vegetation communities in the park. Bat species diversity correlated positively with plant species diversity in all plant species assemblages except assemblage 4. The low species richness and diversity and increased dominance of a few generalist species in the open *Acacia* woodland and on the farms may reflect different levels of disturbance. The absence of rare and specialist bats on the farms may be a further indication of the effects of habitat disturbance on the diversity and distribution of bats.

1 INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Prior to human population explosion and advances in technology, man lived in near balance with the environment. During this time, the imbalance was largely brought about by environmental stochastic events such as climatic changes, hurricanes, fires, floods, and earthquakes. Although these events are still important today in precipitating habitat destruction and fragmentation, their effects are negligible compared to anthropogenic disturbances. Current models of the extinction process and estimates of habitat loss, principally tropical rainforest, predict that species extinctions are occurring at very high rates both at the local and global scale (MacArthur & Wilson, 1963; MacArthur & Wilson, 1967; Pulliam, 1988). The expansion and intensification of human land use has contributed to the loss, destruction and increased isolation of habitat patches (Terborgh, 1974; WCMC, 1992). The effect of this modification to animal species is two-fold: decreases population sizes of many species and splits previously continuous populations into smaller isolated populations (metapopulations). These small populations are then made highly prone to extinction due to stochastic and deterministic factors.

The unprecedented levels at which many known and countless unknown species of plants and animals are being lost due to worldwide habitat degradation has led to what many scientists believe is a biodiversity crisis (Wilson, 1985; Wilson & Peter, 1988; Wilson, 1992; Cole *et al.*, 1994). It has been brought to the attention of conservation biologists that all is not well. The biotas of little-studied areas (many developing countries, for example) are poorly known and the ranges of most species, even in developed countries, are not adequately documented (WCMC, 1992; Pimm & Gittleman, 1992). Similarly, distributional information is generally

available for charismatic taxa, such as large herbivores, primates, large carnivores and certain birds but distributional information for most taxa is anecdotal at best (Sisk *et al.*, 1996). In order to develop policies and strategies for the conservation and management of the world's dwindling biological resources, it has been realised that there is an urgent need to survey and document these resources as a first step towards minimising their loss.

One of the habitats severely affected because of human influence is savannah woodland. This vegetation type covers most of sub-Saharan Africa and supports a diverse bat fauna (White, 1983). These ecosystems are increasingly being affected by settlement, expansion of human land use (mainly agriculture), and firewood collection (WRI, 1992). Disturbance in the form of removal of trees from a vegetation community can reduce biodiversity and modify the structure of the ecosystem (Huston, 1994). Fires, humans or elephants may cause such removal. Although little is known about the specific characteristics of roost sites, the loss of large trees and snags (i.e. dead trees due to fire and firewood collection) is expected to decrease roosting sites of bats and increase distances to foraging areas (Fenton *et al.*, 1998). This movement between roosting and foraging sites may demand high energetic costs. The reproductive success of females may also be affected due to long foraging distances as energy demand increases (Barclay, 1989; Tuttle, 1976). The implication of this is that having numerous, suitable trees benefits the population. If specific cavities provide specialised conditions for roosting, reduced availability could limit populations of bats. Different species of vertebrates respond differently to disturbance depending on the scale of the disturbance (Petraitis *et al.*, 1989) and the ability of the species in question to adapt to the changing conditions. Bats, because of their size and mobility, are variously susceptible to disturbance. Like in other mammal groups, larger species of bats tend to have bigger home ranges than smaller ones (Fenton, 1997), and may not be as affected by habitat perturbation.

Kenya, as is in many developing countries, is faced with a very high human population growth rate (3.5%) (WRI/IUCN/UNEP, 1992). Meru National Park (0^{O} 10' N; 38^{o} 0' and 34^{O} 25' E) occurs in an area with one of the highest human population density in Kenya that are largely dependent on subsistence agriculture. This inevitably creates a serious potential conflict between conservation values of the park on the one hand and the local people on the other. But perhaps a serious threat is the influence of the largely agricultural community on the park, whose activities may effectively render the park an ecological island. Indeed, much of the park has been and continues to be encroached through illegal park activities such as meat poaching and honey gathering. Honey gathering has the consequence of precipitating uncontrolled fires within the park. These activities inevitably lead to habitat modification, which may render it unsuitable for many wildlife species.

Although there is a lot of literature dealing with East African mammals and Kenya in particular (e.g. Kingdon, 1974), the publications deal largely with their taxonomy and biogeography and ignore ecological and conservation aspects (Aggundey & Schlitter, 1984). This is particularly true for bats where most of the literature is found in checklists and museum voucher specimens. For bats of Kenya, little is known about their conservation status except scanty information on the taxonomy and geographic distribution that is based on museum collections (Aggundey & Schlitter, 1984). Fourteen species of bats are recorded to occur in Meru National Park (Williams, 1981), but an overall assessment of their conservation status is not available, and their distribution is virtually unknown. The park has a reasonably high density of elephants, which are confined in the open *Acacia* woodland and some sections of *Combretum* wooded grassland in the park (P. W. Webala, *Pers. Obser.*). The park management has been changing hands almost annually since the 1980s and the use of fire as a management tool has not been strictly controlled over the years (S. Braude, *Pers. Comm.*).

This study examined the effects of vegetation disturbance on the distribution and diversity of bats in Meru National Park. In particular, the study explored differences in bat abundance and diversity in different plant communities broadly grouped as *Acacia/Commiphora* bushland, *Combretum* wooded grassland, and open *Acacia* woodland within the park. Outside of the park, banana, vegetable, "*Miraa*" (*Catha edulis*), sorghum, and maize farms and the grazing field were also assessed for bat species diversity. In order to identify ecological correlates and find patterns that may be indicative of conservation sensitivities and constraints, the type and abundance of bats were compared amongst different vegetation types within the park, and with those in the immediate human settlements around the park. The hypothesis that a less disturbed habitat has higher plant diversity was tested. Higher plant diversity might be expected to correlate with less human disturbance. Higher plant diversity relates to abundant food resources and a greater diversity of foraging and roosting sites for the bats and consequently higher bat diversity. If so, then less disturbed sections of the park were expected to have a higher diversity of bats than more disturbed areas. The entire park was similarly expected to have higher bat diversity than the human settlements around the park. In addition, generalist rather than specialist species were expected in disturbed areas.

In the following review, the effect of habitat heterogeneity and patchiness on species diversity is put in the context of bat ecology. In addition, the two widely used measures of species diversity and the conditions of their applicability are discussed.

1.2 LITERATURE REVIEW

1.2.1 Biological Diversity

The term biological diversity emerged as species extinction rates began to increase at unprecedented levels (Myers, 1979). The occurrence of mass extinctions, coupled with huge gaps in biological knowledge has convinced many scientists that a global biological crisis exists (Wilson, 1985). As habitats are altered, untold numbers of species are disappearing before they are recognised, much less studied (Wilson & Peter, 1988), and the functioning of entire ecosystems threatened. Globally, the need to survey biological resources as a first step to develop management strategies has never been as urgent as at present.

Biological diversity or biodiversity may be defined as "the total diversity and variability of living things and of the systems they depend on and of which they are a part". This covers the total range of variation in and variability among systems and organisms, at the bioregional, landscape, ecosystem and habitat levels, at the various organismal levels down to species, populations and individuals and at the level of populations and genes (Heywood & Gardner, 1995). The concept encompasses diversity at the genetic, species and ecosystem levels. The multiple and hierarchical nature of the concept of biodiversity distinguishes it from the much simpler concept of species diversity (Noss, 1990; Reid & Miller, 1989). Because traditional approaches of conservation were largely species-specific, species diversity was synonymous with biodiversity. This misuse trivialises the broader meaning of biodiversity and promotes misconceptions of conservation uses (Angermeier & Karr, 1993).

At the ecosystem level, the type of habitat, the size of patch, the number of different habitats (habitat diversity) and patchiness are important factors. The distribution of different species

within and among different habitats is also of interest. At the species level, the abundance and density of species is an important ecological attribute. However, while species are, for many purposes, the basic unit of biodiversity, they are made of populations. The local breeding population is the fundamental unit on which evolution and natural selection operates. Individuals of a population contain genetic information and it is this genetic diversity which determines their survival and evolutionary fate and which therefore underlies species diversity. Maintenance of biological diversity should encompass the three levels because they are intertwined. A central problem of the maintenance of biological diversity, however, is the assessment of the relative importance in terms of diversity of different areas, habitats or ecosystems (WCMC, 1992). Only by understanding this can priorities in conservation efforts be usefully assigned.

1.2.1.1 Habitat Heterogeneity and Species Diversity

Habitat heterogeneity affects a variety of ecological processes such as species interactions (Pacala & Roughgarden, 1982; Danielson, 1991); foraging (Roese *et al.*, 1991), and dispersal (Levin, 1974; Gardner *et al.*, 1989; Johnson *et al.*, 1992). The number of different habitats (habitat diversity), the size of each habitat's patch (habitat size) and the patchy distribution of the different habitat patches in the landscape (habitat patchiness) are very important variables of habitat heterogeneity and have important connotations on community composition.

Habitat diversity affects communities because different species may specialize in different habitat types. In the presence of new habitats, more species can exist (MacArthur, 1972). The presence of new habitats may also change the habitat selection of a species and may create more opportunities for coexistence (Rosenzweig, 1991). Hence, a larger area with more habitats is likely to support more species (Fox, 1993; Douglas & Lake, 1994).

Habitat patchiness affects communities because subpopulations of a species may escape local extinction in a few patches and re-colonize those patches later on (Levins, 1969; Holt; 1992). The greater the patchiness, the higher the probability that some individuals of a given population escape extinction in the entire area. This may result in lower extinction rates. However, in contrast to a single-patched habitat with a large area, habitat patchiness will result in a lower per-patch population size. Consequently, each patch will have a higher probability of extinction due to low population size. Taken together, the relationship between the effect of low population size and the disturbance-colonization effect will determine the rate of extinction of a particular population.

1.2.1.2 The Species Assemblage and its Diversity

The biotic component of ecological systems comprises many species of all kinds of biological groups (bacteria, plants, animals, etc.) and various roles (producers, herbivores, predators, decomposers, etc.) in the ecosystem. These species assemblages have overall properties, like number of individuals, biomass, cover and volume, which do not take species identities into account. Assemblages also possess "species diversity", which includes information on species identities and number of different species.

Diversity quantifies (1) how many different items (usually species) are there and (2) and how different these are (Gaston, 1996). The differences between the species are their abundances that may be measured as density, cover, or biomass. There are many expressions (measures and indices) of species diversity. All are based on the species composition in samples within a survey or an experiment, where species composition is simply a list of species of a particular group of organisms and some measure of their quantity (abundance). The organisms whose diversity is measured have three aspects in common: - (1) they have a common resource base

(and are therefore often called "guilds"), (2) they belong to the same taxon or group form (vascular plants, rodents, bats, birds or seed-eaters, trees, etc.), and (3) they occur in the same area.

1.2.1.3 Diversity Indices

Diversity indices incorporate both species richness and evenness into a single value. Because of this, Peet (1974) terms them *heterogeneity indices.* Many studies on biodiversity focus on species richness, which specifies how many species are found within samples. Species richness, however, addresses only part of the diversity and does not indicate how equitable species are within a sample. Using species number therefore is not always a very good way of comparing different samples, especially if they differ in size (total density) or in area (in different studies, for instance). Although diversity indices combine both species richness and evenness, they also have an inherent problem of interpreting the actual meaning of the single statistic. For example, in some cases a given value of a diversity index may be obtained from various combinations of species richness and evenness.

The diversity indices indicate the difference in abundance, which determines how likely it is to encounter each of the species in the community. There are an infinite number of diversity indices (Peet, 1974). The units of these indices differ greatly, making comparisons difficult and confusing, which adds to the interpretation problem. The best-known diversity indices are the Simpson and the Shannon-Weaver index, which use the species' relative abundances (importance values p_i) (Peet, 1974; Wittaker, 1975). The original diversity indices - Simpson's $D = 1/(\Sigma\, p_i^2)$ and Shannon-Weaver's $H' = -\Sigma\, p_i \ln (p_i)$- depend on both the number of species S ands their abundances. One sample is more diverse than a second one with the same number of species if the first is more even. The denominator of the Simpson's index,

which ranges from 0 to 1 gives the probability that two individuals drawn at random from a community belong to the same species. In other words, if the probability is high that both individuals belong to the same species, then the diversity of the community sample is low (Rosenzweig, 1995). On the other hand, Shannon's index, H' is a measure of the average degree of uncertainty in predicting to what species an individual chosen at random from a collection of S species and N individuals will belong. $H' = 0$ if and only if there is one species in the sample, and H' is maximum only when all S species are represented by the same number of individuals, that is, a perfectly even distribution of abundance (Rosenzweig, 1995).

1.2.2 The Order Chiroptera

Bats belong to the Order Chiroptera. The word "Chiroptera" is derived from two Greek words meaning hand-wing. Bats are the only group of mammals that can maintain a sustained and powered flight because of the hand-wing. Other than rodents, bats are the most numerous group of mammals constituting nearly 25% of all known mammals on earth. Approximately 925 species of 177 genera of bats have been recorded although this is by no means a complete list (Koopman, 1993). Bats have a worldwide distribution except in the most extreme polar and desert regions and a few isolated regions (Miller, 1988; Nowak, 1991). This diverse group of mammals is divided into two sharply distinct suborders: the insect-eating bats (Microchiroptera) and the fruit-eating bats (Megachiroptera) (Rosevear, 1965; Koopman, 1993; Nowak, 1991). Insect-eating bats form a diverse group; about 756 species divided over 16 families worldwide and constitute 70% of the entire order (Hill & Smith, 1984; Wilson *et al.*, 1996). In East Africa, 69 species of insect-eating bats are recognised (Kingdon, 1997). Insects are the mainstay diet of these bats although they are known to feed also on other prey including lizards, small rodents, amphibians and even fish. The vampire bats live on the blood

of animals including humans. These vampires, the best known of which occur in South and Central America, are not found anywhere in Africa. Although most insect-eating bats can see quite well, they do not steer themselves by sight but by sound. As they fly, they emit a continuous high-pitched squeak, too high to be heard by the human ear, so that the waves of sound always travel ahead of them. These sound waves strike objects on their path and are reflected back to the bat, which then controls its movements accordingly. This process of producing a sound and detecting an object or prey by interpreting the "echo" is known as "echolocation." Some microchiroptera, however, feed on plant materials, including pollen, nectar and particularly fruit. Fruit or blood-eating microchiropteran bats appear to use vision and olfaction in addition to echolocation to find prey (Eisenberg & Wilson, 1978). Echolocation is a more efficient mechanism of detecting objects or prey than eyesight or smell in fruit-eating bats. The insect-eating bats are generally but not exclusively smaller than the fruit-eating bats.

The fruit-eating bats are very readily distinguishable from insect-eating bats by the presence, in all but a few East Indian and Pacific genera, of a claw on the index finger as well as on the thumb. Fruit-eating bats have a very distinctive large head in relation to the body and have large, endearing eyes that enable a powerful vision in place of echolocation in insect-eating bats. All the fruit-eating bats belong to one family, Pteropodidae containing 166 species (Wilson *et al.*, 1996). The distribution of the fruit-eating bats is exclusively confined in the tropics and subtropics (Nowak, 1991). In East Africa, 18 species of fruit-eating bats have been recorded (Kingdon, 1997). As the name suggests, the fruit-eating bats are almost exclusively frugivorous. However, they feed on other diet as well such as pollen and nectar, some of the fleshier parts of flowers or even the whole of large and succulent buds. They detect the fruits using their well-developed sense of smell.

The insectivorous bats obtain their protein diet from insects and other arthropods, fish, and even small mammals. The fruit-eating bats feed exclusively on figs, pepper, mangoes and bananas, flowers, pollen, and nectar. In the tropics, trees bear fruit throughout the year, and are well distributed spatially giving a constant supply of food. Although the food supply is available throughout the year, it can be very patchy, both temporarily and spatially, and the feeding habits of the bats are moulded by the plants they feed on (Altringham, 1996). Forests are also roosting sites for a great diversity of bats. For instance, the tiny African Vespertilionid (*Mimetillus moloneyi*) roosts behind tree barks and the African Butterfly bat of the genus *Glauconycteris* is known to roost on exposed tree trunks or branches (Kingdon, 1974). Bats have also been recorded to roost inside fallen hollow logs, in smaller cracks or holes in branches, along and in contact with palm-fronds, on underside of large leaves and amongst eroded roots (Vaughan, 1976; Kunz, 1982). In addition, bats have also been known to roost colonially in caves. The implication of this is that a heterogeneous habitat will not only enable diversity of bats and other organisms to occupy it, but will also facilitate co-evolution of species.

Bats face considerable threats worldwide, and available evidence suggests that their populations are on the decline. Worldwide, eight species have not been recorded for the last 50 years or more, and a further four have almost certainly been driven to extinction more recently (Altringham, 1996). Habitat destruction appears to be the greatest threat to bats as with other biological diversity. As a consequence of habitat destruction, bats' foraging and roosting sites are destroyed. For Megachiroptera, the gravest threats are hunting, deforestation, and introduction of exotic predators. The most serious threats to Microchiroptera are habitat destruction or disturbance of roosting caves and mines. Less

understood but also believed to be important are the effects of environmental contaminants on bat populations (Clark, 1981).

Because of their nocturnal habits, bats are shrouded in mystery. In parts of Kenya, for instance among the *Luhya* people of western Kenya, bats are reviled as signs of bad omen (M. N. Simiyu, *Pers. Comm.*). They are exterminated in large numbers because they are alleged to spread rabies while others "suck" human blood. This is far from the truth because no record of the spread of rabies by bats has been recorded in Africa and vampire bats, which "suck" human blood, do not occur in Africa. In all of Asia, Europe, Australia and the Pacific Islands, only two people are suspected of dying from bat-transmitted rabies per year (Miller, 1988). Bats are also exterminated indiscriminately for bad odour in buildings where they roost. Yet bats are very important with a role to play in ecology and evolution. For instance, insect-eating bats are the major predators of harmful insects and help control such insect populations including mosquitoes that transmit malaria and those that damage human crops. Seed dispersal and pollination of tropical trees and shrubs by bats are crucial for the survival of tropical rainforests. In Thailand, for example, a cave-dwelling, nectar-feeding bat is the only known pollinator of durian trees, whose fruit crops are worth roughly $ 90 million per year (Miller, 1988). Many economically important tropical fruits such as bananas, guavas, mangoes, avocados, dates, and figs are heavily dependent on nectar and fruit-eating bats for pollination and seeding. Studies have shown that fruit-eating bats do not destroy edible fruits as they consume over-ripe fruits unsuitable for the market (Hill & Smith, 1984). Additionally, in parts of Asia, families earn a living by periodically scrapping bat droppings or guano and selling it for fertiliser (Miller, 1988).

1.2.3 Rationale

Meru National Park is a complex ecosystem as evidenced by different vegetation types: - *Acacia/Commiphora* bushland, *Combretum* wooded grassland, open *Acacia* and riparian vegetation along the rivers (Ament, 1975). The heterogeneous environment, with complex interactions between, within and among species, may confer a diversity of forage and roosting sites for bats.

Although such parks as Amboseli, Nakuru, Tsavo and Nairobi are better surveyed in Kenya with regard to biological diversity (S. Braude, P*ers. Comm.*), very little has been done in Meru National Park. Indeed, no intensive study has been done to describe the distribution and diversity of bats of the park and their responses to habitat disturbance and/or destruction. In Meru National Park, different vegetation types show distinct structural characteristics. This, coupled with encroachment on the edges of the park and diverse human activities around the park, may have serious effects on biological diversity within the park. The distinct requirements for roosting and foraging in bats makes them respond to structural changes in the structure of the ecosystem and to the landscape pattern (Thomas & West, 1989). Determining the consequences of these changes on the diversities of vertebrates (including bats) inhabiting these "ecological islands" is essential if some park and human practices have to be strictly controlled to mitigate adverse effects. Little is known about the kinds, types and status of bats that occur in Meru National Park. But, in order to conserve, what is to be conserved should first be known. This study will, therefore, be a vital starting point in documenting the diversity and distribution of bats occurring in the park and will assist in the identification of the park's conservation needs and priorities.

1.3 OVERALL AIM

The overall aim of the project was to establish the relationship between habitat disturbance and the distribution and diversity of bats of Meru National Park, Kenya.

1.3.1 Objectives

1. To determine the diversity and distribution of bats in relation to vegetation community structure in Meru National Park
2. To determine the relationship between habitat quality and feeding and roosting habits of both specialist and generalist bats
3. To characterise the vegetation community at Meru National Park and determine the relationship of this to the distribution and diversity of bats

1.3.2 Hypotheses

- More intact park patches offer better foraging and roosting sites, and hence have higher bat species diversity than impacted patches;
- More generalist bats are likely to be abundant in disturbed sites (e.g. in the human settlements) than specialists; and
- Plant species assemblages with higher plant species diversity also have higher bat species diversity

2 STUDY AREA AND RESEARCH METHODS

2.1 THE STUDY AREA

2.1.1 Location

Meru National Park, located in Eastern Kenya, lies on the Equator between latitudes 0° 20'N and 0 ° 10' N and longitudes 38° 0'E and 34 ° 25' E (Fig. 1). The area of the park is 870 km^2. The elevation varies from 1036 metres in the northwestern boundary at the foot of Nyambeni Hills to 304 m a. s. l. at the Tana River on the southeastern boundary.

2.1.2 Geology

Geologically, the park is conveniently divided into two sections. The northern part of the park is formed of Pleistocene-Recent lava, which flowed from the volcanoes that formed the Nyambeni ridge. In the southern part, the Precambrian rock of the basement system is exposed (Ament, 1975). In the river valleys are swamps of varying width and the soil is grey to black. East of the 38°10' meridian, the land flattens and grey volcanic alluvial soils mark the site of Pleistocene lakebeds. The swamps bordering watercourses are wider and between them are flat areas of powdery grey alkaline soil and low lava strewn ridges. Northeast of Murera River, which forms most of the eastern boundary of the park, red sandy soil covers the basement rock. Volcanic alluvial soil is also evident at the Ura Gate approximately 10 km towards north (Ament, 1975).

2.1.3 Climate

Annual rainfall follows the altitude gradient while temperature is inversely proportional to it as the southeastern part of the park, with the lowest altitude, is the driest and the hottest. The amount of rainfall is quite variable throughout the year, averaging at 724 mm with two rain

seasons. The short rains are in November while the long rains are between March and May (Ament, 1975). During the study period, there were heavy rains during the months of November and December 2000. These rains were preceded by a one-year drought period (Ajuoga, *Pers. Comm.*).

The park is well watered by rivers rising in the Nyambeni hills flowing across it in a southeasterly direction to join the Tana River, which marks the southern boundary of the park. Most of the rivers north of river Kiolu carry water throughout the dry season. However, Kiolu and its tributaries dry out. The Ura and the Tana rivers provide the only permanent water in the southern section of the park.

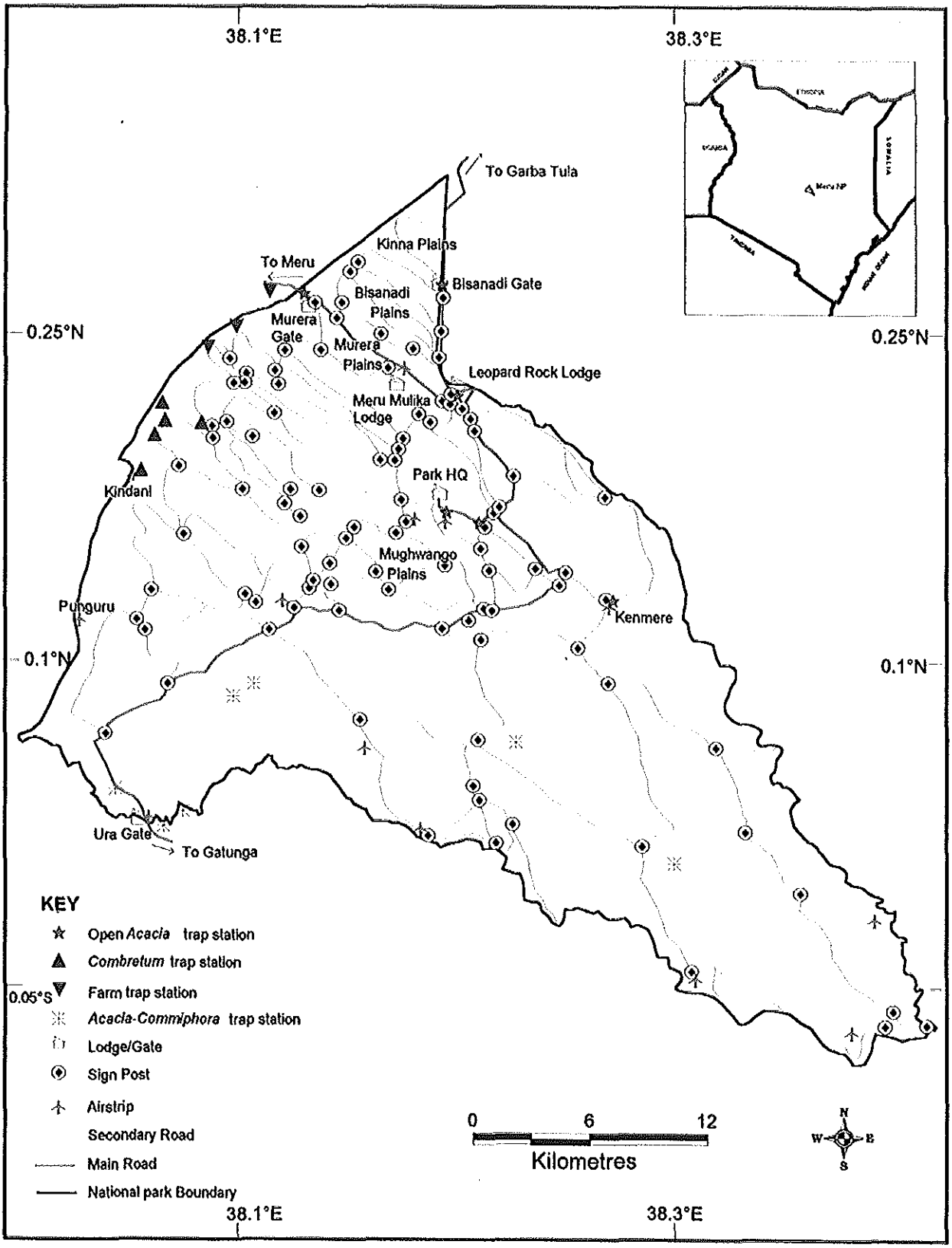


Figure 1. Map of Meru National Park Showing Study Sites

2.1.4 Vegetation

The vegetation of the park can subjectively be characterised into four vegetation communities. These are Open *Acacia* Woodland, *Combretum* Wooded Grassland, *Acacia-Commiphora* Bushland and a unique riverine vegetation (Ament, 1975). The later type of vegetation is found along rivers in all the former vegetation types. These vegetation communities closely correspond to park geological divisions, with *Acacia/Commiphora* bushland being dominant where the basement rock is exposed in the south of the park. *Combretum* wooded grassland, which dominate on the western boundary of the park occurs mostly on slightly acidic volcanic soil. Open *Acacia* on alkaline volcanic alluvial soil dominates the north and northeastern parts of the park (Figs. 2, 3 & 4). In this later section, there are extensive swamps with a distinct plant community. Indeed, the entire park is dissected by seven rivers rising in the Nyambeni hills flowing across it to join the Tana River in the southeastern corner. In the swamps and along rivers, there is a dense riverine forest or stands of *Hyphaene* and *Raphia* palms, especially *Raphia farinifera, Hyphaene coriacea* and *Phoenix reclinata.* On the Tana River, *Populus ilicifolia* and a number of *Ficus sp.* are dominant (Williams, 1981).

2.1.5 Fauna

Meru National Park is endowed with a high diversity of wildlife ranging from carnivores, herbivores, insectivores and decomposers because of its highly heterogeneous ecosystem. Common game species include elephant, buffalo, and hippopotamus. Reticulated giraffe, Grevy's and Common Zebra, Grant's gazelle, Lesser Kudu, Beisa Oryx, and Gerenuk are plentiful. Lion, Leopard and Cheetah are also occasionally observed. Over 332 species of birds have been recorded (Williams, 1981). In the Dom areas, the Red-necked Falcon is common. Pel's Fishing Owl is common on the Tana River. The rare Brown-backed

Woodpecker frequented fig trees along rivers. In the *Acacia* woodland along rivers, the diminutive smaller Black-bellied Sunbird is observed. The park is also rich in different species of rodents, amphibians and reptiles.

Figure 2. *Combretum* Wooded Grassland

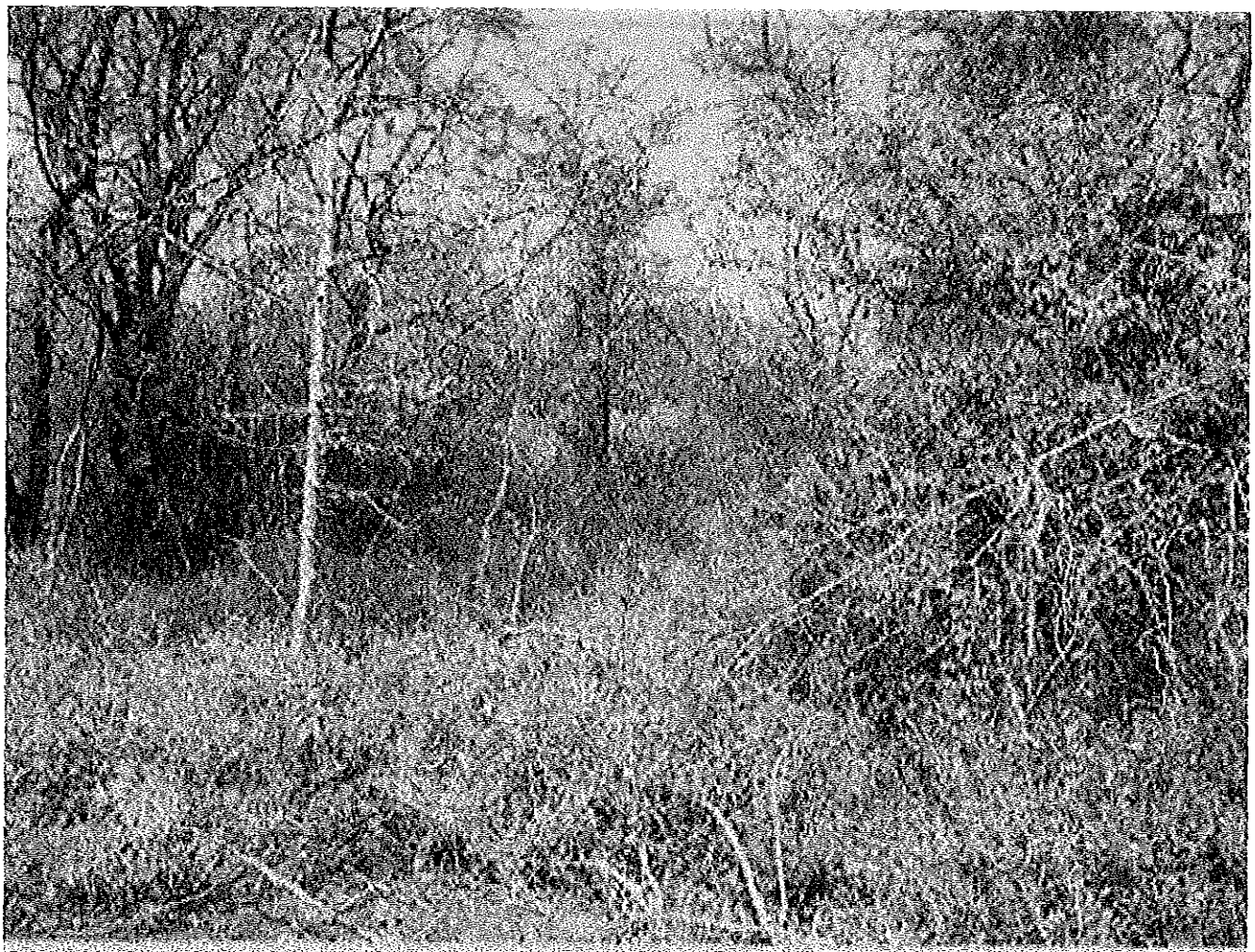
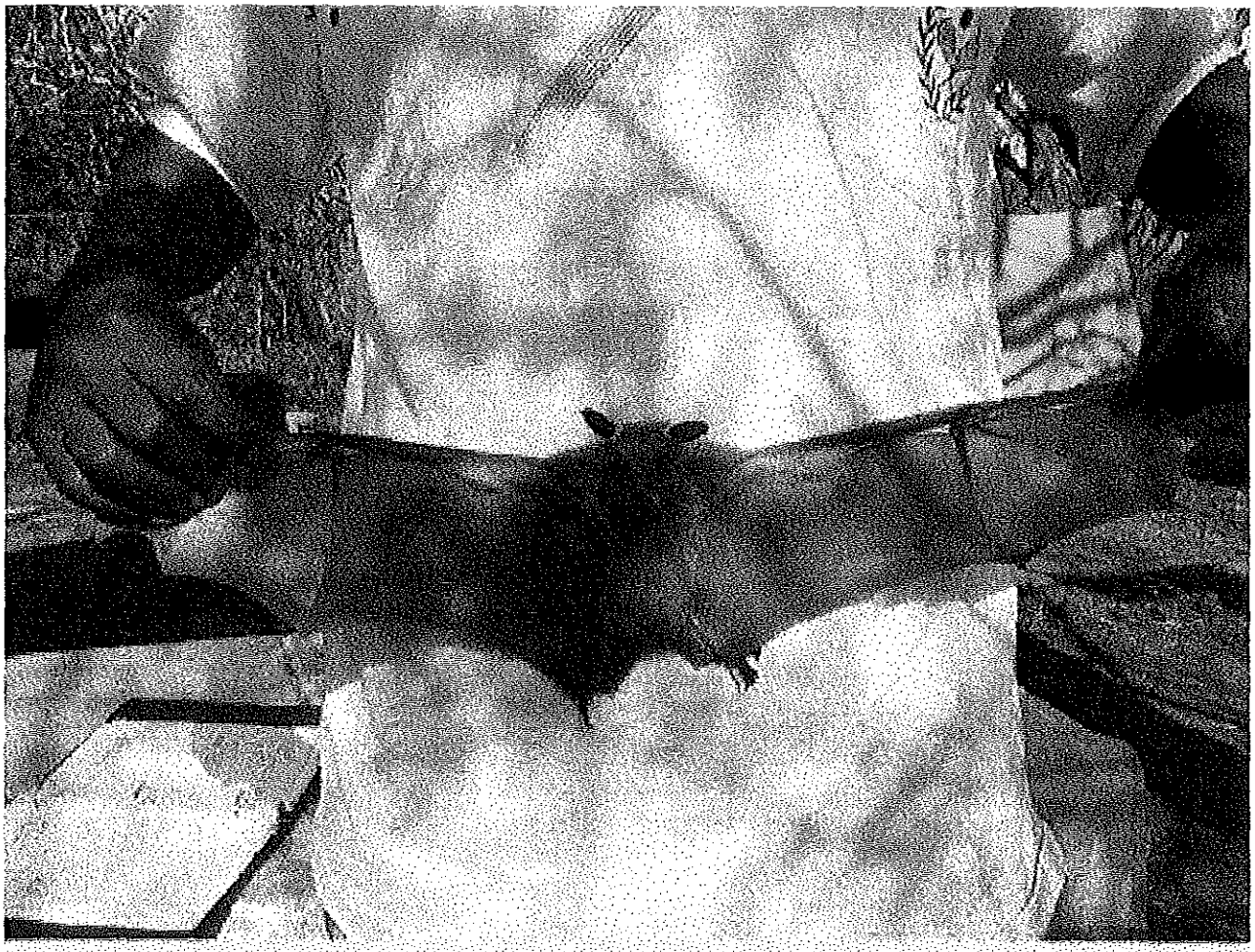


Figure 3. *Acacia-Commiphora* Bushland

Figure 4. *Acacia* Woodland



Figuer 5. One of the studied animals - *Epomophorus wahlbergi*

2.3 MATERIALS AND METHODS

2.3.1 Bat Trapping Techniques

Six representative sites, 3 km apart, were selected from each vegetation type (*Acacia/Commiphora* bushland, *Combretum* wooded grassland, and open *Acacia* woodland) and surveyed for bats. Each of the selected sites was subdivided into 6 netting sites, each separated from the next by 100 m. This implies that each site had 6 net stations (amounting to 36 in total per vegetation type) where mist nets were erected. Mist nets were used to capture bats because they are the most common, easiest and least expensive (Moreno & Halffter, 2000). Given the limited number of nets (6 in number), the netting sites were sampled systematically from one site to another and from one vegetation type to another. Save for the *Combretum* wooded grassland, which had a total trap-line of 360 m, all other vegetation communities and the farms consisted of a total trap-line of 576 m each. Since roost sites were not known, trapping efforts were directed towards expected or potential commuting, foraging and drinking sites. Nets were set along natural flyways such as animal-or human trails but where these were absent, natural gaps were used. The southern and eastern parts of the park were not sampled adequately for bats because of problems of accessibility. Sampling in the open *Acacia* woodland was done after a very long period of drought. In the other vegetation communities within the park, sampling was done after heavy rains in November and December. In the human settlements around the park, six farming systems namely banana, vegetable, "*Miraa*" (*Catha edulis*), sorghum, and maize farms and the grazing field were selected, 3 km apart. Each of the identified farms had 6 trap stations, 100 m apart. Similarly, the farms consisted of 36 trap stations in total.

Standard mist nets (18 m long x 2 m high) were erected using poles averaging 3 m high. The nets were opened before sunset and remained open until 22.00 hours. The nets remained at each netting site for two consecutive trapping nights before being moved to a new location.

Captured bats were identified to species in the field and samples collected for specimen preparation. However, some individuals of the same species that were captured in subsequent trapping efforts were released. Individuals were identified using identification manuals (Kingdon, 1997; Meester & Setzer, 1971). Specimens collected were karyovouchered to allow verification of their identity and update collections at the National Museums of Kenya (NMK). Collected specimens now form part of the reference collection at NMK.

All captured bats were recovered from the nets and catalogued in a field notebook. Measurements obtained included the total length (TL), length of tail vertebrae (TV), length of hind foot (HF), forearm length (FA), and ear length (E) (Nagorsen & Peterson, 1980). Body weights, sex, age, and the reproductive condition for the karyovouchered specimens were also obtained. The reproductive condition was assessed by looking for embryos and placental scars in females and enlarged testes- scrotal- in males. Fluid-preserved specimens were fixed (injecting and soaking) with a solution of 10% buffered (Sodium Phosphate) paraformaldehyde and later transferred into 70% ethyl alcohol. Tissue samples of all collected specimens were preserved in 25% DMSO/EDTA in Sodium Chloride for DNA studies. The netting site and the microhabitat type were recorded for each animal.

2.3.2 Vegetation Sampling Techniques

A transect was established in each of the three vegetation communities; Open *Acacia* Woodland, *Combretum* Wooded Grassland and *Acacia-Commiphora* Bushland. Along each

transect, 15 sampling plots, each 20 X 10 m, were randomly selected amounting to 45 sampling plots for the entire park. Using the modified Braun-Blanquet cover/abundance scale (Appendix II), each plant species (shrubs and trees) in each plot was assigned a cover/abundance rating (Mueller-Dombois & Ellenberg, 1974; Green, 1979).

2.3.3 Data Analyses

2.3.3.1 Bat ecology

Bat abundance was expressed as percentage of total individual bats recorded. Chi-Square (χ^2) test was used to test any differences in the sex ratios of the different species. Chi-Square (χ^2) test of association was also used to test the relationship between sex and the vegetation community. Accumulation curves of number of species against net length were plotted to assess the completeness of the survey. This is because all species in a community cannot usually be enumerated (Krebs, 1989).

Species diversity for the different vegetation communities was computed using the modified inverse of Simpson-Yule diversity of concentration, C, for equally abundant species (Dunstan & Fox, 1996): -

$$D = 1/C$$

$$C = \Sigma^{n}_{i=1} p_i^2$$

P_i is the proportional abundance of the i^{th} species, given by

$P_i = n_i/N$, i = 1, 2, 3... S

S = Species richness which equals to the total number of species in a community. As an index, S is easily conceptualised and comparable across habitats.

N = total number of individuals

The Simpson's index was preferred in this study because it is weighted more towards the abundance of the common species (emphasises evenness) rather than providing a measure of species richness. However, for the purposes of comparison, the Shannon's index, H', was also calculated.

Shannon-Weaver's $H' = - \Sigma^{n}_{i=1} p_i \ln (p_i)$

H' is maximum only when all S species are represented by the same number of individuals, that is, a perfectly even distribution of abundances (Krebs, 1989; Rosenzweig, 1995). Shannon's evenness index, E indicates relative abundances of species in terms of evenness and was based on the Shannon's index of diversity. It is an important measure of heterogeneity. The Shannon evenness index is calculated by the equation:

$E = H'/H'_{max} = H'/\ln S$, where

H'= Shannon's diversity index and

$\ln S$ = the natural logarithm of the number of species

A student t-test was used to inspect any differences in morphometric data between the sexes of different species. Regression equations of weight against the natural logarithm of forearm length of three species of bats that were common in all the vegetation communities and the farms were plotted in order to compare the quality of different habitats.

2.3.3.2 Vegetation ecology

In order to determine similarities (or dissimilarities) in vegetation (species presence/absence, abundance) at the localities where transects were established, the procedure Detrended Correspondence Analysis (DCA) was applied to the vegetation data. DCA is a multivariate indirect gradient analysis technique that searches for the major gradients in the species data irrespective of any environmental variables. DCA is contained in the computer program CANOCO Version 4.0 (Ter Braak, 1987). For the purposes of comparison with the classification obtained from the DCA ordination diagram, the computer program SYNTAX (Podani, 1988) was further used to classify the vegetation data.

2.3.3.3 Vegetation–bat species relationship

To determine the association (correlation) between plant species presence/abundance and species richness of bats, the procedure Detrended Canonical Correspondence Analysis (DCCA) in the computer program CANOCO (Ter Braak, 1988) was applied. In DCCA, regression and ordination techniques of multivariate direct gradient analysis called canonical (or constrained) ordination are integrated. The results of DCCA are based on species presence/abundance and values of environmental variables simultaneously. The ordination axes are constrained to optimise their relationship with a set of environmental variables; the direction of various environmental variables is normally indicated in the ordination diagram by arrows, whose lengths are proportional to the importance of each environmental variable.

The diversity of species of plants was also calculated for each of the five plant species assemblage identified from the dendrogram. In order to determine the relationship between

plant and bat species diversity, bat species diversity was similarly calculated in the five plant species assemblages.

cor and *Pipistrellus nanus* were recorded on the farms (Table 1b). The first three are ecological generalists and common on other vegetation communities in the park while the other, *Pipistrellus nanus* had its preferred habitat on the farms.

Table 1a. Number, species and families of bats based on sex

Family	Species	Abundance		
		Males	Females	Total
Pteropodidae	*Epomophorus labiatus*	82	124	206
Molossidae	*Tadarida condylura*	50	52	102
Pteropodidae	*Epomophorus wahlbergi*	32	48	80
Vespertilionidae	*Nycticeius hirundo*	16	20	36
Megadermatidae	*Cardioderma cor*	16	11	27
Hipposideridae	*Hipposideros commersoni*	13		13
Molossidae	*Tadarida cistura*	5	4	9
Hipposideridae	*Hipposideros caffer*	4	2	6
Vespertilionidae	*Scotophilus leucogaster*	4	1	5
Vespertilionidae	*Pipistrellus nanus*	3		3
Nycteridae	*Nycteris arge*	2		2
Megadermatidae	*Lavia frons*	1	1	2
Molossidae	*Tadarida acetabulosus*	2		2
Rhinolophidae	*Rhinolophus landeri*		1	1
Vespertilionidae	*Myotis welwitschii*		1	1
	Total	**230**	**265**	**495**

Table 1b. Number and species of bats based on vegetation community

Species	Vegetation Community/Farms				
	Acacia	*Combretum*	*A. - Commiphora*	Farms	**Total**
Epomophorus labiatus	72	30	74	30	206
Tadarida condylura	102	0	0	0	102
Epomophorus wahlbergi	3	29	44	4	80
Nycticeius hirundo	3	31	2	0	36
Cardioderma cor	5	4	11	7	27
Hipposideros commersoni	0	13	0	0	13
Tadarida cistura	0	0	9	0	9
Hipposideros caffer	1	2	3	0	6
Scotophilus leucogaster	0	3	2	0	5
Pipistrellus nanus	0	0	0	3	3
Nycteris arge	0	0	2	0	2
Lavia frons	2	0	0	0	2
Tadarida acetabulosus	0	2	0	0	2
Rhinolophus landeri	0	1	0	0	1
Myotis welwitschii	0	0	1	0	1
Total (individuals)	**188**	**115**	**148**	**44**	**495**
Total (species)	**7**	**9**	**9**	**4**	**15**

Table 1c. Abundance of Bats based on vegetation community and sex

	ABUNDANCE		
	MALES	FEMALES	
VEGETATION COMMUNITY			**Total**
Combretum	61	54	115
Acacia-Commiphora	56	92	148
Open *Acacia*	90	98	188
Farms	23	21	44
Total	**230**	**265**	**495**

Table 1d. List of species found exclusively in different habitats

Open *Acacia*	*Combretum* W. G	*A-Commiphora*	Farms
Lavia frons	*Hipposideros commersoni*	*Tadarida cistura*	*Pipistrellus nanus*
Tadarida condylura	*Tadarida acetabulosus*	*Myotis welwitschii*	
	Rhinolophus landeri	*Nycteris arge*	

Bat species diversity was highest in *Combretum* wooded grassland (H' = 1.70 and D = 4.6) and least on the farms (H'= 0.955 and D = 1.99) (Table 2). There was no statistically significant difference in the sex ratio of the overall list of species (χ^2 = 2.4747, P > 0.05) (Table 3a). However, at the species level, only one species *Epomophorus labiatus* showed a significant difference in the sex ratio (χ^2 = 8.5631, P < 0.05) (Table 3b). Additionally, there was some evidence to suggest that sex is associated with vegetation community although this was not significant (χ^2 = 7.17530, P = .06652). On close inspection of Table 1c, it was found that females are closely associated with *Acacia-Commiphora* Bushland than in any other vegetation community.

There was also no significant difference in the morphometric measurements of forearm length (FA), total length (TL), tail length (TV), hind foot length (HF), ear length (EAR) and weight (Wt) between sexes of four species whose data were adequate for analysis (t-test for paired comparison of independent samples, two tailed, P > 0.05) (Table 4, Appendix I).

Table 2. Species Diversity indices

Vegetation Community	**Open** *Acacia*	*Combretum*	*Acacia-Commiphora*	**Farms**
Index				
Species richness Index	$S = 7$	$S = 9$	$S = 9$	$S = 4$
Number of bats	$n_1 = 188$	$n_2 = 115$	$n_3 = 148$	$n_4 = 44$
Shannon- W. Div. Index	$H' = 1.004$	$H' = 1.70$	$H' = 1.36$	$H' = 0.955$
Simpson - Yule Div. Index	$D = 2.26$	$D = 4.6$	$D = 2.87$	$D = 1.99$
Shannon Evenness Index	$E = 0.52$	$E = 0.76$	$E = 0.62$	$E = 0.69$

Table 3a. Chi-Square Test based on Sex Ratio for overall list of Species

SEX	Observed Cases	Expected	X^2	D. F	Significance
Males	230	247.5	2.4747	1	0.1157
Females	265	247.5			
Total	**495**				

Table 3b. Chi-Square Test based on Sex Ratio for individual species

Species *Cardioderma cor*					
Sex	**Observed Cases**	**Expected**	**X^2**	**D. F**	**Significance**
Males	16	13.5	0.9259	1	0.3359
Females	11	13.5			
Total	**27**				
Epomophorus labiatus					
Sex	**Observed Cases**	**Expected**	**X^2**	**D. F**	**Significance**
Males	82	103.0	8.5631	1	0.0034
Females	124	103.0			
Total	**206**				
Epomophorus wahlbergi					
Sex	**Observed Cases**	**Expected**	**X^2**	**D. F**	**Significance**
Males	32	40.0	3.2000	1	0.736
Females	48	40.0			
Total	**80**				
Nycticeius hirundo					
Sex	**Observed Cases**	**Expected**	**X^2**	**D. F**	**Significance**
Males	16	18.0	0.4444	1	0.5050
Females	20	18.0			
Total	**36**				
Tadarida condylura					
Sex	**Observed Cases**	**Expected**	**X^2**	**D. F**	**Significance**
Males	50	51.0	0.0392	1	0.8430
Females	52	51.0			
Total	**102**				

Table 4. t-Test for Morphometric Data

Species	Observed Cases	Mean	Variance	t Stat	P -two tail	t Critical two tail
Epomophorus labiatus						
FA						
Sex						
Male	2	59.5	4.5	-1.85	0.11	2.45
Female	6	61.2	0.567			
TL						
Male	2	95.5	4.5	-0.89	0.41	2.45
Female	6	97.7	9.87			
HF						
Males	2	18	0	1.22	0.27	2.45
Female	6	17	1.2			
EAR						
Male	2	21	0	1.7	0.14	2.45
Female	6	19.58	1.24			
Wt						
Male	2	40.5	0.5	0.89	0.41	2.45
Female	6	35.5	56.3			
Cardioderma cor						
FA						
Sex						
Male	7	56	1.67	0.77	0.46	2.31
Female	3	55.3	1.33			
TL						
Male	7	89.57	360.29	0.24	0.81	2.31
Female	3	86.67	134.33			
HF						
Male	7	18.57	6.95	0.70	0.50	2.31
Female	3	17.33	5.33			
EAR						
Male	7	37.3	10.9	-1.38	0.21	2.31
Female	3	40	0			
Wt						
Male	7	27.43	33.95	-0.60	0.57	2.31
Female	3	29.67	16.33			

...Table 4 Continued

Species	Observed Cases	Mean	Variance	t Stat	P -two tail	t Critical two tail
E. wahlbergi						
FA						
Sex						
Male	5	81.5	24.5	0.15	0.89	2.57
Female	2	80.8	34.7			
TL						
Male	5	137.5	312.5	0.56	0.6	2.57
Female	2	130.6	191.8			
HF						
Male	5	20.5	4.5	-1.37	0.23	2.57
Female	2	22.4	2.3			
EAR						
Male	5	24.5	40.5	0.53	0.62	2.57
Female	2	23.0	4.0			
Wt						
Male	5	84.0	968.0	0.25	0.81	2.57
Female	2	79.0	468.0			
T. condylura						
FA						
Sex						
Male	9	47.89	2.61	1.20	0.25	2.13
Female	8	46.88	3.55			
TL						
Male	9	121.11	4.86	0.74	0.47	2.13
Female	8	120.43	1.29			
TV						
Male	9	48.56	4.03	-0.89	0.39	2.13
Female	8	49.75	11.93			
HF						
Male	9	13.56	0.78	-0.76	0.46	2.13
Female	8	13.88	0.70			
EAR						
Male	9	18.33	0.75	1.51	0.15	2.13
Female	8	17.75	0.50			
Wt						
Male	9	24.00	8.25	1.51	0.15	2.13
Female	8	22.38	1.13			

Except for the farms and in the open *Acacia* woodland (Figs. 7 and 9), species accumulation curves for each of the other vegetation communities reached an asymptote when the number of species was plotted against net length (Figs. 6 and 8). Similarly, the overall cumulative curve for all vegetation communities including the farms reached an asymptote (Fig. 10).

All regression equations of the relationship between weight and the natural logarithm of forearm length of three common species showed a positive linear relationship but the differences were not significant ($r^2 > 0.015$) (Figs. 12-15). There was an exception, however, for the farms in one case for *Epomophorus wahlbergi,* which showed a negative relationship ($r^2 = 0.005$) (Fig. 14d). There was also a weak positive correlation for the same species in the *Acacia-Commiphora* bushland (Fig. 14c).

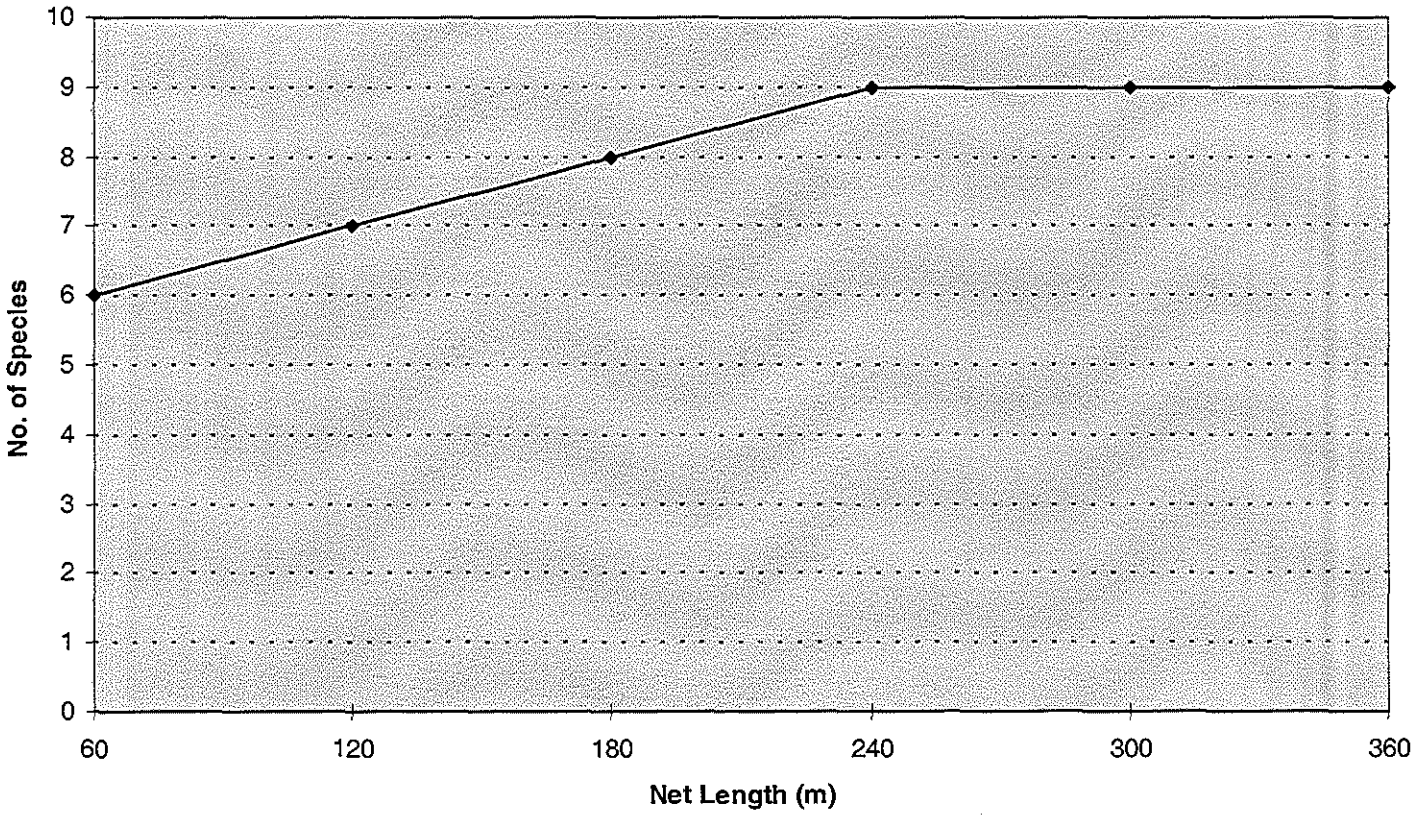


Figure 6. Species-Net Length Relationship in the *Combretum* Wooded Grassland

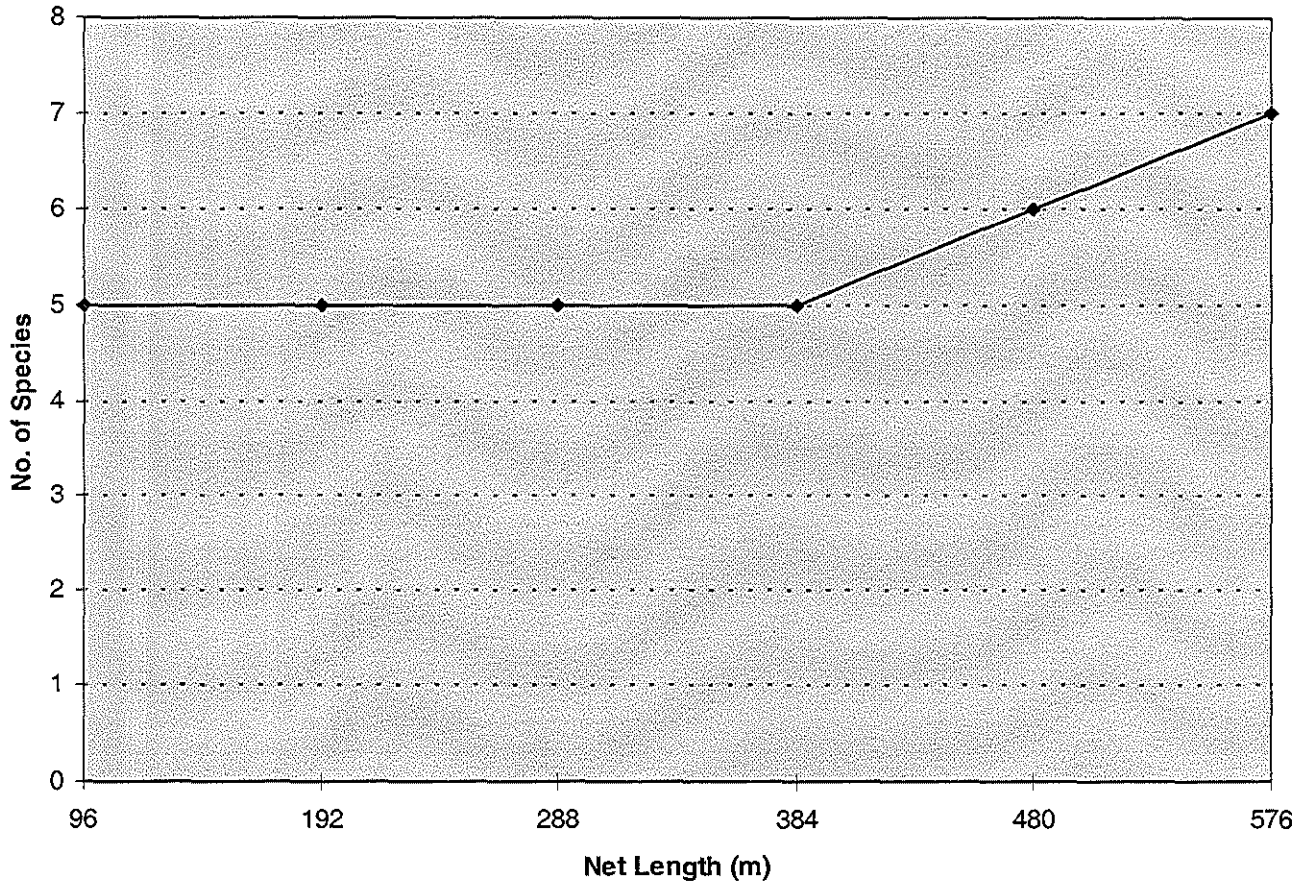


Figure 7. Species-Net Length Relationship in Open *Acacia* Woodland

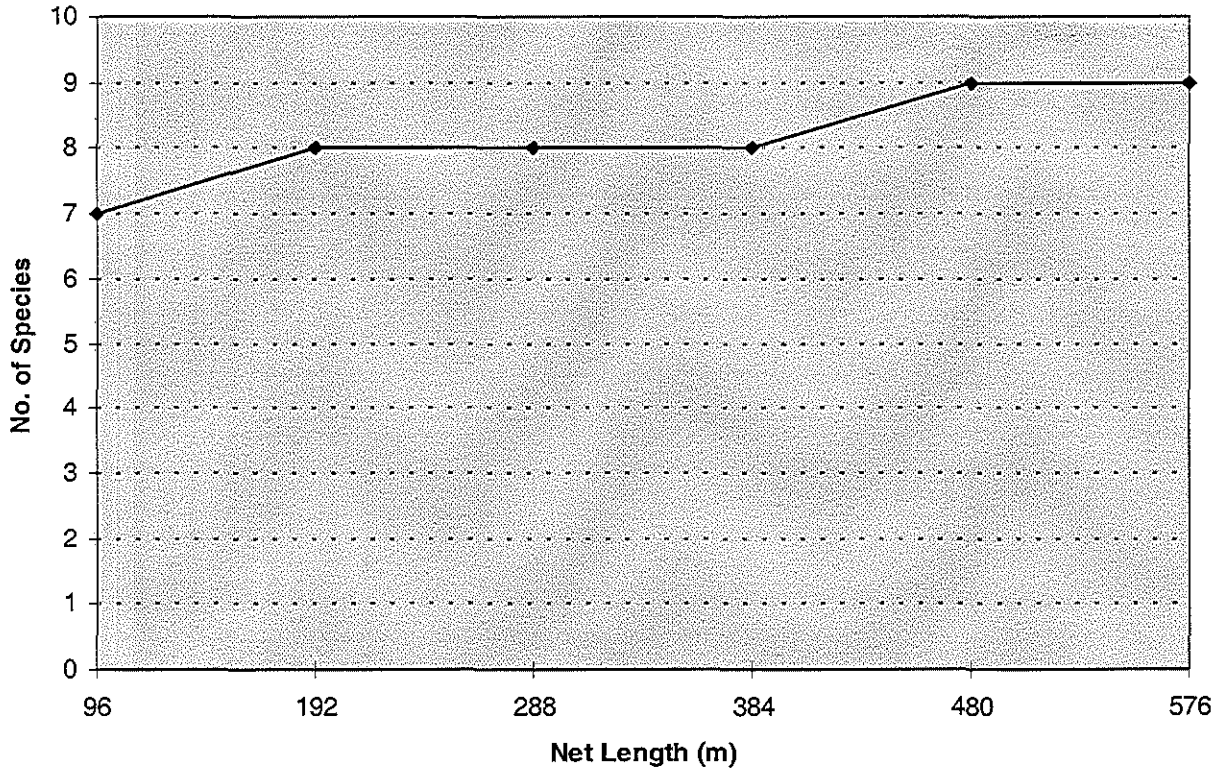


Figure 8. Species-Net Length Relationship in *Acacia-Commiphora* Bushland

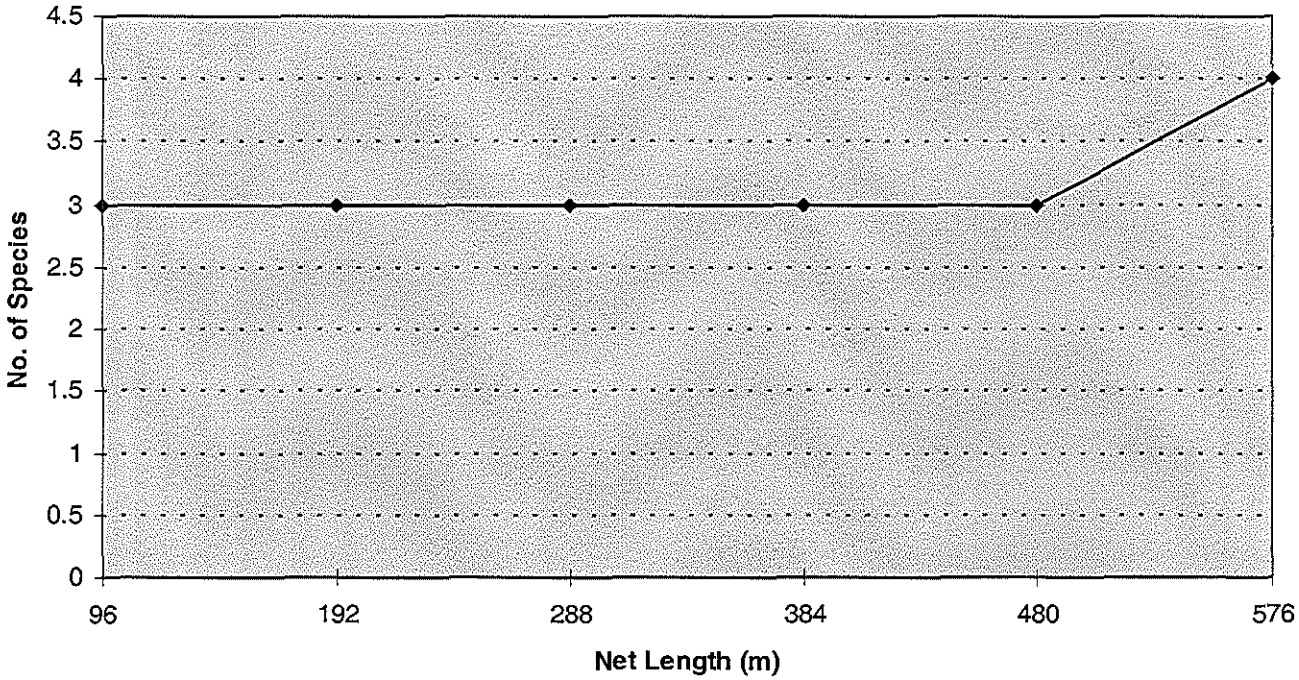


Figure 9. Species-Net Length Relationship on the Farms

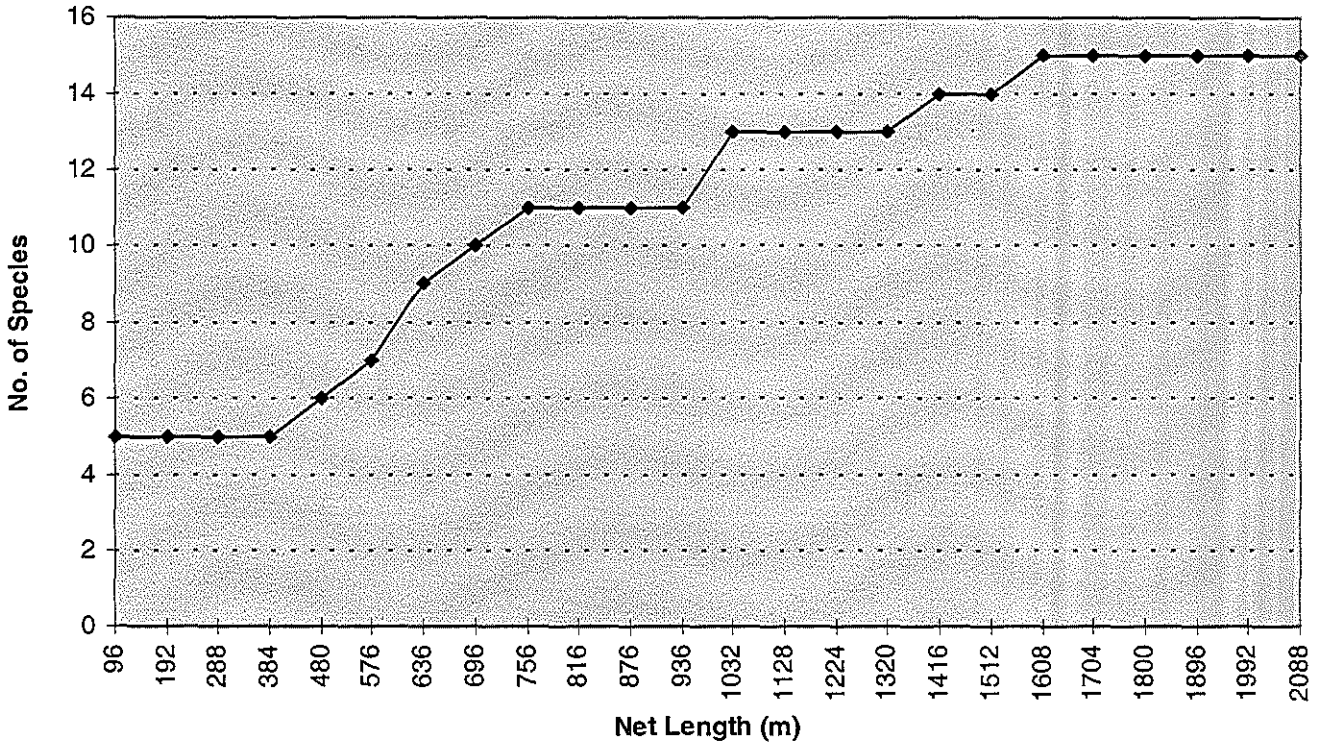


Figure 10. Species-Net Length Relationship in all vegetation communities and farms

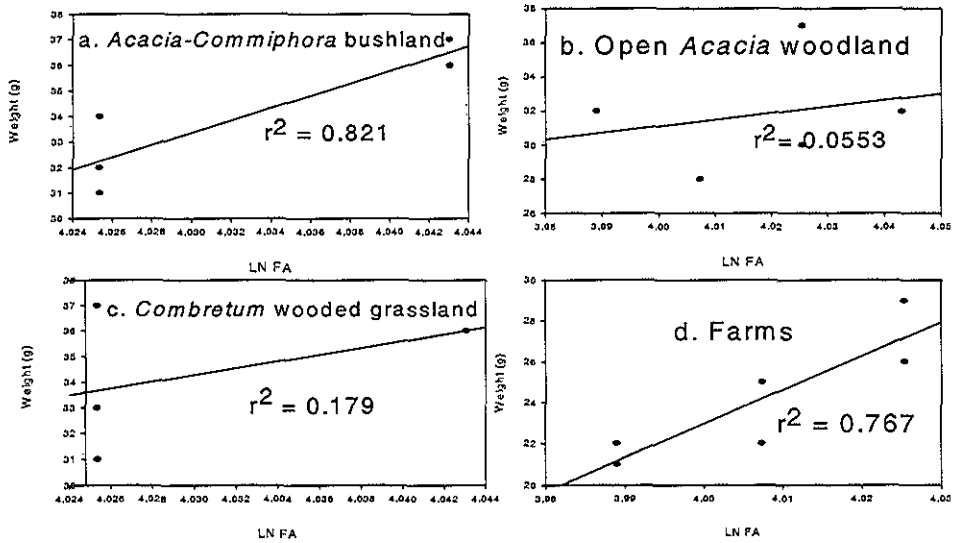


Figure 11. Weight -(LN) forearm relationship of *Cardioderma cor*

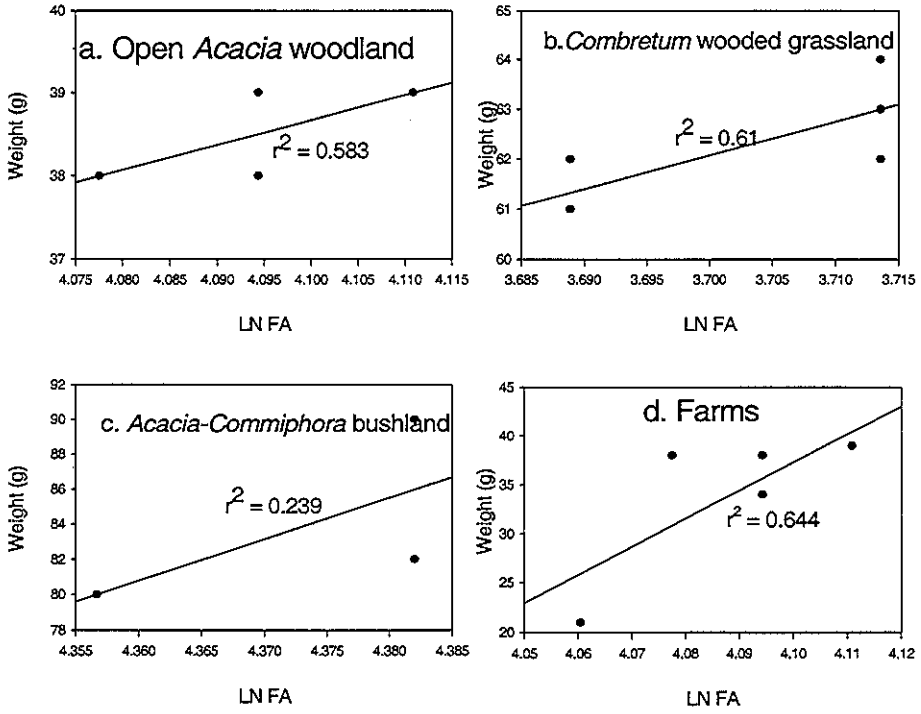


Figure 12. Weight- (LN) forearm relationship of *Epomophorus labiatus*

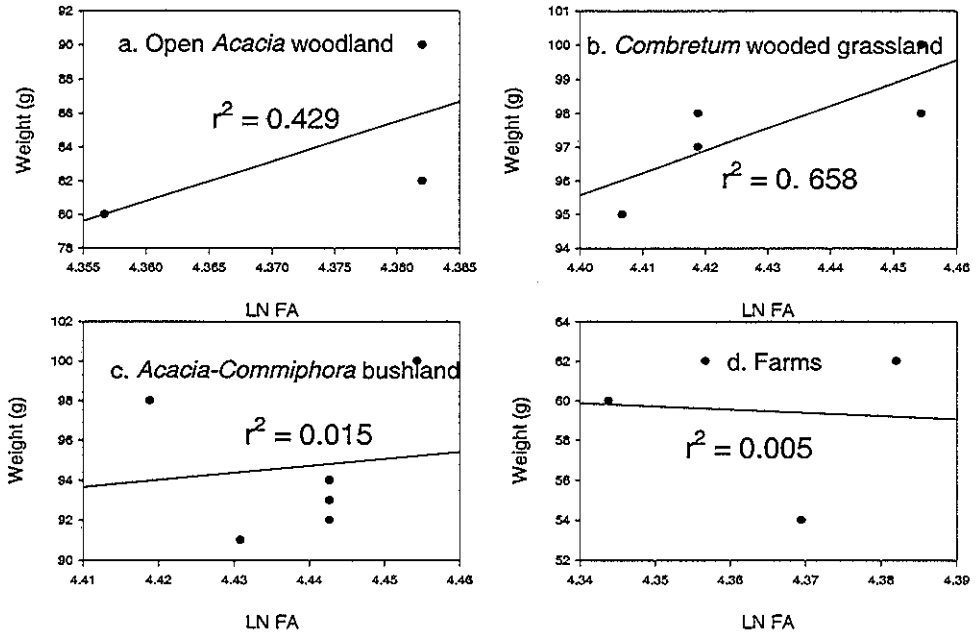


Figure 13. Weight- (LN) forearm relationship of *Epomophorus wahlbergi*

3.2 Vegetation ecology

A cover/abundance rating (Braun-Blanquet) was recorded for one hundred and thirty four plant species in 45 plots, 15 each, for open *Acacia* woodland, *Combretum* wooded grassland and *Acacia-Commiphora* bushland (Appendices 3, 4 & 5). The procedure Detrended Correspondence Analysis (DCA) was then applied to the vegetation data from the three communities to produce an ordination diagram (Fig. 15). On the DCA diagram, a group of sampling plots occurring close together indicates similarity in floristic composition, and vice versa (Table 5). Therefore, from the DCA ordination diagram, seven species assemblages were identified on the basis of their floristic similarity (Tables 6-12). However, only five species assemblages were identified from the SYNTAX output at dissimilarity level of above 0.7 (Fig. 16). The output was therefore more inclusive than the DCA ordination.

Table 5. Species assemblages as indicated from the DCA Ordination Diagram

Species Assemblage	1	2	3	4	5	6	7
	Plot No.	Plot No.	Plot No.	Plot No.	Plot No.	Plot No.	Plot No.
	1	3	31	18	17	16	12
	2	7	32	34	19	20	13
	4	8	33	38	21	24	
	6	9	35	44	22		
	10	15	36	45	23		
	11		37		26		
			39		27		
			40		28		
			41		29		
			42		30		
			43				

Table 6. Species assemblage 1

Sampling Plot		1	2	4	6	10	11	MEAN B – B RATING
Species	**Form**							
Acacia xanthophloea	Tree	4						4.0
Adansonia digitata	Tree	3		4	4		4	3.8
Acacia robusta	Tree		2	4				3.0
Euphorbia candelabrum	Tree			3				3.0
Balanites aegyptiaca	Tree				2	2	3	2.3
Acacia tortilis	Tree				2			2.0
Acacia zanzibarica	Shrubby tree					2		2.0
Commiphora schimperi	Shrub						2	2.0
Acacia mellifera	Shrub/tree	2	1	1	2	3		1.8
Acacia senegal	Tree	1	2			2		1.7
Terminalia spinosa	Tree		2	1		2		1.7
Lonchocarpus eriocalyx	Tree			1	2			1.5
Acacia seyal	Shrubby tree	1	1		2	1		1.3
Bridelia taitensis	Shrub	1			1	1		1.0
Trichilia roka	Tree					1		1.0
Corchorus tenar	Shrub	1			0.5			0.8
Turraea parvifolia	Shrub	0.5				1		0.8
Harrisonia abyssinica	Shrub				0.5		0.5	0.5
Sericocomopsis pallida	Shrub	0.5						0.5
Solanum arundo	Shrub	0.5						0.5
Triaspis niedenzuiana	Shrub			0.5				0.5
Triumfetta flavescens	Woody herb	0.5		0.5	0.5			0.5
Cephalocroton cordofanus	Shrub			0.1				0.1
Commiphora sp.	Sprawling shrub	0.1		0.1				0.1

Table 7. Species Assemblage 2

Sampling Plot		3	7	8	9	15	MEAN B – B RATING
Species	**Form**						
Newtonia hildebrandtii	Tree		5				5.0
Acacia robusta	Tree		4				4.0
Phoenix reclinata	Tree		4		3	3	3.3
Hyphaene coriacea	Tree	3	2	5	3		3.3
Raphia farinifera	Tree	3			2	4	3.0
Acacia elatior	Tree			3	2		2.5
Albizia anthelmintica	Shrub/tree	2					2.0
Garcinia livingstonei	Tree				2		2.0
Acacia mellifera	Shrub/tree	1	2	2			1.7
Cyclocheuon eriantherum	Shrub			1			1.0
Cyperus undulatus	Shrub	1			1	1	1.0
Oncoba spinosa	Shrub				1		1.0
Acacia seyal	Shrubby tree	0.1	1				0.6
Corchorus tenar	Shrub	0.5		0.5			0.5
Sericocomopsis pallida	Shrub	0.5					0.5
Triumfetta flavescens	Woody herb	0.5	0.5				0.5
Caesalpinia longiracemosa	Shrub		0.1				0.1
Corchorus olitorius	Tree				0.1		0.1
Jatropha oblanceolata	Shrub	0.1					0.1
Lawsonia inermis	Shrub			0.1			0.1

Table 8. Species Assemblage 3

Sampling Plot		31	32	33	35	36	37	39	40	41	42	43	MEAN B - B RATTING
Species	Form												
Adansonia digitata	Tree				5								5.0
Ormocarpium keniense	Shrub											4	4.0
Commiphora africana	Shrub/small tree	3	5	4	2	3	2						3.2
Delonix elata	Tree		3										3.0
Terminalia brownii	Tree	4				2					2		2.7
Dobera glabra	Tree						2				2	3	2.3
Acacia bussei	Tree	2						2					2.0
Albizia amara	Tree								2				2.0
Albizia anthelmintica	Shrub/tree									2			2.0
Albizia tanganyicensis	Tree			2								2	2.0
Commiphora rostrata	Shrub	2											2.0
E. robecchii	Tree										2		2.0
Euphorbia pseudograntii	Shrub					2							2.0
Teclea simplicifolia	Shrub		2										2.0
Ziziphus abyssinica	Tree								2	2			2.0
Acacia mellifera	Shrub/tree	1	1	2	2	3	2				1		1.7
Commiphora flaviflora	Shrub	1			2								1.5
Commiphora molle	Tree				1						2		1.5
Vepris eugeniifolia	Shrub	2							1				1.5
Commiphora campestris	Small tree				2	1	1	2	2	1	1	1	1.4
Sterculia africana	Tree				1					1		2	1.3
Acacia ataxacantha	Shrub	1	2	1	1	1	2	1					1.3
Boscia coriacea	Shrub	1		1			1		1				1.0
Boswellia hildebrandtii	Shrub/small tree							1		1		1	1.0
Commiphora engleri	Shrub			1									1.0
Commiphora holtziana	Shrub/small tree									1		1	1.0
Commiphora sambarensis	Shrub/small tree					1	1					1	1.0
Kirkia tenuifolia	Small tree			1									1.0
Tapiphyllum sp.	Shrub									1			1.0
Acacia reficiens	Shrub							2	0.1	1	0.1		0.8
Boscia mossambicensis	Shrub	0.1	1			1		1					0.8
Acacia brevispica	Scrambling shrub	0.5	0.5	1	0.1	1	0.5						0.6
Commiphora madagascariensis	Shrub/small tree		0.5					1			0.1		0.5
Bauhinia tomentosa	Shrub							0.5					0.5
Grewia bicolor	Shrub									0.5			0.5
Premna sp.	Shrub			0.5									0.5
Ruttya fruticosa	Shrub					0.5							0.5
Sterculia stenocarpa	Small tree			1			0.1					0.1	0.4
Bauhinia taitensis	Shrub	0.5					0.1	0.5					0.4
Grewia tembensis	Shrub		0.1		0.1		0.5		0.5				0.3
Grewia lilacina	Shrub			0.1				0.5				0.1	0.2
Abrus schimperi	Shrub					0.1						0.1	0.1
Maerua subcordata	Shrub				0.1								0.1
Premna resinosa	Shrub				0.1								0.1
Sesamothamnus busseanus	Shrub/small tree		0.1				0.1	0.1			0.1		0.1
Terminalia orbicularis	Shrub									0.1			0.1

Table 9. Species Assemblage 4

Sampling Plot		18	34	38	44	45	MEAN B-B RATING
Species	**Form**						
Ficus sycomorus	Tree		4	5	4		4.3
Adansonia digitata	Tree	4					4.0
Tamarindus indica	Tree		5	4	3		4.0
Commiphora africana	Shrub/small tree		3				3.0
Kigelia africana	Tree					3	3.0
Commiphora campestris	Small tree		2	4		2	2.7
Albizia harveyi	Tree		1			4	2.5
Albizia anthelmintica	Shrub/tree					2	2.0
Commiphora molle	Tree				2		2.0
Commiphora rostrata	Shrub					2	2.0
Terminalia brownii	Tree		2				2.0
Vepris eugeniifolia	Shrub		2				2.0
Acacia ataxacantha	Shrub		1				1.0
Acacia mellifera	Shrub/tree		1				1.0
Albizia amara	Tree			1			1.0
Boscia anguistifolia	Tree			1	1		1.0
Carphalea glaucescens	Shrub		1				1.0
Combretum aceleatum	Scrambling shrub	1					1.0
Combretum apiculatum	Tree	1					1.0
Combretum hereroense	Shrub	1					1.0
Commiphora engleri	Shrub					1	1.0
Commiphora flaviflora	Shrub				1		1.0
Commiphora holtiziana	Shrub/small tree			1			1.0
Craibia brevicaudata	Tree		1				1.0
Hunteria zeylanica	Tree				1		1.0
Cordia sinensis	Shrub		0.5	0.5	0.1		0.4
Bauhinia tomentosa	Shrub	0.5				0.1	0.3
Cordia ovalis	Shrub/small tree		0.1	0.5	0.1		0.2
Grewia bicolor	Shrub		0.1	0.1	0.1		0.1
Maerua kirkii	Shrub		0.1	0.1	0.1		0.1
Acacia brevispica	Scrambling shrub		0.1	0.1			0.1
Acacia nilotica	Tree	0.1					0.1
Acacia reficiens	Shrub					0.1	0.1
Adenium obesum	Shrub/small tree			0.1			0.1
Bauhinia taitensis	Shrub	0.1					0.1
Boscia mossambicensis	Shrub					0.1	0.1
Grewia lilacina	Shrub					0.1	0.1
Grewia tembensis	Shrub					0.1	0.1
Sesamothammus busseanus	Shrub/small tree					0.1	0.1

Table 10. Species assemblage 5

Sampling Plot		17	19	21	22	23	26	27	28	29	30	MEAN B-B RATING
Species	**Form**											
Combretum apiculatum	Tree	4	5	1	3	4	3	4	3	4	3	3.4
Combretum collinum	Tree	1		1		2	1					1.3
Terminalia prunioides	Tree		1	1	2				1		1	1.2
Combretum aceleatum	Scrambling shrub	1	1	1	0.1		1	1	2	2		1.1
Albizia anthelmintica	Shrub/tree								1			1.0
Albizia harveyi	Tree										1	1.0
Combretum molle	Tree				1			1				1.0
Lonchocarpus bussei	Tree				1							1.0
Maerua angolensis	Tree										1	1.0
Terminalia brownii	Tree			1						1		1.0
Ziziphus abyssinica	Tree			1								1.0
Combretum hereroense	Shrub	0.5				0.1			1		0.5	0.5
Bauhinia tomentosa	Shrub			0.5								0.5
Caesalpinia volkensii	Shrub				0.5							0.5
Vernonia colorata	Shrub	0.5										0.5
Bauhinia taitensis	Shrub					0.5	0.1					0.3
Securinega virosa	Shrub			0.1						0.5		0.3
Acacia drebanolobium	Tree		0.1									0.1
Combretum mossambicense	Shrub	0.1										0.1
Sterculia africana	Tree										0.1	0.1

Table 11. Species Assemblage 6

Sampling Plot		16	20	24	MEAN B-B RATING
Species	Form				
Terminalia kilmandscharica	Tree			4	4.0
Ficus sycomorus	Tree		4	3	3.5
Combretum apiculatum	Tree	3			3.0
Kigelia africana	Tree	2			2.0
Markhamia hildebrandtii	Tree		2		2.0
Tabemaemontana usambarensis	Tree		2		2.0
Terminalia brownii	Tree	2			2.0
Adinia microcephala	Tree			1	1.0
Combretum aceleatum	Scrambling shrub	1			1.0
Cordia africana	Tree		1		1.0
Cordia sinensis	Shrub			1	1.0
Maerua angolensis	Tree	1			1.0
Melia volkensii	Tree	1			1.0
Rauvolfia caffra	Shrub			1	1.0
Caesalpinia decapetala	Shrub		0.5		0.5
Clerodendrum sp.	Shrub			0.5	0.5
Combretum hereroense	Shrub	0.1	0.5		0.3
Securinega virosa	Shrub	0.1		0.5	0.3
Phyllanthus sepialis	Shrub		0.1		0.1
Ricinus communis	Shrub		0.1		0.1

Table 12. Species Assemblage 7

Sampling Plot		12	13	MEAN B – B RATING
Species	Form			
Acacia elatior	Tree	5	5	5
Kigelia africana	Tree		3	3
Melia volkensii	Tree	2		2
Abrus schimperi	Shrub			0

Note:

B – B = Braun-Blanquet Cover/Abundance Rating

3.3 Vegetation-bat species relationship

The DCCA ordination diagram of the vegetation and bat data shows that most species of bats are associated most with *Combretum* wooded grassland and *Acacia-Commiphora* bushland and least with open *Acacia* woodland (Fig. 17). Bat species diversity correlated positively with plant species diversity in all plant species assemblages except plant species assemblage 4, which was omitted during ordination as it had a negligible variance possibly after adjustment for covariances (Table 13). For instance, bat species diversity was highest in plant species assemblage 5 (*Combretum* wooded grassland) (H' = 1.70) and this was also true for plant species diversity (H' = 3.85).

Table 13. Relationship between bat and plant species diversity in four plant species assemblages

Plant species assemblage	Community type	Bat Species Diversity (H')	Plant Species Diversity (H')
1	*Acacia*	0.85	3.05
2	*Acacia*	0.78	2.50
3	*A. -Commiphora*	1.36	3.81
4	-	-	2.88
5	*Combretum*	1.70	3.85

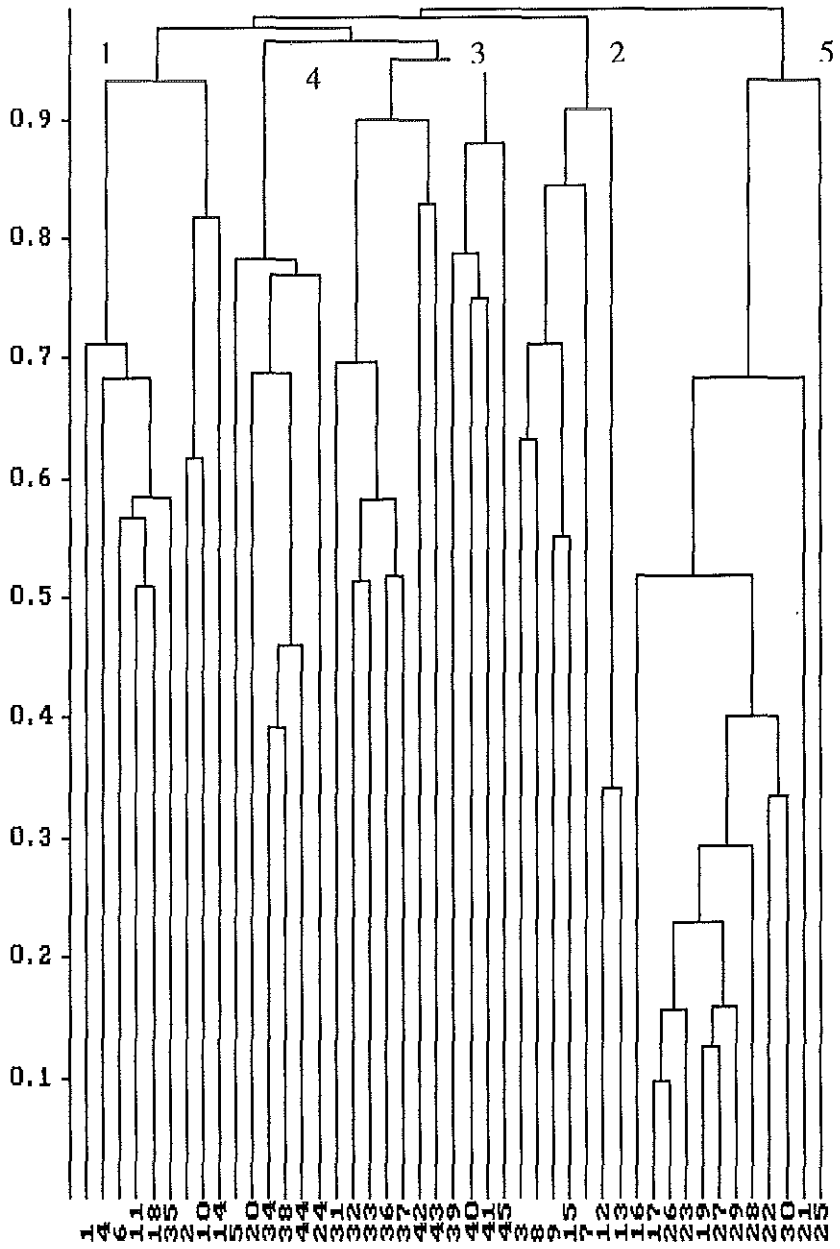


Figure 15. Dendrogram of species assemblages of vegetation (Y-axis represents the dissimilarity level while the X-axis represents assemblages)

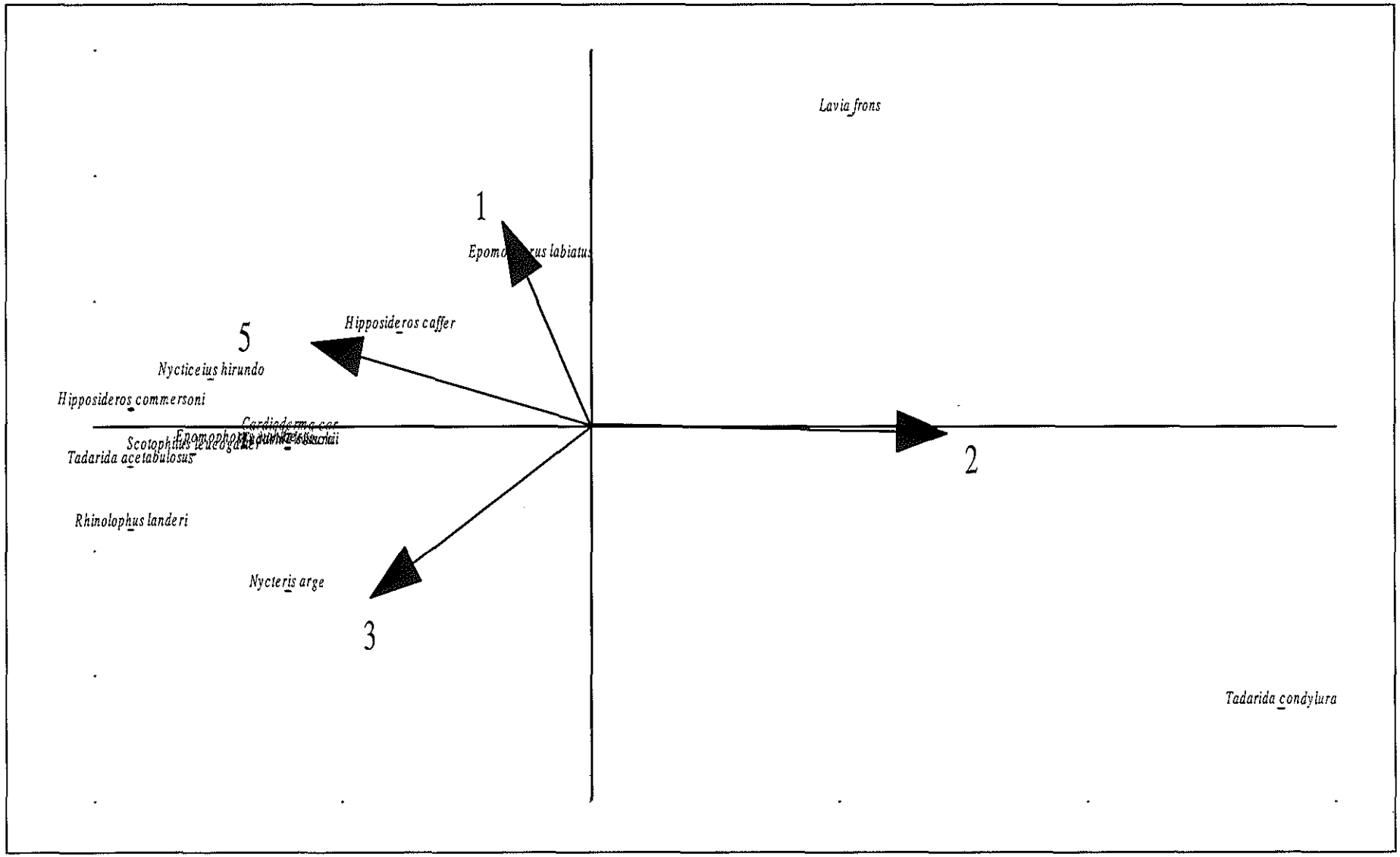


Figure 16. DCCA ordination of bats and plant species assemblages data

4 DISCUSSION

Five plant species assemblages identified from the dendrogram corresponded closely with the broad classification of vegetation at Meru National Park by Ament (1975). According to Ament (1975), three major vegetation communities were identified and these were open *Acacia* woodland, *Acacia-Commiphora* bushland and *Combretum* wooded grassland. Plant species assemblages 1 and 2 correspond to open *Acacia* woodland while 3 and 5 to *Acacia-Commiphora* bushland and *Combretum* wooded grassland respectively. It is on the basis of this broad classification of vegetation that the distribution and diversity of bats are discussed.

There were clear differences in bat diversity in the three vegetation communities within the park and adjacent farms. The major trend showed that with greater disturbance there was lowered richness and evenness and increased dominance of fewer species. However, the Shannon evenness index was lower in the *Acacia-Commiphora* bushland than on the farms because two species of *Epomophorus labiatus* and *Epomophorus wahlbergi* constituted 80% of the total number of bats recorded. Similarly, two species of the genus *Epomophorus*, *Epomophorus labiatus* and *E. wahlbergi* and the other of the family Megadermatidae, *Cardioderma cor* were dominant in both open *Acacia* and on the farms. The two habitats were the most disturbed with frequent burning and large congregations of elephants in the open *Acacia* woodland.

While open *Acacia* recorded the highest number of bats (n = 188), it was less diverse than both *Combretum* wooded grassland and *Acacia-Commiphora* bushland. The high number of individual bats recorded in the open *Acacia* woodland is attributed to the fact that individuals of one species *Tadarida condylura* constituted 54% of all the bats recorded. The

bats were trapped one night as they emerged from their building roost. Sampling of bats in the open *Acacia* woodland, unlike in other vegetation communities, was done after a very long period of drought. The low species diversity, therefore, could also be a reflection of bat emigration. Such movement would allow bats to escape lengthy periods of food scarcity brought on by seasonal extremes of rainfall and community productivity (O'Shea & Vaughan, 1980). As an indication of this probable emigration, subcutaneous fat deposits were noted in *Hipposideros commersoni* of the family Hipposideridae, which were recorded only in *Combretum* wooded grassland after the rains of December 2000. The large amounts of fat may provide energy for long distance foraging.

Bat diversity (based on Simpson's index, D and Shannon's index, H') decreased in more disturbed habitats. In addition, the decrease in the total number of bat species corresponded with increased domination by one or two species in the community. *Combretum* wooded grassland had the lowest dominance by any one species and also contained a more even distribution of bat species ($E = 0.76$). Habitats with fewer dominant bat species were also more vegetatively diverse and heterogeneous than the more highly disturbed habitats (e.g. open *Acacia* woodland). Higher bat diversity in *Combretum* wooded grassland and *Acacia-Commiphora* bushland could be attributed to changes in successional stage of the habitat or vegetational diversity and heterogeneity and diverse microhabitats.

Except for *Pipistrellus nanus,* all other bat species recorded on the farms: *Epomophorus wahlbergi, E. labiatus* and *Cardioderma cor* are ecological generalists. Such species may be more prevalent in modified habitats since they usually are more common and are less likely to be affected by habitat disturbance or are more likely to re-colonise after a disturbance (Connell, 1978; Denslow, 1985; Hansson, 1991). Less disturbed habitats may favour more

specialised species. For more specialised organisms, bats or otherwise, the loss of biological diversity in the sites that were sampled is likely to be more severe.

In a similar study carried out in the Miombo Woodland in northern Zimbabwe, Fenton *et al* (1998) found that bat species composition did not differ significantly between intact and impacted sites. However, in the same study, smaller species of bats (< 10g) were affected more by the loss of canopy trees than larger ones. In the present study, smaller species were only captured in intact rather than disturbed areas. In the open *Acacia* woodland, the combination of high elephant densities and fire may have resulted in the change from closed canopy cover to open grassland and thicket in some areas. The destructive effect of elephants on the vegetation and the suppression of fire in open *Acacia* woodland and tree clearance on the farms may have changed tree species composition in those areas. Burning of vegetation favours shade tolerant species. However, shade intolerant species may be the only trees that are large enough and old enough to provide the cracks, crevices and cavities for tree roosting bats (Campbell *et al.*, 1996). Fire also destroys snags (i.e. dead trees) that are important roosting sites for such genus as *Scotophilus.* The reduction in the availability of roost sites may increase distances to foraging sites. Flight permits bats to move considerable distances quickly and efficiently (de la Cueva *et al.*, 1995). This, however, costs high energy demands. Smaller species of *Hipposideros caffer* and *Nycteris arge* (< 10g) and *Nycticeius hirundo* and *Scotophilus leucogaster* (< 20g) may not cover larger areas to meet their requirements for food and roost. The timing of the captures of *Scotophilus leucogaster* and *Nycticeius hirundo* in the early part of the evening in the present study corresponds with the findings of the same study, that species of the genus *Scotophilus* usually roost in intact and forage in adjacent impacted areas. Captures of members of the genus *Scotophilus* in the early part of the evening occurred near their roost sites (Fenton *et*

al., 1998). Therefore, the removal of canopy trees in disturbed park patches and adjacent farms could have probably affected roost availability for bats because smaller species could not commute long distances between roost sites and feeding grounds as larger ones.

From the DCCA ordination diagram of the vegetation and bat data, most species of bats are associated most with *Combretum* wooded grassland and *Acacia-Commiphora* bushland and least with open *Acacia* woodland. This may be a further indication of the level of disturbance in the open *Acacia* woodland relative to other vegetation communities in the park. However, regression equations of the relationship of weight against the natural logarithm of forearm length of three common species did not indicate any significant differences in habitat quality probably because the data were not sufficient enough for analysis.

Species found only in one habitat type may be good indicators of the effects of habitat disturbance if a certain level of disturbance restricts their range. For example, *Nycteris arge* and *Tadarida acetabulosus*, which were recorded only in Kiolu dry River valley and ground water forest respectively, may be indicative of habitat disturbance. In the absence of data addressing qualitative differences in diversity, it may be useful to use these species as indicators of habitat quality outside their range. However, it could also be possible that a particular species prefers a particular microhabitat. For example, in a study carried out in dry woodlands of Kruger National Park, South Africa (Rautenbach, Fenton & Whiting, 1996), 10 of the 12 rhinolophids caught were recorded in riverine forest. Nycterids, two bats of *Nycteris arge* of which were recorded in the present study, were recorded in dry forest of Kruger National Park and represented only 1.1 % of 568 bats recorded in that study.

Among critical resources for bats, roost and foraging sites rank first (Cross, 1988). Roosts influence ecology, metabolic regulation, social behaviour and survival of their population and must be in the vicinity of foraging and drinking habitats (Kunz, 1982; Campbell *et al.*, 1996). Although the present study did not directly evaluate the effect of removal of cover on bat species diversity, it contrasts sharply with a study carried out to determine the effects of the conversion of old-growth coniferous forests into a mosaic of young patches in the Pacific Northwest (Campbell *et al.*, 1996). In this study, it was found that plots containing roosts exhibited less canopy cover, shorter height of understory and less vegetative cover than did random plots. This was attributed to the fact that a reduced amount of canopy closure and understory would decrease impediments to flight. In the same study, however, it was found that the retention and recruitment of snags (i.e. dead trees) are important for conservation of bats.

Except for the farms and in the open *Acacia*, species accumulation curves for all the other vegetation communities reached an asymptote. This is also true for the overall species accumulation curve for all vegetation communities within the park and adjacent farms. In the *Acacia-Commiphora* bushland, two bats of *Nycteris arge* were added to the list at the last two trap stations respectively. *Nycteris arge* is considered new in eastern Kenya. The same is true for the farms where one species *Epomophorus wahlbergi* was added to the list on the last two nights. However, in the later case, *Epomophorus wahlbergi* and two other species, *Epomophorus labiatus* and *Cardioderma cor* were recorded in all vegetation communities within the park. These species may have been tourist species on the farms and their presence on the farms is restricted to brief periods because the farms do not provide sufficient resources to maintain populations. These species may have stable populations in the park and their presence on the farms may be indicative of habitat disturbance. Based on

the species accumulation curves, the inventory does not, therefore, represent a satisfactory level of completeness both within the park and on adjacent farms. Even in the *Combretum* wooded grassland and in the *Acacia-Commiphora* bushland, the inventory may not have been complete. For example, out of the fourteen (14) species of bats recorded to occur at the park (Williams, 1981), only eleven (11) were recorded in the present study. However, four (4) new species- *Nycteris arge*, *Myotis welwitschii*, *Tadarida cistura* and *Tadarida acetabulosus*– that had not been previously recorded in eastern Kenya were recorded. The other four were probably either earlier misidentified or were not recorded at all in the present study.

Consequently, the results of this study i.e. the significant reduction of bat diversity from *Combretum* wooded grassland to farming systems outside the park may underestimate the differences in diversity and distribution among habitats. Based on bat community sampled (bats that were trapped in mist nets), the loss is most likely a conservative estimate. In addition, the results may be biased because only 3 m in height of the vegetation was sampled as mist nets were set at ground level. Survey of bats at the ground level underestimates the presence of molossids that often forage for insects above the canopy (Rautenbach, Fenton & Whiting, 1996; Fenton & Griffin, 1997; Kalko, 1997). Mist nets may also under-represent some species known to be adept fliers, such as vespertilionids (Aldridge & Rautenbach, 1987; Rautenbach, Fenton & Whiting, 1996; Kalko, 1997) and emballonurids (Kalko, 1997). O'Farrell and Gannon (1996) compared results of acoustic versus capture techniques (mist nets and double frame harp-traps) in the south-western United States and found that captures accounted for 63.5% and acoustic sampling 86.9% of the combined species present. They reported that acoustic sampling is a more powerful tool but should be used with various techniques for the inventory of bat communities.

5 CONCLUSION AND RECOMMENDATIONS

Habitat disturbance resulted in removal of canopy trees and snags. This affected the distribution and diversity of bats because the bats' roosting sites were reduced. The reduction in the number of roosting sites could have increased distances to foraging sites. However, different species responded differently to habitat modification and disturbance, with smaller and specialised species being the most affected. Park encroachment had negative impacts on rare and specialist species of bats and other elements of biodiversity.

Based upon the studies on bats carried out at Meru National Park, the following recommendations are made:

- Specific management initiatives (e.g. fire burning to allow regeneration of grasses and herbs for herbivores) that target specific species or species groups may have deleterious effects on other elements of biodiversity. Therefore, comprehensive management strategies should target the entire ecosystem rather than being species specific. The focus on preserving biological diversity must be at the landscape level, because the variety of species in any region depends on the size, variety and dynamics of patches (ecosystems) and corridors. A shift of focus from populations and species to landscapes could help improve policy effectiveness.
- Human encroachment on the park should be minimised to minimise loss of biodiversity.
- In future studies, trapping methods should be modified to also cover aerial feeding bats and those that are adept at flying [e.g. by use of both capture techniques (mist nets and harp traps) and acoustic sampling]. For instance, molossids can be captured in large numbers over water across a river when they come to drink. These bats fly and forage over the canopy. Suspending mist nets high up in the forest sub-canopy

and canopy levels using different rigging methods can also be used to capture such canopy bats.

- Identification of roost sites by use of radio-tracking techniques of echolocating bats may help elucidate the direct effects of removal of canopy cover on bats and other vertebrates.
- In order to adduce direct evidence of habitat disturbance by using bats as indicators, direct methods of inventorying bats are therefore recommended.

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Appendix I. Morphometric Data of species of bats recorded at Meru National Park

Species	Family	FA	TL	TV	HF	EAR	Wt	SEX	Reproductive Data	Remarks
Nycteris arge	Nycteridae	43	101	50	10	28	9	M	Testes -Scrotum Large	
Tadarida cistura	Molossidae	47	115	48	12	21	16	M	Testes Abdominal	Sub-genus Chaerophon
Tadarida cistura	Molossidae	47	110	46	13	20	20	F	Vagina perforated	Gravid, Subgenus Chaerophon
Tadarida cistura	Molossidae	46	106	46	13	19	17	F	Vagina perforated	Gravid, Subgenus Chaerophon
Tadarida cistura	Molossidae	46	108	45	12	19	19	M	Testes - Scrotum Large	Gravid, Subgenus Chaerophon
Myotis welwitschii	Vespertilionidae	58	137	68	14	22	15	F	Vagina Imperforated	Sub-genus Chrysopteron
Epomophorous wahlbergi	Pteropodidae	74	125	-	23	25	100	F	Vagina Imperforated	
Epomophorous labiatus	Pteropodidae	61	101	-	19	20	34	F	Vagina Closed	
Cardioderma cor	Megadermatidae	57	112	-	16	40	30	M	Testes - Scrotum Large	
Cardioderma cor	Megadermatidae	56	112	-	20	40	27	M	Testes Abdominal	
Cardioderma cor	Megadermatidae	56	100	-	20	40	32	F	Vagina perforated	
Nycteris arge	Nycteridae	42	100	50	10	28	8	M	Testes -Scrotum Large	
Cardioderma cor	Megadermatidae	56	105	-	14	36	21	M	Testes -Scrotum Large	
Epomophorous wahlbergi	Pteropodidae	78	125	-	19	20	62	M	Testes Abdominal	
Epomophorous wahlbergi	Pteropodidae	83	140	-	23	25	81	F	Vagina Perforated	
Epomophorous wahlbergi	Pteropodidae	75	120	-	22	23	54	F	Vagina Closed	
Hipposideros commersoni	Hipposideridae	97	152	37	25	31	83	M	Testes Scrotum	
Hipposideros commersoni	Hipposideridae	100	157	40	23	29	98	M	Testes Abdominal	
Hipposideros commersoni	Hipposideridae	99	157	40	24	29	80	M	Testes Scrotum	
Nycticieus hirundo	Vespertilionidae	32	89	35	10	12	16	F	Vagina perforated	Gravid, Subgenus Scotoecus
Epomophorous wahlbergi	Pteropodidae	86	150	-	20	21	100	F	Testes Abdominal	
Hipposideros commersoni	Hipposideridae	100	165	45	23	30	99	M	Testes Abdominal	
Nycticieus hirundo	Vespertilionidae	34	92	34	11	12	16	F	Vagina perforated	Gravid, Subgenus Scotoecus
Scotophilus leucogaster	Vespertilionidae	46	115	46	11	15	19	M	Testes Abdominal	
Nycticieus hirundo	Vespertilionidae	35	91	35	10	15	13	M	Testes Abdominal	Subgenus Scotoecus
Epomophorous wahlbergi	Pteropodidae	85	150	-	22	29	106	M	Testes Abdominal	
Tadarida acetabulosus	Molossidae	37	93	34	10	17	15	M	Testes Abdominal	Subgenus Mormopterus
Tadarida acetabulosus	Molossidae	33	93	35	10	17	14	M	Testes Scrotum	Subgenus Mormopterus
Cardioderma cor	Megadermatidae	55	75	-	21	40	22	M	Testes Scrotum	

Species	Family	FA	TL	TV	HF	EAR	Wt	SEX	Reprod. Data	Remarks
Hipposideros caffer	Hipposideridae	48	82	31	9	11	10	M	Abdominal	
Hipposideros caffer	Hipposideridae	46	81	32	8	10	10	M	Abdominal	
Rhinolophus landeri	Rhinolophidae	45	78	23	10	20	13	F	Perforated	Gravid
Scotophilus leucogaster	Vespertilionidae	49	120	51	11	16	20	M	Abdominal	
Hipposideros commersoni	Hipposideridae	98	160	42	23	32	108	M	Abdominal	
Tadarida condylura	Molossidae	47	119	45	14	18	22	F	Imperforated	
Tadarida condylura	Molossidae	49	114	46	15	18	22	F	Imperforated	
Cardioderma cor	Megadermatidae	56	79	-	16	40	25	F	Imperforated	
Cardioderma cor	Megadermatidae	54	76	-	21	38	24	M	Scrotum	
Cardioderma cor	Megadermatidae	58	72	-	19	31	26	M	Scrotum	
Lavia frons	Megadermatidae	58	64	-	17	41	20	M	Scrotum	
Cardioderma cor	Megadermatidae	56	75	-	19	36	32	M	Scrotum	
Epomophorous wahlbergi	Megadermatidae	86	118	-	24	21	60	F	Imperforated	
Epomophorous labiatus	Megadermatidae	60	96	-	17	21	38	F	Perforated	Lactating
Epomophorous labiatus	Megadermatidae	58	94	-	18	21	41	M	Scrotum	
Epomophorous labiatus	Megadermatidae	62	94	-	17	19	39	F	Perforated	
Epomophorous labiatus	Megadermatidae	41	69	-	16	16	21	F	Imperforated	
Epomophorous labiatus	Megadermatidae	61	97	-	18	21	40	M	Scrotum	
Epomophorous labiatus	Megadermatidae	62	97	-	17	20.5	41	F	Imperforated	
Nycticieus hirundo	Vespertilionidae	31	41	27	7	9	9	F	Imperforated	Subgenus Scotoecus
Nycticieus hirundo	Vespertilionidae	39	59	35	9	11	12	M	Scrotum	Subgenus Scotoecus
Nycticieus hirundo	Vespertilionidae	34	55	29	11	12	11	M	Abdominal	Subgenus Scotoecus
Tadarida condylura	Molossidae	48	120	47	12	19	21	F	Imperforated	
Tadarida condylura	Molossidae	47	126	48	12	19	22	M	Abdominal	
Tadarida condylura	Molossidae	48	112	54	14	18	23	F	Imperforated	
Tadarida condylura	Molossidae	48	120	52	18	19	24	M	Scrotum	
Tadarida condylura	Molossidae	58	117	43	14	18	23	F	Imperforated	
Tadarida condylura	Molossidae	47	122	47	14	18	24	M	Abdominal	
Tadarida condylura	Molossidae	47	117	46	13	17	22	M	T Abdominal	

Species	Family	FA	TL	TV	HF	EAR	Wt	SEX	Reprod. Data Remarks
Tadarida condylura	Molossidae	48	115	48	15	17	30	M	Abdominal
Tadarida condylura	Molossidae	48	119	47	14	19	28	M	Abdominal
Tadarida condylura	Molossidae	52	122	48	13	19	25	M	Abdominal
Tadarida condylura	Molossidae	44	107	43	14	16	21	F	Imperforated
Tadarida condylura	Molossidae	47	126	61	14	16	24	F	Imperforated
Tadarida condylura	Molossidae	44	121	49	14	17	23	F	Imperforated
Tadarida condylura	Molossidae	47	122	50	14	19	28	M	Abdominal
Tadarida condylura	Molossidae	47	119	51	14	18	19	M	Abdominal

Note:

Measurements of forearm (FA), total length (TL), tail length (TV), hind foot (HF), and ear length are in millimetres (mm) while weight was measured in grams (g)

Appendix II. The Modified Braun-Blanquet Cover/Abundance Scale

Symbol	Cover/Abundance
5	Any number of individuals, with a cover of more than 75% of plot area
4	Any number of individuals, with a cover of 50% -75% of plot area
3	Any number of individuals, with a cover of 25% -50% of plot area
2	Any number of individuals, with a cover of 5% -25% of plot area
1	Numerous individuals, but with a total cover of less than 5% of plot area
r	Few individuals, with small cover
+	Solitary individual with small cover

Note:

The term "modified" arises because the last two scales (r and +) were not in the original scale as proposed by Braun-Blanquet. 0.5 is assigned to r while 0.1 to +.

Appendix III. Cover/Abundance rating in *Acacia* Woodland

Sampling Plot			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Species	**Form**	**Code**															
Sericocomopsis pallida	Shrub	1	0.5		0.5												
Lawsonia inermis	Shrub	1		0.5		0.5		1		0.1							
Oncoba spinosa	Shrub	1					2				1						
Terminalia spinosa	Tree	1		2		1						2					
Garcinia livingstonei	Tree	1					4				2						
Corchorus olitorius	Tree	1					0.5				0.1						
Triumfetta flavescens	Woody herb	1	0.5		0.5	0.5		0.5	0.5								
Corchorus tenar	Shrub	1	1		0.5			0.5		0.5							
Adansonia digitata	Tree	1	3			4		4					4				
Triaspis niedenzuiana	Shrub	1				0.5											
Bridelia taitensis	Shrub	1	1					1				1					
Cephalocroton cordofanus	Shrub	1				0.1											
Euphorbia candelabrum	Tree	1				3											
Euphobia polyantha	Shrub	1														3	
Jatropha oblanceolata	Shrub	1			0.1												
Caesalpinia longiracemosa	Shrub	1							0.1								
Acacia elatior	Tree	1								3	2			5	5		
Acacia hockii	Tree	1															
Acacia mellifera	Shrub/tree	1	2	1	1	1		2	2	2		3					
Acacia robusta	Tree	1		2		4			4								
Acacia seyal	Shrubby tree	1	1	1	0.1			2	1			1					
Acacia tortilis	Tree	1						2									
Acacia xanthophloea	Tree	1	4														
Acacia zanzibarica	Shrubby tree	1										2					
Albizia anthelmintica	Shrub / tree	1			2												
Newtonia hildebrandtii	Tree	1							5								
Lonchocarpus eriocalyx	Tree	1				1		2									
Ficus sycomorus	Tree	1					5										

...Appendix III Continued

Sampling Plot			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Species	**Form**	**Code**															
Harrisonia abyssinica	Shrub	1						0.5					0.5				
Balanites aegyptiaca	Tree	1						2				2	3				
Commiphora schimperi	Shrub	1											2				
Commiphora sp.	Sprawling shrub	1	0.1			0.1											
Melia volkensii	Tree	1												2			
Trichilia roka	Tree	1										1					
Turraea parvifolia	Shrub	1	0.5									1					
Lecaniodiscus fraxinifolius	Tree	1					1										
Solanum arundo	Shrub	1	0.5														
Kigelia africana	Tree	1					4								3		
Cyclocheuon eriantherum	Shrub	1								1							
Lantana camara	Shrub	1														1	
Hyphaene coriacea	Tree	1			3				2	5	3						
Phoenix reclinata	Tree	1					3		4		3						3
Raphia farinifera	Tree	1			3						2						4
Cyperus undulatus	Shrub	1			1						1						1
Acacia senegal	Tree	1	1	2								2				3	

Appendix IV. Cover/Abundance rating in *Combretum* Wooded Grassland

Sampling plot			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Species	**Form**	**Code**															
Maerua angolensis	Tree	2	1														1
Combretum aceleatum	Scrambling shrub	2	1	1	1	1		1	0.1				1	1	2	2	
Combretum apiculatum	Tree	2	3	4	1	5		1	3	4		1	3	4	3	4	3
Combretum collinum	Tree	2		1				1		2			1				
Combretum hereroensis	Shrub	2	0.1	0.5	1		0.5			0.1					1		0.5
Combretum molle	Tree	2							1					1			
Combretum mossambicense	Shrub	2		0.1													
Terminalia brownii	Tree	2	2					1								1	
Terminalia kilmandscharica	Tree	2									4						
Terminalia prunioides	Tree	2				1		1	2						1		1
Sterculia africana	Tree	2															0.1
Adansonia digitata	Tree	2			4												
Argomuellera macrophylla	Shrub	2										0.5					
Phyllanthus sepialis	Shrub	2					0.1										
Ricinus communis	Shrub	2					0.1										
Securinega virosa	Shrub	2	0.1					0.1			0.5					0.5	
Bauhinia taitensis	Shrub	2			0.1					0.5			0.1				
Bauhinia tomentosa	Shrub	2			0.5			0.5									
Caesalpinia decapetala	Shrub	2					0.5										
Caesalpinia volkensii	Shrub	2							0.5								
Acacia drebanolobium	Tree	2				0.1											
Acacia nilotica	Tree	2			0.1												
Albizia anthelmintica	Shrub	2													1		
Albizia harveyi	Tree	2															1
Baphia keniensis	Shrub	2										0.5					
Lonchocarpus bussei	Tree	2							1								
Ficus sycomorus	Tree	2					4				3						
Ziziphus abyssinica	Tree	2						1									
Brucea sp.	Shrub	2										0.5					

.... Appendix IV Continued

Sampling plot			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Species	**Form**	**Code**															
Melia volkensii	Tree	2	1														
Blighia unijugata	Tree	2										3					
Diospyros abyssinica	Tree	2										3					
Diospyros mespiliformis	Tree	2										3					
Pachystela brevipes	Tree	2										1					
Rauvolfia caffra	Shrub	2									1						
Tabemaemontana usambarensis	Tree	2					2										
Adinia microcephala	Tree	2									1						
Oxyanthus oxycarpus	Shrub	2										0.1					
Psychotria riparia	Shrub	2										0.5					
Vangueria acutibola	Tree	2										1					
Vernonia colorata	Shrub	2		0.5													
Cordia africana	Tree	2					1					2					
Cordia sinensis	Shrub	2									1						
Kigelia africana	Tree	2	2														
Makhamia hildebrandtii	Tree	2					2										
Adhatoda englerana	Shrub	2										0.5					
Clerodendrum sp.	Shrub	2									0.5						

Appendix V. Cover/Abundance rating in *Acacia-Commiphora* Bushland

Sampling plot			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Species	Form	Code															
Boscia anguistifolia	Tree	3								1						1	
Boscia coriacea	Shrub	3	1		1				1			1					
Boscia mossambicensis	Shrub	3	0.1	1				1			1						0.1
Maerua kirkii	Shrub	3				0.1				0.1						0.1	
Maerua subcordata	Shrub	3					0.1										
Terminalia brownii	Tree	3	4			2		2						2			
Terminalia orbicularis	Shrub	3											0.1				
Grewia bicolor	Shrub	3				0.1				0.1			0.5			0.1	
Grewia lilacina	Shrub	3			0.1						0.5				0.1		0.1
Grewia tembensis	Shrub	3		0.1			0.1		0.5			0.5					0.1
Sterculia africana	Tree	3					1						1		2		
Sterculia stenocarpa	Small tree	3			1				0.1						0.1		
Adansonia digitata	Tree	3					5										
Euphorbia cuneata	Shrub	3															
Euphorbia pseudograntii	Shrub	3						2									
E. robecchii	Tree	3												2			
Bauhinia taitensis	Shrub	3	0.5						0.1		0.5						
Bauhinia tomentosa	Shrub	3									0.5						0.1
Delonix elata	Tree	3		3													
Tamarindus indica	Tree	3				5				4						3	
Acacia ataxacantha	Shrub	3	1	2	1	1	1	1	2		1						
Acacia bussei	Tree	3	2								2						
Acacia mellifera	Tree	3	1	1	2	1	2	3	2					1			
Acacia brevispica	Shrub	3	0.5	0.5	1	0.1	0.1	1	0.5	0.1							
Acacia reficiens	Shrub	3									2	0.1	1	0.1			0.1
Albizia amara	Tree	3								1		2					
Albizia anthelmintica	Shrub	3											2				2
Albizia harveyi	Tree	3				1											4
Albizia tanganyicensis	Tree	3			2										2		
Abrus schimperi	Shrub	3						0.1							0.1		
Craibia brevicaudata	Tree	3				1											
Ormocarpium keniense	Shrub	3													4		
Ficus sycomorus	Tree	3				4				5						4	
Dobera glabra	Tree	3							2					2	3		
Ziziphus abyssinica	Tree	3										2	2				
Teclea simplicifolia	Shrub	3		2													
Vepris eugeniifolia	Shrub	3	2			2						1					
Kirkia tenuifolia	Small tree	3			1												
Boswellia hildebrandtii	Shrub/small tree	3									1		1		1		

.... Appendix V Continued

Sampling plot			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Species	Form	Code															
Commiphora africana	Shrub/small tree	3	3	5	4	3	2	3	2								
Commiphora campestris	Small tree	3				2	2	1	1	4	2	2	1	1	1		2
Commiphora flaviflora	Shrub	3	1				2									1	
Commiphora holtiziana	Shrub/small tree	3								1			1		1		
Commiphora madagascariensis	Shrub/small tree	3		0.5							1			0.1			
Commiphora mollis	Tree	3					1							2		2	
Commiphora rostrata	Shrub	3	2														2
Commiphora samharensis	Shrub/small tree	3						1	1						1		
Adenium obesum	Shrub/small tree	3								0.1							
Hunteria zeylanica	Tree	3														1	
Carphalea glaucescens	Shrub	3				1											
Tapiphyllum sp.	Shrub	3											1				
Commiphora engleri	Shrub	3			1												1
Cordia ovalis	Shrub/small tree	3				0.1				0.5						0.1	
Cordia sinensis	Shrub/small tree	3				0.5				0.5						0.1	
Sesamothammus busseanus	Shrub/small tree	3		0.1					0.1		0.1			0.1			0.1
Ruttya fruticosa	Shrub	3						0.5									
Premna resinosa	Shrub	3					0.1										
Premna sp.	Shrub	3			0.5												
Kigelia africana		3															3