ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

THE DIVERSITY AND ABUNDANCE OF AMPHIBIANS IN MERU NATIONAL PARK, KENYA

DOMNICK VICTOR WASONGA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF THE ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTERS OF SCIENCE IN DRYLAND BIODIVERSITY

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By:

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Declaration

This thesis is my original work and has not been presented for a degree in any other university. All sources of materials used in the write up have been duly acknowledged.

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This work has been submitted with my approval as the university supervisor.

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This work has been submitted with my approval as co-supervisor

Dr. Stefan Lőtters ________________________

Dedication

To my mother, Jane Olik, for her unwavering support and inspiration and to all herpetologists

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ABSTRACT

A study on the diversity and abundance of amphibians was conducted in Meru National Park (Kenya) from October 2002 to January 2003. Transect sampling, drift-fence and pitfall trapping as well as opportunistic collections were used to detect amphibians. A total of 430 individuals of amphibians comprising eleven species and six families were observed. Amphibian species diversity was correlated with plant species cover/abundance in three vegetation communities. *Acacia* wooded grassland had the highest amphibian species diversity (H' = 2.071, D = 6.74). *Acacia-Commiphora* bushland ranked second (H' = 1.858, D = 5.88) while *Combretum* wooded grassland had the least diversity (H' = 1.581, D = 5.076). The *Acacia* wooded grassland had the highest abundance (173 individuals) as well as species richness (10 species). *Combretum* wooded grassland had eight species (113 individuals) while the *Acacia-Commiphora* bushland had seven species (144 individuals). Differences in sex ratios within and between vegetation communities were not statistically significant (ANOVA, F = 8.3026, P = 0.6914). No differences were detected on a species by species basis (X^2 Test). There was positive linear correlation between amphibian species diversity and plant species diversity in all vegetation communities. *Hemisus marmoratus* and *Phrynomantis bifasciatus* were exclusively recorded in the *Acacia* wooded grassland. Five plant species assemblages were identified from DCA ordination. These closely matched the three broad vegetation communities known for the park. There was least habitat disturbance in the *Acacia* wooded grassland and a high probability of disturbance in the *Combretum* wooded grassland. The study confirmed earlier reports that amphibian diversity and abundance can vary on a very small spatial scale. Impacts of habitat disturbance were also demonstrated. The need for long term monitoring of the amphibian population in Meru National Park, by considering additional environmental parameters and introducing a new fire management policy for the park is recommended.

Key words: ***Diversity, Abundance, Amphibians, Meru (Kenya).***

1. INTRODUCTION AND LITERATURE REVIEW

1.1. Introduction

The herpetodiversity of Kenya is proportionately substantial and hence form a significant contribution to the overall biodiversity of the country. There are about 327 documented species of amphibians and reptiles in Kenya (Spawls, 1978; Duff-Mackay, 1980; Welch, 1982; Frost, 1985; Spawls and Rotich, 1997). This includes: 96 species of amphibians belonging to the orders Anura (93 species) and Gymnophiona (3 species); 231 species of reptiles comprising the orders Chelonia (17 species), Crocodylia (1 species) and the Squamata (213 species). This latter group is divided into two suborders namely Sauria (99 species) and Serpentes (114 species). According to WRI (1988), fifteen reptiles are endemic to Kenya. Stubbs (1987) listed a total of 20 amphibian species in Kenya as endemic.

Habitat loss within the tropics, which is a precursor to species loss in general, is widely considered as the worst threat to the world's wildlife. Many of the species known today inhabit tropical savannas and forests. For example, tropical forests make up only 6 % of the Earth's land surface, but they are home to an estimated 50-90 % of known animal and plant species (WRI, 1988). Counting species loss and calculating habitat loss are two widely used indices of the global condition of wildlife (WRI, 1988). In Kenya, out of the original 569, 500 km^2 of wildlife habitat only 296, 140 km^2 remained by 1996 implying 48 % loss (Mackinnon and Mackinnon, 1986 cited in WRI, 1988).

The amphibians of Kenya like of other parts of the world are poorly documented, except for inventory studies giving short comments and species lists. Loveridge (1957) compiled a checklist of reptiles and amphibians of East Africa; Drews (1999) provided an inventory of forest amphibians of Arabuko Sokoke forest in Coast Province. Duff-Mackay (1980) produced an annotated checklist of amphibians of Kenya. An M.Sc. project on the ecological survey of the herpetofauna of Arabuko Sokoke and Gede forests was carried out by Chira (1983). An ongoing project under BIOTA (www.gadag.org) is looking at biodiversity change in the context of global amphibian declines at mid altitude forests in central and western Kenya. In general, ecological and conservation aspects of herpetofuana of Kenya are yet to be studied. Most of the published data is based on museum records. While museum databases and reference materials provide very strong foundations for further investigations, some records are very old and the geographical coverage of such databases are far from complete.

The biodiversity (in general) of Meru National Park has been little studied. There are faunal lists for large mammals and birds (Williams, 1981). A preliminary analysis of the vegetation carried out by Ament (1975) distinguished three main vegetation types. No work has been done to document the amphibians of the park and the existing records according to the National Museums of Kenya (NMK) database are quite limited to just about four species.

In the current study, an ecological survey of the diversity and abundance of the amphibians of the park in relation to habitat characteristics was conducted. The study explored the differences in amphibian distribution in three major plant communities in

Meru National Park namely:- *Acacia* wooded grassland, *Combretum* wooded grassland and *Acacia-Commiphora* bushland. A number of biotic and abiotic factors are known to influence the

diversity and abundance of amphibians. The demographic characteristics as well as eco-morphology of some frog species have been noted to vary on a very small spatial scale (Ovaska, 1991). Some of these characteristics include maturity, adult body size, residency time (in terms of immigration and emigration), number of transients, sex ratio and juvenile to adult ratio. Early maturity and small adult body size, for instance, are associated with an expanding population in a fluctuating environment. On the other hand, short residency time, large number of transients and high juvenile to adult ratio are indicators of a stable population. In amphibian population studies, male-biased sex-ratio may reflect more frequent reproduction hence unavailability of females for capture.

Most terrestrial animals show association to certain vegetation types. According to Schiotz (1967), this relationship could be primarily because of the vegetation and the resulting conditions like microclimate, or because of the physical factors determining the vegetation in question.

In the ecology of terrestrial anurans, the availability of moisture and diurnal retreat sites constitute essential or key resources (Dobson and Murie, 1987). Stewart and Pough (1983) showed experimentally that availability of retreats can locally limit the population size of *Eleutherudactylus coqui* in Puerto Rico.

In the following account, the measures of species diversity and patterns of amphibian distribution and abundance are reviewed.

1.2. Literature review

1.2.1. Trends in amphibian diversity and abundance

In a given ecosystem, the type of habitat, its size, the number of different microhabitats and patchiness are important factors that influence species diversity. When assessed at the species level, the abundance and density of species are important ecological parameters. Individuals of a species, the basic unit of biodiversity, make up a population. The local breeding population is the fundamental unit on which evolution and natural selection operates. Members of a population are known to contain genetic information and it is this genetic diversity which guarantees species' survival and their evolutionary fate. Therefore, maintenance of species diversity must encompass all these levels of diversity (Rosenzweig, 1995).

Diversity itself quantifies how many different entities there are and how different these are (Gaston, 1996). Differences between the species are their abundances that can be measured as density, cover or biomass. Species diversity can be measured in terms of richness, evenness and dominance (Heinen, 1992). For purposes of comparisons across sites and habitats, diversity indices which incorporate both species richness and evenness into a single value, are normally computed. These indices indicate the difference in abundance, which determines how likely it is to encounter each of the species in the community (Peet, 1974). Some of the best known indices are the Simpson's and the Shannon-Weaver diversity indices, which use species relative abundances or importance values (P_i) (Peet, 1974). However, the original diversity indices – Simpson's $D = 1/C$ where, $C = \sum P_i^2$ and Shannon-Weaver's $H' = - \sum P_i \ln P_i$ - depend on both the number of the species and their abundances. For instance, one sample is more diverse than the 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. If the probability is high that the two individuals belong to the same species, then the diversity of the community sample is low (Rosenzweig, 1995). On the other hand, 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. For a sample with only one species, H' = 0. But if all S species are represented by the same number of individuals (even distribution), H' is maximum (Rosenzweig, 1995).

An area can be divided in many ways to determine the distribution patterns of species richness e.g. geographically isolated zones or different vegetation zones in a continuous area (Real *et al*., 1993). A number of hypotheses have been advanced to explain observed gradients (regional or local) in the richness of species. Some of these hypotheses are based on ecological or evolutionary time, spatial heterogeneity, the degree of competition or predation, climatic stability, disturbances, productivity, environmental energy and favourableness (Real *et al*., 1993). Amphibian species richness would vary between any two habitats with different environmental characteristics. The hypothesis of spatial heterogeneity (Pianka, 1966 cited in Real *et al*., 1993) states that the more heterogeneous and complex the physical environment, the more diverse and complex will be the communities that inhabit it. Disturbances of intermediate magnitude and frequency maintain the highest levels of species richness (Real *et al*., 1993). This is so because they do not allow sufficient time for interspecific competition and exclusion and do allow the species to recover after the disturbance. On a scale ranging from favourableness to severity, species richness is known to be favoured when the mean values of the environmental variables lie within the optimal range for the physiological needs of the species. Some of the associated variables include temperature, precipitation, humidity, water balance, potential and actual evapo-transpiration, hours of sunshine and solar radiation. According to the productivity hypotheses of Tillman (1982) cited in Real *et al*. (1993), the number of species would increase with the increase of the resources. Within a range of moderate resources, species richness will be maximum and it will decrease as the resources become more abundant. In the same vein, the area size hypothesis of MacArthur and Wilson (1967) has been tested for many species in ecological studies. The number of species is a function of the area of the region which may be through a power or linear model.

The species richness of anurans (frogs and toads) is known to be highest in tropical regions where species have developed unusual reproductive modes like placement of eggs or larvae in microhabitats other than ponds or streams (Duellman 1988, 1992). This character has evolved partially as a result of the selection caused by predation on eggs and larvae by generalized microphagous and carnivorous tadpoles rather than fish (Magnusson and Hero, 1991). However, possible regional patterns of this diversity cannot be evaluated because studies still remain scarce (Giaretta *et al*., 1997). For instance, in South America samples of litter frogs are restricted to the Amazon forest (Allmon, 1991). Tropical Africa remains least studied. A number of studies here have only looked at leaf litter amphibians (and reptiles) (Lieberman, 1986; Vonesh, 2001). As such, the factors influencing (leaf litter) amphibians in tropical environments are not well understood (Heinen, 1992).

Studies of amphibians (and reptiles) from the Neotropics and South East Asia have demonstrated that species composition and abundance can be influenced by a variety of environmental characteristics and may vary on both diel and seasonal basis (Lieberman, 1986). Such habitat characteristics include climate, elevation, moisture, leaf-litter depth, understorey vegetation density and leaf litter arthropod abundance. Disturbance e.g. through human activity (Scott, 1976; Inger, 1980a; Lieberman, 1986; and Vonesh, 2001) and seasonality (Scott, 1976 and Lieberman, 1986) also influence patterns of amphibian diversity, density and/or biomass. Temporal shifts in amphibian abundance have also been found on a diel basis (Slowinski *et al.*, 1987). Ovaska (1991) predicted that a habitat having abundant potential diurnal retreat sites due to dense ground vegetation would support a greater density of frogs. Forest cover is also an important aspect. The type and quantity of leaf litter may affect leaf litter and arthropod availability. In the case of disturbed sites, the time since disturbance may influence the amphibian fauna as the canopy cover changes through the successional process. One may predict that both richness and evenness may decline from a primary forest to a disturbed site, and hence that dominance of some species in the sample would increase (Ovaska, 1991). Fewer species can tolerate the disturbance and those that can frequently have life history traits such as high rates of intrinsic growth (r), wide ecological amplitude and wide dispersal abilities, which may allow them to become numerous. These are termed "opportunistic populations".

1.2.2. The Class Amphibia

There are about 5,500 known amphibian species in the world (Stuart, 2002). Three living orders are recognized. The Apoda (Caecilians) are highly specialized wormlike amphibians. They are limbless, fosssorial and possess smooth skins with minute scales imbedded in the skin. Caecilians are mainly found circum-Equatorial throughout the tropics. The Caudata are tailed, mainly holarctic amphibians which do not occur in Africa south of the Sahara. The third Order is the Anura (frogs and toads). These are tailless forms which have large hind legs for jumping. They are known from all continents except the Antarctics.

The best known amphibians are the anurans. One hundred and sixty one species are known from East Africa (Howell, 2002) in addition to some 10 species of caecilians. Kenya has about 96 species and subspecies of amphibians (Duff-Mackay, 1980). A total of 20 species are listed as endemic (Stubbs, 1987). However, the majority of the species have not been reviewed. Their status in terms of taxonomy, range, life history and conservation needs investigation.

Typically, the majority of species of frog lays eggs in water where tadpoles develop and undergo metamorphosis (e.g. *Bufo*, Fig. 7). There are however more than 30 modes of reproduction especially concerning egg-laying. Some of the breeding strategies in African tree frogs are discussed by Schiotz (1999). Eggs may be laid in water attached to vegetation (e.g. *Hyperolius viridiflavus*), adhered by jelly to vegetation above water (e.g. most *Hyperolius*), or deposited in a nest (leaf glued around egg-mass) above water (e.g. *Afrixalus*). Some species construct foam nests above the water from which fully developed tadpoles emerge (e.g. *Chiromantis*). Yet in others, large yolk-filled eggs are laid in a burrow in the ground some distance away from the water (e.g. *Leptopelis*). Their tadpoles grow to a considerable size while getting nourishment from the yolk, and later wriggle to the water. Some form of parental care has been shown in other anurans by way of guarding nests, but most species abandon their eggs once they are laid (Stewart, 1967) (e.g. *Hemisus*). Eggs have to be laid in moist conditions to avoid desiccation since they have no shell. Two layers of transparent gelatinous material surrounding the eggs help protect the embryo inside. Exposed embryos are usually pigmented, those laid in concealed places lack pigment. Most frogs and toads are extremely seasonal in their reproductive behaviour. In drier periods, many seem to simply disappear, they seek shelter where they will not be exposed to desiccating conditions, and are not seen or heard during daytime or night (Howell, 2002). Their presence is mostly noticeable just after the rain. During breeding, male frogs and toads of many species produce loud vocalizations that serve to advertise their presence in order to attract females and also to defend their territories from other males.

Feeding in amphibians is also as diverse as reproductive strategies. Frogs possess large mouths with substantial gape. In all but exclusively aquatic forms, the tongue is well developed, attached anteriorly to the floor of the mouth, free and pointing towards the pharynx used in food ingestion. Mouth glands produce sticky secretions which cover the tongue to facilitate transfer of food to the mouth. Teeth are small and degenerate (or completely absent in many genera). Food is not masticated, and the teeth only serve to restrain struggling prey prior to swallowing (Passmore and Carrathers, 1979). Adult frogs are carnivorous and usually feed on live moving prey. They are largely unselective feeders taking a large variety of insect prey. To reduce interspecific competition for food, species are separated by food size and foraging area (Passmore and Carrathers, 1979). Large frogs ingest large prey items and vice versa. Similarly, different species often feed in areas which are quite different in composition of the insect fauna. Savanna feeders would take a greater proportion of orthopterans. At the edge of the waters, aquatic or aquatic associated insects would be important. Arboreal species and burrowing forms would both utilize different portions of the insect fauna.

1.2.3. Threats to conservation of amphibians

It is unfortunate that the survival of the amphibian fauna is faced with a myriad of both natural and anthropogenic problems. They are threatened in most habitats by many kinds of influences. The number of species that are endangered is not really known. However, the recent and seemingly sudden decline in many amphibian populations throughout the world suggest that many more species and populations are in a precarious state than predicted five or ten years ago (Zug, 1993). According to Stuart (2002), preliminary evidence suggests that nearly half of the species in the Caribbean Islands fall into the IUCN categories of Critically Endangered and Endangered. In Madagascar, 99 % of the known species are endemic. Further, many new species have been discovered in recent years. Major threats include habitat loss and over-collecting. High levels of threat have also been recorded for Africa, Tropical Asia, China and Central America. Amphibian population declines, which is part of what is globally defined as biodiversity crisis (Wilson, 1985; Wilson and Peter, 1988; Wilson, 1992 and Cole, *et al.*, 1994), seem to be poorly understood worldwide i.e. it is not known if they exist! Currently there is limited data on the impacts of pesticides. But given the increasing use of agro-chemicals, and the general increase in aquatic pollution, there is need to monitor the levels of pollutants in the environment as well as in the tissues of amphibians. The effect of drought is not an exception. Even savanna species that breed in seasonal wetlands require dry season refuges. Isolation of once continuous populations can be a serious conservation concern since the resulting small populations (metapopulations) are highly prone to extinction due to stochastic and deterministic factors. Long term effects of such isolations in amphibians have not been investigated (Howell, 2002).

Human population increase has had a profound and seemingly irreversible effect on all forms of wildlife in many areas. Between 1950 and 1987, the world human population doubled, thus increasing the demand for material goods more or less commensurately resulting in a direct spatial impact on the wildlife habitat. There is little doubt that the rate of extinction today is far much greater than ever before (WRI, 1988). Due to this increased demand, land within protected area systems has not been spared from encroachment either. Human activities like drainage of wetlands result in complete removal of breeding grounds for amphibians and the result may be elimination of the local populations. Deforestation to provide timber, land for settlement, agriculture as well as other infrastructure have assumed alarming proportions today. Traditional land use practices like livestock grazing, collections of fuelwood, fruit and honey gathering have also continued to affect the localized pristine environments that remain today. Meru National Park is found within one of the highest populated areas in Kenya (WRI/IUCN/UNEP, 1992) and as such is highly exposed to the risk of human encroachment.

1.2.4. Declining amphibian populations - Overview

Vanishing amphibians may be considered as an alarm system to biodiversity in general for the reasons that (a) these animals undergo a biphasic life cycle (i.e usually with aquatic larvae and terrestrial adults), (b) are very sensitive to environmental change because of their relatively thin and highly water permeable skin and (c) often possess relatively short life span of generations. From the late 1980s, a lot of scientific and conservation efforts have been dedicated to this problem as evidenced by the establishment of a Declining Amphibian Populations Task Force (DAPTF: http://www.open.ac.uk/daptf/) under the auspices of The World Conservation Union's (IUCN) Species Survival Commission (SSC). Regional working groups of the task force are composed of scientists and conservationists who monitor the status of amphibians in their respective areas, with the results being documented in publications such as the DAPTF's bimonthly newsletter "FROGLOG" (http://www2.open.ac.uk/biology/froglog/). Investigations along similar goals are also being conducted by the Global Amphibian Diversity Analysis Group (GADAG).

What is puzzling is the observation that even species in protected and pristine areas without human impact seem to suffer from the problem of "global amphibian population declines". Some of the problems have been documented from Canada, northwest America (e.g. Sierra Nevada), Central America, the Andes of Venezuela and Ecuador, Atlantic Brazil rainforests, several locations in Europe as well as northeast Australia (Wake, 1991; Tyler, 1991).

Regarding declines in relatively undisturbed areas, some possible causes have been postulated. These include increased ultra-violet (UV) radiation due to thinned ozone layer. In Spain, UV radiation has been noted to affect early developmental stages of amphibians (Blaustein *et al*., 1996; Blaustein *et al*., 1998). Amphibian harvesting in parts of Romania has decreased local amphibian populations by reducing the number of offspring as females get killed before breeding (Nemes and Kovasznay, 2001). Problems of infectious diseases like chytridiomycosis and ranaviral disease have been recorded in regions like Ecuador where at least 26 species have declined (Ron and Merino, 2000). Similarly, the decline of the common midwife toad in protected areas of Central Spain has been attributed to the chytrid fungus (Bosch *et al*., 2000). Presence of chytridiomycosis has been confirmed in South Africa (Hopkins and Channing, 2002; Weldon, 2002). Pesticide pollution is a possible reason for the decline in agricultural regions of Argentina (Izaguirre *et al*., 2001).

The effects of organochlorine contaminants are known to be remote in both space and time due to their long environmental persistence, continued toxicity and the potential for long distance atmospheric transport. Most African amphibian populations have not been studied in the context of mass declines.

1.2.5. Role of amphibians in the ecosystem

It is quite worrying that even most current publications relating to wildlife management essentially ignore the existence of amphibians. This is due to the historical association of wildlife ecology with such agencies as agriculture, fish and game which are concerned with management of species having more obvious economic and/or recreational importance. In fact, amphibians are equally important if not more beneficial. Being ectotherms, they have a lower metabolic rate averaging 10 – 20 % and a daily energy requirement of 3 – 4 % compared to similar sized endotherms. This gives amphibians ability to survive prolonged periods of unfavourable environmental conditions. They, therefore, have a net energy conversion reaching 98 %, which is 35 times above endotherms; Amphibians have greater importance in the food web of most biological communities (Scott and Seigel, 1992). Many insect species are consumed by amphibians including those that are harmful to human health and part of agriculture. Tadpoles of some species feed primarily on mosquito larvae. Amphibians are also nutritionally valued in many parts of the globe. Amphibians have been used as indicators of environmental changes due to their sensitivity to changes in environmental parameters. This concept has been widely applied in biological monitoring.

1.3. Justification

Data on the number of species of the amphibians of Kenya found at any one locality remain extremely limited and largely anecdotal. Reliable estimates of the species richness of the amphibians at a single site are eminently attainable and the acquisition of these approximate datasets is a particular prerequisite as a baseline for drawing up overall conservation policies or making sound recommendations. There is a practical need to conduct population studies of these amphibians if not autecological treatments so as to demonstrate their habitat relationships. Knowledge of these relationships is necessary for several reasons. It has practical applicability to species conservation and restoration. Such empirical results can be used to design manipulative studies to test factors that may affect amphibians.

Due to lack of prior amphibian surveys and also owing to its widely heterogeneous ecosystems, Meru National Park offers an excellent opportunity for the proposed study. The complexity of the environment is evidenced by the three major vegetation types as outlined by Ament (1975). An ecological survey of the amphibians harboured in this seemingly "ecological island" surrounded by a sea of human pressure will be an important positive step towards the conservation of the park's biodiversity in general. Amphibians in particular are an important group to study since they act as ecological indicators owing to their sensitivity to environmental change. Perhaps the major feature that makes them so important is the fact that they are primarily active during specific periods of the year under certain weather conditions. Studies conducted at such a time are most informative and comparable among sites.

Studies of this nature would also serve as a means to highlight the conservation status of amphibians (www.gadag.org). In Kenya, as might be the case in most parts of the world, amphibians have only been given protection fortuitously. There has been no deliberate action aimed at conserving all the "important 'amphibian' areas". Moreover, there has been a great deal of concern about declines of amphibian populations in many parts of the world. Much more information is needed on the status of many species in a variety of habitats. This study would be a step towards realizing these needs.

1.4. Objectives of the study

1.4.1. Overall objective

The objective of the present study is to carry out an ecological survey of amphibians and to estimate their diversity and abundance in various habitats in Meru National Park, Kenya.

1.4.2. Specific objectives

Under the above major goal, the specific objectives of the investigation are as follows:-

- To identify the amphibian species found in Meru National Park and estimate the species diversity.
- To provide an estimate of the community structure (i.e. relative abundance).
- To identify the link between species diversity with the habitats of their occurrence.

2. THE STUDY AREA

2.1. Location

Meru National Park is located in Eastern Province of Kenya about 360 km to the north east of Nairobi. It lies on the Equator between latitudes 0^{o} 20' north and 0^{o} 10' south, 38^{o} 0' and 38^{o} 25' east (Figs. 1 and 2). It is within the administrative boundaries of North Meru District which borders Isiolo, Tana River, Tharaka and Central Meru Districts. The park covers an area of 870 km^2 of lowlands. The altitude varies from over 850 m a.s.l. along the west boundary near the Nyambeni Hills to about 300 m a.s.l. towards the southeastern corner where the Tana River forms part of the park boundary. The elevation follows a steadily descending gradient from northwest to southeast.

2.2. Climate

As the case with most dryland environments, data for annual rainfall of the park shows great variability. The humid season is dependent on localized rainfall and recharge from ground water which is governed by the level of the water table in the adjacent Nyambene Hills. The maximum annual rainfall is almost four times as great as the minimum. The average annual rainfall is 724 mm with a bimodal pattern. The short rains in November are much more intense than the March-May long rains (Ament, 1975). The network of rivers flowing across the park in a southeasterly direction to join the Tana River presents a good drainage system. Most rivers in the north are permanent while the Tana and the Ura Rivers are the only permanent waters in the southern section.

Meru Area

Figure 1. Map of Kenya showing the location of Meru National Park

Figure 2. Map of Meru National Park showing the sampling sites

2.3. Soils

Two major soil types are recognized within the park. The northern section is formed of Pleistocene-Recent lava, produced from the volcanoes of the Nyambenis. Towards the south, the Precambrian rock of the basement system is exposed. The lava is mainly olivine basalt. In the northwest of the park, lava-stewn ridges of powdery –grey to grey-brown soil slope gently towards the Nyambeni Hills. Within the river valleys are various swamps and the soil is grey to black. There is an area of fossiliferous limestone on the banks of Rojewero River as it approaches confluence with the Murera. Northeast of the Murera River, the eastern boundary of the park, red sandy soil covers the basement rocks (Ament, 1975).

2.4. Flora

Floristically, Meru National Park belongs to the Somali Maasai Regional Center of Endemism (White, 1983). The vegetation composition within the park can be broadly divided into three communities (Ament, 1975). *Acacia* wooded grassland covers the eastern part of the Nyambeni lava flows and the volcanic alluvial soils along the northeastern boundary of the park. Dominant tree species include *Acacia tortilis* and *A. senegal* mainly on the low stewn ridges, but are replaced by *Hyphaene coriacea* in the low swampy areas besides the rivers. *Combretum* wooded grassland covers the western park boundary. Here *Combretum apiculatum* is dominant while *C. molle* and *C. collinum* are both common. *Ziziphus* sp. and *Harrosonia abyssinica* occur in scattered clumps and *Lawsonia inermis* is common near rivers. *Sehima nervosum* is the dominant grass species. Scattered patches of *Chrysopogon plumulosus* and *Aristida adsceniosis* also occur, the latter being found where land has recently been disturbed e.g. by burning (Fig. 3). There are some swampy patches where *Acacia seyal* var. *fistula* and *A. drepanolobium* occur with the grass *Chloris gayana* being dominant. The swamps are also dominated by a variety of palms (Fig. 4).

The third vegetation type is *Acacia-Commiphora* bushland, which is dominant where the basement rock is exposed towards the southern region of the park. The trees and shrubs are taller and there is a better grass cover near the western boundary where *Acacia mellifera, A. nilotica, A. brevispica* and *A. ataxacantha* are common. Further southeast*, A. senegal* and *A. reficiens* dominate. In many places, there is a dense low understorey bush of *Bauhinia taitensis*, *Grewia villosa*, *Combretum aculeatum* among other species. Other minor vegetation types include riverine forests, iselbergs, groundwater forest, and swamps. The latter commonly found in the most northerly triangle.

2.5. Fauna

The heterogeneity of habitats found within Meru National Park is a contributing factor to the diverse wildlife species found in the park. Mammal species include elephants, buffaloes, hippopotami, Grevy's and common zebras, Grant's gazelles, lesser kudus, beisa oryx, white rhinos, baboons, kongoni, reticulated giraffe, waterbuck, and gerenuk. Lions, cheetahs, and leopards are also present. Webala (2001) recorded 15 species of bats in Meru National Park and surrounding farms. Other small mammals such as rodents are also present. Over 332 species of birds have been observed in Meru National Park(Williams, 1981). The reptiles present in the park include nile crocodiles, several species of snakes, turtles, tortoises and monitor lizards. Several species of amphibians are believed to occur though only a few have been documented. These include *Hyperolius montanus* and *H. viridiflavus ferniqei,* both of which are endemic to Kenya. Many species of *Bufo* (e.g. *B. garmani*, Fig. 5) and *Ptychadena* (e.g. *P. porosissima*, Fig. 6) are known to have range extensions in Meru National Park.

2.6. Landuse

Meru National Park is part of what is called Meru Conservation Area. Other units making up the conservancy are Bisanadi National Reserve, Kora National Park, Mwingi National Reserve and Rahole National Reserve. The western park boundary is covered with rich agricultural land at the foot of the sprawling Nyambene ranges. The northern section is occupied by the Borana pastoralists. The Tharaka pastoralist and subsistence farming community are found in the south.

Figure 3. Routine fire management in Meru National Park, burnt section of *Acacia* wooded grassland

Figure 4. A suitable frog breeding habitat

Figure 5. Male and female Olive Toad, *Bufo garmani*, in amplexus

Figure 6. *Ptychadena porosissima*, one of the species recorded in Meru National Park

Figure 7. Strings of eggs of *Bufo* sp.

3. MATERIALS AND METHODS

3.1. Study sites

Nine study sites were sampled for amphibians in Meru National Park (Fig. 1). These included three randomly selected representative localities within each vegetation community (Fig. 2). The study was conducted between the months of October 2002 and January 2003. Three vegetation communities namely *Acacia* Wooded Grassland, *Combretum* Wooded Grassland and *Acacia-Commiphora* Bushland were sampled.

3.2. Amphibian sampling techniques

The transect method of sampling amphibians as described by Heyer *et al*. (1994) was employed. In each study site, a 600 m transect in rectangular form, was established starting from a random point. The transect ran for 200 m N, turned W 100 m, then S for 200 m, and finally back to the starting point for 100 m. A bandage of 2 m along the transect was used for sampling. A GPS reading was taken for each transect location. A team of two persons working for two hours per search night (4 man-hours) made three visits to each site. The sites were sampled in a random rotational sequence in order to minimize bias. Sampling was carried out during the short rainy season from late October to December 2002. In addition, several opportunistic records were made during and after the rains. The spacing of sampling sites was largely determined by security concerns and accessibility, while attempts were also made to minimise off-road driving. Thus, no transects were laid within a large section of the Acacia-Commiphora bushland in the southeastern triangle (Fig. 2).

Several parameters were recorded during each sampling visit: date and time (start and end of sampling), general weather condition, temperature and humidity were recorded using a hygrometer-thermometer at 1 m above the ground, and any other information of general interest. For each amphibian species encountered, the following information was recorded:- a) species name (identification), b) sex, c) snout-vent length (measured using a vernier calipers, 0.01 cm), d) weight (taken by the use of a digital scale Precisa BJ210C, 0.01 g), e) tibial length and f) any other special behaviour e.g. calling. Toes were clipped before release to avoid double counting. In cases where double collections were encountered, they were ignored.

In order to supplement amphibian encounters from transects, straight-line drift fence and pit-fall trapping technique was also used (Karns, 1986; Heyer *et al*., 1994). Due to the intensity of the work involved, only one trap station was established in each vegetation community. A 20 m drift fence made of polythene flashing 50 cm above the ground and 5 cm below the surface was used. Ten pitfalls (20 l buckets) were each placed flash with the ground surface and alternately on either side of the fence at 2 m intervals. Traps were checked shortly after sunrise and late evening. Species data from captures were collected in the same manner as explained above. Two trap nights were conducted in each trap station.

Voucher specimens were collected either purposely for making a reference collection to be deposited at the National Museums of Kenya (NMK), for identification. Specimens were killed using chlorobutanol solution, then fixed with 98 % ethanol. For the collected specimens, tissues (toes) were stored in 98 % ethanol (in tissue vials) for future genetic analysis. The specimens and tissues were individually catalogued in a field notebook with corresponding field numbers. Only voucher specimens were transferred, after fixation, to 70 % ethanol. Acoustic surveys were also conducted and call vouchers recorded using a Sony Professional Stereo Cassette Recorder (WM-D6C), dynamic headphones (MDR-51) and a directional microphone (Sennheiser ME - 80). TDK cassettes were used for recording the calls. The call vouchers, which partly assisted in species identifications were added to the NMK frog call library.

3.3. Vegetation sampling techniques

In each sampling area , a transect was established along which fifteen plots, each measuring 20 x 10 m^2, were randomly selected. Within each plot, the Braun-Blanquet cover abundance scale was used to assign various plant species a cover/abundance rating (Appendix 1) following Mueller-Dombois and Ellenberg (1974). Plant species were identified at the East African Herbarium (EA), Nairobi.

3.4. Data analyses

3.4.1. Amphibian abundance and diversity

Amphibian abundance was expressed in terms of numbers of individuals observed. Two factorial analysis of variance (ANOVA) was used to test for differences in sex ratios in various vegetation communities. Chi-Square (x^2) was used to assess differences in sex ratio at the species level (Zar, 1996).

Species diversity indices were computed for amphibian species recorded in each vegetation community. For comparison, both Shannon-Weaver's Index (H') and the inverse of Simpson's index (D) were computed.

Shannon-Weaver Index, $H' = - \sum P_i \ln P_i$

Where Pi is the proportional abundance of the ith species

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

n_i = abundance of the i^{th} species

N = Total number of individuals

S = Species richness, total species in community

Shannon diversity index is one of the heterogeneity or information theory indices (Magurran, 1988). They take both evenness and species richness into account (Peet, 1974). H' assumes that individuals are randomly sampled from an infinitely large population and that all species are represented in the sample. H' is maximum (H_{max}) when all S species are represented by the same number of individuals (even distribution) (Krebs, 1989). It is possible to calculate a separate additional measure of evenness. This is given by the ratio of observed diversity to maximum diversity. It is termed Shannon's Evenness Index (E).

$E = H'/H_{max}$

Where, $H_{max} = \ln S$

H' = Shannon's Diversity Index

lnS = the natural logarithm of species richness

Simpson's index measures the probability that any two individuals drawn at random from an infinitely large community belong to different species. It is sometimes referred to as Yule index since it resembles the measure G. C. Yule devised to characterize the terminologies used by different authors. It is termed a dominance measure since it is weighted towards the most abundant species while being less sensitive to species richness (Magurran, 1988).

Simpson's index is given by the equation:

$$D = 1/C$$

Where, $C = \sum P_i^2$

Number of species recorded was plotted against search effort (man-hours) to obtain a species accumulation curve. This was to assess the completeness of the inventory. In order to examine the suitability of the different habitats sampled, regression equations of weight against snout-vent length were obtained for two randomly selected species.

3.4.2. Vegetation analysis

Detrended Correspondence Analysis (DCA) was applied to the vegetation data as contained in the computer program CANOCO version 4.0 (Ter Braak, 1987). This procedure combines regression and ordination into a technique of multivariate gradient analysis termed "canonical (or constrained) ordination". In the DCA ordination diagram, the location of sampling plots is indicated as the centriod of species scores for species occurring in that sampling plot. Sampling plots that occur close together are floristically similar (using presence-abundance data).

3.4.3. Correlation of amphibian species and vegetation structure

To examine the correlation between plant species presence/abundance and amphibian species richness, the procedure Detrended Canonical Correspondence Analysis (DCCA) in the computer program CANOCO (Ter Braak, 1988) was used. DCCA is a direct gradient analysis procedure. The ordination axes are constrained to optimize their relationship with a set of environmental variables, whose directions are indicated in the bi-plot by arrows. The lengths of these arrows are proportional to the importance of each environmental variable. Species are represented by points. These points represent the approximate values the weighted averages of species with respect to the environmental variables. One can estimate species distribution optima along each environmental variable by projecting the species point perpendicularly to each arrow.

4. RESULTS

4.1. Amphibian population analysis

A total of 430 individuals of amphibians were observed within a search effort of 108 man-hours in Meru National Park, Kenya. Eleven species of amphibians belonging to six families were recorded (Table 1). The *Acacia* wooded grassland had the highest species abundance (Fig. 8) as well as richness with a total of 173 individuals falling in ten species (Tables 2 & 3). Eight species (113 individuals) were recorded from the *Combretum* wooded grassland, while the *Acacia-Commiphora* bushland had seven species (144 individuals) (Table 3). Two species, *Phrynomantis bifasciatus* and *Hemisus marmoratus* were exclusively recorded in the *Acacia* wooded grassland. *Ptychadena mascareniensis* and *Bufo gutturalis* were both absent in the *Acacia-Commiphora* bushland. *Bufo garmani* did not occur in the *Combretum* wooded grassland while *Xenopus laevis* was not recorded in the *Acacia* wooded grassland. Five species (*Ptychadena porosissima, Ptychadena anchietae, Phrynobatrachus natalensis, Bufo maculatus and Hyperolius viridiflavus ferniquei*) were common to all vegetation communities. One of the species, *Hyperolius v. ferniquei*, a sub-species of the "viridiflavus complex" is endemic to Kenya. It, however, has a range extension including areas of Central Kenya. The taxonomy is still not resolved for many forms (e.g. *Ptychadena mascareniensis, Phrynobatrachus natalensis*). Hence, there could probably be more species and/or endemics for Kenya or Meru involved.

By comparing amphibian species diversity across the vegetation communities, the results showed that *Acacia* wooded grassland had the highest species diversity (H' = 2.071, D = 6.74) (Table 3). This was followed by *Acacia-Commiphora* bushland, while *Combretum* wooded grassland had the least diversity (H' = 1.581, D = 5.076). The difference in the sex ratio between and within the vegetation communities was not statistically significant

(Two factor ANOVA, F = 8.3026, P = 0.6914). Similarly, there was no statistically significant difference in sex ratio on a species by species basis (Chi-Square, χ^2) (Table 4). However, from Table 1, females of *Ptychadena anchietae* and males of *Hyperolius viridiflavus ferniquei* tended to be dominant.

Table 1. Abundance of amphibian species based on sex

		Abundance		
Family	**Species**	**Males**	**Females**	**Total**
Ranidae	*Ptychadena porosissima*	33	38	71
	Ptychadena mascareniensis	16	15	31
	Ptychadena anchietae	24	33	57
	Phrynobatrachus natalensis	14	13	27
Bufinidae	*Bufo maculates*	22	15	37
	Bufo garmani	19	13	32
	Bufo gutturalis	9	14	23
Hyperoliidae	*Hyperolius viridiflavus ferniquei*	54	37	91
Hemisotidae	*Hemisus marmoratus*	11	16	27
Microhylidae	*Phrynomantis bifasciatus*	5	3	8
Pipidae	*Xenopus laevis*	12	14	26
	Total	**219**	**211**	**430**

Figure 8. Graph showing the absolute and percentage abundance of amphibian species per vegetation community

Table 2. Amphibian abundance based on vegetation community and sex

	Abundance		
Vegetation Community / Sex	***Acacia* Grassland**	***Combretum* Grassland**	***Acacia-Commiphora***
Male	83	58	78
Female	90	55	66
Total individuals	**173**	**113**	**144**

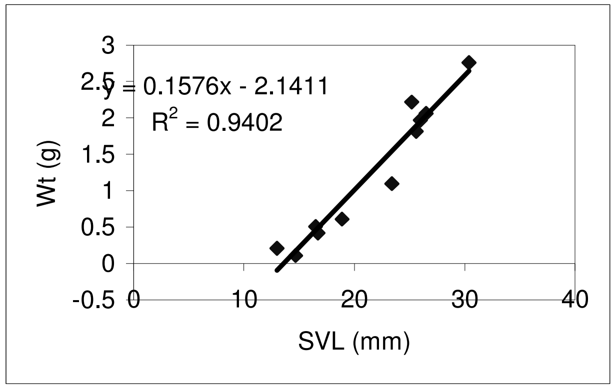
Table 3. Amphibian diversity indices in three vegetation communities

	AMPHIBIAN DIVERSITY		
INDEX	*Acacia* Wooded Grassland	*Combretum* Wooded Grassland	*Acacia-Commiphora* Bushland
Species Richness	10	8	7
No. of Individuals	173	113	144
Shannon-Weaver Index, H’	2.071	1.851	1.858
Simpson’s Index, D	6.74	5.076	5.88
Shannon Evenness Index, E	0.899	0.89	0.956

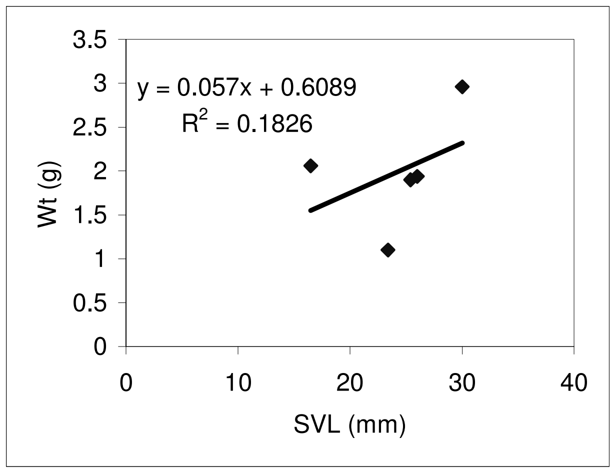
Table 4. Chi-Square test based on sex ratio for individual species (Obs. fre. = Observed frequency, Exp. fre. = Expected frequency)

Species	**Sex**	**Obs. fre.**	**Exp. fre.**	**X^2**	**df**	**P-Value**
Ptychadena porosissima	M	33	35.5	0.3522	1	P > 0.5
	F	38	35.5			
Ptychadena mascareniensis	M	16	15.5	0.0322	1	P > 0.5
	F	15	15.5			
Ptychadena anchietae	M	24	28.5	1.421	1	P > 0.5
	F	33	28.5			
Phrynobatrachus natalensis	M	14	13.5	0.0370	1	P > 0.5
	F	13	13.5			
Bufo maculatus	M	22	18.5	1.3243	1	P > 0.5
	F	15	18.5			
Bufo garmani	M	19	16	1.125	1	P > 0.5
	F	13	16			
Bufo gutturalis	M	9	11.5	1.0870	1	P > 0.5
	F	14	11.5			
Hyperolius v. ferniquei	M	54	45.5	3.176	1	P > 0.5
	F	37	45.5			
Hemisus marmoratus	M	11	13.5	0.926	1	P > 0.5
	F	16	13.5			
Phrynomantis bifasciatus	M	5	4	0.5	1	P > 0.5
	F	3	4			
Xenopus laevis	M	12	13	0.154	1	P > 0.5
	F	14	13			

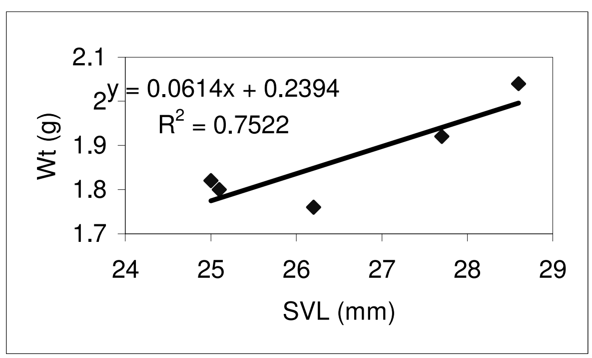
The suitability of the various habitats was evaluated by plotting body weights against snout-vent lengths of two randomly selected species. All the regression equations showed positive linear relationships (Figs. 9 & 10) except *Phrynobatrachus natalensis* which only showed a weak positive relationship in the *Combretum* wooded grassland (R^2 = 0.1826) (Fig. 9b). In order to assess the completeness of the survey, the search effort (man-hours) was plotted against the number of species recorded to obtain a species accumulation curve. In the *Acacia* Wooded Grassland, the curve did not reach asymptote (Fig. 11). Species accumulation curves for *Combretum* wooded grassland and *Acacia-Commiphora* bushland both reached asymptote (Figs. 12 & 13). Similarly, an asymptote was attained when data were pooled for all the vegetation communities (Fig. 14).



(a) *Acacia* wooded grassland

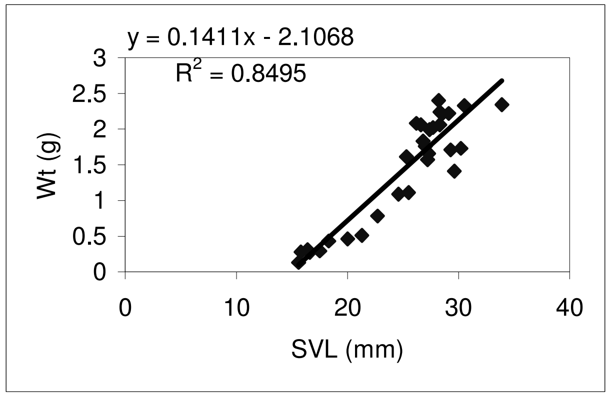


(b) *Combretum* wooded grassland

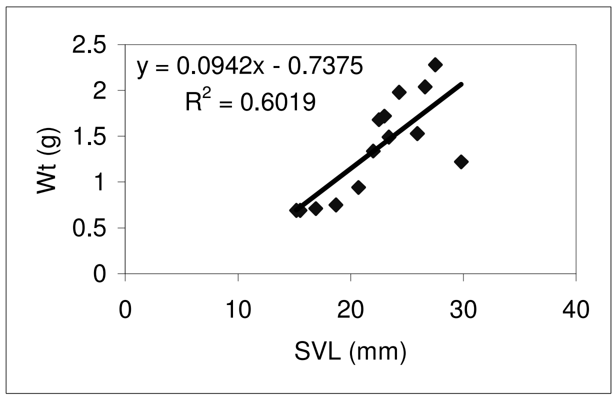


(c) *Acacia-commiphora* bushland

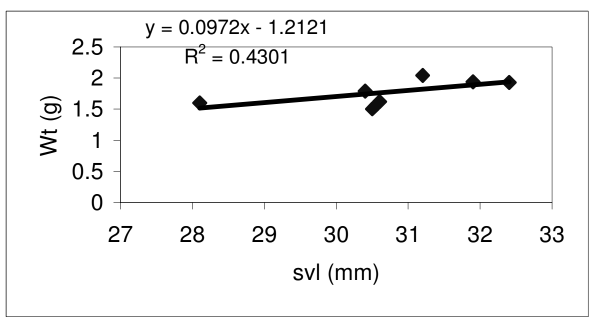
Figure 9. Relationship between weight and snout-vent length of *Phrynobatrachus natalensis*



(a) *Acacia* wooded grassland



(b) *Combretum* wooded grassland



(c) *Acacia-Commiphora* bushland

Figure 10. Relationship between weight and snout-vent length of *Hyperolius v. ferniquei*

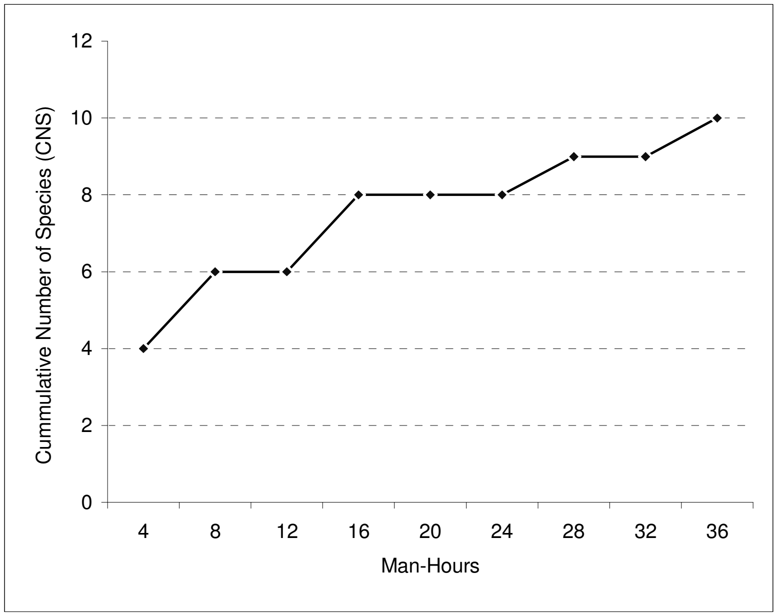


Figure 11. Species accumulation curve in the *Acacia* wooded grassland

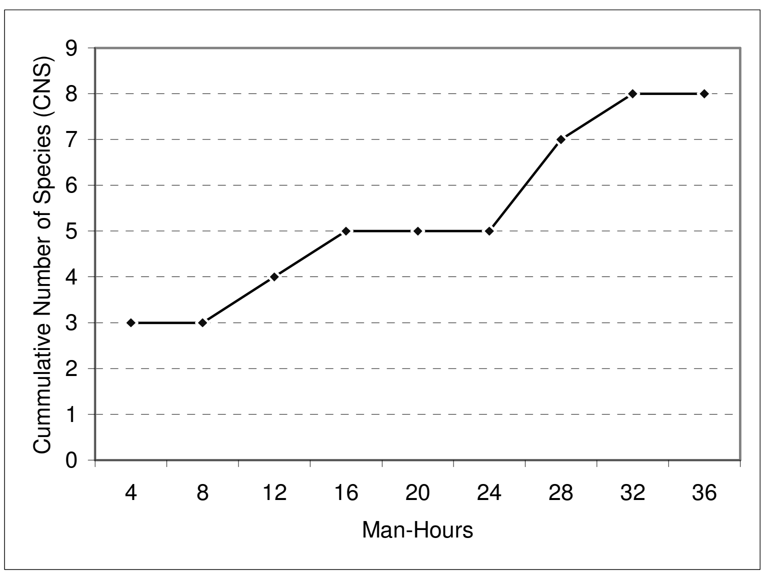


Figure 12. Species accumulation curve in the *Combretum* wooded grassland

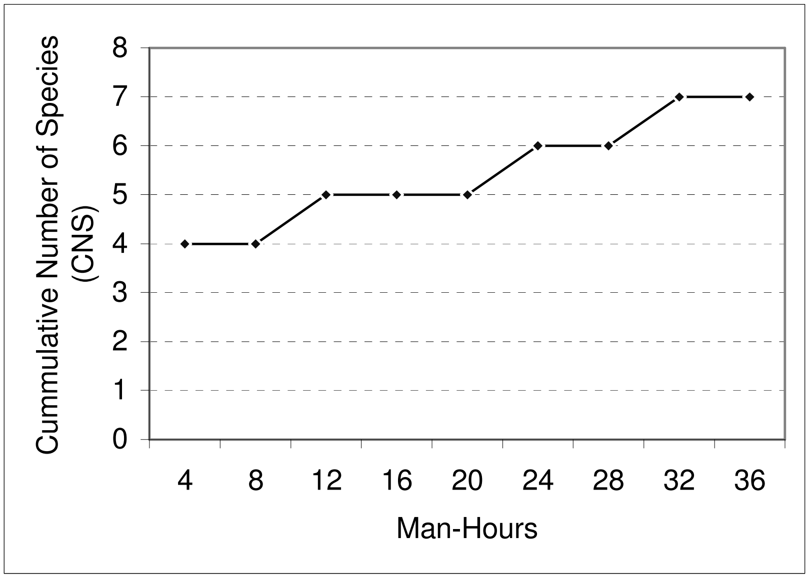


Figure 13. Species accumulation curve in the *Acacia-Commiphora* bushland

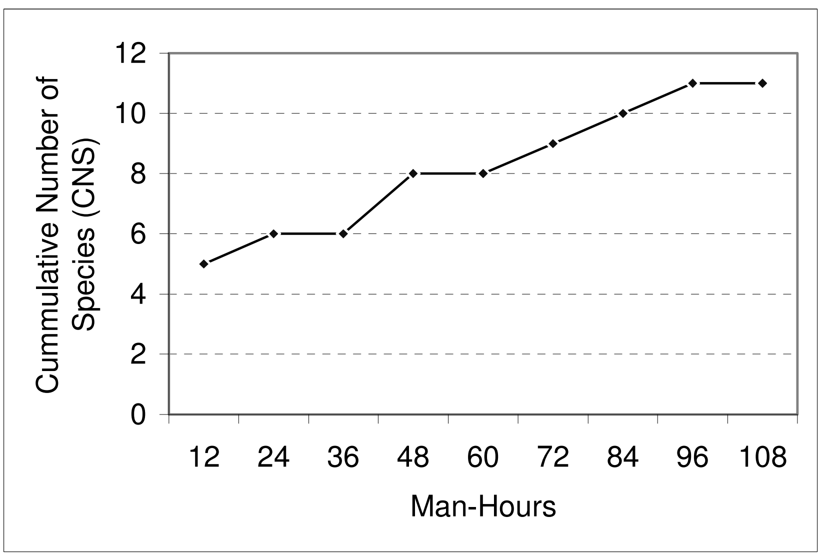


Figure 14. Overall species accumulation curve

4.2. Vegetation structure

Braun-Blanquet cover abundance was recorded for 122 plant species in 45 plots. This comprised, 15 plots each in *Acacia* wooded grassland, *Combretum* wooded grassland and *Acacia-Commiphora* bushland vegetation communities (Appendices 2 - 4). In figure 15, the plots are arranged in order of similarity, which is the output from the procedure Detrended Correspondence Analysis (DCA). In the ordination diagram, the plots are arranged such that the plots that occur close together (in two dimensional space) correspondingly have similar species composition. From the data, five species assemblages were identified as summarized in Table 5 (Appendices 5 – 9).

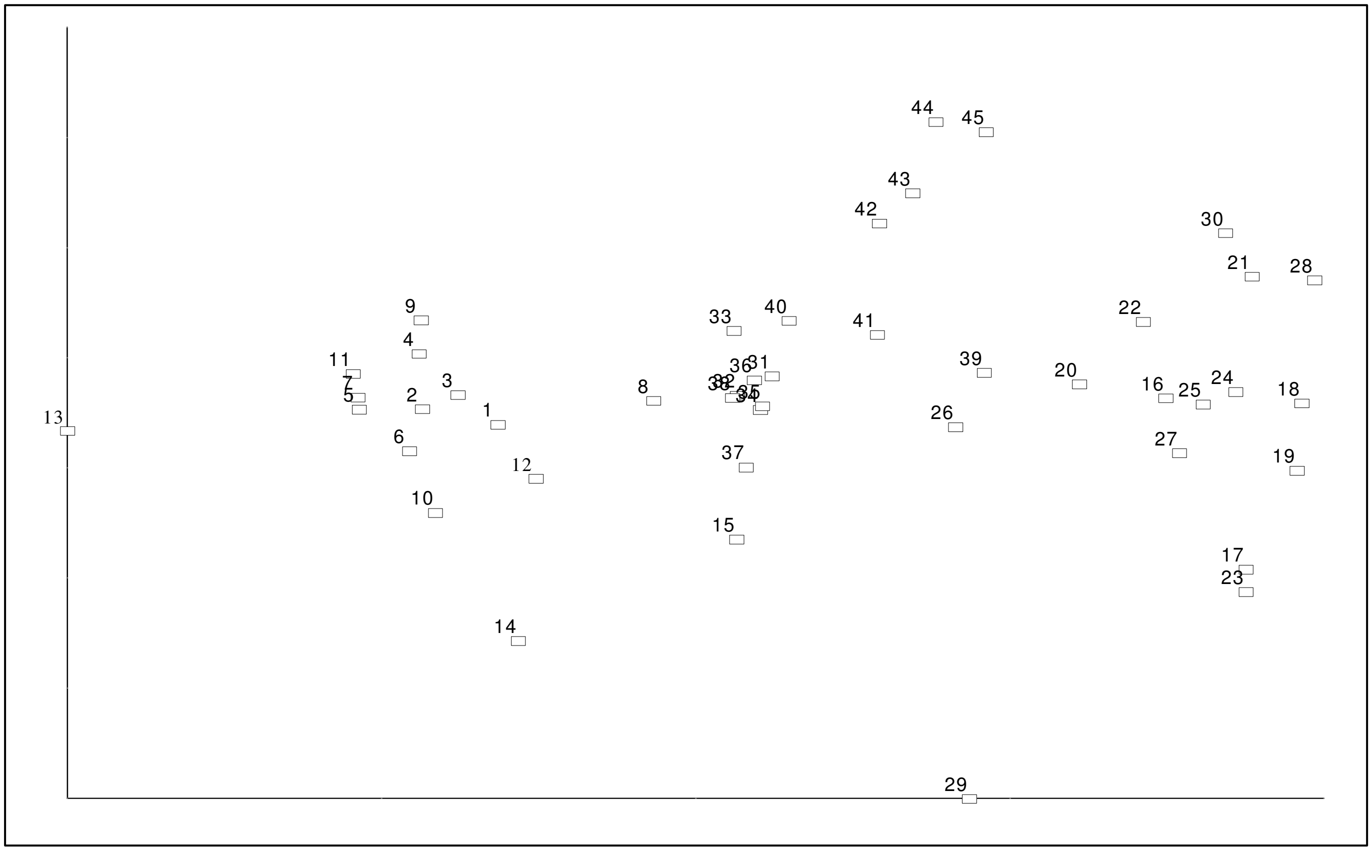


Figure 15. DCA Ordination diagram of vegetation data at Meru National Park. Numbers refer to sampling plot; numbers 1-15 – *Acacia* Wooded Grassland, 16-30 *Combretum* Wooded Grassland, and 31-45 – *Acacia-Commiphora* Bushland

Table 5. Plant species assemblages resulting from DCA ordination of vegetation data at Meru National Park.

Species Assemblage	Constituent Sampling Plots
I	8 15 26 31 32 33 34 35 36 37 38 39 40 41
II	1 2 3 4 5 6 7 9 10 11 12
III	16 18 19 20 22 24 25 27
IV	42 43 44 45
V	21 28 30
OUTLIER PLOTS	29 13

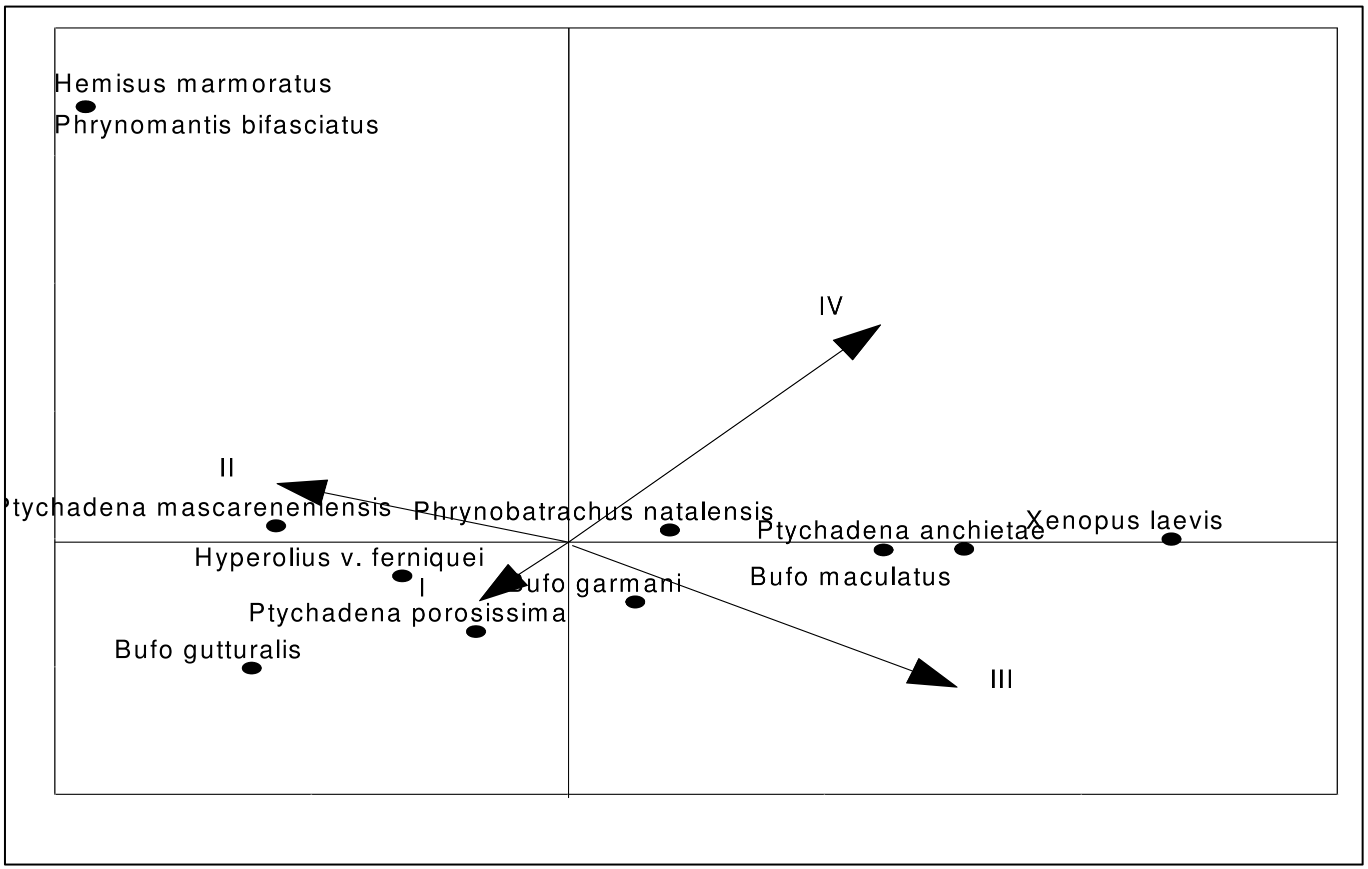


Figure 16. DCCA Ordination diagram of amphibians at Meru National Park and plant assemblages (I-IV).

4.3. Association between amphibian species and vegetation

From the DCCA ordination diagram (Fig. 16), *Hyperolius viridiflavus ferniquei, Ptychadena porosissima* and *Bufo gutturalis* showed a weak positive association with *Acacia-Commiphora* bushland while *Phrynobatrachus natalensis* strongly preferred this vegetation community. *Phrynomantis bifasciatus, Hemisus marmoratus* and *Ptychadena mascareniensis* were distributed more in the Acacia wooded grassland than others. *Bufo maculatus, Ptychadena anchietae* and *Xenopus laevis* shared both *Acacia-Commiphora Bushland* and *Combretum* Wooded Grassland but were negatively correlated with the *Acacia* Wooded Grassland. On the other hand, amphibian species diversity correlated positively with plant species diversity in all vegetation communities (Table 6). Amphibian species diversity was highest in the *Acacia* grassland (D = 6.74), the vegetation community which also showed the highest plant species diversity (D = 8.83).

Table 6. Relationship between amphibian and plant species diversity in three vegetation communities.

Vegetation Community	Amphibian diversity, D	Plant species diversity, D
Acacia Grassland	6.74	8.83
Combretum Grassland	5.076	6.97
Acacia-Commiphora	5.88	7.08

5. DISCUSSION

Spatial trends in richness of species, by measurement of regional or local gradients, have been reported in many taxa. But only in the last few decades have they been accurately measured (Real *et al*., 1993). Schiotz (1967) observed that for most terrestrial animals, these trends follow a vegetational gradient. He went further to demonstrate such an association for the Rhacophoridae of West Africa. His study showed that some of the species were always found calling and breeding together in the same localities, while other species present in the same geographical area formed breeding aggregations on other localities. Three well delimited 'faunas' were distinguished: the savanna fauna, the high forest fauna and the farm-bush fauna. Other workers have also supported this vegetation split hypothesis (Stewart and Pough, 1983; Howell, 1993). There is an agreement that there is a basic split between forest and non-forest species, save for the fact that the physiological reasons for forest dependence are not well understood. But the number of hiding or retreat sites is a possible critical factor in limiting tropical anuran populations, especially if forest quality is altered and/or forest patch size decreases (Stewart and Pough, 1983; Howell, 1993). The present study followed this pattern to assess the diversity and abundance of amphibians of Meru National Park on the basis of three distinct vegetation communities.

The five species assemblages obtained from the DCA ordination closely matched the broad vegetation communities earlier identified by Ament (1975). Our plant species assemblages I and IV correspond to *Acacia-Commiphora* bushland, assemblage II correspond to *Acacia* wooded grassland, while both assemblages III and V correspond to *Combretum* wooded grassland.

Amphibian diversity varied across the vegetation communities. Dominance was not prominent in all vegetation communities as reflected by both percent species compositions and Shannon's Evenness index. This contradicted with an earlier observation of Giaretta, *et al*. (1999) that high values of dominance are typical of seasonally stressed environments.

The variation in the amphibian diversity could have reflected varying levels of disturbance in the three vegetation communities. Two major classes of disturbance were noted in Meru national Park. These included frequent burning by park authorities and grazing and/or trampling by the herbivore population (*Pers. Obs*). The Acacia wooded grassland emerged the least disturbed and recorded the highest species richness and diversity. This was also supported by the fact that two specialist species, *Hemisus marmoratus* and *Phrynomantis bifasciatus*, were exclusively recorded from this community. On the other hand, *Combretum* wooded grassland was in a most disturbed state. The higher species diversity in the Acacia wooded grassland could be attributed to vegetational diversity as well as heterogeneity of microhabitats. Furthermore, the northern triangle of the park covered by this vegetation community is served by the highest number of permanent streams as opposed to the southern or southeastern sections. This guarantees availability of retreat sites in periods of moisture stress and hence preferred by frogs. Ovaska (1991) also observed that the presence of moist retreat sites for the frogs could modulate fluctuations in environmental conditions to allow for an increased time, on both seasonal and diel basis, for foraging.

Several authors have compared species richness between intact and impacted sites using different classes of disturbance. In tropical America and Southeast Asia, Lieberman (1986), Heinen (1992) and Inger (1980b), have recorded high herpetofaunal abundance and density in tree plantations relative to primary forests. Inger (1980b) from Southeast Asia and Vonesh (2001) from tropical Africa, both agreed that herpetofaunal densities were lowest in the unlogged site and highest in the logged and plantation sites. Vonesh (2001) recorded higher species richness in both disturbed sites and higher diversity in pine plantation. However, Heinen (1992) recorded higher richness in a primary forest. The latter concurs with findings in this study that high species richness and diversity are found in undisturbed sites.

The effect of fire is manifold and is quite detrimental to the predominantly ground dwelling amphibians. It destroys leaf litter, ground vegetation cover as well as canopy. This greatly interferes with the moisture balance in an ecosystem. Worse still, burning eliminates arthropods, the major source of food to the amphibian fauna. Giaretta, *et al*. (1999) noted that fire is known to have a deleterious effect on the litter frogs. They observed that, although the soil becomes covered with some leaves soon after the burns, there is little leaf compaction so that the litter cannot retain humidity. This most likely prevents immediate recolonisation by frogs. On the other hand, large numbers of game animals are associated with long-term wallowing which can damage resident tadpole communities and increase the population of leeches, which may feed on blood of amphibians. The latter can lead to transmission of parasites (Koracs and Papp, 2002). In Meru National Park the situation is worsened during the dry season. Large numbers of animals congregate around limited water holes. These are also the same refuges used by the amphibian community.

The present results from the DCCA ordination could further confirm the trends of disturbance revealed by species diversity indices. It was observed that more amphibian species were associated with *Acacia* wooded grassland and *Acacia-Commiphora* bushland. There was least association with *Combretum* wooded grassland which had the lowest species diversity. Pough, *et al*. (1999) noted that amphibians are highly susceptible to local habitat disturbances. This is because they possess small body sizes, have limited locomotion mechanisms and restricted home ranges. This could explain the observed variation in species richness and diversity in the three vegetation communities. Regressions of body weight and snout vent length for two species yielded high positive correlation for both species in all habitats except one – *Phrynobatrachus natalensis* with weak positive correlation in the *Combretum* wooded grassland. A similar association was recorded for bat species by Webala (2001).

In the assessment of the completeness of the survey, Howell (2002) stated that if the curve for cumulative number of species flattens out at the end of the sampling period, then it is likely that the sampling has detected most of the species which are detectable using that method. In this study, the curve did not flatten out in the Acacia wooded grassland where one species was added during the ninth sampling period. Perhaps more species would have been recorded, had the sampling period been extended while maintaining similar sampling techniques. The rest of the curves for the other two vegetation communities demonstrated an asymptotic trend. The same trend was observed for the overall species accumulation curve. However, since the study period was short and data on comparative study on the amphibians of Meru is lacking, no authoritative comment can be given on the completeness of the species list even for these two vegetation communities. Four species were earlier documented as occurring in Meru park (NMK database), of which only two species, *Phrynomatis bifasciatus* and *Hyperolius v. ferniquei*, were detected in the current study. But since the GPS data was lacking for the said records, it was likely the other two species, *Bufo kisoloensis* and *Hyperolius montanus*, were recorded from adjacent areas and not inside the park. Moreover, *H. montanus* would have been an unusual record for Meru National Park given the low altitudinal range. It was therefore not surprising that this species was not recorded.

The study at Meru was conducted during one of the rainy seasons (October – December) and the observed non significant differences in the sex ratios was possibly due to breeding activity. This would have made individuals of both sexes fairly equally available. On another note, it can also be deduced that due to the harsh weather conditions (hot and dry) in the park for most months in a year, there could be selection against dispersal behaviour during wet seasons because of the risk of entering seasonally dry sites. There was a possibility that amphibians of Meru aggregated along stream margins as was observed along such transect segments during the survey.

A generalization cannot be made of the association of the amphibian species and the plant species assemblages because the study only covered the rainy season. This limitation was also noted by Schiotz (1967) who stated that if collecting is done almost entirely in the breeding season, only an impression can be obtained of the connection between the amphibians in the breeding season and their surroundings. Nothing can be said of this connection outside the breeding season. For a complete analysis therefore, it would be necessary to follow a certain area throughout the year and to undertake the very labourious task of finding the amphibians during the dry season. The other aspect is associated with sampling bias. In a study conducted in Florida, Dodd (1991) analysed Drift-fence associated sampling bias of amphibians. He predicted that some amphibians are able to circumvent a drift-fence pitfall trap as they move toward or away from an ephemeral pond. His laboratory trials confirmed that frogs easily crossed the fence by walking up the side or hoping over it. Some species may not go over the fence but use tunnels to go under the fences in field conditions. Other species are known to burrow directly under the fence. Considering the impacts of such issues, it was likely that in this study, a portion of the amphibian population was missed. So a detailed study on a longer duration should be carried out to get complete information.

6. CONCLUSIONS AND RECOMMENDATIONS

It has been observed that, for most populations of Kenyan amphibians, insufficient data are available to allow population trends to be described. This is the first study to document and provide species diversity and richness data for a savanna habitat in Kenya. In the past, inventory and taxonomic surveys have concentrated on the highlands and coastal forests. It is important to underscore the fact that understanding the patterns of species habitat use and their response to dramatic changes in their habitat constitute a basis for sound conservation practice. From this study, it has been observed that: -

- Habitat disturbance, of various classes and magnitude, constitute an important selective force in shaping the population structure of frogs. Human activities or natural influences have a profound influence on amphibian diversity and abundance patterns.
- The demographic pattern of an amphibian population can vary on a very small spatial scale.
- Given the current reports of amphibian declines, this study provides the much needed baseline data from one of the less studied habitats of East Africa.

For further improvement on the management of Meru National Park as an ecosystem particularly conserving the amphibian population, the following considerations should be taken into account: -

- The Meru amphibian population could be used in a long term monitoring project in order to gain more insight into the population trends. Being a protected area, the park satisfies some of the DAPTF's criteria for a monitoring site.
- Further investigations that examine the effects of other environmental variables – e.g. moisture, seasonality – on this population would be more productive.
- In view of the fact that the principle of conservation should take an ecosystem approach, the management plan for Meru park should consider the requirements of the lower vertebrates (e.g. amphibians) and the higher vertebrates (e.g. elephants) in perfect balance. In particular, the use of fire should be reviewed to include fire avoidance programmes.

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8. APPENDICES

Appendix 1: Braun-Blanquet Cover abundance scale

Symbol	Cover/Abundance
5	Any number of individuals, with a cover of more than75 % 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 last two scales (r and +) were not in the original scale as proposed by Bruan-Blanquet hence the term ‘modified’. They are assigned values 0.5 and 0.1 respectively.

Appendix 2: Plant species recorded in the *Acacia* wooded grassland and their cover/abundance scores

		PLOTS														
Species	**Form**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Acacia zanzibarica	Shrubby-tree					2				1						
Acacia nilotica	Tree									1	2		0.5			
Acacia mellifera	Shrubby-tree	3	2	1	1	2	2	1	2			1	2			
Combretum apiculatum	Tree			2												1
Lawsonia inermis	Shrub	1			0.5		1	1			0.5				1	
Acacia tortilis	Tree		2						1			0.5				
Balanites aegyptiaca	Tree									4						
Hyphaene coriacea	Tree			3		2		4				2		3		
Ziziphus mauritiana	Tree	1					0.5								0.1	
Ormocarpum sp.	Shrub							0.5								
Kigelia africana	Tree			3						2			2			
Tamarindus indica	Tree								4							
Milletia oblata	Shrub				0.5						0.1					
Albizia anthelmintica	Shrub						1									2
Asparagus setaceus	Shrub	0.5			1											
Cordia crenata	Shrub			1				1				1				
Cordia sp.	Tree													0.5	0.1	
Flueggea virosa	Shrub															1
Harrisonia abyssinica	Shrub		0.5			0.5		1								1
Terminalia spinosa	Tree	2			1				1				2			
Cordia sinensis	Shrub														2	
Leucas schweinfurthii	Shrub		1											0.5		
Diospyros abyssinica	Tree				1					2						

Spirostachys venerifera	Tree	0.5				1										1
Craibia brevicaudata	Tree												0.5			
Lepisanthes senegalensis	Tree			0.1			0.5									
Albizia harveyi	Tree			1		2										
Phoenix reclinata	Tree								3		4		4		3	2
Acacia elatior	Tree			2		3		5	2	5						
Acacia hockii	Tree			2						1						
Acacia robusta	Tree			4		2		3			4					
Acacia xanthophloea	Tree			3						2	4					
Oncoba spinosa	Shrub					2										
Garcinia livingstonei	Tree				3			2		4						
Corchorius olitorius	Tree	0.1											0.5		1	
Adansonia digitata	Tree		4		2		3	4			2					
Euphorbia polyantha	Shrub											2				
Acacia seyal	Shrubby-tree	1		1		0.5			0.1			1				
Commiphora schimperi	Shrub													3		
Cyerus undulatus	Shrub		1		1		0.5			1.0			1			
Acacia senegal	Tree		1		2		3	3		2						
Melia volkensii	Tree														2	
Solanum arundo	Shrub													0.5		0.1
Raphia farinifera	Tree			2			4				3					

Appendix 3: Plant species recorded in the *Combretum* wooded grassland and their cover/abundance scores

		PLOTS														
Species	**Form**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tamarindus indica	Tree					4										
Harrisonia abyssinica	Shrub	1										2				
Phoenix reclinata	Tree														2	
Terminalia brownii	Tree		0.5	1												
Diospyros mespiliformis	Tree								1			1				
Trichilia emetica	Tree	2														
Flueggea virosa	Tree									0.5						0.1
Bridelia taitensis	Shrub				0.1											
Polysphaeria lanceolata	Shrubby-tree	1						0.5				1				
Erythroxylum fischeri	Tree			2										0.5		1
Kigelia africana	Tree											2				
Pilostigma thonningii	Tree	1			2											
Combretum molle	Tree		2	1		1.0					1					
Combretum collinum	Tree	1	1		2			2						1		0.5
Maerua angolensis	Tree			1					0.1						1	
Lawsonia inermis	Shrub	0.5				1							0.5			0.1
Combretum fragrans	Tree	2				1		1			2					
Rauvolfia caffra	Shrub				1								0.5			
Lannea schweinfurthii	Tree		2													
Lantana camara	Shrub		0.5					0.1								
Lantana trifolia	Shrub															0.5
Euclea divironum	Tree				0.1											
Tithonia diversifolia	Tree											1				
Ficus sycomorus	Tree						3									
Lonchocarpus eriocalyx	Tree	1									1					1

Combretum hereroense	Shrub	0.5		0.1		1	0.1	1						1		0.5
Rhus natalensis	Tree		1						2				1			
Ormocarpum keniense	Shrub		0.1													
Sclerocrya birrea	Tree											0.1			1	
Combretum apiculatum	Shrub	5	3		2	4	3	2	1		4	2	3	1		1
Combretum mossambicense	Shrub			0.5						1						
Terminalia kilmandscharica	Tree														1	
Terminalia prunioides	Tree			1		1	2		1	1						
Sterculia africana	Tree													0.5		
Phyllanthus sepialis	Shrub							0.1								
Lonchocarpus bussei	Tree				1							1				
Bauhinia tomentosa	Shrub	0.5				1					0.5					
Ziziphus abyssinica	Tree		0.1													1
Blighia unijuguta	Tree				2				3						0.5	
Securinega virosa	Shrub															
Caesalpinia decapetala	Shrub									0.5			0.5			
Ricinus communis	Shrub			1												
Diospyros abyssinica	Tree							3								1
Cordia africana	Tree					3						2				
Makhamia hilderbrandti	Tree		1												2	
Vernonia colorata	Shrub															0.5
Tabemaemontana usambarensis	Tree			1										2		
Psychotria riparia	Shrub						1									0.5
Combretum aculeatum	Shrub	1		1	2	1	1	2		0.5	1		1	2		

Appendix 4: Plant species recorded in the *Acacia-Commiphora* bushland and their cover/abundance scores

		PLOTS														
Species	**Form**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Terminalia prunioides	Tree		1				0.5									
Acacia refisciens	Shrub	0.1		1	1	0.1		1	1							
Commiphora africana	Tree				5	2	3	4	3	2		2				
Boscia angustifolia				1		1		0.5								
Cordia crenata	Shrub	0.5											1			
Acacia ogadensis	Tree	1		2	1	1									1	
Grewia villosa	Shrub	0.1												0.1		0.5
Combretum aculeatum	Shrub		0.5													
Albizia anthelmintica	Shrub	1											0.5			
Grewia lilacina	Shrub			0.5		1		1			0.1					
Acacia pentagona	Tree									2			0.1	1	0.1	2
Dalbergia melanoxylon	Shrub		2													
Ochna inermis	Shrub	1			1				0.5							
Tennantia sennii	Shrub	0.1		0.5												
Bauhinia taitensis	Shrub												1		0.5	1
Acacia xanthophloea	Tree		1		1		2									
Terminalia brownii	Tree										1	2				1
Ochna ovata	Tree									1		1				
Diospyros mespiliformis	Tree	1			1			0.5								
Combretum apiculatum	Tree									9				0.5		
Acacia brevispica	Shrub			0.5	1	1	2	0.5			1	0.1				
Allophylus sp.	Tree														1	
Grewia bicolor	Shrub		1		0.1				0.5							
Acacia tortilis	Tree						0.5	0.1		0.1		0.5		0.5		
Lannea typhylla	Tree	1														

Combretum hereroense	Shrub												2		1	
Acacia macrothyrsa	Tree	1		2			1	1								
Tabernaemontana stapfian	Tree											2		1		
Thunbergia alata	Tree		0.1		0.1				1							
Ormocarpum keneinse	Shrub															0.1
Tamarindus indica	Tree															3
Spirostachys venenifera	Shrub														0.1	
Kigelia africana	Tree			3												
Phoenix reclinata	Tree							2								
Maerua kirkii	Tree			0.1			1		0.5	1						
Synadenium glaucescens	Shrub													0.5		1
Boscia coriacea	Shrub	1	1		1		2				0.1					
Maerua subcordata	Shrub					1						0.5				
Boscia mossambicensis	Shrub	0.1		0.5												
Euphorbia cuneata	Shrub			0.1						1						
Euphorbia robecchii	Tree															2
Acacia ataxacantha	Shrub			1	2	1	1		1	2	1	1	1			
Albizia amara	Tree							1				2				
Albizia tanganyicensis	Tree						2				1			2		
Acacia bussei	Tree	2	1		2		2	1								
Acacia mellifera	Tree		3		2	1	1	2	3		2					
Commiphora holtiziana	Shrubby-tree											1		1		1
Commiphora madagascariensis	Shrubby-tree									0.1		1		1		
Commiphora rostrata	Shrub					2		1				2				
Commiphora mollis	Tree				1			2		2		1				
Commiphora flaviflora	Shrub												1	1		2
Commiphora samharensis	Shrubby-tree										1	0.5			1	
Commiphora campestris	Shrubby-tree	4	1	2	2		3		2	2	1	1	2	1		

Appendix 5. Species composition of assemblage I: Plots 8, 15, 26, 31, 32, 33, 34, 35, 37, 38, 39, 40, 41. (B-B rating – mean Braun-Blanquet Cover/Abundance Rating)

Species	**Form**	**B-B Rating**
Combretum apiculatum	Tree	4.0
Tamarindus indica	Tree	4.0
Commiphora africana	Tree	3.0
Kigelia africana	Tree	2.5
Phoenix reclinata	Tree	2.3
Acacia mellifera	Shrubby-tree	2.1
Acacia elatior	Tree	2.0
Cordia africana	Tree	2.0
Acacia pentagona	Tree	2.0
Dalbergia melanoxylon	Shrub	2.0
Tabernaemontana stapfian	Tree	2.0
Commiphora campestris	Shrubby-tree	1.9
Commiphora rostrata	Shrub	1.7
Albizia anthelmintica	Shrub	1.5
Harrisonia abyssinica	Shrub	1.5
Terminalia brownii	Tree	1.5
Albizia amara	Tree	1.5
Acacia bussei	Tree	1.5
Commiphora mollis	Tree	1.5
Acacia macrothyrsa	Tree	1.3
Acacia ataxacantha	Shrub	1.3

Species	Form	B-B Rating
Acacia ogadensis	Tree	1.3
Flueggea virosa	Shrub	1.0
Terminalia spinosa	Tree	1.0
Spirostachys venerifera	Tree	1.0
Acacia xanthophloea	Tree	1.0
Polysphaeria lanceolata	Shrubby-tree	1.0
Tithonia diversifolia	Tree	1.0
Terminalia prunioides	Tree	1.0
Lonchocarpus bussei	Tree	1.0
Ochna ovata	Tree	1.0
Lannea typhylla	Tree	1.0
Albizia tanganyicensis	Tree	1.0
Commiphora holtiziana	Shrubby-tree	1.0
Diospyros mespiliformis	Tree	0.9
Boscia angustifolia		0.8
Ochna inermis	Shrub	0.8
Boscia coriacea	Shrub	0.8
Maerua subcordata	Shrub	0.8
Commiphora samharensis	Shrubby-tree	0.8
Acacia refisciens	Shrub	0.7
Acacia brevispica	Shrub	0.7
Grewia lilacina	Shrub	0.7
Euphorbia cuneata	Shrub	0.6
Commiphora madagascariensis	Shrubby-tree	0.6

Species	Form	B-B Rating
Grewia bicolor	Shrub	0.5
Maerua kirkii	Tree	0.5
Cordia crenata	Shrub	0.5
Combretum aculeatum	Shrub	0.5
Acacia tortilis	Tree	0.4
Thunbergia alata	Tree	0.4
Tennantia sennii	Shrub	0.3
Boscia mossambicensis	Shrub	0.3
Acacia seyal	Shrubby-tree	0.1
Solanum arundo	Shrub	0.1
Sclerocrya birrea	Tree	0.1
Grewia villosa	Shrub	0.1

Appendix 6. Species composition of assemblage II: Plots 1, 2, 3, 4, 5, 6, 7, 9, 10, 11 (B-B rating – mean Braun-Blanquet Cover/Abundance Rating)

Species	**Form**	**B-B Rating**
Balanites aegyptiaca	Tree	4.0
Phoenix reclinata	Tree	4.0
Acacia elatior	Tree	3.8
Acacia robusta	Tree	3.3
Acacia xanthophloea	Tree	3.0
Garcinia livingstonei	Tree	3.0
Adansonia digitata	Tree	3.0
Raphia farinifera	Tree	3.0
Hyphaene coriacea	Tree	2.8
Kigelia africana	Tree	2.3
Acacia senegal	Tree	2.2
Combretum apiculatum	Tree	2.0
Oncoba spinosa	Shrub	2.0
Euphorbia polyantha	Shrub	2.0
Acacia mellifera	Shrubby-tree	1.7
Terminalia spinosa	Tree	1.7
Acacia zanzibarica	Shrubby-tree	1.5
Diospyros abyssinica	Tree	1.5
Albizia harveyi	Tree	1.5
Acacia hockii	Tree	1.5
Acacia tortilis	Tree	1.3
Acacia nilotica	Tree	1.2

Species	**Form**	**B-B Rating**
Albizia anthelmintica	Shrub	1.0
Cordia crenata	Shrub	1.0
Leucas schweinfurthii	Shrub	1.0
Cyerus undulatus	Shrub	0.9
Acacia seyal	Shrubby-tree	0.9
Lawsonia inermis	Shrub	0.8
Ziziphus mauritiana	Tree	0.8
Asparagus setaceus	Shrub	0.8
Spirostachys venerifera	Tree	0.8
Harrisonia abyssinica	Shrub	0.7
Ormocarpum sp.	Shrub	0.5
Craibia brevicaudata	Tree	0.5
Milletia oblata	Shrub	0.3
Lepisanthes senegalensis	Tree	0.3
Corchorius olitorius	Tree	0.3

Appendix 7. Species composition of assemblage III: Plots 16, 18, 19, 20, 22, 24, 25, 27 (B-B rating – mean Braun-Blanquet Cover/Abundance Rating)

Species	Form	B-B Rating
Tamarindus indica	Tree	4.0
Combretum apiculatum	Tree	3.3
Diospyros abyssinica	Tree	3.0
Cordia africana	Tree	3.0
Trichilia emetica	Tree	2.0
Erythroxylum fischeri	Tree	2.0
Blighia unijuguta	Tree	2.0
Combretum collinum	Tree	1.7
Pilostigma thonningii	Tree	1.5
Combretum fragrans	Tree	1.5
Combretum aculeatum	Shrub	1.2
Harrisonia abyssinica	Shrub	1.0
Terminalia brownii	Tree	1.0
Combretum molle	Tree	1.0
Maerua angolensis	Tree	1.0
Lonchocarpus eriocalyx	Tree	1.0
Rhus natalensis	Tree	1.0
Terminalia prunioides	Tree	1.0
Lonchocarpus bussei	Tree	1.0
Ricinus communis	Shrub	1.0
Tabemaemontana usambarensis	Tree	1.0
Polysphaeria lanceolata	Shrubby-tree	0.8

Species	**Form**	**B-B Rating**
Rauvolfia caffra	Shrub	0.8
Combretum mossambicense	Shrub	0.8
Lawsonia inermis	Shrub	0.7
Bauhinia tomentosa	Shrub	0.7
Combretum hereroense	Shrub	0.7
Flueggea virosa	Shrub	0.5
Caesalpinia decapetala	Shrub	0.5
Bridelia taitensis	Shrub	0.1
Lantana camara	Shrub	0.1
Euclea divironum	Tree	0.1
Phyllanthus sepialis	Shrub	0.1

Appendix 8. Species composition of assemblage IV: Plots 42, 43, 44, 45 (B-B rating – mean Braun-Blanquet Cover/Abundance Rating)

Species	**Form**	**B-B Rating**
Tamarindus indica	Tree	3.0
Euphorbia robecchii	Tree	2.0
Albizia tanganyicensis	Tree	2.0
Combretum hereroense	Shrub	1.5
Commiphora campestris	Shrubby-tree	1.5
Commiphora flaviflora	Shrub	1.3
Cordia crenata	Shrub	1.0
Terminalia brownii	Tree	1.0
Acacia ogadensis	Tree	1.0
Allophylus sp.	Tree	1.0
Tabernaemontana stapfian	Tree	1.0
Acacia ataxacantha	Shrub	1.0
Commiphora holtiziana	Shrubby-tree	1.0
Commiphora madagascariensis	Shrubby-tree	1.0
Commiphora samharensis	Shrubby-tree	1.0
Bauhinia taitensis	Shrub	0.8
Acacia pentagona	Tree	0.8
Synadenium glaucescens	Shrub	0.8
Combretum apiculatum	Tree	0.5
Acacia tortilis	Tree	0.5
Albizia anthelmintica	Shrub	0.5
Grewia villosa	Shrub	0.3
Spirostachys venerifera	Tree	0.1
Ormocarpum keneinse	Shrub	0.1

Appendix 9. Species composition of assemblage V: Plots 21, 28, 30 (B-B rating – mean Braun-Blanquet Cover/Abundance Rating)

Species	**Form**	**B-B Rating**
Ficus sycomorus	Tree	3.0
Terminalia prunioides	Tree	2.0
Tabemaemontana usambarensis	Tree	2.0
Combretum apiculatum	Tree	1.7
Combretum aculeatum	Shrub	1.5
Diospyros abyssinica	Tree	1.0
Lonchocarpus eriocalyx	Tree	1.0
Ziziphus abyssinica	Tree	1.0
Erythroxylum fischeri	Tree	0.8
Combretum collinum	Tree	0.8
Psychotria riparia	Shrub	0.8
Combretum hereroense	Shrub	0.5
Lantana trifolia	Shrub	0.5
Sterculia africana	Tree	0.5
Vernonia colorata	Shrub	0.5
Lawsonia inermis	Shrub	0.1
Flueggea virosa	Shrub	0.1