USE OF BONE DECAY RATE (TAPHONOMY) IN DETERMINING WILDLIFE NUMBERS AND DISTRIBUTION IN MERU NATIONAL PARK, KENYA

By

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DECLARATION

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

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Date JAN. 26, 2011

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DEDICATION

This thesis is dedicated to my parents who have given me the opportunity for education from the best institutions and support throughout my life.

TABLE OF CONTENTS

LIST OF FIGURES

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ABSTRACT

Bone surveys method was used in Meru national Park to estimate wildlife numbers and their distribution where bone decay rates were used to estimate the period the animal concern existed (back-censusing) in the landscape. The results were further compared to previous aerial wildlife count data to determine the suitability of bone decay rates method as a viable technique in wildlife counts. Valuable data were generated on wildlife population sizes, distribution, and species abundance in relation to three main habitats in Meru National Park. Species diversity was higher in the bone survey (H'=0.723) for the 1990-2002 time bin when compared to the aerial survey diversity (H' =0.044) for the same period. Similarly diversity was also higher for the bone survey (H'=1.158) when compared to the live aerial survey (H'= 0.713) for the 2003-2008 time bin. In the grassland there were 14 species encountered using the bone survey method for the 2003-2008 time bin, which had a higher diversity (H'= 0.93) compared to the aerial survey which also recorded 14 species (H'= 0.55). In the bushland 12 species were observed using the aerial survey and 16 using the bone survey resulting in diversity index values of H'=0.75 and H'=1.03 respectively.

There was a significant difference ($F_{1, 27}$ = 102, $p < 0.05$) when the densities of the two surveys were compared, aerial survey had 8 individuals km^{-2} while the bones had 4 individuals km^{-2}. Thickets had the highest diversity (H'=1.09) in terms of the species encountered using the bone survey with 18 species compared to only 5 that were sampled using the aerial census (H'=0.52).

The results show that there was a significant relationship between wildlife numbers estimated using the aerial and the bone method (y=0.7405x - 0.9302, R^2 = 0.748) an indication that taphonomic bone surveys can be used for back-censusing wildlife and estimating their relative abundance in a given area. The method is inexpensive compared to other wildlife census methods and can accurately be used to estimate past wildlife population sizes where no past data previously existed. The result also show that this method is able to capture rare and elusive species which would be relatively difficult using other methods.

LIST OF ACRONYMS

BNR	: Bisanadi National Reserve
FSO	: Front Seat Observer
GIS	: Geographical Information System
GPS	: Geographical Positioning System
HWC	: Human Wildlife Conflict
KNP	: Kora National Park
KWS	: Kenya Wildlife Service
MCA	: Meru Conservation Area
MNI	: Minimum Number of Individuals
MNP	: Meru National Park
MNR	: Mwingi National Reserve
NMK	: National Museums of Kenya
PA	: Protected Area
RSO	: Rear Seat Observer

CHAPTER ONE

1.0 INTRODUCTION AND LITRATURE REVIEW

1.1 INTRODUCTION

Studies have shown that bones record ecological change; in a monitored ecosystem, and populations of bones that accumulated over different time intervals can be distinguished using weathering stages (Behrensmeyer, 1978; Western and Behrensmeyer, 2009). Bone surveys provide a method of back censusing animal populations in areas where their bones are abundant and visible. The method may thus be useful as a low cost way of obtaining data on animal species in arid lands or in other relatively open habitats.

Bone sampling records ecological changes in terms of when certain species died in a certain area. For example, mortality can remain stable for the whole area, while shifts in places where the animals live and die change the patterns of bone abundances. Recent bones are a source of ecological information that can complement indirect methods of censusing animal populations and can give evidence concerning their distribution through time (Behrensmeyer *et al*., 1979). The method may, therefore, be used to estimate the population of wildlife that used to exist in an area when the data is lacking. Valuable baseline data can also be generated on the distribution and abundance of species in relation to habitat and the distributions of critical ecological resources (food and water) as well as areas used intensively by humans.

Surveys comparing the live and the dead fauna have generated adequate data to test agreement in rank order and relative abundance for specific types of organisms and environments. Studies on vertebrates and shelly invertebrates have shown that remains can accumulate over long periods of time; in the process such assemblages can accurately represent original community structure, even during periods of marked population and habitat change (Kidwell and Flessa, 1995; Behrensmeyer *et al*., 2000; Kidwell 2001; 2007; Kidwell and Holland 2002; Western and Behrensmeyer, 2009).

The number of published studies on comparisons of live and dead fauna vertebrate communities on land is still too few to provide a sound basis for predicting live abundance from abundance data based on bone assemblages (Behrensmeyer, 1993, Western and Behrensmeyer, 2009). The aim of this study therefore was to use taphonomic bone survey to back-census wildlife in Meru Park to test whether bones accurately record ecological information about the past animal communities.

1.2 LITERATURE REVIEW

Census provides data to managers, at the most basic level they can determine the presence or absence of different species at different sites, they can also be used to establish the number and structure of populations, which is important for understanding the ecological status of a particular population. It can also provide data on the seasonal movement and vegetation utilization, which is necessary to identify key grazing and watering areas as well as basic migratory routes and areas of high species density and diversity (Norton-Griffiths, 1978). No form of wildlife management is possible without reliable information on the numbers, population dynamics, and movement of animals (Norton-Griffiths, 1978).

The methods used in census can be broadly categorized into direct methods, which involves the actual sighting of the species and indirect methods, which are based on counting animal signs. Examples of the direct method include road counts which involve use of vehicles to cover designated blocks or transect in an area, aerial counts which involve use of aircrafts to count wildlife in designated blocks and foot counts that is usually used where other methods are impracticable for instance in thick vegetation (Norton-Griffiths, 1978).

1.2.1 Direct Method

Aerial survey method can either be total or sample counts. In total counts all wildlife in the area of interest are counted whereas in the sample count certain blocks are selected that are later extrapolated for the entire area. Total aerial counts rely heavily on the experience of the counting crew. The aerial survey area is divided into discrete counting blocks, bordered by well-defined features such as roads, rivers, and the Reserve/Park boundary. Aerial survey can cover large areas of country economically, and is the mostly applicable for censusing animals in areas where access on the ground is difficult or impossible. The method is limited when the vegetation is thick and animals cannot be seen from the air, or if the animals concerned are very small (Norton-Griffiths, 1978). In Meru National Park, aerial survey was the choice for wildlife estimation in the 1970s, and later after restocking of species following the poaching of wildlife in the 1980s, when most of the wildlife was eliminated through poaching.

Road counts are widely used where data obtained treated cautiously as the method is open to many biases. For example, the edges of roads tend to be 'habitat' for some species, and this leads to a consistent overestimate of numbers of density (Norton-Griffiths, 1978). Roads are also rarely distributed randomly across an area as they usually pass through 'good game viewing areas' and they tend to be placed along contours rather than across. Vehicle/ road counts are excellent for obtaining data on the seasonal patterns of distribution within different vegetation types, and additional information can be obtained on the behavior and condition of the animals that cannot be obtained from the aircraft. Vehicle counts are therefore ideal for detailed studies in small study areas and their use is limited when the ground access is difficult or when the area to be covered is very large.

Foot counts are not often used nowadays and are only necessary if other methods are impracticable. Foot survey walks are used in two ways: either for a quick first assessment (a reconnaissance survey), or for a more methodical evaluation of relative abundance or population density, through the use of carefully positioned transects (straight trails). Reconnaissance surveys differ from transect surveys in that they 'follow the line of least resistance' through the vegetation in order to cover as much ground as possible. They may use existing human or animal paths, follow streambeds or concentrate in areas of sparse undergrowth where it is possible to walk in a straight line without clearing vegetation (Walsh and White, 1999). Some of the advantages are that they are quick; also they can be carried out during routine activities such as patrolling by park rangers. Their limitation is that the area covered will be small, and it is difficult to ensure that the data are representative of the whole area, or the whole population.

1.2.2 Indirect surveys

Indirect surveys rely mainly on signs such as wildlife dropping and footprints. It can be time consuming, hence is undertaken only at sites where there is evidence that animals are frequent visitors. It also requires some skills in identifying the animal signs. Indirect surveys are advantageous as they can be used for wildlife that are shy and secretive.

1.2.3 Taphonomic bone survey method

This is an indirect method of survey; the study of taphonomy in general investigates how animals and plants become part of the fossil record. Bones may accumulate in soil for tens or to hundreds of years or even longer periods. This phenomenon is known as taphonomic time-averaging (Behrensmeyer, 1993), and it's particularly important for bone assemblages that formed from normal (attritional) processes of mortality rather than catastrophic events (Behrensmeyer, 1993). Attritional death in wildlife populations generates a scatter of bones across modern landscapes, preserving a history of the living populations.

Comparisons of bone assemblages with the living community can be informative at two levels of resolution, most simply in terms of species representation (presence or absence) and more precisely in terms of species abundance (Behrensmeyer *et al.*, 1979). Abundance of species in modern ecosystems is a key variable for characterizing diversity and various measures of dominance, allowing the use of such information for investigating the history of biodiversity.

Factors that determine the use of taphonomic survey to estimate past mammalian population trends include the fact that the time necessary to achieve successive weathering stages has been calibrated using carcasses (Behrensmeyer, 1978); this is therefore useful in knowing the abundance of a particular species that existed within a certain time period. Recent studies by Behrensmeyer and Western (2009) show there is a correlation between the living and the dead wildlife population within a period of 40 years.

1.2.3.1 Dispersion of bones

Bones are usually dispersed from the site of death in the savannah ecosystem, and bone deposition patterns including spatial density, degree of scattering, and species representation, have been assessed in relation to ecological variables such as predation and prey habitat preferences, proximity to water and surrounding vegetation (Tappen, 1995). When an animal dies on a land surface and its skeleton disarticulates, this could be due to carnivores and scavengers that may remove parts of carcass from the site of death and may in turn produce other secondary concentrations areas (e.g., hyena den bone accumulations) composed of remains of different individuals. In the case of many skeletons, scattering occurs around the point of death. This leads to dispersion of remains over a considerable area that could be up to 100's of square meters after the initial depredation of carnivores (Hill, 1979).

Work by Hill (1979) shows that the sequence of bone disarticulation was very consistent even among different mammalian taxa of varying sizes and in a variety of micro environmental situations. This consistency is probably due primarily to the anatomical similarities of the animals concerned. But disarticulation patterns may be modified by the environmental conditions and by the behavior of animals important in the disarticulation process, thus producing different styles in diverse circumstances (Hill and Behrensmeyer, 1984).

1.2.3.2 Bones and scavengers

Scavengers such as hyenas transport carcasses or parts of these (Kruuk 1972), and this could affect the distribution of bones in relation to the habitats used by the living animals. However, observations in Amboseli National Park indicate that scavenging is probably not important in moving a significant number of whole carcasses from one habitat to another (Behrensmeyer 1979). Hyena transport of bones appears to be more or less random with respect to habitat. Research in Amboseli has also shown that species are relatively habitat selective and bones represent spatial patterns of mortality for wildebeest and zebra (Behrensmeyer *et al.*, 1979).

Studies on carnivore gnawing damage to bone provide a baseline which may be useful in the interpretation of bone assemblages. In his studies, Haynes (1980) showed the timing of death of prey often seems to correlate with the degree of gnawing on bones by some carnivores. During seasons when predators can more easily bring down prey, carcasses may be greatly under-utilized, resulting in usually light gnawing damage. Alternatively, we would expect greater carcass utilization and carnivore damage to the surficial bone assemblage when predators are competing for limited numbers of prey (Faith and Behrensmeyer, 2006).

1.2.3.4 Bone Weathering

Weathering stages defined by easily observable criteria were established by Behrensmeyer (1978). Weathering is a potentially useful tool in taphonomic bone studies. By monitoring a carcass of known weathering stage and time since death over several years, it is possible to accurately judge the most probable number of years (or a range of years) of exposure of any bone of a given weathering stage, thus developing a rough "taphonomic clock" for different ecosystems. This method can be further refined by increased understanding of how weathering rates vary in different ecosystems, climates, vegetation, and microhabitats (Behrensmeyer, 1978).

Weathering stages appear predictably linked to time since death in Amboseli National Park, in spite of variation in habitat and microenvironments represented by the carcass sample. Within the first three years of exposure, most carcass fall within Behrensmeyer's weathering stages 0 or 1. In stage 0 the bone surface shows no sign of cracking due to weathering, usually the bone is still greasy, marrow cavities contain grease, and there is still skin and muscle/ligament. Stage 1 shows cracking, normally parallel to the fiber structure, fat, skin and other tissue may not be present. Stage 2 shows the outermost concentric thin layers of bone flaking, usually associated with cracks, in that the bone edges along the cracks tend to separate and flake first.

In Stage 3 the bone surface is characterized by patches of rough, homogeneously weathered compact bone, resulting in fibrous texture, weathering does not penetrate deeper than 1.0-1.5 mm at this stage, and bone fibers are still firmly attached to each other. Stage 4 presents a bone surface with coarsely fibrous and rough texture; large and small splinters occur and may be loose enough to fall away from the bone when it is moved, weathering penetrates into inner cavities, cracks are open and have splintered or rounded edges.

In stage 5, the bone is falling apart in situ, with large splinters lying around what remains of the whole. If the bone has a mesh of hollows on the inside (e.g., vertebral centra), this portion may outlast all traces of the former more compact, outer parts of the bone.

It is therefore possible to distinguish carcasses exposed for less than three to five years with fair certainty using weathering stages, and this likely can be applied to other ecosystems once it has been determined how long a bone will take to move from one weathering stage to the next. In general the six weathering stages are usually applicable to mammals larger than 5kg body weight, and weathering classification have not been attempted for smaller animals.

Behrensmeyer et al. (1979) observed that there could be several biases against animals of smaller body size in the surface bone assemblage; this could be due to one of the following reasons,

- Small populations sizes and low death rates resulting in a smaller yield of carcasses
- A sampling bias in the part of the observer (e.g., low visibility in dense vegetation)
- More rapid burial of smaller bones
- Greater vulnerability of small carcasses to destruction by physical and or biological process prior to burial

Size biasing phenomenon for species greater than 15kg also can be extended to species smaller than 15kg, since the important taphonomic process should be increasingly effective in destroying smaller bones. However other factors may also add to poorer representation of small species in the surface bone sample, including rapid burial, underground death (in burrows) or simply low population densities (Behrensmeyer *et al.*, 1979). With live census data it is possible to test some of the above factors; it's also probable that some of the processes above could operate on smaller individuals within species.

1.3 Justification of the Study

Paleontologists have long used taphonomic studies of bones in modern ecosystems as a means of understanding the fossil record (Behrensmeyer *et. al* 1979). In the course of this research, it has become apparent that modern bone assemblages provide valuable information about the living vertebrate communities (Behrensmeyer 1993; Western and Behrensmeyer, 2009). Thus, surveys of recent wildlife bones in current landscapes represent a valuable but underutilized tool for monitoring past wildlife population trends.

The goal of this study is to develop taphonomic survey methods as an ecological tool for back-censusing animal communities especially in areas where records of past wildlife numbers are not available. The method would be particularly important for application in Meru National Park following the poaching and 'shifta' invasion that brought to a stop all ecological monitoring activities among other park operations in the 80's and part of the 90's. The technique was further aimed at constructing past wildlife numbers during the period when animal counts were not possible. It is also important at this time when re-introduction of species in the park is taking place to determine target species and their preferred areas of release. The following is the main objective of the study and its specific objectives.

1.4 Objectives

1.4.1 Main objective

The main objective of this study was to assess the suitability of taphonomic method (bone decay rates) in determining the wildlife numbers and distribution in Meru National Park compared to other conventional wildlife counting techniques.

1.4.2 Other objectives

1. To assess the use of bone decay rates in estimating past wildlife numbers (back censusing) in relation to past aerial census data.
2. To determine wildlife species distribution, composition and their mortality hotspots in the study area.

1.5 Research hypotheses

Bone weathering stages can be used as a tool in determining the wildlife numbers, distribution, composition comparatively to other wildlife count techniques as well as give information on herbivore species predation.

CHAPTER TWO

2.0 STUDY AREA AND METHODOLOGY

2.1 Location

Meru National Park (MNP) (Figure 1) is part of a protected area that makes up the third largest conservation area in Kenya, the Meru Conservation Area (MCA). The park is 80 km east of Meru town, 348 km from Nairobi and is on the northeast of Mount Kenya. MNP is located in Igembe North District, Eastern province of Kenya, and it covers 870 km^2. It is between latitudes 0° 17'N and 0° 32' S and longitudes 38° 1'E and 39° 1' E. The elevation varies from 1,036 meters in the North-western boundary at the foot of Nyambene Hills to 304 m a. s. l. at the Tana River on the South-eastern boundary (KWS, 2002).

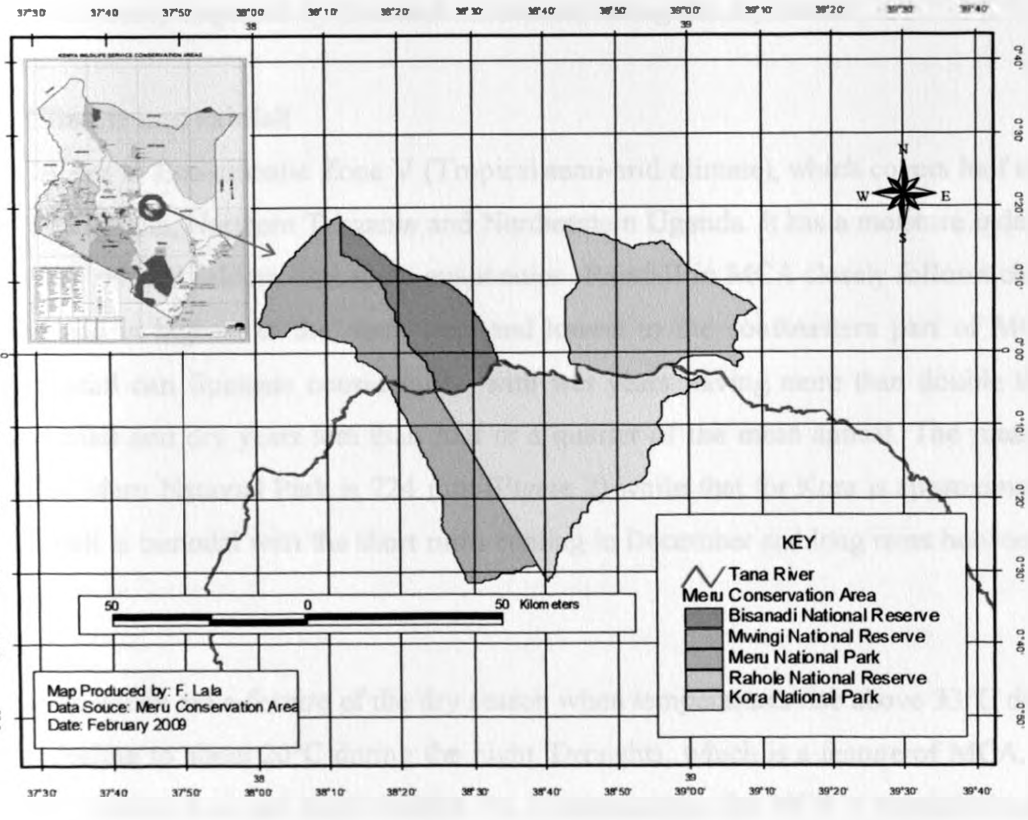

Figure 1: The location of MNP within the larger Meru Conservation Area; inset- Map of Kenya showing the geographic location of Meru Conservation Area.

Exceeded in size only by Tsavo East and Tsavo West, the MCA is comprised of MNP, Kora National Park (KNP), Bisanadi National Reserve (BNR), Mwingi National Reserve (MNR), Rahole National Reserve (RNR) and the Ngaya forest. In total, the MCA covers 5,278 km^2. KNP, BNR, MNR and RNR form the protective screens to the east and south of MNP allowing the latter's wildlife more freedom of movement and at the same time restricting human encroachment. All four of these protected areas are under-developed with virtually nonexistent roads limiting access to MCA.

Meru National Park has the highest concentrations of wildlife in the MCA, has been the focus of tourism and management in the MCA, and currently contains the majority of Protected Area (PA) infrastructure, such as roads, airstrips and entrance gates. Much of the western boundary of the park is fenced to reduce Human Wildlife Conflict (HWC), and it is the only PA in the MCA that is not seriously impacted by livestock incursions during the dry season.

2.2 Climate and rainfall

The MCA lies in Eco-climatic Zone V (Tropical semi-arid climate), which covers half of Kenya as well as Ethiopia, Northern Tanzania and Northeastern Uganda. It has a moisture index of –42 to –51, with rainfall seldom exceeding evaporation. Rainfall in MCA closely follows changes in elevation and is highest to the north-west and lowest to the southeastern part of MCA. The annual rainfall can fluctuate considerably, with wet years having more than double the mean annual rainfall and dry years less than half or a quarter of the mean annual. The mean annual rainfall for Meru National Park is 724 mm (Figure 2) while that for Kora is approximately 500 mm. Rainfall is bimodal with the short rains coming in December and long rains between March and May.

Desiccating winds are a feature of the dry season when temperatures rise above 33°C during the day and decline to about 20°C during the night. Droughts, which is a feature of MCA, can last anywhere between four and eight months. As a consequence, the MCA is characterized by dry thorn-bush land (KWS, 2003).

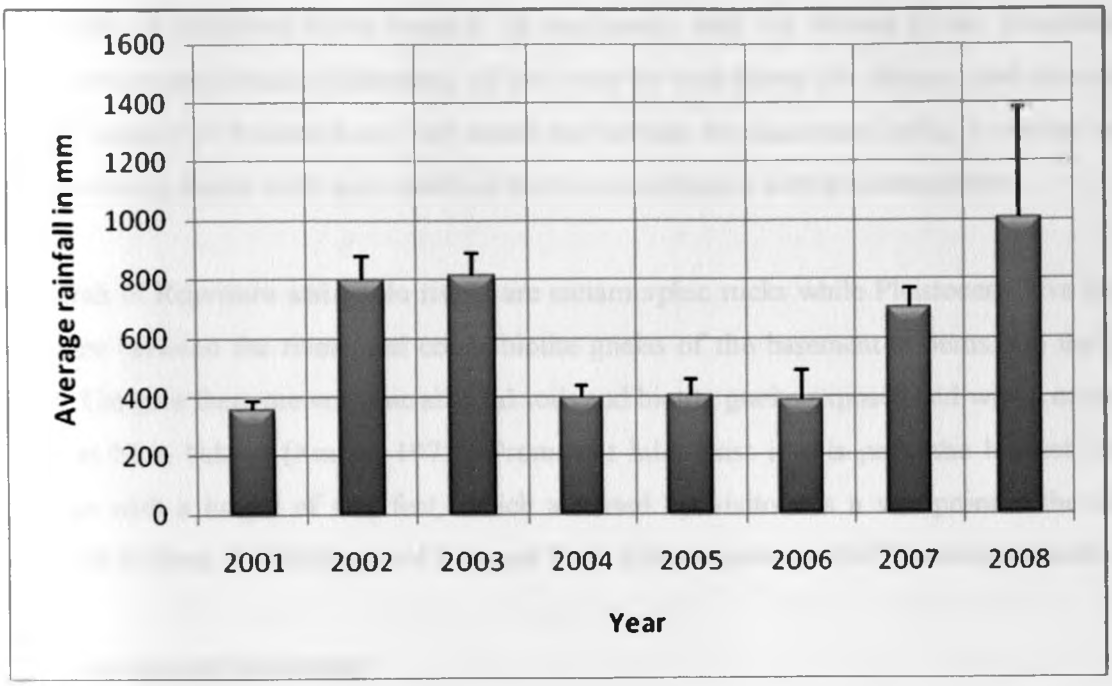

Figure 2: Average rainfall in Meru National Park (Mean±S.E) for the past 8 years, from 2001 to 2008.

2.3 Geology and topography

The geology of MNP is conveniently divided into two sections, namely the Northern and the Southern part. The Northern part is formed of Pleistocene or recent lava flows from the Nyambene ridges that are associated with the Mount Kenya volcanic complex, while the southern part comprises exposed pre-Cambrian rock basement (Ament, 1975).

The eruption of the Nyambene hills created lava that flowed along pre-existing river valleys, blocking the watercourses. The result was rivers that flowed along the edge of tongue-shaped lava flows, with their confluence uniting at tongue points as evidenced at the Kindani-Rojewero River confluence. The olivine-basalt lava flows produce greyish brown soils on gentle slopes toward the Nyambene Ridges and greyish-black soils in swampy and river valleys (Ament, 1975). Other areas have grey volcanic alluvial soils formed in pre-existing lakebeds from the Pleistocene Epoch.

On the banks of Rojewero River towards its confluence with the Murera River, fossiliferous limestone occurs as a result of damming of the rivers by lava flows. On the east park boundary and north eastern of Murera river, red sandy soil covers the basement rocks, a similar soils system also being found in the park north of the river confluence with Rojewero river.

To the south of Rojewero and Kiolu rivers are metamorphic rocks while Pleistocene lava flows form ranges between the rivers and cover biotite gneiss of the basement systems. On the Ura river near Ura gate there are volcanic alluvial soils and biotite gneiss exposed and with a cover of red soils at Ntoe Ndogo (Ament, 1975). Prominent hills exist in this park, the highest being Mugwongo with a height of 660 feet, which are used by visitors as a viewpoint. Other hills include Ntoe Kubwa, Ntoe Ndogo and Leopard Rock that are composed of Precambrian rocks.

2.4 Drainage and hydrology

The Tana River marks the southern limit of the geomorphic area. It is the largest river in Kenya and starts north of Nairobi, 250 km from the park. Fourteen permanent rivers that cross MNP are namely Tana, Rojewero, Kiolu, Ura, Murera, Bisanadi, Bwatherongi, Mutundu, Makutano, Mulika, Njoru ya Kina, Kindani, Utambachago and Kachoradu. The swamps include Mulika, Bwatherongi, Leopard, Mururi and Mungwongo. The distribution of water resources is critical to understanding the MCA's ecosystems; indeed it is the key to the natural plant life distribution and important to the habitats favourable to wild fauna.

2.5 Flora

Floristically, MNP belongs to the Somali– Masaai Regional Center of Endemism (White, 1983). The vegetation composition within the park can be broadly divided into three communities (Aments, 1975). Inselberg's occur throughout the MCA; these include Mughwango and Leopard Rock. They contain flora such as *Albizzia tanganyikensis*, *Terminalia browni*, *Sterculia stegonocarpa*, *Sclerocarya birrea*, *Combretum apiculatum*, *Euphorbia nyikae*, *Euphorbia candelabrum*, *Euphorbia heterochroma*, *Commiphora hildebrandtii* and *Boscia agustifolia* (Ament, 1975).

2.5.1 *Acacia/Commiphora* woodland

Southern parts of MNP are composed of *Acacia* and *Commiphora* bush land which is dominant where the basement rock is exposed towards the southern region of the park. Near the western boundary of *Acacia/commipihora* bushland *Acacia mellifera, Acacia nilotica* and the scrambling *Acacia brevispica* and *Acacia ataxacantha* are common. Further south- east *Acacia senegal* and *Acacia rafiens* dominate. (Ament, 1975). *Commiphora africana* is the most frequent species near the western boundary and *Commiphora boiviniana* is common, sometimes growing in a scandent liane-like form. Further east *Commiphora campestris* appears and replaces *Commiphora africana* as the commonest *Commiphora.*

2.5.2 *Combretum* woodland

The western boundary is dominated by *Combretum* wooded grassland whereas the north and northeastern areas are mainly *Acacia* wooded grassland (Ament, 1975). *Combretum apiculatum* is the dominant throughout the *Combretum* wooded grassland area. *Sehima nervosum* is the dominant grass throughout most of the *Combretum* wooded grassland, and there are scattered patches of *Chrysopogon plumulosus* and *Aristida adscenionis*, the latter particularly where the land has been recently disturbed. In the *Combretum* wooded grasslands south of the Kiolu River *Sehima nervosum* occurs, but is not clearly dominant. *Sorghum veriscolor*, *Chrysopogon plumulosus* and *Aristida adscensionis* alternate with weedy patches; many of the ubiquitous grasses such as *Rottboellia exaltata*, *Cenchrus ciliaris* and *Themeda triandra* occur in scattered clumps.

2.5.3 Riverine vegetation

The third community is found along the watercourses and in the swamps and consists mainly of stands of Doum palm (*Hyphaene multiformis)* and Wild date palm (*Phoenix reclinata*) and a network of fig trees. There are also numerous Riverine swamps with sedges (*Cyprus sp*), grasses like *Echinochloa haplocoda* and *Pennisetum mezianum* (Ament, 1975). *Acacia eliator* is feature of the permanent rivers and *Acacia robusta* of the less permanent ones. The Tana river has its own community; the most striking member is *Populus ilicifolia*, the Tana River poplar, and large *Ficus* species. Further from the water there is strip of bush dominated by *Salvadora persica*.

2.5.4 Acacia wooded grassland

This covers the eastern part of the Nyambeni lava flows and the volcanic alluvial soils along the northeastern boundary of the park. *Acacia tortilis* and *Acacia senegal* are abundant on the lower boulder strewn ridges, giving way to *Hyphaene coriacea* in the low swampy areas besides the rivers. Towards the north-west boundary and in the swampy valleys *Hyphaene coriacea* is dominant. *Acacia senegal* and *Acacia tortilis* form tall trees near the rivers; *Phoenix reclinata* forms the main part of the riverine thicket. *Chloris gayana* is the dominant grass with *Echinochloa haploclada* forming pure stands in the damper places. The better drained grasslands towards the eastern boundary of the Rojewero river are slightly wooded with *Acacia senegal* and *Acacia tortilis*, and some nearly pure stands of *Terminalia spinosa*; *Balanites aegyptica* is common. The grass *Sorghum versicolor* and *Chrysopogon plumulosus* alternative with patches of *Sehima nervosum*. *Aristida adscensionis* is common where the ground has been disturbed.

2.6 Fauna

A large population of resident herbivores is a feature of MNP together with a diversity of other fauna including carnivores, rodents, and insectivores. Some of the commonly sighted species include the lion (*Panthera leo*), cheetah (*Acynonyx jubatus*), leopard (*Panthera pardus*), eland (*Taurotragus oryx*), waterbuck (*Kobus ellipsiprymnus)*, grant's gazelle (*Gazella granti*), oryx (*Oryx beisa*), buffalo (*Syncerus caffer)*, reticulated giraffe (*Camelopardalis reticulata*), Impala (*Aepyceros melampus*), burchell's zebra (*Equus burchelli*), grevy's zebra (*Equus grevyi*), Coke's Hartebeest (*Alcelaphus buselaphus cokii*) and warthog (*Phacochoerus aethiopicus*).

A variety of bird species are also found in MNP including the palm nut vulture (*Gypohierax angolensis*) and martial eagle (*Polemaetus bellicosus*), which are common in the dense vegetation alongside the watercourses.

2.7 METHODS

2.7.1 Transect selection

A hundred random points were created by computer random generator in Arc GIS, 9.2 (Data Management tools- feature class- create random points). The random points, study area boundary and image were geo-referenced to the same coordinate system for proper overlay. Sixty transects starting points were then randomly chosen from the 100 using random tables for bone surveying as shown in *Figure 3.* All random points were located in the field using a GPS unit. The transects for the bone surveys were oriented perpendicular to the drainage system.

The number of transects in each habitat was determined by the percentage area coverage of the habitat; the bushland area coverage was 246.7 km² and had 17 transects (28% of the total transect), Grassland 239.5 km² had 16 transects (27% of all transects) and the thicket had the majority coverage of 392.4 km² with 27 transects (45% of all transects). A land cover map of the study area was used to identify the vegetation types and its accuracy assessed.

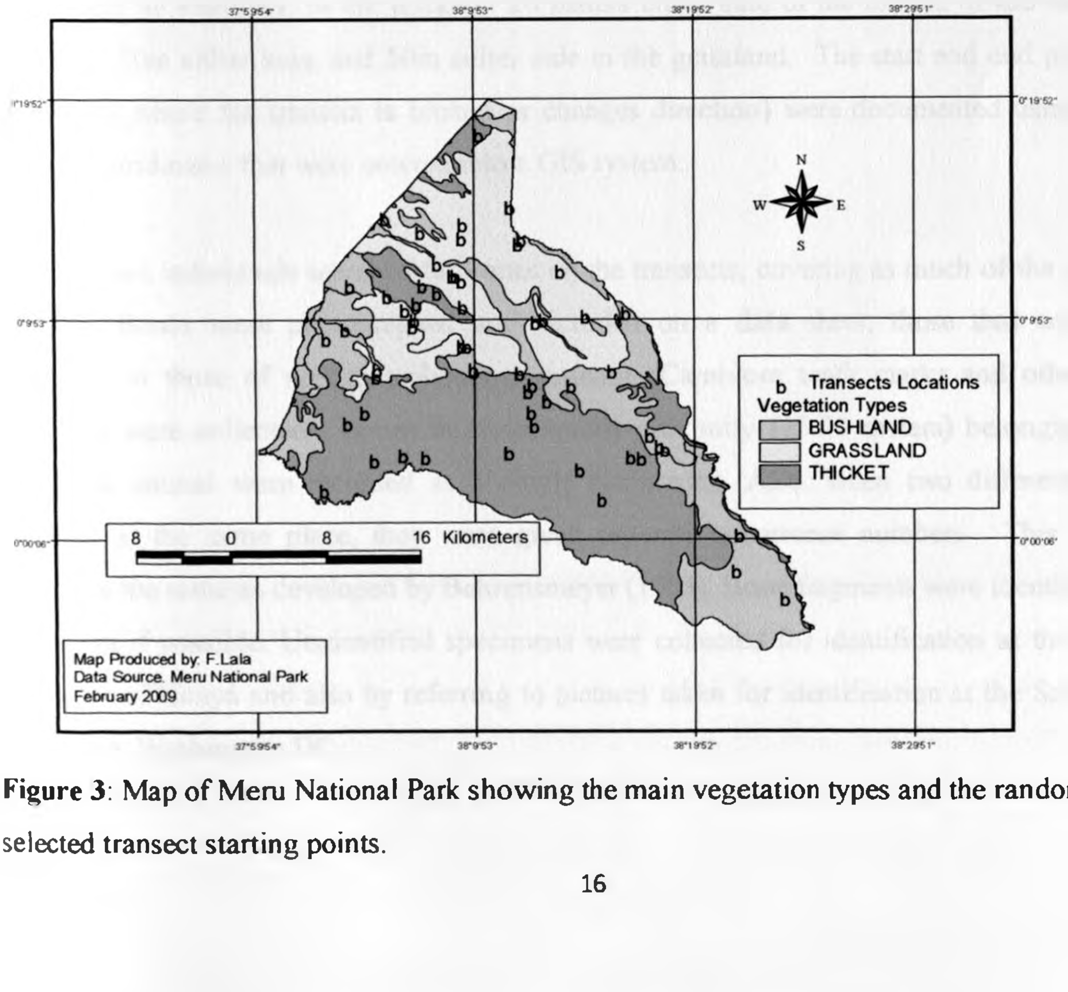

Figure 3: Map of Meru National Park showing the main vegetation types and the randomly selected transect starting points.

2.7.2 Bone data collection

The bones were divided into two time bins using weathering stages (WS) (Behrensmeyer, 1978); bones in WS 0-2 represented the later time bin whereas WS 3-5 represented earlier time bin; this was done so as to compare the past and present populations of wildlife, especially before and after the re-introductions of wildlife to MCA from the year 2005. The two time bins are for the years 1990-2002 and 2003-2008. The aerial data available was also categorised into the two distinct categories. Aerial counts for the years 1990-2002 were mainly based on the mega-herbivores, the elephant, the buffalo and the rhino (Appendix 1). The later aerial counts 2003-2008 focused on all wildlife species that could be sighted from the air and as a result offer a more comprehensive comparison with the bone data.

The sampling period was from November 2007 to August 2008, covering the rainy season during the months of November-January, March and April, and the dry season in the months of January, February, May, June, July and August. Each transect was 1 km long. Transect widths were determined by visibility: in the thickets 20 meters either side of the middle of the transect; in bushland, 30m either side, and 50m either side in the grassland. The start and end points (and any points where the transect is broken or changes direction) were documented using GPS to provide coordinates that were entered into a GIS system.

Five or more individuals searched for bones on the transects, covering as much of the ground as possible. Bones were photographed and recorded on a data sheet; those that couldn't be identified or those of special taphonomic interest (Carnivore tooth marks and other unique damages) were collected. Bones in close spatial proximity (15-20 meters) belonging to one individual animal were recorded as a single occurrence. Also, when two different animals occurred at the same place, they were given separate occurrence numbers. This sampling method is the same as developed by Behrensmeyer (1993). Bone fragments were identified down to species if possible. Unidentified specimens were collected for identification at the National Museums of Kenya and also by referring to pictures taken for identification at the Smithsonian Institution, Washington DC.

Data recorded included species, age (adult, juvenile), skeletal parts present, habitat, WS, breakage and other damage features such as tooth marks, and the degree of burial. The Minimum Number of Individuals (MNI) was determined for each transect as well as the density. MNI is based on the number of different individual animals that account for the documented bones. Decisions about whether or not a bone occurrence represents a new individual were made in the field, based on body size, species identification, growth stage (juvenile vs. adult) and weathering stage (Behrensmeyer, 1993). Plate 1 shows the different weathering stages criteria as established by Behrensmeyer (1978).

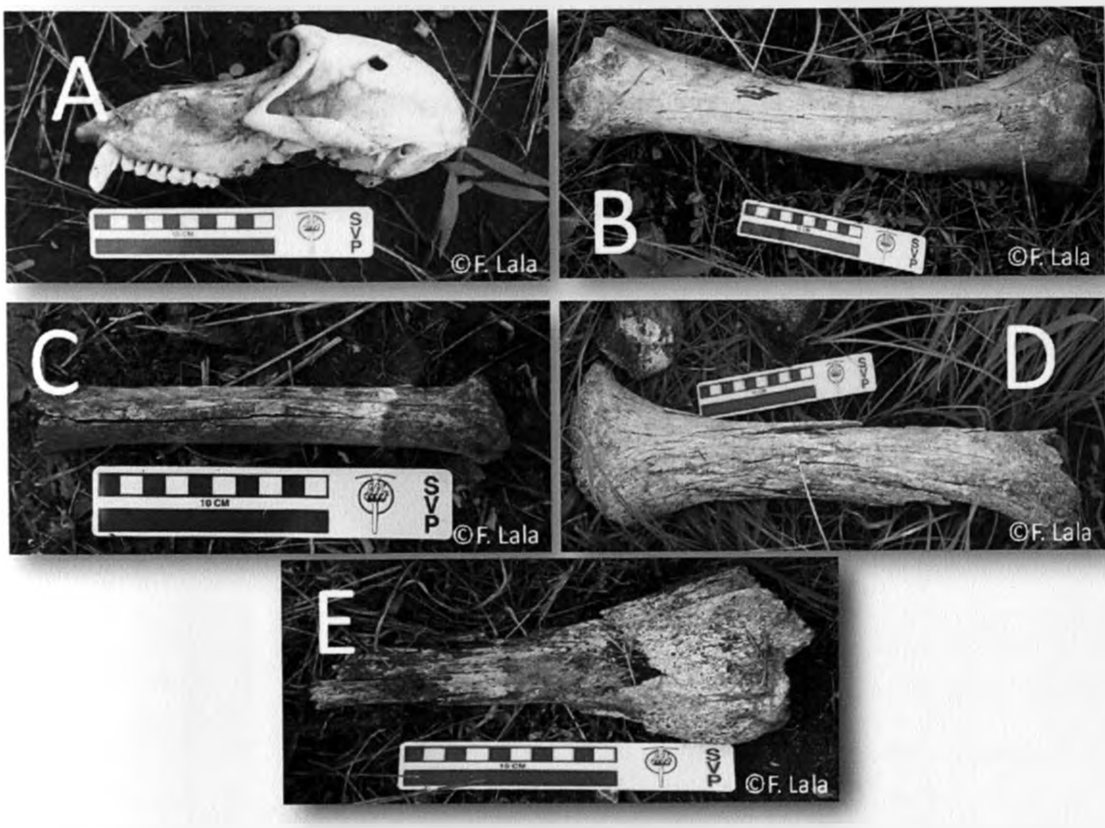

Plate 1: Weathering stages criteria as were established by Behrensmeyer (1978). A: Stage 1: Baboon skull with initial cracking to the bone fiber. B: Stage 2: Buffalo right tibia showing flaking of outer bone layers. C: Stage 3: Lesser Kudu left Metacarpal showing rough texture and remnants of surface bone. D: Stage 4: Buffalo left femur showing deep cracks, coarse layered fiber. E: Stage 5: Buffalo right radius showing the final stages of cracking and splitting.

Using GPS technology, carcasses were mapped on a transect by recording GPS coordinates at the center of the occurrence. This allowed for the development of spatial documentation of where different species are dying and how this has changed through time.

2.8 Data Analysis

Data entry and pretreatment was done in MS Excel spreadsheet. Data presentation was then carried out using Excel graphing, and for statistical tests Past (Ver. 1.81), SPSS statistical packages. All comparisons were done using one way ANOVA, two tailed t-tests and General Linear Models to establish significant differences betweeen various variables.

Further, comparison of the live-dead relative abundance data was accomplished by using Spearman's rank order correlaton coefficient test after the bone and live data were transformed as the values ranged over several orders of magnitude. Species diversity was established using the Shannon Weiner index using the formulae:-

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

while distribution patterns maps were produced using Arc view 3.2 software.

CHAPTER THREE

3.0: RESULTS

3.1 Bone occurrences as indication of mammalian numbers (MNI)

A total of 1,422 bones for large, small mammals, birds and reptiles were encountered belonging to a minimum number of 287 animals from 32 species. Buffalo (*Syncerus caffer)* had the highest number of individuals (Figure 4) as deduced from their bone occurrences, followed by the waterbuck (*Kobus ellipsiprymnus)*. The bohor reedbuck (*Redunca redunca*), bush pig (*Potomochoerus porcus*), bushbuck (*Tregelaphus scriptus*), hyena (*Crocuta crocuta*), marsh mongoose (*Herpestes paludinosus*) and porcupine (*Hystrix cristata*) had the least number of individuals that were judged from their occurences in the study area.

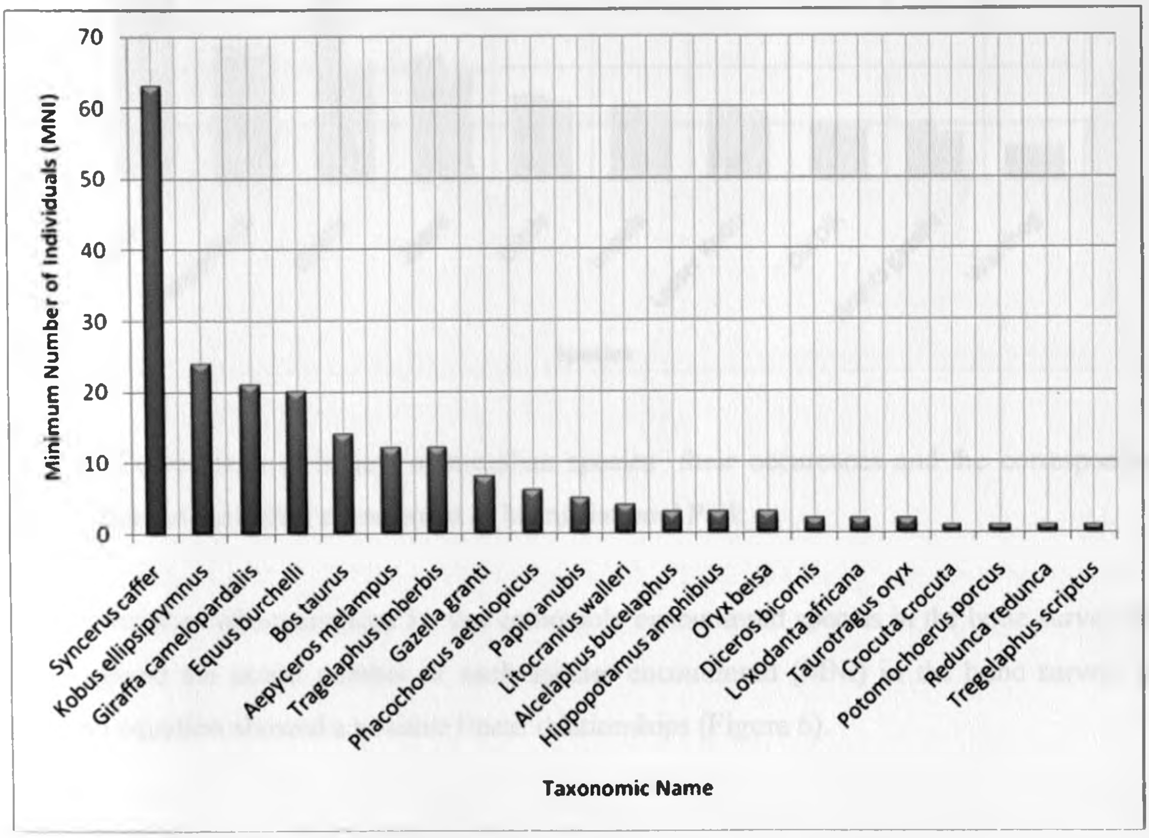

Figure 4: Minimum Number of Individuals (MNI) of t21 species of large mammals (>15kg) as a function of the bone occurrence in MNP.

Large mammals (>15 kg) had 1,251 bones in 256 occurrences, representing 221 individuals (Appendix 3). Figure 5 shows that bone occurrences for different mammalian species were closely corresponding to the minimum number of individuals (MNI) of animals in the study area. This was a clear indicator that bones were not highly scattered from the point of animal death. Large mammals such as buffalo, waterbuck, giraffe and zebra had high bone occurrence probably due to their resistance to weathering as compared to other smaller mammalian species with less than 15kg live weight.

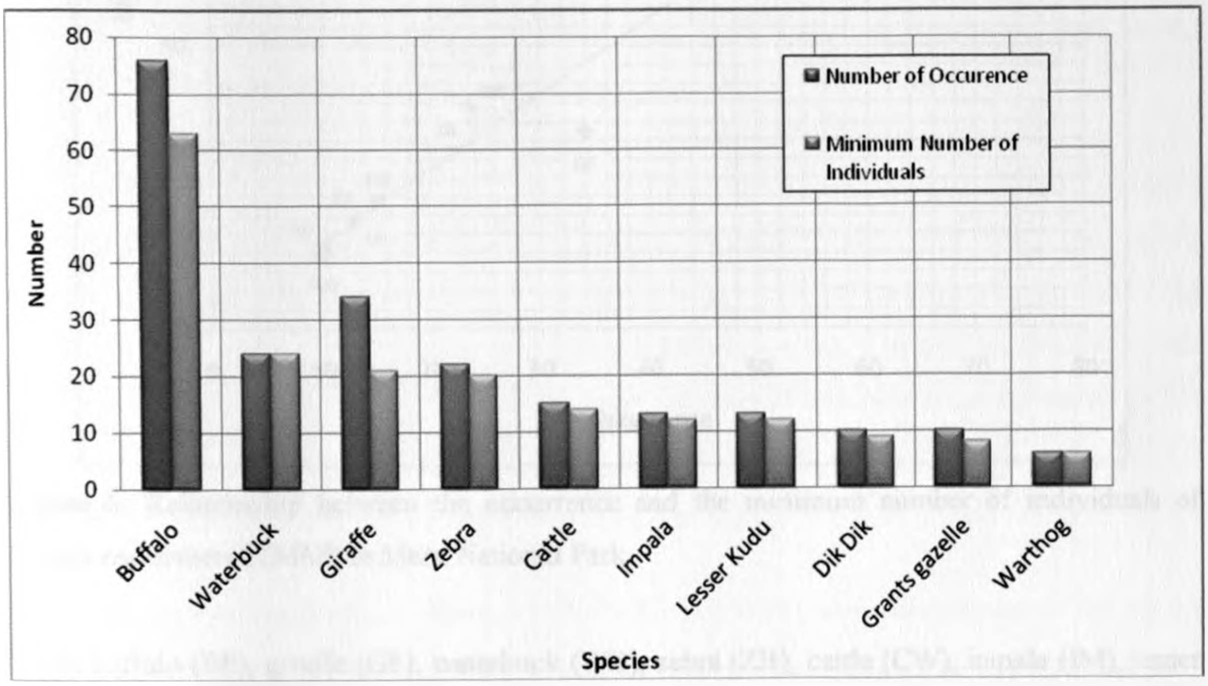

Figure 5: Comparison of larger mammalian species their occurences and the corresponding number of individuals they represented in Meru National Park.

When the number of occurrences for the commonly encountered species in the bone survey was plotted against the actual number of each species encountered (MNI) in the bone survey, the regression equation showed a positive linear relationships (Figure 6).

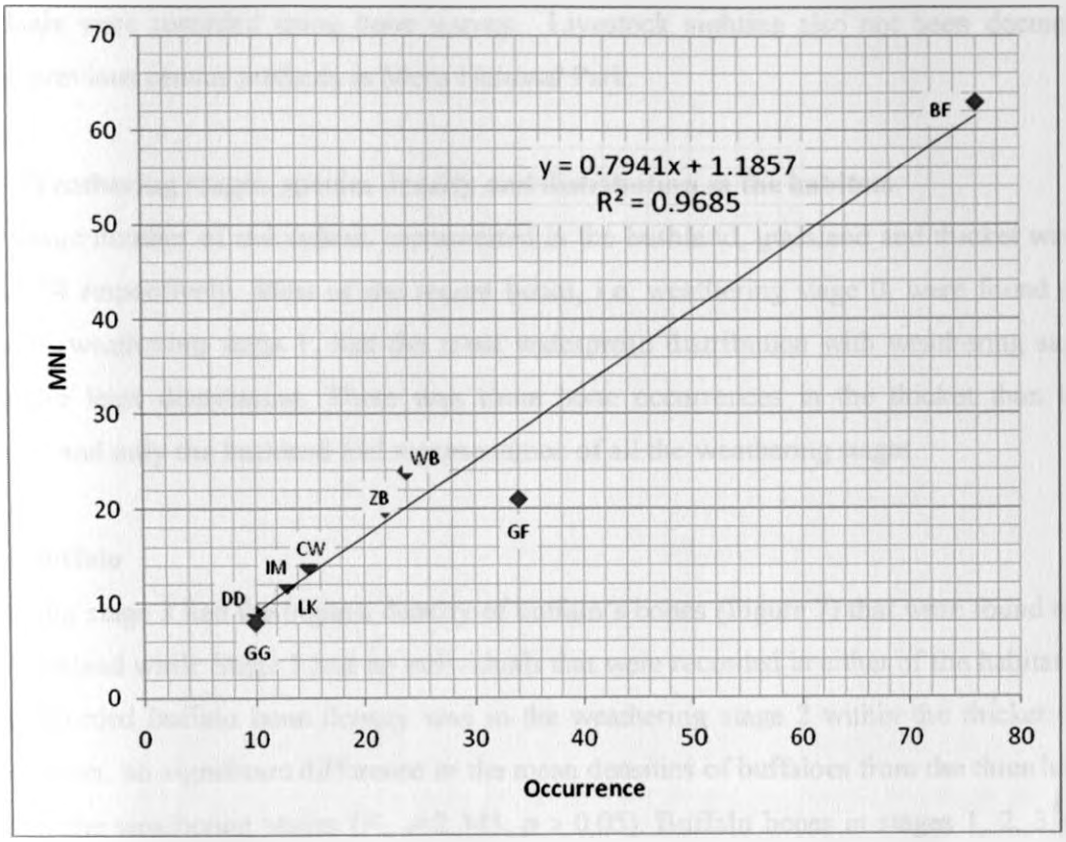

Figure 6: Relationship between the occurrence and the minimum number of individuals of species encountered (MNI) in Meru National Park

KEY: buffalo (BF), giraffe (GF), waterbuck (WB), zebra (ZB), cattle (CW), impala (IM), lesser kudu (LK), dik dik (DD) and grants gazelle (GG).

The bone survey also recorded species that had not been captured by the aerial count in the previous surveys in the park. This included the wild cat (*Felis lybica*), baboon (*Papio anubis*), kongoni (*Alcelaphus bucelaphus*), hyena (*Crocuta crocuta*), marsh mongoose (*Herpestes paludinosus*) and porcupine.

Species such as the bush pig (*Potomochoerus porcus*) which was recorded by the bone survey had not been documented previously by any other form of inventory or census. Incidences of livestock were also observed by the presence of cattle bones (*Bos taurus*), where a total of 14 individuals were recorded using bone survey. Livestock sighting also not been documented through previous census methods in Meru National Park.

3.2 Weathering stages, species density and distribution in the habitats

The average number of individuals encountered in the bushland, grassland and thicket were 23, 16, and 24 respectively. Most of the recent bones, i.e. weathering stage 0, were found in the grassland; weathering stage 1, had the most widespread distribution with weathering stage 5, having the least distribution. There was more bone occurrences in the thicket than in the bushland; and only the bushland had representation of all the weathering stages.

3.2.1 Buffalo

Weathering stage 3 had the highest density of buffalo's bones (Figure 7) that were found mainly in the bushland while Stage 5 had no individuals that were recorded in either of the habitats. The lowest recorded buffalo bone density was in the weathering stage 2 within the thicket. There was, however, no significant difference in the mean densities of buffaloes from the three habitats across all the weathering stages ($F_{3,9}$=2.343, $p > 0.05$). Buffalo bones in stages 1, 2, 3, and 4 were represented in all the three habitats.

There was also no significant difference ($t = 0.182$, $p > 0.05$) when the density of the recent weathering stages, i.e., stage 0 to stage 2 (Later time bin, 2003-2008 period) 7 individuals km^{-2} were compared with the densities of the earlier time bin (Stage 3 to stage 5, 1990-2002) which were 6 individuals km^{-2}.

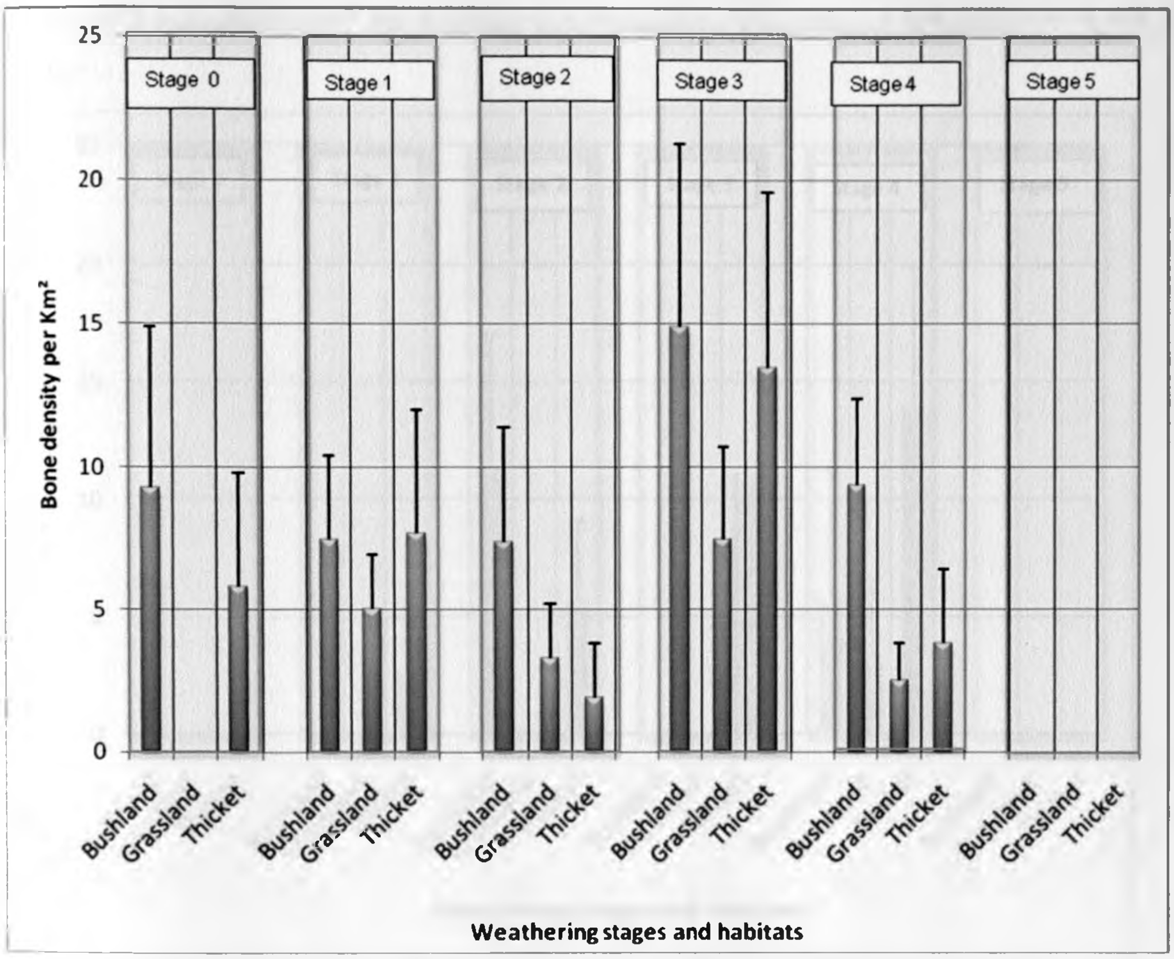

Figure 7 : Comparison of the buffalo bone densities (Mean ± S.E) in the different weathering stages across the three habitats.

3.2.2 Giraffe

Weathering stage 4 (Figure 8) had the highest density of giraffe bones recorded in the thicket; there were no individuals rerecorded in stage 5. Weathering stage 4 was the only stage that had a representation of the giraffes in all the three habitats. No significant difference ($F_{3, 9} = 0.613$, $p > 0.05$) was observed when the densities of the giraffes were compared between habitats.

Comparison between the densities of the recent weathering stages, i.e., stage 0 to stage 2 (2003-2008 period) had 7 individuals km^{-2}, while the later time bin (Stage 3 to stage 5, 1990-2002) had a density of 9 individuals km^{-2}, the densities were however not significant difference ($t = 0.378$, $p > 0.05$).

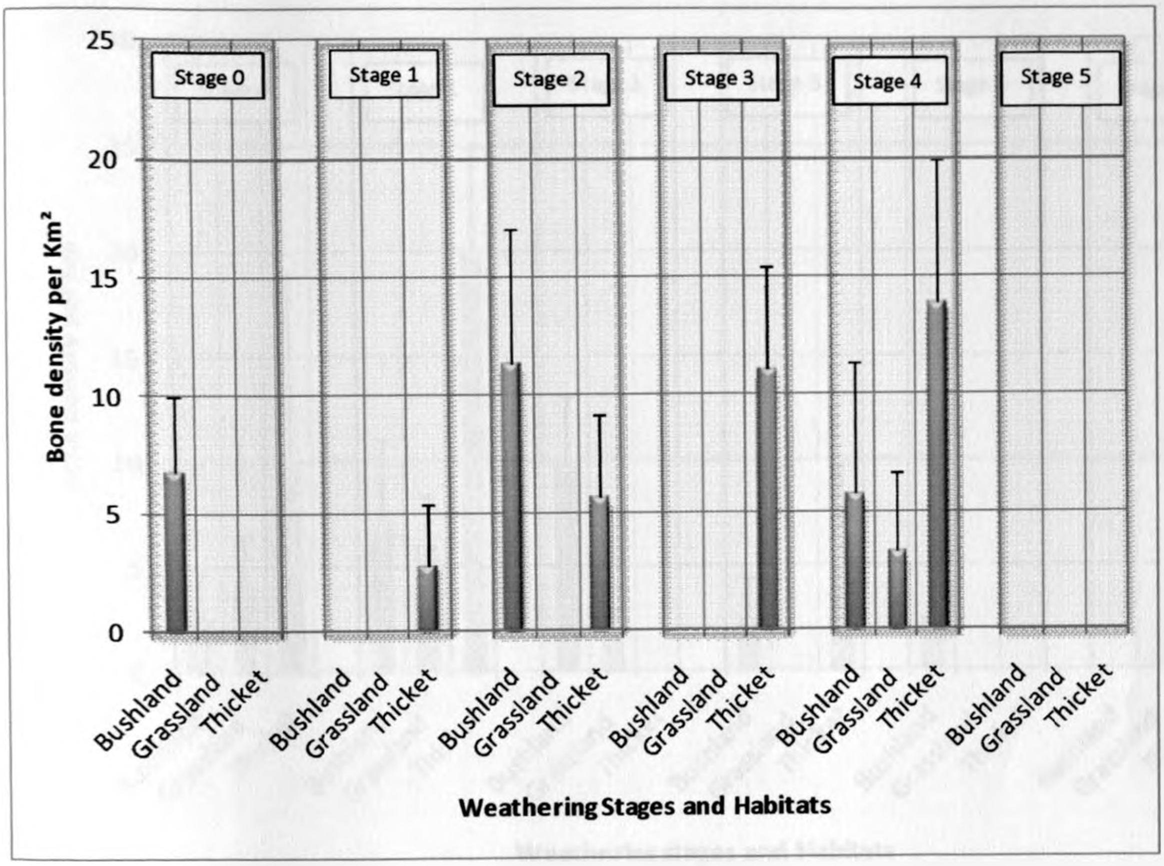

Figure 8: Comparison of the giraffe bone densities (Mean ± S.E) in the different weathering stages across the three habitats.

3.2.3 Waterbuck

Weathering stage 1 recorded the highest density in the thicket and no observations were made in stage 5 (Figure 9). There was no significant difference ($F_{3,9}=1.885$, $p > 0.05$) in the densities of the waterbuck in the three habitats across the weathering stages. However, there was significant difference ($t = 2.763$, $p < 0.05$) when the densities of the recent weathering stages, i.e., stage 0 to stage 2 (2003-2008 period) had 7 individuals km^{-2}, and densities of the later time bin (Stage 3 to stage 5, 1990-2002) was 2 individuals km^{-2}.

Only weathering stage 0 and weathering stage 2 had a representation of waterbuck in all the three habitats.

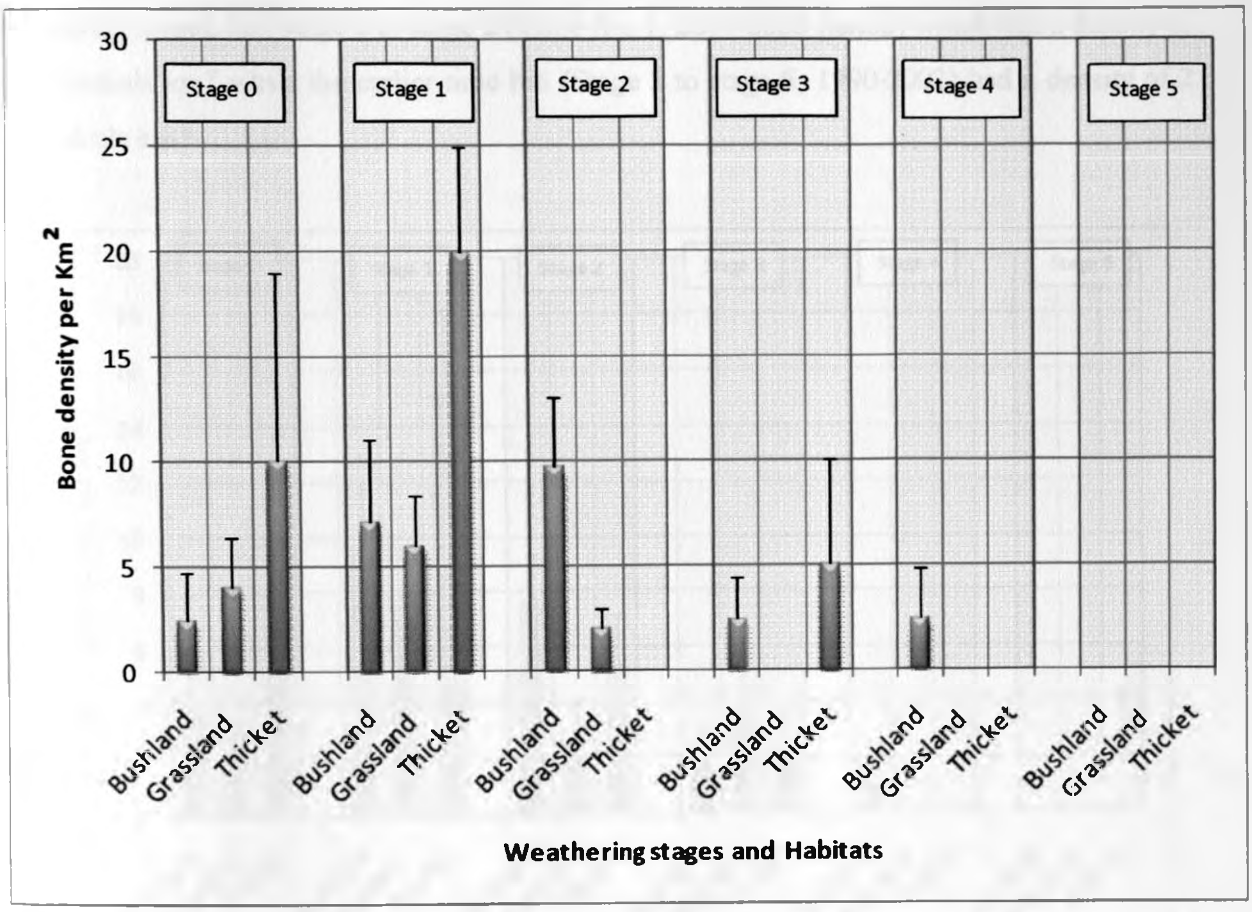

Figure 9 : Comparison of the waterbuck bone densities (Mean ± S.E) in the different weathering stages across the three habitats.

3.2.4 Other species

The highest density of all other species (zebra, impala, gerenuk, dik dik, elephant, grants gazelle, warthog, baboon, hippopotamus, bohor reedbuck, bush pig, hyena, rhino, and lesser kudu) was recorded in weathering stage 1 in the thicket; stage 5 had no individuals recorded, stage 0-3 had representatives in all the three habitats (Figure 10). There was a significant difference ($F_{3,9}$ = 9.313, $p < 0.05$) in the density of the other species between the weathering stages in the three habitats. The significant difference (Tukey test) was mainly between weathering stage 1 and 0, stage 1 and 3, stage 1 and 4.

Significant difference ($t = 4.02$, $p < 0.05$) was recorded when the densities of the recent weathering stages, i.e., stage 0 to stage 2 (Time Bin 1, 2003-2008 period) which had a density of 7 individuals km^{-2} while the earlier time bin (Stage 3 to stage 5, 1990-2002) had a density of 2 individuals km^{-2} .

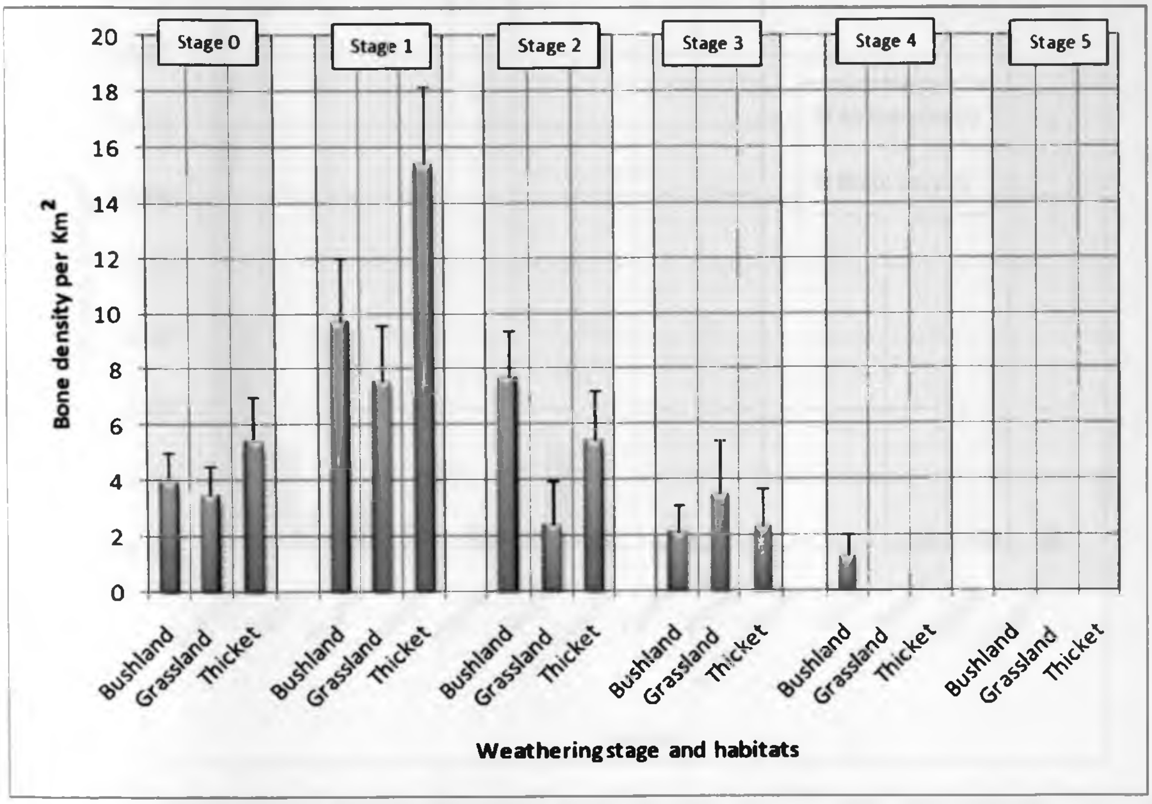

Figure 10: Comparison of other species bone densities (Mean ± S.E) in the different weathering stages across the three habitats.

3.3 Comparison of bone and aerial survey species density in the different habitats

Apart from buffalo, elephant, impala and zebra, the rest of the species encountered showed equal or higher density in the bone survey (Figure 11) in the grassland. There was no significant difference ($F_{1, 20} = 0.0002$, $p > 0.05$) when the densities of the species using the two modes of survey were compared.

For the bone survey, only the buffalo and the waterbuck had a density of over 2 individuals per km^2 in the grassland, whereas only the buffalo and the zebra had a similar density of more than 2 individuals per km^2 for the aerial census. Species such as the impala, grants gazelle, rhino, reedbuck, oryx, eland, hippopotamus and kongoni had a density of less than 1 individual per kilometer square in both surveys in the grassland.

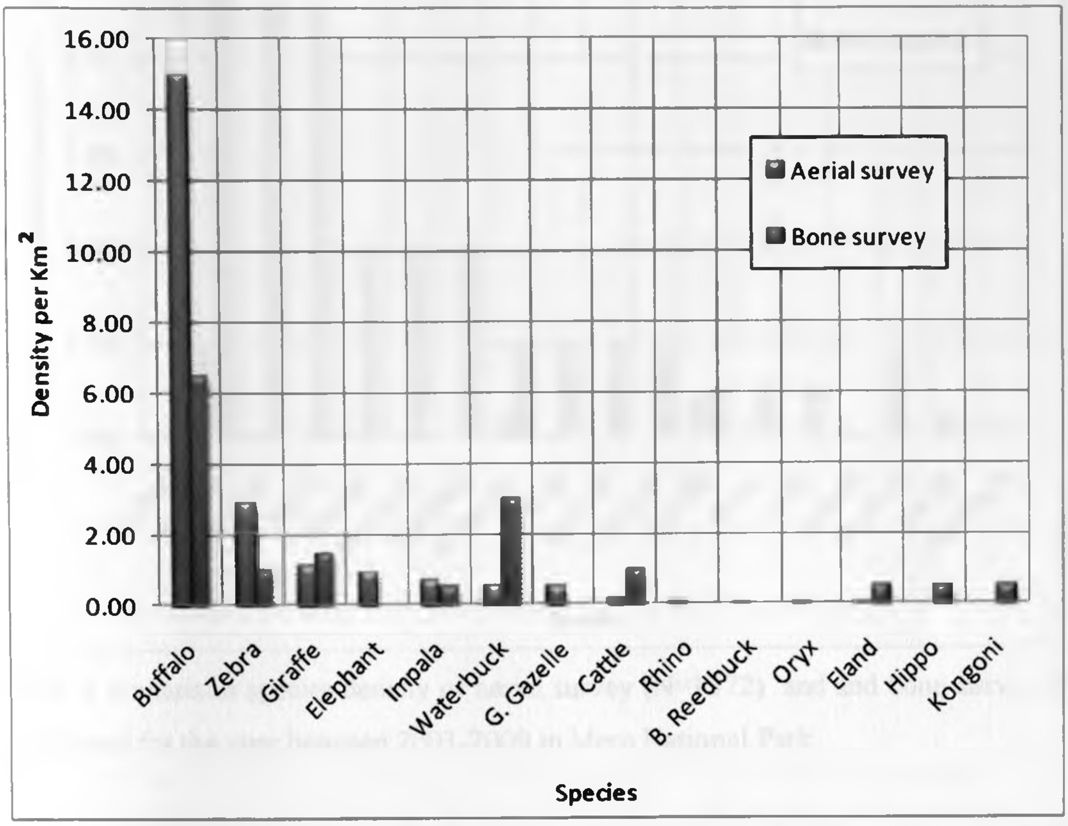

Figure 11: Comparison of species density of aerial survey (N=5371) and bone survey (N=31) in the grassland for the years between 2003-2008 in Meru National Park.

Species such as buffalo, waterbuck, zebra, lesser kudu, warthog and baboon had a higher density in the bone survey while elephant and dik dik had a higher density in the aerial survey in the bushland (Figure 12).

There was a significant difference ($F_{1, 27} = 102$, $p < 0.05$) when the densities in the bushland for the two surveys were compared. Only buffalo and elephant recorded a density of more than one ındividual per km² in the bushland using the aerial census. Apart from the impala, elephant, dik dık and bushbuck, all the other species had a higher density in the bone survey in the bushland.

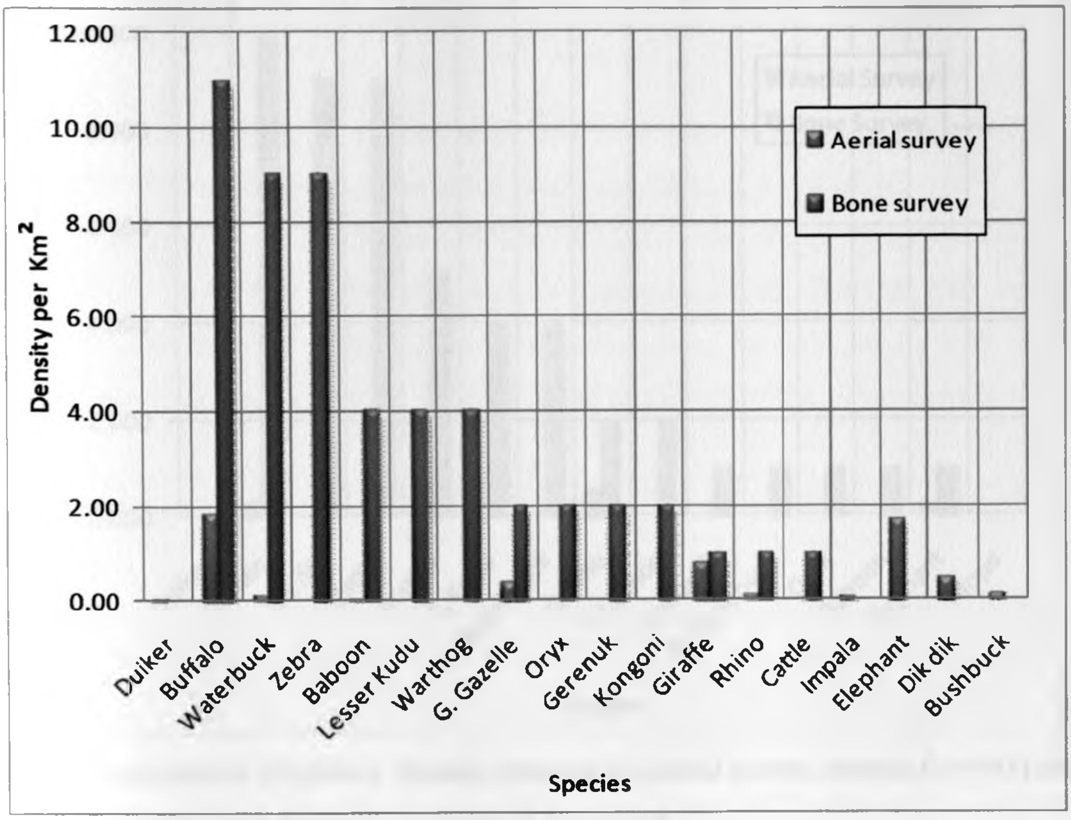

Figure 12: Comparison species density of aerial survey (N=1372) and and bone survey (N=58) in the bushland for the year between 2003-2009 in Meru National Park.

Bone survey had more than 2 individuals per kilometer square for the speceis buffalo, dik dik, cattle, impala, lesser kudu, and waterbuck in the thicket(Figure 13).

None of the species in the thicket was noted to have a density of more than 1 individual per km² in the aerial census with only buffalo, dik dik, giraffe, elephant and hippopotamus being recorded. There was also a significant difference ($F_{1, 22}$ = 13.12, $p < 0.05$) between the density obtained by aerial survey method and the bone survey method in the thicket.

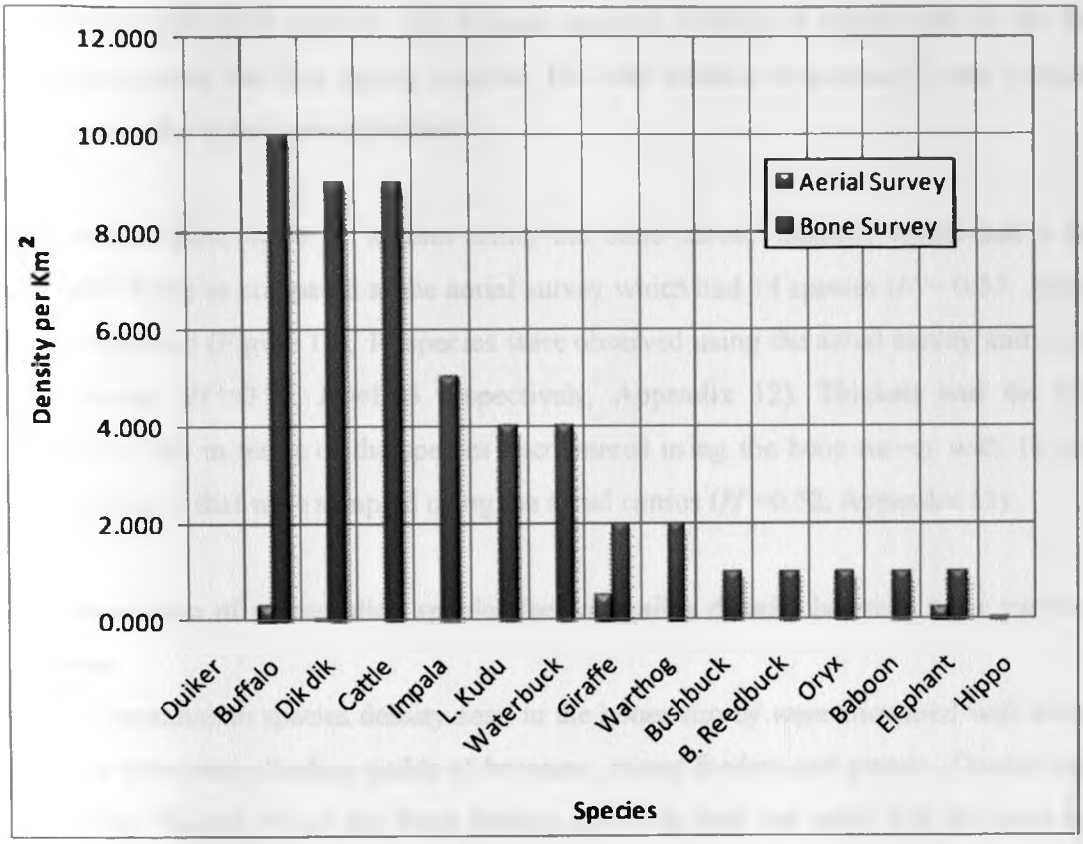

Figure 13: Comparison of species density between the aerial survey method (N=445) and and bone survey (N=44) in the thicket for the period 2003-2008.

3.4 Comparisons of species diversity for the two time bins in the three habitats

In the earlier time bin (1990-2002), aerial counts of species diversity could only be compared to a few species from the bone survey because the aerial census focused only on buffalo, elephant and rhino. In the later time bin, aerial census focused on all species that could be sighted from the plane (Appendix 1 and Appendix 2).

Species diversity was higher in the bone survey (H'=0.723) for the 1990-2002 time bin when compared to the aerial survey diversity (H' =0.044) (Appendix 4). Diversity was also higher for the bone survey (H'=1.158) when compared to the aerial survey (H'= 0.713) for the 2003-2008 time bin (Appendix 5). Comparison of the species diversity for the aerial and bone survey methods showed that with the bone survey, higher species diversity was observed in all the habitats for the 2003-2008 periods. The highest recorded number of species was in the thicket with 18 species using the bone survey method. The least number of species (5) was recorded in the thicket using the aerial survey method.

In the grassland there were 14 species using the bone survey method, which had a higher diversity (H'= 0.93) as compared to the aerial survey which had 14 species (H'= 0.55, Appendix 11). In the bushland (Figure 10), 12 species were observed using the aerial survey and 16 using the bone survey (H'=0.75, H'=1.03 respectively, Appendix 12). Thickets had the highest diversity (H'=1.09) in terms of the species encountered using the bone survey with 18 species compared to only 5 that were sampled using the aerial census (H'=0.52, Appendix 13).

3.5 Comparison of mammalian species feeding guilds density between bone survey and aerial census

The data on mammalian species density seen in the bones survey were compared with the aerial census in the three main feeding guilds of browsers, mixed feeders and grazers. Grazers had the highest density (Figure 14) of the three feeding guilds in both the aerial and the bone survey while the least was the mixed feeders.

There was no significant difference ($F_{1,12}$ = 2.83, $p > 0.05$) in the density of the browsers when the aerial census data were compared to the bone data. Browsers (based on the bone survey data) were common in the thickets and bushland (Appendix 6). Giraffe, gerenuk and lesser kudu were the only browsers that were also found in the grassland. Dik dik was found in the thickets and the bushland, while rhinos were found only in the bushland.

Grazers showed no significant difference ($F_{1,12}$= 2.017, $p > 0.05$) when the two techniques were compared. Grazers were found in all the three habitats (Appendix 7) with the buffalo having the most widespread distribution; Coke's hartebeest was the only species that was found in one habitat (grassland). Most of the species bones found in the grassland were close to the periphery of other habitats, either bushland or thickets.

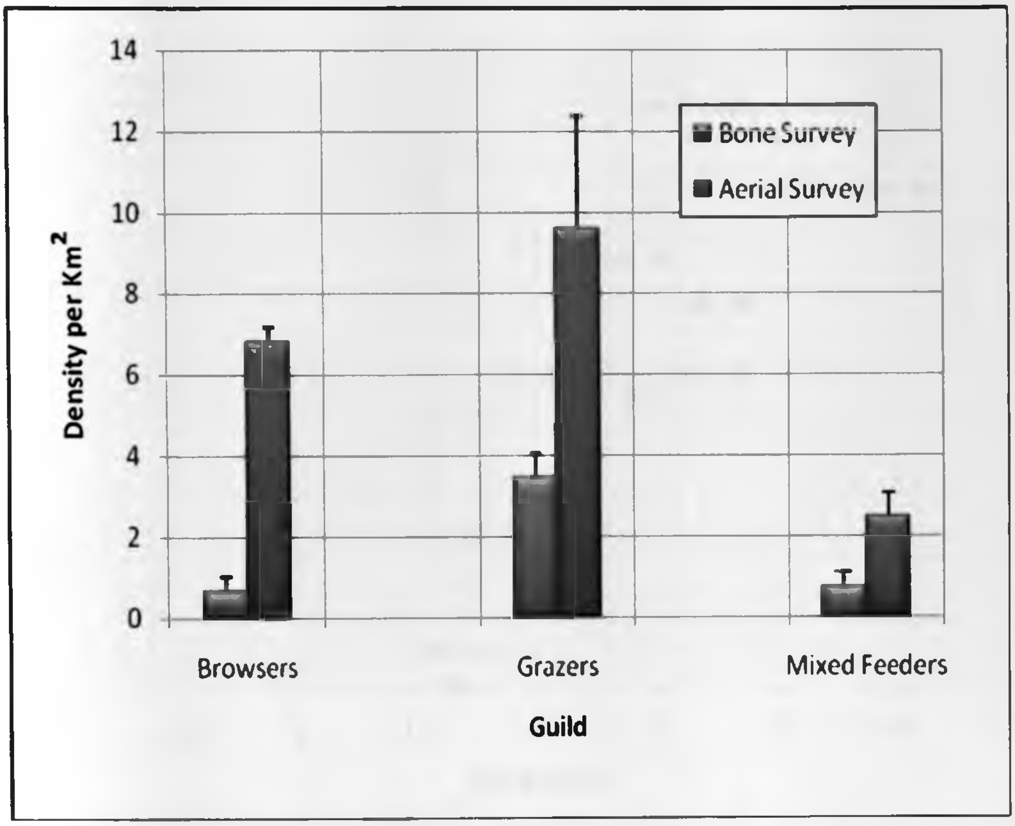

Figure 14: Comparison of guild density (Mean ± S.E) using aerial and bone survey data for the main herbivores in Meru National Park (all habitats) for the year 2000-2008.

No significant difference ($F_{1, 8} = 1.93$, $p > 0.05$) was observed when the mixed feeder's density from the aerial survey was compared to the bone survey density. Mixed feeders bones were found in all the habitats (Appendix 8), elephant and bush pig were found in the thickets, eland was found only in the grassland, while the warthog was found in the bushland and the thickets.

When the number of individuals in the bone survey and the aerial survey for the 10 most common species in both surveys were plotted against each other the regression equation showed a positive linear relationships (Figure 15).

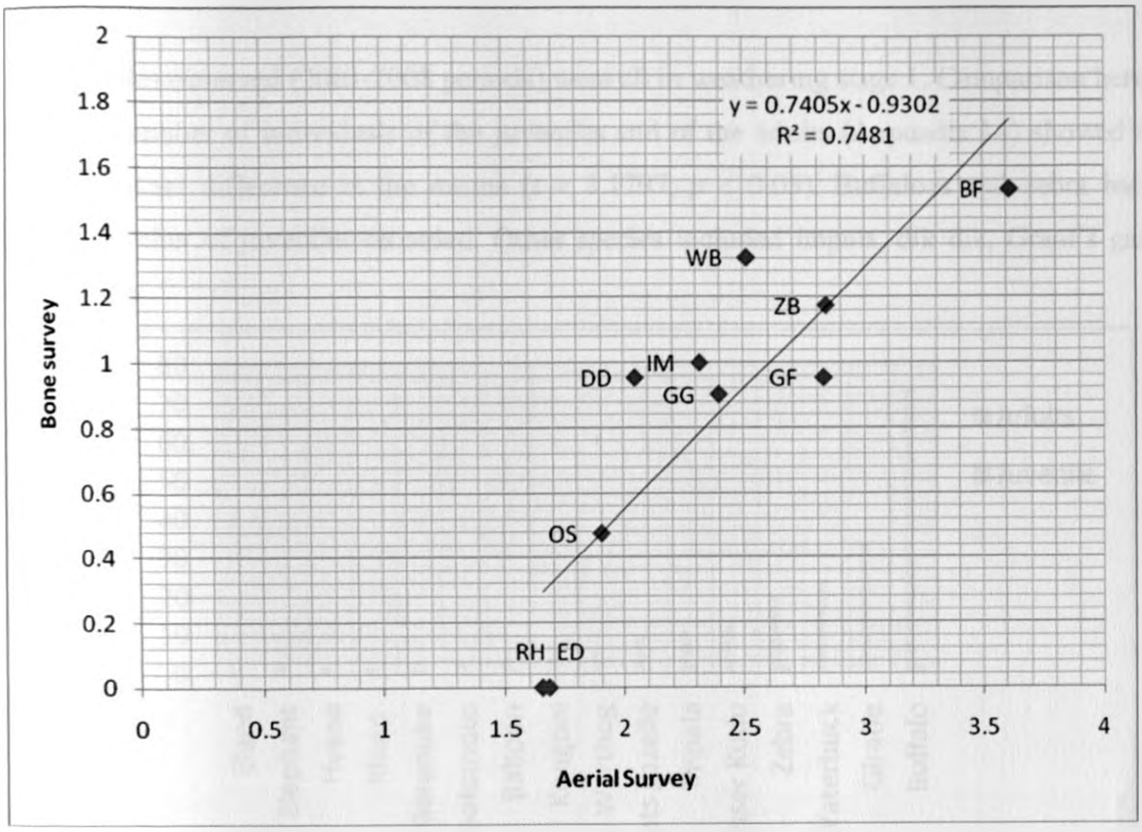

Figure 15: Regression of total aerial survey (N = 6530 counted individuals) against the total bone survey (N = 111 individuals), using transformed {log 10} abundances of the 10 most abundant herbivore species.

KEY: BF, Cape buffalo; GF, giraffe; GG, Grant's gazelle; IM, impala; WB, waterbuck; OS, ostrich; RH, black rhino; ED, Eland; DD, Dik dik; ZB, Burchell's zebra

During the survey other species <15kg were encountered, these included the naked mole rat, marsh mongoose and porcupine. These were found in the thicket and bushland habitats.

3.6 Adult and juvenile Comparison

Through the bone survey, juvenile species were documented (Figure 16). This was however not possible with the aerial census due to the nature of the technique. Juvenile bones were identified by the unfused epiphyses and the stage of the dental eruption. No juveniles were recorded in the bone samples for the years 1990-2002.

The juveniles observed (2003-2008 periods) were all in weathering stage 1. Comparison between the mean number of individuals of the juveniles and of the adults (Appendix 14) showed there was significant difference in the means (t = 3.1797, $p < 0.05$). Buffaloes and zebra had the highest number of juveniles recorded. Other species included impala, dik dik, Grant's gazelle and baboon.

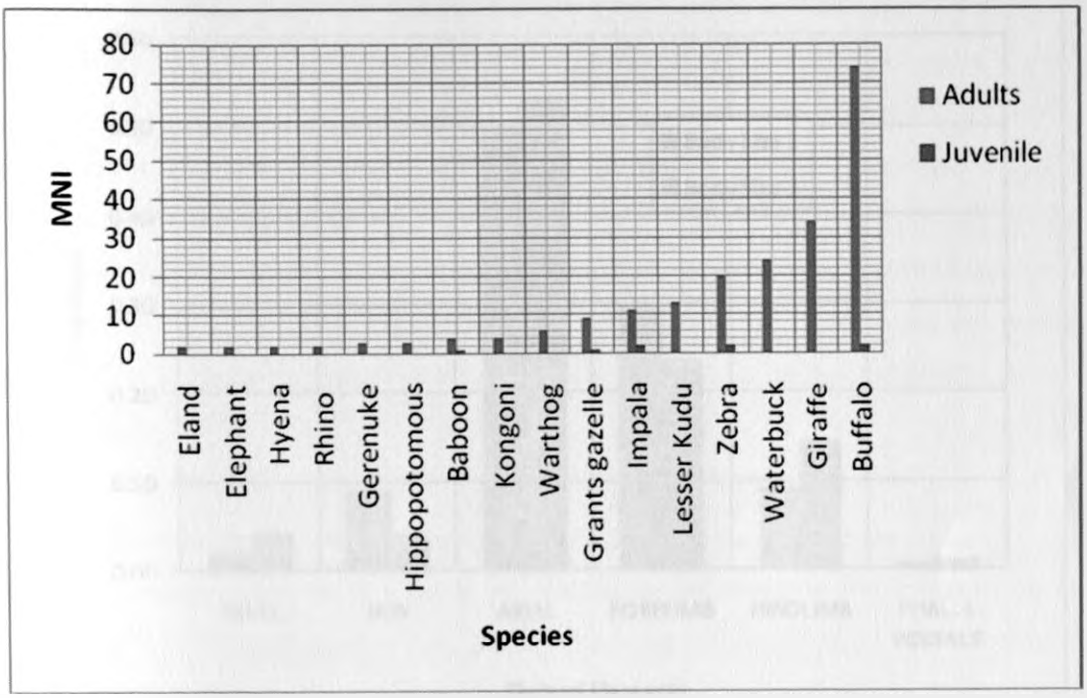

Figure 16: Adult and juvenile comparison of number of individuals (MNI) of mammals bone survey for the period 2003-2008 period in Meru National Park.

3.7 Skeletal elements

The skeletal elements sampled during the survey were grouped into six distinct categories comprising the axials (N=511), forelimb (N=218), hind limb (N=135), skull (N=38), jaw (N=51) and phalanges together with the podials (N=12). Phalanges and podials were the least observed in the survey (Figure 17). The axials were found to be the most common type of bone for species with body size 2 (animals weighing 15-50kg) and body size 3 (animals weighing 50-200kg). Body sizes are based on description by Western (1975) and the categorization of Bunn (1982).

There was a significant difference ($F_{5, 132} = 3.885$, $p < 0.05$) between the skeletal elements. Significant difference (Turkey test) was observed between the axial and skull, the axial and jaw and between the axial and phalanges-podials (Appendix 15). No significant difference was observed when the other skeletal parts (skull, jaw, forelimb, hind limb and phalanges- podials) were compared among each other.

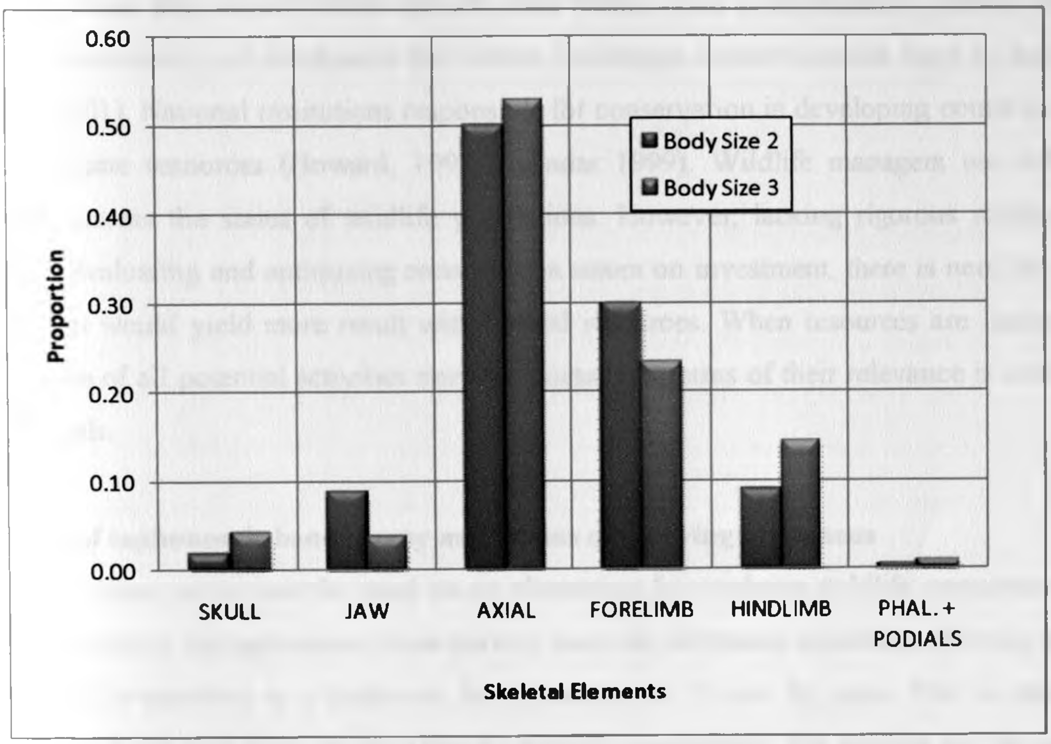

Figure 17: Comparison between body size and skeletal elements encountered (N=965) in the bone survey.

CHAPTER FOUR

4.0 DISCUSSION

Monitoring wildlife populations serves as a means of evaluating conservation work, thus providing indicators against which the success of conservation efforts can be measured, particularly when they are set within specific time frames. This is important to identify critical threats to biodiversity and emphasize the limited challenges conservationists have to deal with (Douglas, 2001). National institutions responsible for conservation in developing countries often have inadequate resources (Howard, 1991; Inamdar 1999). Wildlife managers use different methods to assess the status of wildlife populations. However, lacking rigorous methods for objectively evaluating and optimizing conservation return on investment, there is need for using methods that would yield more result with limited resources. When resources are limited, the relative value of all potential activities must be assessed in terms of their relevance in achieving the basic goals.

4.1 Use of taphonomic bone survey as a means of carrying out census

Taphonomic bone survey can be used as an alternative for studying wildlife populations and trends; furthermore, the taphonomic bone surveys have the additional advantage of being used to recreate wildlife numbers in a landscape for a past period of over 30 years. This is important especially for areas that have no past data on wildlife populations. The surveys can be used to reconstruct changes in animal populations and their structure over a period. Some of the advantages of this method as compared to the aerial survey are, firstly, the opportunity to monitor animals that are relatively small, nocturnal, or otherwise difficult to survey using standard survey techniques such as aerial or ground surveys of live animals. Secondly, examining the species relative abundance across weathering stages, bone surveys provide a means of looking at change in wildlife populations through time ("back-censusing"). These methods can then be applied to examine change through time in wildlife populations in areas that do not have long-term census data and provide a baseline for study into future decades. Thirdly, it is possible to assess the age at death (roughly) of an animal using bone surveys. Bone surveys also have the additional advantage in that they cause minimal disturbance to the animals as compared to aerial surveys, which can disturb wildlife as a result of the noise from the low flying aircrafts introducing biases in population estimates. In terms of cost, the method is less expensive as compared to the aerial survey.

Bone survey species distribution concurred with aerial live species distribution. The three main guilds (browsers, grazers and mixed feeder) showed similarity in the two methods when the densities were compared. Most zebra carcasses were prevalent in bushland habitats compared to grassland. This was probably due to either predator's preferred bushy feeding sites that acted as hide-outs to prevent competition or zebras were more vulnerable to predators in bushy areas.

There were some species which had suffered as result of poaching during the earlier time bin (1990-2002) and consequently could not be picked during the surveys, however following the improved security in the later time period such species such as the gerenuk and lesser kudu could be seen in larger numbers. It was also observed that no impala bones could be found in the earlier time bin (1990-2002). The impalas were part of the species that were decimated by poachers. During a restoration exercise in 2003 the first batch of 411 impalas were translocated to MNP and later in 2007 when 1,016 impalas were translocated, it was possible to record bones in the lower weathering stages, i.e., bones of the years 2003-2008. This further clearly illustrates that it is possible to monitor change in species numbers in an ecosystem and even be able to know which species existed in a given landscape at a given period using the taphonomic bone survey.

Studies by Nyafwono (2007) on elephant mortalities in MCA showed that mortalities were high on the dispersal areas of BNR and the northern grazing area; few cases were reported in MNP. A large proportion of the elephants have in the past been recorded outside MNP; in the 2006 aerial count for instance, 69.4% (n=350) of the total number of elephants were recorded in the northern grazing area, Bisinadi National Reserve recorded 18.7% (n=94); 10.3% (n=52) of the total number was recorded in Kora National Park, while the rest 1.6% (n=8) were recorded in Meru National Park. This could be the reason why very few individuals were documented using the bone survey.

The abundance of the ten most common species in the aerial and bone survey methods showed a positive linear relationship ($y=0.7405x - 0.9302$, $R^2 = 0.748$); this shows the prospect of the bone survey method being used to estimate the relative abundance of species in a given area as the method would provide similar results compared to other methods.

4.2 Aerial and bone survey species diversity and density

Aerial census in the 1990-2002 period was mainly focused on the mega-herbivores (elephant, rhino, giraffe and buffalo). This resulted in the low aerial survey diversity index. The 2003- 2008 period aerial survey focused on all species that could be observed from air; species as small as the dik dik were able to be captured by the aerial survey. The bone survey was able to capture 6 more species than the aerial survey with a higher diversity ($H'=1.158$) compared to the aerial survey ($H'= 0.713$). This shows the importance of using the taphonomic bone surveys in establishing the diversity of an area. The bone survey method apart from capturing all the species the aerial method is able to capture is an important method that captures other species that the aerial method cannot document. Its applicability in closed habitats (bushland and thickets) gives it an upper hand when compared to the aerial survey

4.3 Unique species identification

The number of species that the bone method was able to capture shows that it can be used to carry out inventories and census. It was able to document the presence of the bush pig, which had never been captured by other forms of surveys in the MNP. Small mammals that are not documented by aerial method mostly due to the noise that forces them to hide during aerial census were captured in the bone survey. Species such as the marsh mongoose, porcupine, the elusive naked mole rat and the wild cat were captured by the bone method. The method would therefore be important for carrying out survey for species that are known to be shy or nocturnal hence reducing the bias associated with aerial census.

Illegal activities such as cattle incursions are currently a major threat to the protected areas due to the degradation associated with the incursions; through taphonomic bone survey it was possible capture the presence of cattle bones in MNP; this had not been recorded previously by the aerial censuses. The method therefore gives a clear picture of what species have been in a particular area and at what period. Such information can be important for advising on species re-introductions in areas where there is no information of what types of species used to exist as well as ensuring intensified protection of certain habitats that could be having the endangered species.

4.4. Comparison between adult and juvenile

It was possible to compare the adult and juvenile population using the bone survey. The aerial census method rarely groups species into the two age brackets; when they are grouped, it is usually for the mega-herbivores. For the earlier time period (1990-2002) no juveniles were recorded in the bone survey method, this could be attributed to faster disintegration of bones which are not fused and low numbers of wildlife that was not viable hence could not reproduce optimally. In the later time bin (2003-2008) however following the reintroductions of species such as the zebra, giraffe, reedbuck and impala it was possible to observe juveniles in the later time bin. The bone survey method therefore could aid in understanding the health of certain species by knowing whether a certain population is viable or not; the data could also help to know if the juveniles are being predated on more than the adults and hence help the wildlife managers in protecting the juveniles of threatened and endemic species that may be suffering the effects of an imbalanced predator- prey relationship.

4.5 Skeletal elements

The significant difference between the different skeletal elements ($p=0.02$, $p < 0.05$) would play an important role for future surveys in MNP as people carrying out the survey could be taught how to identify the most common elements leading to more accurate interpretation of the living population. The axials were the most encountered skeletal elements in MNP; this could be due to the fact that they usually disarticulate relatively late hence preserved more as shown in studies by Hill and Behrensmeyer (1984). It could also be due to the fact that they occur in anomalous proportions when compared with the numbers in a single skeleton.

4.6 Conclusion

Taphonomic bone surveys provide a method of censusing animal populations in areas where their bones are abundant and visible. Bones can record ecological change in a monitored ecosystem, and populations of bones that accumulated over different time intervals can be distinguished using weathering stages. The results of this study have clearly demonstrated that taphonomic bone surveys can be used to estimate wildlife population and distribution in a given habitat as well as assess the past population ("back-censusing"), furthermore determination and composition of various species in different habitat can be done apart from providing a better record of smaller and rarer mammals than currently provided by other methods of census.

Different weathering stages in an environment can indicate duration of species occupation, which can help ecologists investigate how long certain carcasses have been on the surface and help in making sound management decisions. Bone weathering rates, when known for different areas and habitats, will help ecologists carry out census and inventories in different habitats. This method can then be applied to examine change through time in wildlife populations in areas that do not have long-term census data. The method can also help in documenting unusual mortality patterns and also help in correcting bias in habitat use patterns resulting from aerial counts. The study was able to establish changes in wildlife distribution and abundance in relation to the existing vegetation types in Meru National Park.

4.7 Recommendations

- Future Taphonomic bone surveys should be for the entire Meru Conservation Area since the current survey was only restricted to Meru National Park; this will help to understand the distribution and numbers of some of the species known to migrate from Meru National Park.
- Training on bone identification especially the axials which were more prevalent during the survey is important when future surveys are carried out.
- Kenya Wildlife Service and other wildlife research institutions can use the method to determine past wildlife data in areas where data is not available.

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6.0 APPENDICES

Appendix 1: Meru Conservation Area aerial census background

Scientific monitoring of wildlife in the Meru ecosystem began in 1976 with Total and sample counts by Ian Douglas-Hamilton and Hillman; this was mainly for the elephants and rhinos. From 1980 to 1989 KREMU (later DRSRS) continued to sample count wildlife and in Meru National Park and the surrounding districts as part of their general rangeland survey. The 1990 aerial count by Ian Douglas-Hamilton in Meru National Park and Bisanadi was a wet count and was a two day event; the census concentrated mainly on the larger herbivores as in previous census, these were manly the Elephant, Giraffe , rhino and buffalos. The park was divided into 14 blocks used in previous counts (1976) and each block was searched with an overlap to ensure the ground was adequately covered. Large herds of wildlife were later photographed and animals counted in the photo. The search rate was 68km²/hr.

The 1992 count was also a dry count; the objective of this count was to make total count of the elephants, buffaloes, giraffes and zebras in Meru National Park after being subjected to heavy poaching. The park was divided into 3 counting blocks after merging 14 blocks that had been used in the previous census. GPS was used in this census and this ensured coverage of the enlarged block.

In 2002 another Dry count was carried in Meru National Park with the objectives of determining the elephant's distribution and carcass in MCA, documenting any changes in elephant size and their distribution, documenting the distribution of other species such as the rhino, buffaloes and livestock. The method used was the one devised by Ian Douglass- Hamilton et.al 1994 and Douglass-Hamilton 1997. The count adopted the GPS technique with pathfinder software used for plotting species distribution maps.

The last dry count was conducted in 2005; this was also the first comprehensive large mammal count that targeted all the wildlife species; it was also the first aerial count after the translocation aimed at restocking wildlife in MCA, following concerns of low population of wildlife in MCA. The methodology was as described by Ian Douglass-Hamilton (1997) and Norton Griffith.

Subsequent aerial censuses in 2006 and 2007 were wet counts done to provide wet season baseline data on the total number of the different species in MCA.

Appendix 2: Summary data of aerial count in Meru Conservation Area from 1990- 2007.

SPECIES	2007	2006	2005	2002	1999	1997	1992	1990
Buffalo	1310	822	1968	1084	1337	1244	1449	1418
Bushbuck	29	3	-	-				
Baboon	-	4	-	-				
Cattle	-	38	-	400				519
Camel	-	3	-	-				
Crocodile	-	3	-	-				
Dik Dik	1	111	-	-				
Duiker	-	5	-	-				
Elephant	268	8	474	272			264	251
Eland	16	1	28	-				
Giraffe	294	196	181	-			230	166
Grant's gazelle	123	90	38	-				
Gerenuk	13	31	-	-				
Hippo	-	2	20	-				
Impala	153	29	26	-				
Lesser kudu	13	24	-	-				
Ostrich	-	54	26	-				
Oryx	10	7	-	-				
Reed Buck	-	7	-	-				
Rhino	17	20	11	4				
Waterbuck	52	105	171	-				
Warthog	27	-	-	-				
Plains zebra	418	112	157	-				
Grevys zebra	-	-	-	-	-	-	1	-
Total	**2761**	**1675**	**3107**	**1760**	**1337**	**1244**	**1944**	**2354**

Appendix 3: Species, Number of occurrences, number of bones and the number of individuals encountered (MNI).

Taxonomic Name	Common Name	Number of Occurences	Number of Bones	Minimum Number of Individuals
Syncerus caffer	Buffalo	76	484	63
Kobus ellipsiprymnus	Waterbuck	24	89	24
Giraffa camelopardalis	Giraffe	34	120	21
Equus burchelli	Common Zebra	22	121	20
Bos taurus	Cattle	15	126	14
Aepyceros melampus	Impala	13	51	12
Tragelaphus imberbis	Lesser Kudu	13	47	12
Madoqua kirki	Dik Dik	10	16	9
Gazella granti	Grants gazelle	10	41	8
Phacochoerus aethiopicus	Warthog	6	12	6
Papio anubis	Baboon	5	54	5
Litocranius walleri	Gerenuk	3	11	4
Hippopotamus amphibius	Hippopotamus	3	13	3
Alcelaphus bucelaphus	Kongoni	4	8	3
Oryx beisa	Oryx	3	5	3
Taurotragus oryx	Eland	2	3	2
Loxodonta africana	Elephant	2	2	2
Diceros bicornis	Rhinocerus	2	2	2
Felis lybica	Wild cat	2	14	2
Redunca redunca	Bohor reedbuck	1	1	1
Potomochoerus porcus	Bush pig	1	1	1
Tragelaphus scriptus	Bushbuck	1	3	1
Crocuta crocuta	Hyena	2	20	1
Herpestes paludinosus	Marsh mongoose	1	2	1
Hystrix cristata	Porcupine	1	5	1
TOTAL		**256**	**1,251**	**221**

Appendix 4: Comparisons of species diversity between the aerial census method and the bone survey method for the 1990-2002 period.

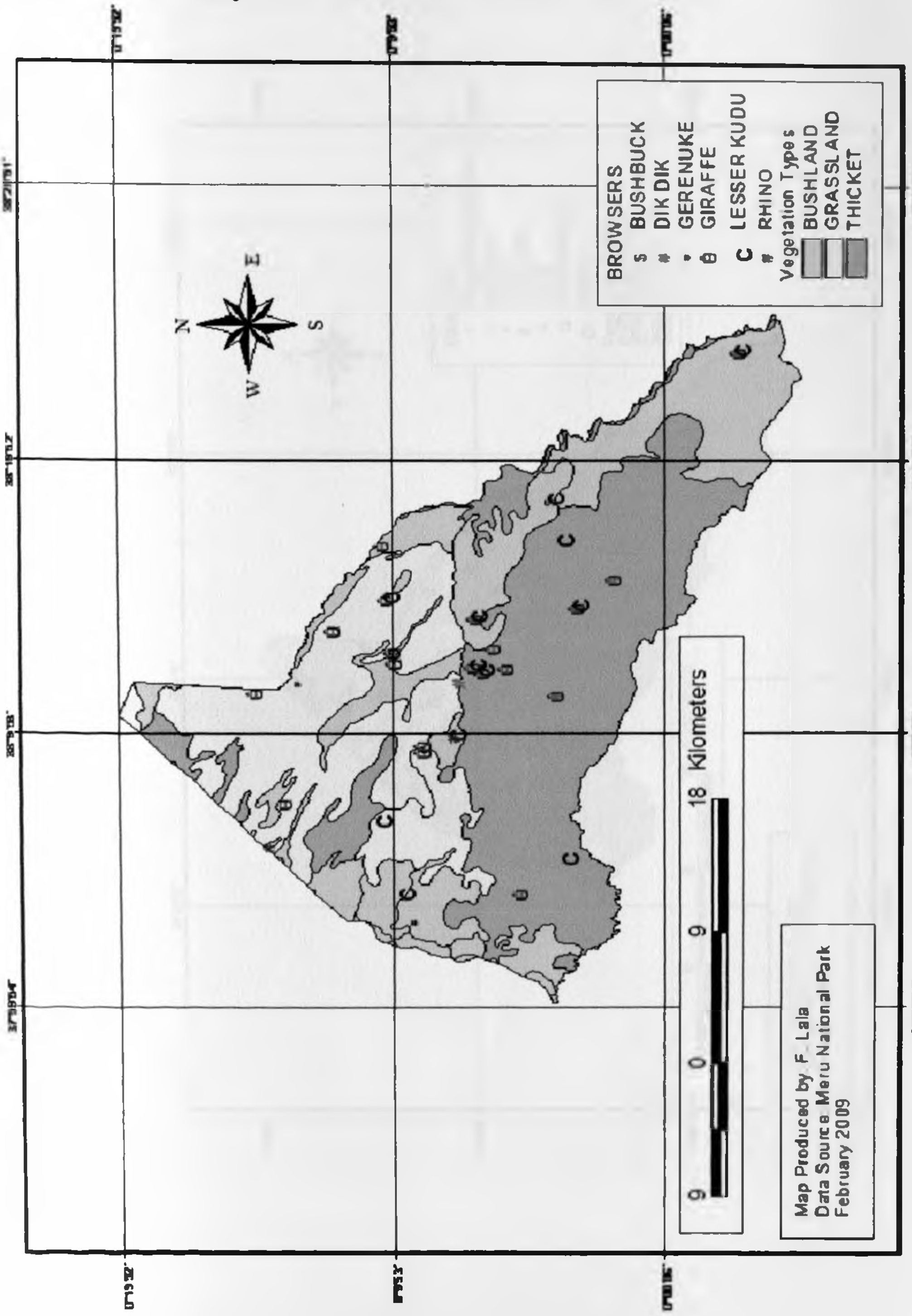
Common Name	**Aerial census**	*Pi*	*Log Pi*	(Pi)(Log Pi)
Elephant	515	0.119823	-0.92146	0.11041
Giraffe	396	0.092136	-1.03557	0.09541
Cape Buffalo	2867	0.667054	-0.17584	0.11729
Grevy Zebra	1	0.000233	-3.63327	0.00085
Cattle	519	0.120754	-0.9181	0.11086
	4298			0.43483
Common Name	**Bone survey**	***Pi***	***Log Pi***	**(Pi)(Log Pi)**
Elephant	1	0.016667	-1.77815	0.02964
Rhinocerus	1	0.016667	-1.77815	0.02964
Giraffe	12	0.2	-0.69897	0.13979
Cape Buffalo	29	0.483333	-0.31575	0.15261
Burchell's Zebra	5	0.083333	-1.07918	0.08993
Waterbuck	3	0.05	-1.30103	0.06505
Cattle	4	0.066667	-1.17609	0.07841
Eland	1	0.016667	-1.77815	0.02964
Hippopotamus	1	0.016667	-1.77815	0.02964
Lesser Kudu	1	0.016667	-1.77815	0.02964
Impala	2	0.033333	-1.47712	0.04924
	60			0.72321

Appendix 5: Comparisons of species diversity between the aerial census method and the bone survey method for the 2003-2008 period.

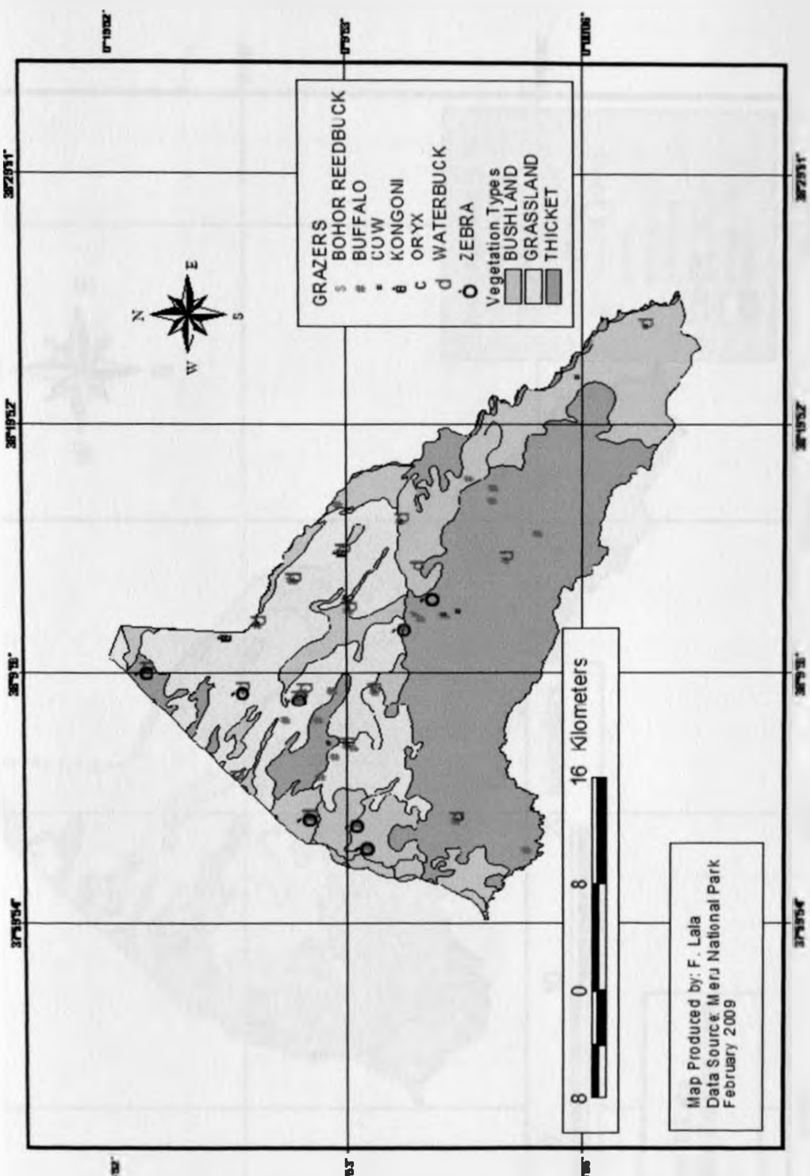
Common Name	Aerial census	Pi	Log Pi	(Pi)(Log Pi)
Elephant	750	0.100847	-0.99634	0.10048
Rhinocerus	48	0.006454	-2.19016	0.01414
Giraffe	671	0.090225	-1.04468	0.09426
Cape Buffalo	4100	0.551298	-0.25861	0.14257
Burchell's Zebra	687	0.092376	-1.03444	0.09556
Waterbuck	328	0.044104	-1.35552	0.05978
Bohor Reedbuck	7	0.000941	-3.0263	0.00285
Bushbuck	32	0.004303	-2.36625	0.01018
Cattle	38	0.00511	-2.29161	0.01171
Eland	45	0.006051	-2.21819	0.01342
Hippopotamus	22	0.002958	-2.52898	0.00748
Lesser Kudu	37	0.004975	-2.3032	0.01146
Oryx	17	0.002286	-2.64095	0.00604
Ostrich	80	0.010757	-1.96831	0.02117
Grant's gazelle	251	0.03375	-1.47172	0.04967
Impala	208	0.027968	-1.55333	0.04344
Dik dik	112	0.01506	-1.82218	0.02744
Baboon	4	0.000538	-3.26934	0.00176
	7437			0.71341

Common Name	Bone survey	Pi	Log Pi	(Pi)(Log Pi)
Elephant	1	0.00625	-2.20412	0.01378
Rhinocerus	1	0.00625	-2.20412	0.01378
Giraffe	9	0.05625	-1.24988	0.07031
Cape Buffalo	34	0.2125	-0.67264	0.14294
Burchell's Zebra	15	0.09375	-1.02803	0.09638
Waterbuck	21	0.13125	-0.8819	0.11575
Bohor Reedbuck	1	0.00625	-2.20412	0.01378
Bushbuck	1	0.00625	-2.20412	0.01378
Cattle	10	0.0625	-1.20412	0.07526
Eland	1	0.00625	-2.20412	0.01378
Hippopotamus	2	0.0125	-1.90309	0.02379
Hyena	1	0.00625	-2.20412	0.01378
Lesser Kudu	10	0.0625	-1.20412	0.07526
Marsh Mongoose	1	0.00625	-2.20412	0.01378
Bush Pig	1	0.00625	-2.20412	0.01378
Kongoni	3	0.01875	-1.727	0.03238
Oryx	3	0.01875	-1.727	0.03238
Ostrich	3	0.01875	-1.727	0.03238
Warthog	6	0.0375	-1.42597	0.05347
Grant's gazelle	8	0.05	-1.30103	0.06505
Impala	10	0.0625	-1.20412	0.07526
Gerenuk	4	0.025	-1.60206	0.04005
Dik dik	9	0.05625	-1.24988	0.07031
Baboon	5	0.03125	-1.50515	0.04704
	160			1.1582

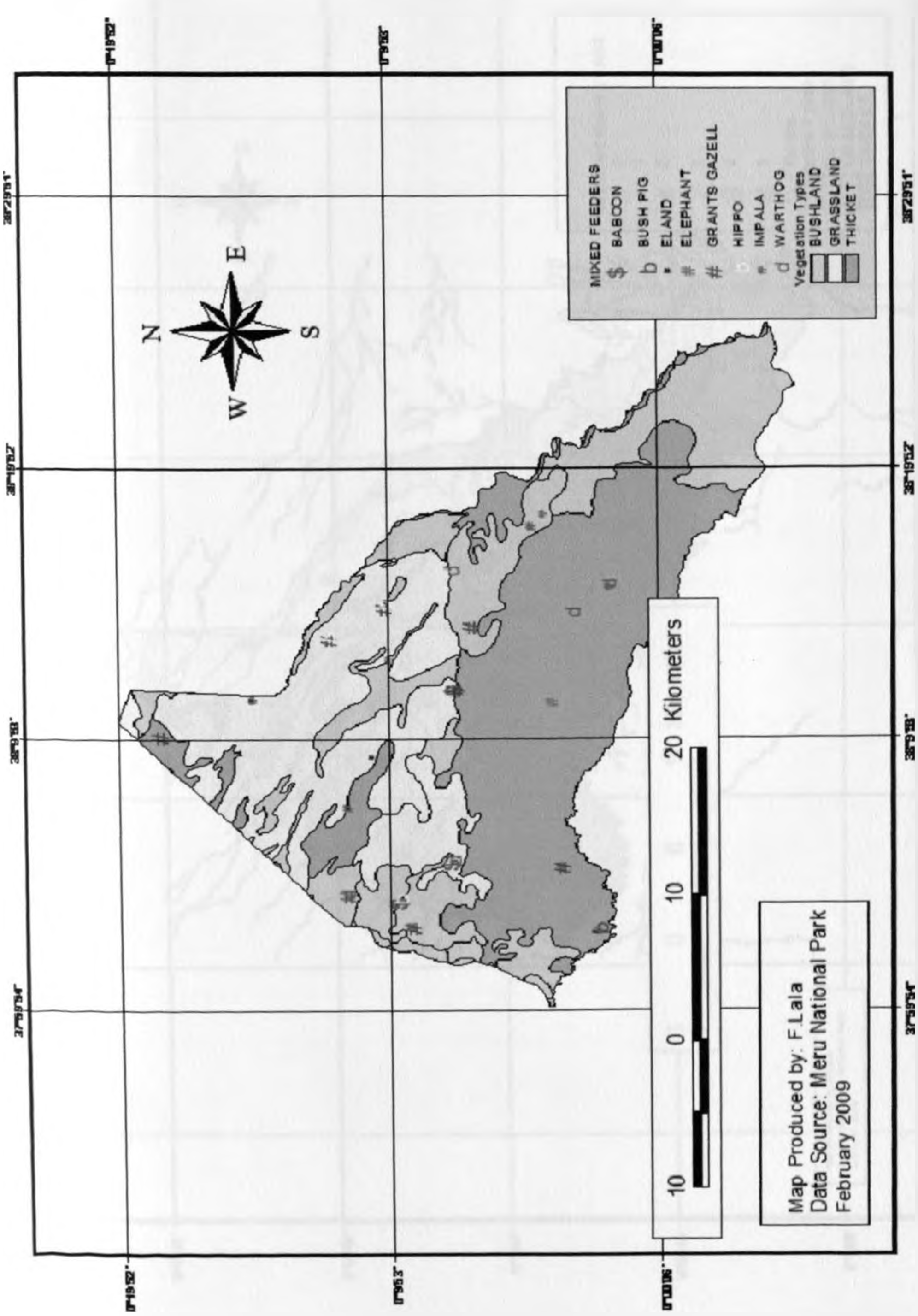
Appendix 6: Distribution of browser bones occurrences in the three main habitats in Meru National Park for the years between 2000- 2008.



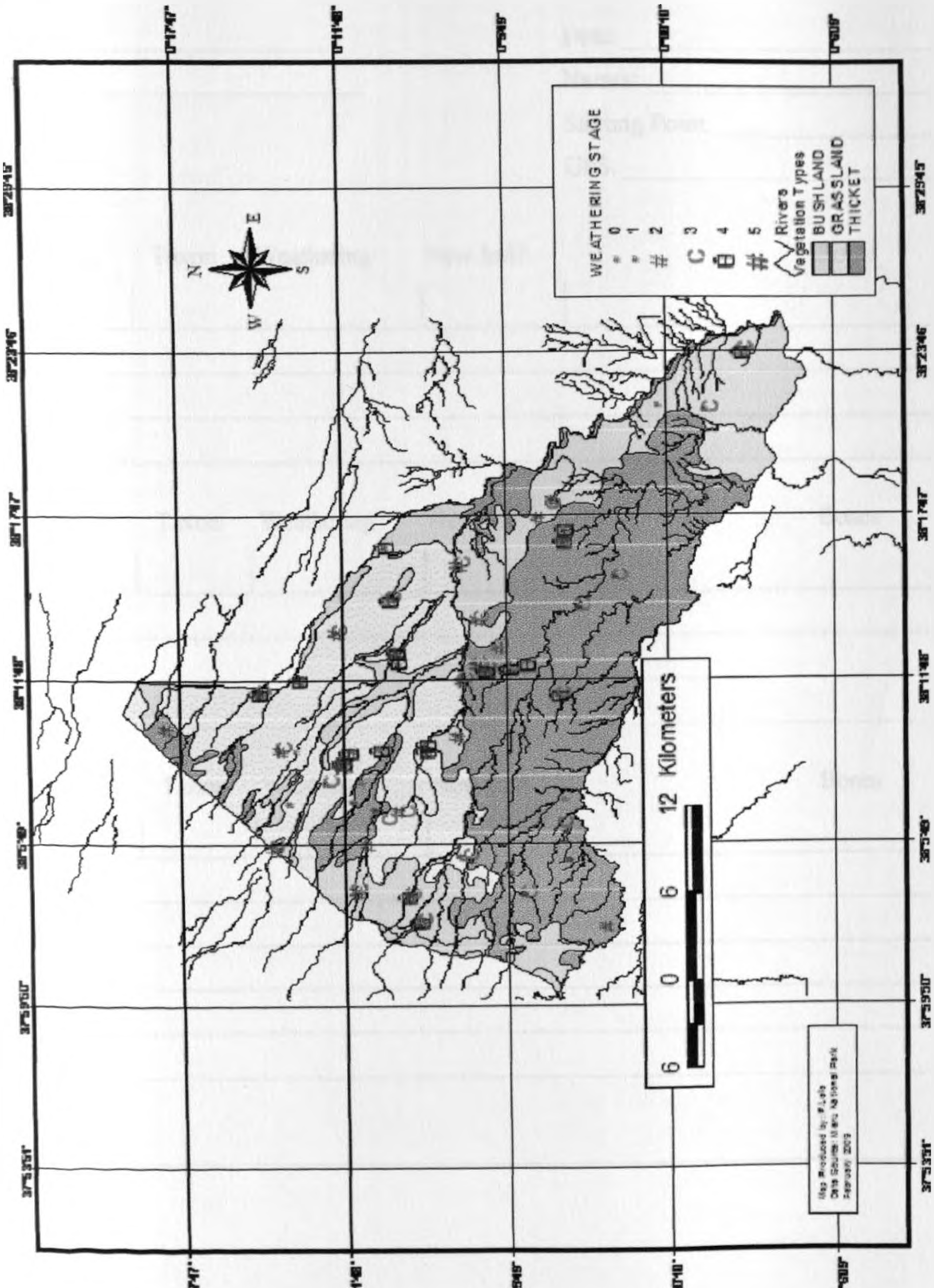
Appendix 7: Distribution of grazer bones occurrences in the three main habitats in Meru National Park for the years between 2000- 2008.



Appendix 8: Distribution of mixed feeder bones in the three main habitats in Meru National Park for the years between 2000- 2008



Appendix 9: Distribution of bones in the different habitats of Meru National Park and their weathering stages for the years 2000 to 2008



Appendix 10: Data sheet used Meru Bone Survey

Habitat: ____________________ Date: ____________________

Transect: ____________________ Names: ____________________

Starting Point: ____________________

GPS: ____________________

Occurrence	Taxon	Weathering	New Ind?	Bones

Occurrence	Taxon	Weathering	New Ind?	Bones

Occurrence	Taxon	Weathering	New Ind?	Bones

Notes

Appendix 11: Comparison of aerial survey and the bone survey of species diversity for species found in the grassland for the period 2003- 2008.

Aerial		Pi	Log Pi	[Pi][Log Pi]
BOHOR REEDBUCK	7	0.001303	-2.88495711	0.00375995
BUFFALO	3595	0.669335	-0.17435626	0.1167028
CATTLE	38	0.007075	-2.15027156	0.01521324
ELAND	1	0.000186	-3.73005515	0.00069448
ELEPHANT	231	0.043009	-1.36644317	0.05876901
FRANCOLIN	26	0.004841	-2.3150818	0.01120688
GIRAFFE	274	0.051015	-1.29230459	0.06592654
GRANTS GAZELLE	120	0.022342	-1.65087391	0.03688417
IMPALA	162	0.030162	-1.52054014	0.0458625
ORYX	7	0.001303	-2.88495711	0.00375995
OSTRICH	67	0.012474	-1.90398035	0.02375101
RHINO	24	0.004468	-2.34984391	0.01050014
WATERBUCK	132	0.024576	-1.60948122	0.0395553
ZEBRA	687	0.127909	-0.89309842	0.11423545
	5371			0.54682143
Bone		**Pi**	**Log Pi**	**[Pi][Log Pi]**
BUFFALO	13	0.288889	-0.53926916	0.15578887
CATTLE	2	0.044444	-1.35218252	0.060097
ELAND	1	0.022222	-1.65321251	0.03673806
FRANCOLIN	1	0.022222	-1.65321251	0.03673806
GIRAFFE	3	0.066667	-1.17609126	0.07840608
HIPPOPOTOMUS	1	0.022222	-1.65321251	0.03673806
IMPALA	1	0.022222	-1.65321251	0.03673806
KONGONI	1	0.022222	-1.65321251	0.03673806
NAKED MOLE RAT	10	0.222222	-0.65321251	0.14515834
OSTRICH	1	0.022222	-1.65321251	0.03673806
TORTOISE	1	0.022222	-1.65321251	0.03673806
WATERBUCK	6	0.133333	-0.87506126	0.11667484
WILD CAT	2	0.044444	-1.35218252	0.060097
ZEBRA	2	0.044444	-1.35218252	0.060097
	45			0.93348552

Appendix 12: Comparison of aerial survey and the bone survey of species diversity for species found in the bushland for the period 2003- 2008.

TAXON	Aerial			
		Pi	*Log Pi*	(PIXLog PI)
BABOON	4	0.002904866	-2.53687	0.00736928
BUFFALO	450	0.326797386	-0.48572	0.15873249
BUSHBUCK	32	0.023238925	-1.63378	0.03796738
DIK DIK	111	0.080610022	-1.09361	0.088156
ELEPHANT	420	0.305010893	-0.51568	0.15728944
GIRAFFE	189	0.137254902	-0.86247	0.11837853
GRANTS GAZELLE	93	0.067538126	-1.17045	0.07905007
IMPALA	20	0.014524328	-1.8379	0.02669432
OSTRICH	4	0.002904866	-2.53687	0.00736928
RHINO	24	0.017429194	-1.75872	0.03065312
WATERBUCK	25	0.01815541	-1.74099	0.03160846
Duiker	5	0.003631082	-2.43996	0.00885971
	1377			0.75212807
	Bone	*Pi*	*Log Pi*	(PIXLog PI)
BABOON	4	0.054794521	-1.26126	0.06911029
BUFFALO	11	0.150684932	-0.82193	0.12385249
CATTLE	1	0.01369863	-1.86332	0.02552497
FRANCOLIN	17	0.232876712	-0.63287	0.1473816
GERENUKE	2	0.02739726	-1.56229	0.04280254
GIRAFFE	1	0.01369863	-1.86332	0.02552497
GRANTS GAZELLE	2	0.02739726	-1.56229	0.04280254
KONGONI	2	0.02739726	-1.56229	0.04280254
LESSER KUDU	4	0.054794521	-1.26126	0.06911029
ORYX	2	0.02739726	-1.56229	0.04280254
OSTRICH	1	0.01369863	-1.86332	0.02552497
RHINO	1	0.01369863	-1.86332	0.02552497
TORTOISE	3	0.04109589	-1.3862	0.05696719
WARTHOG	4	0.054794521	-1.26126	0.06911029
WATERBUCK	9	0.123287671	-0.90908	0.1120784
ZEBRA	9	0.123287671	-0.90908	0.1120784
	73			1.03299902

Appendix 13: Comparison of aerial survey and the bone survey of species diversity for species found in the thicket for the period 2003- 2008.

TAXON	Aerial	*Pi*	*Log Pi*	(PI)(Log PI)
BUFFALO	115	0.258426966	-0.587662171	0.151867752
DIK DIK	1	0.002247191	-2.648360011	0.005951371
ELEPHANT	99	0.22247191	-0.652724816	0.145212937
GIRAFFE	208	0.46741573	-0.330296676	0.154385862
HIPPOPOTOMUS	22	0.049438202	-1.30593733	0.064563194
	445			0.521981115
	Bone	*Pi*	*Log Pi*	(PI)(Log PI)
BABOON	1	0.01754386	-1.755874856	0.030804822
BOHOR RHEEDBUCK	1	0.01754386	-1.755874856	0.030804822
BUFFALO	10	0.175438596	-0.755874856	0.132609624
BUSHBUCK	1	0.01754386	-1.755874856	0.030804822
CATTLE	9	0.157894737	-0.801632346	0.126573528
DIK DIK	9	0.157894737	-0.801632346	0.126573528
ELEPHANT	1	0.01754386	-1.755874856	0.030804822
FISH	1	0.01754386	-1.755874856	0.030804822
GIRAFFE	2	0.035087719	-1.45484486	0.051047188
HORNBILL	2	0.035087719	-1.45484486	0.051047188
HYENA	1	0.01754386	-1.755874856	0.030804822
IMPALA	5	0.087719298	-1.056904851	0.092710952
LESSER KUDU	4	0.070175439	-1.153814864	0.080969464
MARSH MONGOOSE	1	0.01754386	-1.755874856	0.030804822
ORYX	1	0.01754386	-1.755874856	0.030804822
TORTOISE	2	0.035087719	-1.45484486	0.051047188
WARTHOG	2	0.035087719	-1.45484486	0.051047188
WATERBUCK	4	0.070175439	-1.153814864	0.080969464
	57			1.091033889

Appendix 14: Comparison between adult and juvenile occurrences.

SAMPLES

A		B	
N:	22	N:	22
Mean:	9.4545	Mean:	0.36364
95%:	(3.5159 15.393)	95%:	(0.071917 0.65536)
Var.:	179.4	Var.:	0.4329

95% conf. for difference between means: (3.3211 14.861)

TESTS

F:	414.42	p(same):	5.6633E-23
t:	3.1797	p(same):	0.0027689
Uneq. var t	3.1797	p(same):	0.0044925
Permutation t test (N=10000):		p(same):	< 0.0001

Appendix 15: *Post Hoc* Tests Skeletal analysis- Multiple Comparisons

Dependent Variable: NUMBER

	(I) SKELETAL	(J) SKELETAL	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	skull	jaw	-.4643	4.82166	1.000	-14.3706	13.4420
		axial	-16.8929(*)	4.82166	.008	-30.7992	-2.9865
		fore limb	-6.4286	4.82166	.766	-20.3349	7.4777
		hind limb	-3.4643	4.82166	.979	-17.3706	10.4420
		phalanges	.9286	4.82166	1.000	-12.9777	14.8349
	jaw	skull	.4643	4.82166	1.000	-13.4420	14.3706
		axial	-16.4286(*)	4.82166	.011	-30.3349	-2.5223
		fore limb	-5.9643	4.82166	.818	-19.8706	7.9420
		hind limb	-3.0000	4.82166	.989	-16.9063	10.9063
		phalanges	1.3929	4.82166	1.000	-12.5135	15.2992
	axial	skull	16.8929(*)	4.82166	.008	2.9865	30.7992
		jaw	16.4286(*)	4.82166	.011	2.5223	30.3349
		fore limb	10.4643	4.82166	.257	-3.4420	24.3706
		hind limb	13.4286	4.82166	.065	-.4777	27.3349
		phalanges	17.8214(*)	4.82166	.004	3.9151	31.7277
	fore limb	skull	6.4286	4.82166	.766	-7.4777	20.3349
		jaw	5.9643	4.82166	.818	-7.9420	19.8706
		axial	-10.4643	4.82166	.257	-24.3706	3.4420
		hind limb	2.9643	4.82166	.990	-10.9420	16.8706
		phalanges	7.3571	4.82166	.648	-6.5492	21.2635
	hind limb	skull	3.4643	4.82166	.979	-10.4420	17.3706
		jaw	3.0000	4.82166	.989	-10.9063	16.9063
		axial	-13.4286	4.82166	.065	-27.3349	.4777
		fore limb	-2.9643	4.82166	.990	-16.8706	10.9420
		phalanges	4.3929	4.82166	.943	-9.5135	18.2992
	phalanges	skull	-.9286	4.82166	1.000	-14.8349	12.9777
		jaw	-1.3929	4.82166	1.000	-15.2992	12.5135
		axial	-17.8214(*)	4.82166	.004	-31.7277	-3.9151
		fore limb	-7.3571	4.82166	.648	-21.2635	6.5492
		hind limb	-4.3929	4.82166	.943	-18.2992	9.5135

* The mean difference is significant at the .05 level.