EFFECTS OF HABITAT VARIABILITY ON RODENT DISTRIBUTION AND DIVERSITY IN NAIROBI NATIONAL PARK, KENYA

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DECLARATION

I hereby wish to declare that this thesis is my original work and has not been submitted elsewhere for examination or award of a degree. Where other people's work has been used, this has been properly acknowledged and referenced in accordance with the University of Nairobi's requirements.

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DEDICATION

This thesis is dedicated to my parents, Mr. Amos Mungai and Mrs. Milka Mungai for supporting

me this far in my education.

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LIST OF ABBREVIATIONS

AIC   Akaike Information Criteria

ANOVA   Analysis of variance

GC   Ground Cover

GPS   Global Positioning System

KWS   Kenya Wildlife Service

MAD   Median Absolute Deviation

NNP   Nairobi National Park

PCA   Principal Component Analysis

PCQ   Point-centered-quarter Method

TD   Tree Density

ABSTRACT

Rodents are among the most diverse and abundant vertebrates that occupy both natural and semi-natural habitats. Their diverse diet and contribution to predation food chain makes them suitable candidates for motoring environmental change due to human habitat alterations and pollution. The purpose of this study was to investigate the status of rodent populations in Nairobi National Park, a protected area that is facing immense pressure of urbanization and socio-economic activities in Nairobi City County. The specific objectives were to determine the rodent community structure and how habitat variability and human activities have influenced species diversity and relative abundance. Line transects were used to sample rodents in the main habitats: savannah grassland, upland and riverine forests, and human disturbed sites in Nairobi National Park during the dry and wet seasons. The results indicated that the park was not endowed with a rich diversity of rodent species. A total of 56 individuals belonging to five species were trapped during the study period. The five species were identified as *Lemniscomys striatus, Hylomyscus* sp*, Rattus rattus, Mus mus* and *Otomys tropicalis.* Rodent species diversity was therefore low (Shannon Weiner Diversity H = 1.40) while Pielou's species evenness was moderate (J = 0.44), indicating that the rodent species occurred widely in all the major habitats in the park. Univariate generalised linear models indicated that rodent population abundance was influenced by season, vegetation type and habitat structural features. Human disturbed sites, such as residential compounds, camp sites and picnic sites as well as habitat edges found along roads and park boundaries showed significant variation in rodent abundance. Predictive multivariate models indicated that rodents were more abundant in all habitats during in wet season compared to the dry season. The seasonal abundances were also positively correlated with increased tree and shrub densities in the study sites. Rodent species richness was positively

correlated with higher tree density while vegetation type had marginal effects the diversity of rodent species. It was concluded that the tropical savannah vegetation in NNP was not rich rodent species. There was no significant invasion of the park by feral rodents across the park boundaries or from human disturbed areas in the park. The abundance of rodents was influenced by season, and finer vegetation metrics but not human disturbance. Anthropogenic activities, such as camping, picnic, solid waste disposal and heavy tourist traffic did not significantly influence rodent species distribution and abundance. The invasive *Rattus rattus* was restricted to human occupied areas. The sample size obtained and sampling effort should be enhanced through further research so as to confirm the observations made during this study. However, this study has provided reliable baseline data and information that can aid future monitoring rodent species in Nairobi National Park.

CHAPTER ONE

1.1   INTRODUCTION

Nairobi National Park (NNP) is a park with a global importance and unique conservation area in Kenya. The park ecosystem is fragile (Mundia, 2005), given its position within the city of Nairobi, among the fast-growing cities in Africa. The ecological integrity of this park is threatened by pressure of urbanization. One of the essential ecological guides of ecosystem presentation are the variations in mammalian demography. Some small mammals including rodents (Order Rodentia) are more delicate bio indicators than others.

Rodent population dynamics studies have been investigated in variable protected areas like in wildlife park and forest reserves (Boitani and Mortelliti, 2006), that determine the abundance and composition as well as connotation with both seasonality and habitat organisation (Fasola and Canova, 2000). In most studies, it indicates rainfall pattern directly modulates on richness on some type of species (Makundi *et al.,* 2009) whereas, species diversity is promoted by habitat heterogeneity (Tews *et al.,* 2004).

There are three dominant vegetation structures in NNP: the riverine forests, the dry upland, open savannah grassland and open woodland (Deshmukh, 1986). Little is known on how these prime vegetative biomes in the park impact the density and diversity of rodents. This remains primarily because data on small mammal community composition and diversity in the park is scanty. The available data and information in the public domain derives from studies conducted in the 1970s in Embakasi plains, which is approximately 20 km away from the park. Rodents trapped out of 4,320 night-traps, only *Mastomys coucha* and *Crocidura fumosa* rodents were caught (Hartman, 1966).

Order Rodentia have a hasty reaction to habitat disruption which makes them perilous bio indicators and constituents of a purposeful ecosystem. They are also the most abundant mammals and in many ecosystem they play key functions in dispersal of seeds, linking food webs and nutrient cycling (Wolff and Sherman 2007; Kingdon, 1997).

Further, knowledge about the impact of anthropogenic activities on the population development of small rodents in NNP is insufficient, specifically their abundance and diversity. Human undertakings that cause disturbance on habitats have been associated with an increased total abundance of small mammals while in contrast both mammal diversity and shrub cover consistently decline.

This implies that as cover of shrub diminishes, species richness and diversity of small rodents is adversely affected (Men *et al.,* 2015). A specific outcome of human intrusion to conservation areas is the formation of 'edge habitat' at the adjacent land utilization outside and within the protected areas. The edge territory is prospective to impact the social structure of order Rodentia whereby habitat 'generalists' can bloom over the habitat 'specialists' rodents (Laurance and Yensen, 1991). However, the impact of edge environment is not static and changes with space and time while feedback by animal populations may vary with, season, species and microhabitats (Flaspohler *et al.,* 2001).

 This study aims at determining the effects of habitat edge variability, seasonality and crucial habitat assembly on relative abundance and the conformation of rodents in Nairobi National Park.

1.2 Problem Statement of the study

NNP is a vital conservation space within the city of Nairobi. Identical to any park near the city, NNP is fronting innumerable forms of forces from human activities that array from, pollution and encroachment to environmental land modification where these dynamics have contributed to a substantial damage in biodiversity. Despite there being continuous monitoring of large mammals in NNP and outcome showing sturdy decline, there is inadequate data on small mammal rodents.

Rodent population recruitment success is chiefly essential because of them being profound to environmental perturbations. This can aid as appropriate bio-indicators of varying eco-friendly surroundings in secure conservation regions.

This study seeks to manage habitat variability on rodent distribution and diversity allied to park edges, and evaluate how seasonality and vital habitat assembly variables impact the rodent community in Nairobi National Park.

1.3 Research Questions

1. Does vegetation characteristics and human disturbances influence the distribution of rodents in Nairobi National Park?
2. What is the status of rodent community structure (species composition, diversity richness, evenness and abundance) in Nairobi National Park?
3. How do seasonal change and human disturbance influence the structure of rodent community in Nairobi National Park?

1.4 General and specific objectives

The boundaries of conservation areas receive new species from the human-dominated landscape outside the protected area and allow species to escape from the conservation area. The general objective of this study to assess how changes in the edge habitats and human disturbance influenced the rodent community in Nairobi National Park. The specific objectives of the study were threefold:

1. To determine the effects of vegetation characteristics and human disturbances on the distribution of rodents in Nairobi National Park in Kenya.
2. To determine rodent community structure in the major vegetation types of Nairobi National Park.
3. To determine how seasonal changes and human disturbance influenced rodent community structure in Nairobi National Park.

1.5 Research hypothesis

Habitat characteristics, seasonal changes and human disturbance have no effect on the rodent community structure and abundance in Nairobi National Park.

1.6 Justification of the Study

NNP is fronting innumerable tribunals that impend its endurance and explicitly, the abundance and diversity of its fauna and flora. Precisely, human activity factors are progressively more prominent succeeding sequential years of infrastructural connections in the park combined with road constructions and anthropological settlements around it. Furthermore, weather pattern in current years has been characterized by fluctuating periodicity of short and long precipitation that have been erratic. The coherence of these influences could have adverse inferences on the ecosystem integrity of the protected NNP. Hence, observing the influences of natural and human drivers of change around and in NNP is crucial to aggravate suitable justifiable measures. Rodents are sensitive to habitat modifications therefore serve as bio indicators of ecological integrity. However, there is no dependable information on rodent abundance and diversity in NNP which can be used for perpetual monitoring of natural ecosystems arising from human activities on land neighbouring conservation areas. Therefore, this study will provide introductory information on small rodent community structure and assess the effects of seasonality, vegetation structure and edge effect of small mammal diversity for use in forthcoming monitoring of the health of NNP ecosystem.

CHAPTER TWO

2.0   LITERATURE REVIEW

2.1   Taxonomic diversity of mammalian Order Rodentia

Among the placental mammals, Order Rodentia is the most diverse and populous, accounting for over 40% of the mammalian species (Wilson and Reeder, 2005). Rodents comprise about 29 families, of which most species are in five families, Dipodidae Sciuridae, Heteromyidae Echymydae, and Muridae, (Wolff and Sherman, 2007). Out of the five families, Muridae, which is latin and means 'mouse' is the largest and most diversified with over 500 species that includes numerous species of rats, mice, and gerbils and occurs in Africa, Eurasia and America.

The family Sciuridae include squirrels, and chipmunks with the latter occurring in Africa, Americas and Europe, hence adapted to a wider habitat conditions. Family Echymydae comprises neotropical spiny rats, which are considered the most ecologically diverse rodents because they include terrestrial, arboreal and semi-aquatic species (Lara *et al.,* 1996). Although, spiny rats look like rats, they are more narrowly linked to guinea pigs and chinchilla. The Kangaroo rats and pocket mice, which are endemic in southern America, and are adapted to the arid environments, belong to the family Heteromyidae. Rodents in the family Dipodiade are found in the Northern hemisphere and include the jumping mice (*Jaculus jaculus*).

Africa has 290 species of rodents, which belong to 14 families. The most shared rodents in sub-Saharan Africa are the multi-mammate rats, belonging to the Family Muridae and genus Mastomys (Leirs *et al.,* 1996). The East African region hosts about 101 species of rodents

constituting 12 of the 14 families found in Africa (Fiedler, 1994). With its high habitat diversity and climatic zones, Kenya has about 106 rodent species (Musila *et al.,* 2019).

2.2   Habitat and dietary adaptation of rodents

The high adaptability of rodents to different habitat conditions, food types and sources as well as short reproductive cycles, are attributed to its success and wide distribution (Grzimek, 1988). For instance, habitats occupied by different species of rodents range from deserts, semi-arid savannah grasslands, wetlands, scrublands and forest (Delany 1974; Kingdon 1974). Further, rodents are extremely variable in their body shapes, size, diets, and lifestyle (Nedbal *et al.,* 1996). For instance, size of rodents may range from the small African pygmy mouse (*Mus minutoides*) weighing only 5 g and the largest rodent, crested porcupine (*Hystrix cristate*) weighing 20 kg. The diet of rodents is varied and includes roots, fruits, seeds and insects (Kingdon, 1974). Most rodents forage on plants including seeds, grains and small fruits, while omnivore species like mice and rats also feed on meat.

2.3   Life history strategies of rodents

The average gestation period of rodents is 21 to 23 days with a litter size of 5 or 6. Rodents are phylogenetically related, yet their morphology is heterogeneous while lifespans are extremely diverse. For example, based on chewing muscles, orbits and teeth, the squirrel is classified as a group of Sciuromorphs while the porcupine forms Hystricomorph and the rat form Myophorms. These are the three major rodent groups, have conspicuously different levels. Some have a short lifespan and relatively low to very high reproductive latent period (Willan, 1992; Auffray *et al*., 2009). For instance, *Mastomys natalensis* species may produce over 100 offspring annually

(Willan, 1992). Whereas in many situations, species of similar family show vast transformation in lifespan.

In a solitary family of Sciuridae, life cycle varies in twofold between chipmunks and tree squirrels. The eastern grey squirrel (*Sciurus carolinensis*) is an example of rodent that has an extreme lifespan of 24 years. Correspondingly, lengthy lifespans are predictable for other species of tree squirrels like the Indian giant squirrel (*Ratufa indica*) lives for 20 years while the Prevost's squirrel (*Callosciurus prevostii*) that has a lifespan of 21 years.

Rodents are habitat specialized with each retorting inversely to variations in landscape intricacy (Gentili *et al.,* 2014). There are open land and forest specialists as well as habitat generalists e.g., forest specialists avoid open patches including human-disturbed areas whereas the habitat generalists, *Apodemus sylvaticus* and *Sorex araneus* (common shrew) and are able to thrive in a wide range of environment (Tattersall *et al.,* 2002).

2.4   Ecological significance of rodents

Rodents are susceptible to slight environmental alterations and play precarious roles in many ecosystems (Ernst and Brown, 2001), hence being beneficial indicator species in foreseeing the significances of climate change and human land use alteration (Cameron and Scheel, 2001). In most cases, a high proportion of *Mastomys couch* in certain habitats indicates a high level of disturbance in the area (Avenant, 2011).

Rodents also act as prey to many predators, including birds of prey, snakes and terrestrial mammals (Greenwood, 1982 and Maxson and Oring, 1978). They are also vicious predators of

insects and molluscs. They are important in the food chains of diverse mammals, reptiles and birds (Willan, 1992). They also act as agents of seed dispersal (Fogel and Trappe, 1978) and contribute in spread of many communicable diseases to humans and domestic animals (Ross, 1983). Rodents also help in productivity of some plant species through inducing growth of shoots (Smirnov and Tomakova, 1971) when they graze on them. They have also contributed to crop failure (Gashweiler, 1970) and also destroying some crops thus lessening their ability to seed (Batzli and Pitelka, 1970).

Some species such as the prairie dogs (*Geomys bursarius*), mole rats (Bathyergidae) and the blind mole rats (*Spalax ehrenbergi*), that make tunnels through digging enhance soil quality through modification of the chemical and physical properties of soils and also improved aeration (Bakker *et al.,* 2004; Jones *et al.,* 1994). Additionally, rodents through the deposition of urine and faeces contribute significantly to the nutrients in grasslands and cycling of nitrogen (Clark *et al.,* 2005; Halffter, 1998).

2.5   Rodents Community Structure

The long-term biotic interactions, which may be direct or indirect, among diverse rodent species, within a defined location represents a community. Habitat stability and interaction among rodent species, such as predator-prey, herbivory, parasitism, mutualism and competition determine the structure of the community (Price *et al.,* 1986). Fundamentally, community ecology aims to address three areas, namely diversity, which addresses the number of species an area supports, relative abundance which addresses common or rare species and lastly phenotypic attributes

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addressing the behaviour and physical appearance of coexisting species. All these attributes also influence the structure of the rodent community (Price *et al.,* 1986).

In Kenya, species diversity or composition vary across ecological heterogeneities. In Kakamega forest, the rodent community comprised of eight species, (*Praomys jacksoni, Lophuromys flavopunctatus, Graphiurus* sp., *Hylomyscus stella, Mus (Nannomys), Lemniscomis* sp., *Minutoides, Mastomys* sp *Otomys* sp.) with *Praomys jacksoni* the most dominant with remarkable difference in composition between disturbed and non-disturbed sections of the forest (Mortelliti and Boitani, 2006). At the Kenyan coastal forest, Canova and Fasola, (2000) recorded a community of six rodent species completely different from Kakamega forest who's namely, Black tailed gerbil (*Tatera nigricauda*), Huet's bush squirrel (*Paraxerus ochraceus*), Multimammate rat (*Mastomys natalensis*, Spiny mouse (*Acomys* cf. *wilsoni*), Bush rat (*Aethomys hindei*) and Nile rat (*Arvicanthis niloticus*). At Mabira forest, Uganda, 14 species were identified with *Lophuromys stanleyi* being the most dominant species (Ssuuna *et al.,* 2020). The ecological differences, including altitudinal variations at the Kenyan Coast, Kakamega (inland Kenya) and Mabira (inland Uganda) coupled with differences in sampling techniques and efforts could account for the heterogeneity in community species composition.

The species composition or diversity may also differ between biomes or by altitudes. Young *et al.,* (2017) reported that a savannah grassland, Laikipia County in Kenya, have relatively high numbers of rodent species, which includes (*Mus sorella, Lemniscomys striatus, Arvicanthis niloticus, Zelotomys hildegardeae, Rattus rattus, Dendromus mysticalis, Dasymys incomtus, Xerus erythropus* and *A. nairobae, Paraxerus ochraceus,*). Interestingly, rodent diversity seems

to be structured within the savannah, depending on the land use or environmental modifications. Young *et al.,* (2017), demonstrated that *Mus minutoides* dominated croplands, *Gerbillus pusilus* dominated pastoral land while *Saccostomus mearnsi* dominated both wildlife used areas and big game excluded plots.

2.6   Determinants of Rodent diversity

Rodents are some of the most diverse mammals, with global distribution, (Nowak, 1999) having abilities to adapt to a wide range of habitats in Africa (Bekele, 1996). The wide variety of climatic situations and distinctive topography are reasons for varied biotic resources (Mulligan, 2010). Population crescendos of rodents undergoes frequent instabilities suggested to be subjective to the ecological and environmental factors (Utrera *et al.,* 2000). Given that most rodents are specialised according to habitat conditions, each species will respond differently to changes in landscape complexity and dominate variable biomes (Gentili *et al.,* 2014).

Hence there are rodents that are altitude generalists whereas there are those that can endure in a constricted altitudinal change (Mukinzi *et al.,* 2005). The damage of ground undergrowth leads to lack of food source for small rodents thereby decreasing rodent diversity but accumulate predation risk (Hoffmann and Zeller, 2005). Lack of ground cover and ample food principally regulate the number of specific rodents in a certain region while species structure in various habitat types is affected by predation risk and habitat structure (Massawe *et al.,* 2007). Harmless sites for propagation and development of herbaceous vegetation are provided by bushy vegetation therefore offer assortment of rodent's food resource (Kerley *et al.,* 2004).

In the presence of ample food in habitats such as forests, grasslands and bushland, the density of rodents is heightened (Lentic and Dickman, 2005). Supply of different resources resulting from

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habitat variability can lead to diversity of species (Crammer and Willig, 2002). Inevitable impacts on demographic parameters of rodents may be synchronized at fine scale of or large scale over time by changes in landscape and habitats (Krohne and Burgin 1990: Ranta *et al*., 1995., Bowman *et al.,* 2001).

Population dynamics and breeding of several rodent species have been strongly associated with climatic parameters mostly rainfall (Leirs *et al.,* 1992; Leirs *et al.,* 1996). According to Massawe *et al.,* (2011) rainfall is directly linked to habitat productivity on which rodents depend and thus density fluctuations often correspond with rainfall patterns. Rainfall influence vegetation height and amount of resulting cover, which are components of a suitable habitat for rodents (Bakker *et al.,* 2009). Less vegetation cover increases predation risk, reduces food quality and advances negative competition which eventually affects population performance (Keesing 1998; Flowerdew and Ellwood 2001; Vroni 2007).

2.7 Determinants of rodent abundance

In ecology, population density is an important measure of species demographics and performance and is determined by the number of all individuals in a determined volume or area. In studies based on attraction e.g., baited traps, it is often a challenge to define and calculate the size of the studied area. This is because the studied area would be influenced by multiple factors such as the location where the trap is stationed, the bait type and animal mobility (Cavia *et al.,* 2012). Mobility is dependent on terrain, species, age, sex or reproductive stage, therefore, studies use relative abundance which is number of individuals with regard to measurement different from the surface or volume (Seber, 1992). This type of abundance is related to the sampling effort, e.g., the number of traps set over a determined time. Relative abundance may be estimated

by the trap success (Seber, 1992) or relative abundance index (Begon, *et al*., 1987), both of which estimates the number of different animals trapped / number of active trapping kits (traps) multiplied by the time that the kits are left to be active.

Even if the entire abundance values are unknown, the advantage of using relative abundance estimators allows the assessment of the abundance among sites or of the similar site at diverse times (Cavia *et al.,* 2012). With home ranges generally declining with accumulative population density, the animal space utilization structures can be affected by the intra- and interspecific density of individuals competing for resources. If resources are abundant, rodent tend to reduce home ranges and this series may result from increased abundance of resources basically linked with increased density populations, if the two species were responding to different subgroups of resources. Intraspecific density directly diminish home ranges, because families are more possible to hinder each other due to the overlying of space utilization arrangements. Consequently, results suggest corresponding resource use patterns or space between species, with resulting frail competition and niche variation (Habrerie, 2019).

Home ranges of the two co-existing rodents seem to be affected by conspecifics, across several years and population densities only, suggesting that the two species may cohabit in the area of study owing to partial space or resource use intersection (Casula, 2018). Environmental factors e.g., climatic conditions, habitat exploitation by humans, predation, nature and density of vegetation influence the distribution and abundance of rodents (Johnson and Horn, 2008).

2.8 **Effect of human activities and the habitat edge effect in Nairobi National Park**

In animal ecosystems, disturbance, which can be triggered by natural factors or human, is termed as "a change in conditions which interferes with the normal functioning of a biological system" (Van Andel *et al.,* 1987). Off road driving, vegetation trampling and refuse dumping which is caused by human has caused habitat disturbances (Schonewald-Cox and Buechner, 1992), recurrent fires (Sauvajot, 1995), propagation of human paths (Bolger *et al.,* 1997) and other social and frivolous amenities.

Some of these anthropological turbulences may be progressive while others may be perpetual but have variable influence on animal populations. Outdoor recreational infrastructures in protected areas are widely accepted in many parts of the world (Eagles *et al.,* 2002) as they are perceived to be more compatible with biodiversity conservation (Larson *et al.,* 2016).

On the contrary, recreation is one of the leading factors endangering the flora and fauna in the United States of America (Losos *et al.,* 1995), especially the 188 bird species at risk worldwide (Steven and Castley, 2013). Recreational facilities, such as picnic sites, cleared-off enclosures have been linked to several impacts on animal and habitat ecology e.g., changes in temporal and spatial habitat use (George and Crooks, 2006; Rogala *et al.,* 2011), declines in habitat abundance, density or occupancy (Reed and Merenlender, 2008; Heil *et al.,* 2007), depressed fecundity (Finney *et al.,* 2005), community composition and altered species diversity (Riffel *et al.,* 1996; Kangas *et al.,* 2010).

Habitat edges are abrupt transition zones between ecosystems or habitats and their effects include any changes that occur as a consequence of that transition (Bestelmeyer *et al.,* 2011). These transitions in vegetation at edges are usually associated with similarly sudden changes in

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climate, with consequent impacts on animals and plants as a result of changing resource distribution and biotic interactions (Fagan *et al.,* 1999).

While habitat edge effect is incredibly common and is generally thought to help explain large-scale patterns in community structure and species distribution, it is also considered to be stochastic and highly dynamic over time and space. The responses of wildlife communities at adjoining land-uses often vary by species, microhabitat and season (Zachary, 2013).

Edges in different habitats were once considered advantageous for biodiversity but as studies focused on anthropogenic edges, their detrimental effects became apparent (Rand *et al.,* 2006). Within agricultural lands, native wildlife communities often exploit isolated patches of intact indigenous vegetation scattered throughout the croplands. One conservation concern about this landscape conformation is that conditions created at the boundary (edge) of agricultural lands are likely to modify wildlife communities within natural areas, favouring generalists at the expense of specialists. Unique conditions near edges are often similar to those of disturbed habitats and may therefore favour invasion by species that prefer those resources (Chen *et al.,* 1993). As a consequence, diversity of organisms often increases near edges (especially in forest fragments), both the forest interior and the newly created open area causing the edge (Yahner, 1988; Laurance, 1994; Gascon *et al.,* 1999; Pardini, 2005).

Edges between tropical forests and human settlements are of precise concern because of the contrast between the more continuous forest interior and the variegated temperatures and enormous extremes of the neighbouring open areas, which may be urban or rights of way for road agricultural, pylons or rail (Matlack, 1993; Pohlman *et al.,* 2007; Laurance *et al.,* 2009). As

natural areas become progressively fragmented, understanding the effects of edges and fragmentation is important for conservation. The impact of wildfires on the diversity of small mammals is intricate and poorly assumed as edge effects. Studies in non-tropical ecosystems, including grasslands deserts, and temperate forests have recorded a decline in the abundance of some species immediately after a wildfire, reduced abundance in areas that are burned recurrently or the supremacy of a few species in burned areas (Simon *et al.,* 2002; Converse *et al.,* 2006).

In most cases, the time elapsed since the disruption seems to be an important variable determining the alignment of the mammalian community (Simon *et al.,* 2002; Torre and Diáz 2004; Fisher and Wilkinson 2005). In the Cerrado, (vast tropical savannah eco-region of Brazil), Briani *et al.,* (2004) and Vieira (1999) observed that small mammals were relatively tolerant to such effects, and were especially abundant during the early successional stages.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

3.1.1   Location

The study was carried out at Nairobi National Park (NNP), located seven kilometres from the Nairobi city, Central Business District, a protected region in Nairobi County (Figure 1). The park has a perimeter electric fence with the exception of one side, southern part that is open as a passageway for animal dispersion.

In the recent past, the park has been impacted by heavy infrastructural developments, including construction of a tarmac highway along the southern bypass, the Standard Gauge Railway line and several human settlements at the park boundary besides occupied areas inside.

3.1.2   Climate

The park experiences annual bimodal pattern in precipitation with heavy rainfall in March to May and low rainfall in October to December, with variable amounts each year. Between 2000 and 2017, the intra seasonal rainfall variability increased (Ogega *et al.,* 2019). According to Ng'ang'a, (1992), the temperature fluctuates between warm season in December to April and the cool period extends from June to August. Relative humidity oscillates between 55% during the day and increases to 80% at night.

3.1.3   Natural Vegetation

There are three vegetation biomes in NNP. The principal biome consists of the open grasslands dominated by *Pennisetum mezianum* and *Themeda triandra,* grass species. There are dispersed low laying canopy of *Acacia drepanolobium* (Deshmukh, 1986). The other vegetation

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ecosystem is the open woodland forest, which is on the raised areas in the west side of NNP and

finally the riverine woodland biome along the numerous streams inside the park.
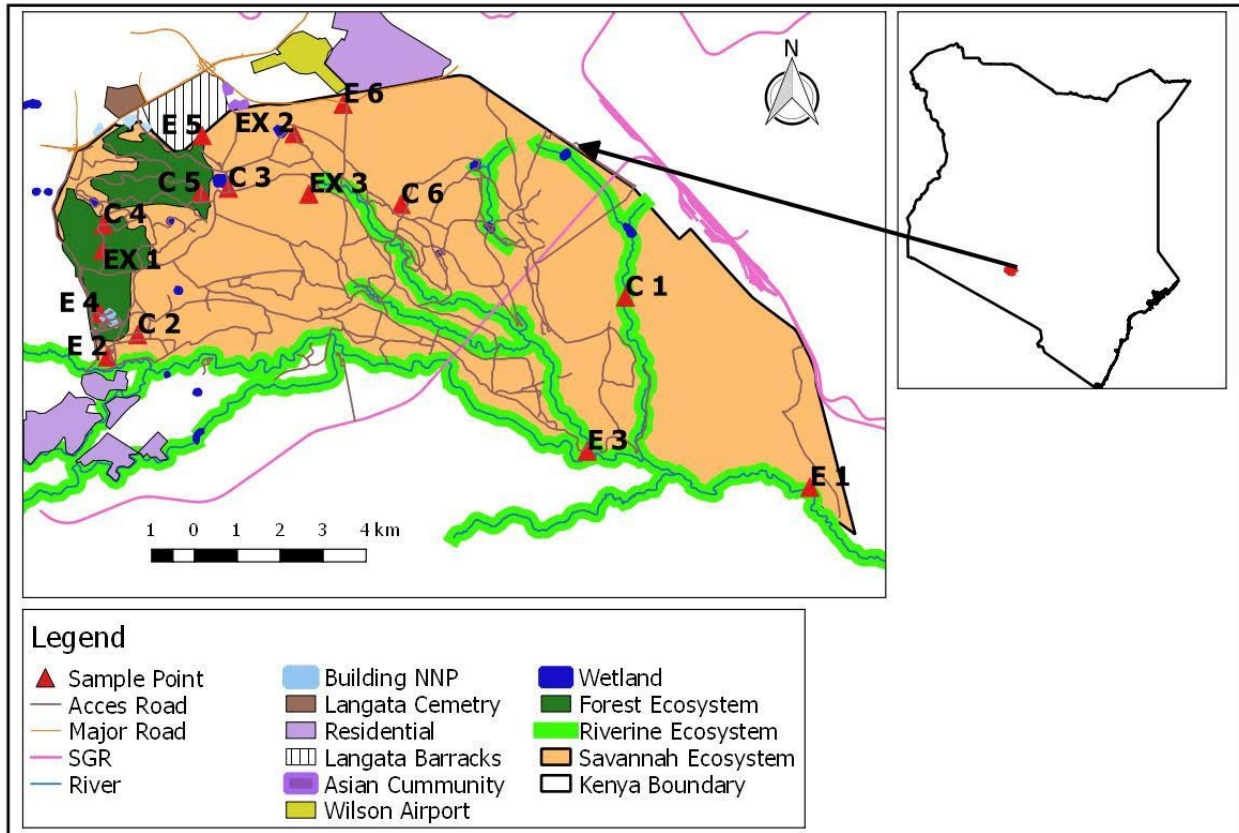
Figure 1: The Nairobi National Park showing the sampling points in the Savanna, Forest and Riverine Ecosystems (E – Edge habitat, E1 Athi Basin, E2 Bangla, E3 Mokoiyet, E4 David Sheldrick, E5 Clubhouse, E6 Asian Settlement, C – Sampling points acting as control for the edge habitats, C1- Lion Dip, C2- Kingfisher, C3- Nangolomon Dam, C4- Nairobi Tented Camp, C5- Nangolomon Circuit, C6- Southern Bypass, EX – extra sampling points within the park, EX1- Nairobi Tented Camp, EX2- Hyena Dam and EX3- Park Point 2B) (Source: Muthoni, 2021).

3.1.4 Wildlife

This park has an entertaining variety of big mammals i.e. herbivores e.g., several species of zebra (*Equus quagga*), and carnivores e.g., jackal *(Canis aureus)* and lion *(Panthera leo)* among others. It is also a nature reserve for many bird species as well as lesser mammals such as several small rodents, bats and shrews. The rodents are hunted upon by wild animals like snakes and wild cats, and other smaller mammals. NNP serves as a conserved region that offers vital ecosystem facilities to humanity and an entertaining service for the city inhabitants. Nevertheless, NNP also charges entry preservation fee for use in the upkeep of the facility. Therefore, the park is an essential conservation area and a great source of revenue for Kenya's economy.

3.2 Materials and methods

3.2.1 Rodent sampling

The various types of traps used for trapping rodents are divided into live traps and kill traps. Live traps (Figure 2), capture the animal and it is found alive in the trap by the collector. These traps include Havahart/Tomahawk trap, Longworth trap, Sherman trap and Plastic mouse trap.

Havahart/ Tomahawk trap:

- Used to capture large rodents while still alive

Longworth trap:

- Is a live trap, currently outdated. It was used to trap small rodents but was replaced by Sherman trap.

Sherman trap:
- The most updated and commonly used rodent trap.
- Captures live rodents.
- Very portable and can be collapsed (Folded), therefore transportation is easy and occupy small space.
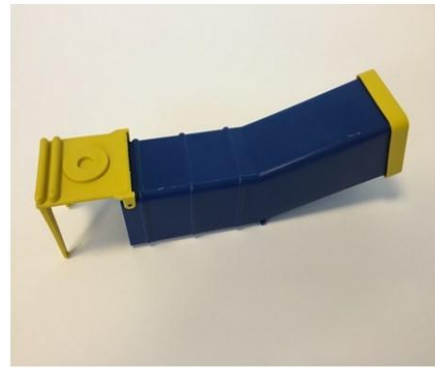
Plastic/Seesaw mouse trap:
- Currently not used, but was used to capture small rodents.
- Bias in capturing only small sized rodents missing on the large ones.

Figure 2: Tomahawk, Longworth, Sherman and Seesaw traps commonly used for live trapping of rodents.

Advantages of live traps is that it catches live animals and hence extra data are available e.g., fresh blood and fresh tissue samples and are more selective as opposed to snap traps where the latter even captures undesired catch. Disadvantages of using live traps is that they are more bulky, catch a few animals, and requires technical know-how and they are expensive.

Kill Traps (Figure 3) are traps which are set with a trigger mechanism which is disturbed by an animal and it snaps and strikes, resulting into serious injury or death of the captured animal example include snap trap. Advantages of kill traps is that they are generally lighter, less bulky and simpler locking mechanism, can be purchased or made locally and they are generally cheaper.

Disadvantages of kill traps is that they kill or injure the specimen, are non-selective, limits the type of data that can be collected, and captured specimen can be lost to other prey in the trapping area since the catch is exposed.

Trapping areas of rodents can be trapped by targeting where they sleep overnight or where they forage (eat) at night or daytime. Trapping should be done depending on whether it is a nocturnal or diurnal species and also on preference of habitat, which could be rocky cliffs, forest, savanna or riverine areas and many others too.
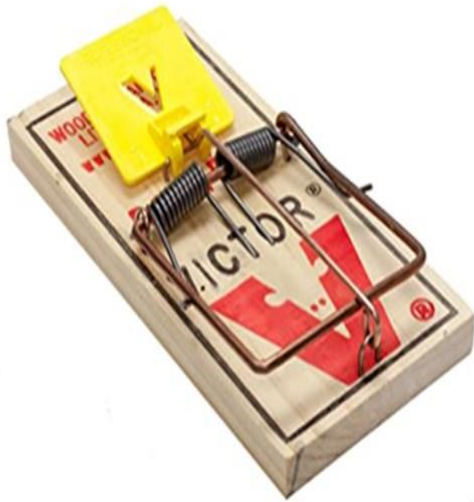
Snap trap (Victor trap):
- Made of wood.
- It kills rodents by hitting them when triggered.

Snap trap:
- Made of metal.
- It kills rodents instantly.

Figure 3: Images of Snap traps, which are common kill traps for rodents

3.2.2 Habitat structure of Nairobi National Park

Most abundance and species composition, change as disintegration occurs in the landscape by losing the species that require vast areas (Koprowski, 2005). They choose the desired habitat for their survival. The indigenous vegetation left after variations may reduce in size and may be detached from nearby continuous habitat. This patchiness can create discontinuity of distribution of critical resources for rodents where many habitats of mammals are undergoing degradation due to great human encroachment of infrastructural establishment (Ewers, 2006).

In Kenya the forest area covers 2.4% (approximately, 1,400,000 ha) where 1,240,000 ha is indigenous while 160,000 ha comprises plantation forests out of which 164,000 ha of land are gazetted as forest Reserves (IUCN, 1996). Even though forests cover are relatively a small

proportion of the total land area in Kenya, they still contain 30% of birds, 40 % of the larger mammals and 50% of the nation's tree species (KIFCON, 1994).

Vegetation dominated by woody plants, principally trees, a canopy of which covers below 10 per cent of the ground surface, occurring in climates with a dry season of about three months or more and profoundly important for rodents, is what defines a dry forest (Chidumayo, 2010). This definition incorporates vegetation types commonly termed savannah, wooded grassland, shrubland woodland and thicket as well as dry forest in its strict sense. Woodlands in Africa are diverse vegetation realizations that include thicket, bushland and woodland proper and in some instances, wooded grassland. Water is a critically important resource that determines the survival of all animal species, particularly in the arid and semi-arid environments. Water is the most important limiting factor to the abundance and distribution of wildlife in the savannahs of East Africa, especially in the dry seasons. The importance of water to the survival of wildlife has been reported in most literature (Ogutu, 2010). The effect of water on wildlife and its dependence on it, is crucial to the species. Most of the water dependent species are the grazers while the browsers tend to be water independent therefore presence of large water sources allow wild animals to spread out during rainy season (Ogutu, 2010).

Studies indicate that (Tews *et al.,* 2004) species diversity is prompted by habitat heterogeneity whereas (Makundi *et al.,* 2009) the abundance of some species is directly modulated by rainfall pattern. High rainfall has been linked with surge of some types of food and general presence for rodents and hence increasing the carrying capacity for appropriate habitats (Odhiambo *et al.,* 2008). Generally, rodents exhibit precise habitat specialization where some are categorised as

open land or habitat generalists and each group respond otherwise to habitat organisational variability (Gentili *et al.,* 2014).

Agreeing to the Köppen Geiger's climate grouping, the climate types associated with woodlands and dry forests in Africa include very dry, warm dry and warm sub-humid climates. These types are tropical with sporadic dry and wet seasons in which rainfall is caused by the penetration of the Inter-Tropical Convergence Zone (ITCZ) during the period of increased sun. The period of decreased sun is characterized by trade winds linked with a discrete dry season.

The abundance and distribution of wildlife population will vary with food supply, seasonality, predator activity and a host of other biotic and abiotic factors (Morrison *et al.,* 1986).

Furthermost studies on the ecology of African rodents have been fixated on communities in secondary bush, formerly cultivated land or savanna, henceforth tropical rainforests are the most understudied of key habitat types (Delany, 1974; Isabyrie-Basuta and Kasenene, 1987).

3.2.3   Study design for rodents

Stratified random sampling of rodents was carried out in three distinct vegetation types: Savanna open grassland, upland dry forest and riverine forest or woodland. Line transect approach was used because from previous studies, sampling return versus effort was low compared to data from similar savanna parks in Kenya where a grid system was used because line transect provided better resolution of community structure for a given effort (Wato, 2006).

There were 15 sampling points distributed in all the three main habitats in the park. Within these habitats, traps were placed in line transects 100m long in different areas: at the edges of human settlements and along the park boundaries. In addition, for each habitat and edge characteristic, a line transect of traps was placed on representative control sites. 20 Sherman traps in each

trapping station baited with a mixture of peanut butter and whole oats was laid and observed for three consecutive nights. Trap inspection was done each morning, removing and identifying the captured rodents and determining their age, mass, sex, and reproductive condition, and marking them before releasing them on site. All the information was recorded on a field notebook and included GPS location of the site, site name, and the animal species trapped, sex gender and its relative age. Additionally, the following morphometric measurements were taken on all individuals trapped: Head to tail length, tail length, ear lobe length, left hind foot length and fresh body weight. This procedure was carried out every two months to capture seasonal variations in the year. The invasive rodent species, *Rattus rattus,* were collected and taken the mammalogy laboratory in the National Museums of Kenya.

Sampling for vegetation was done by assessing other parameters like the shrubs, trees where each plot was subdivided into 10m by 10m by 10m grid along the identified rodent sampling transect. Two observers surveyed all the plants and identified them to species level using field guides. Trees were classified in the form of tree density and were represented as percentage cover. The understory vegetation (grasses) was surveyed in all the seasons of the collection period. A 10-pin point frame was centered within the quadrat and then the total number of vegetation pin hits for each species recorded.

3.2.4 Sampling of vegetation at the study sites

The site characteristics were specifically described by tree and shrub densities, amount of ground cover by herbaceous layer and leaf litter, and land gradient.

3.2.4.1   Estimating tree density

Point-centred-quarter (PCQ), method was used (Mitchell, 2007). This method offered a means of taking rapid, quantitative samples of vegetation which was free from subjective estimates and which yielded data of species compositions.

It was done by selecting an area along the identified transect. A grid map was used to pinpoint the sampling sites. Descriptive vegetation stands categorized by homogeneity in species composition and physiognomic structure were selected for sampling. In each of these chosen sites, starting points for line transects were randomly selected. Transects alignment from the starting point were determined by nature of the topographic characteristics of the area, with transects cutting across the habitat of choice. Sampling points were systematically selected along the transect line. The area around each point was divided into quarters by use of another second line perpendicular to the line transect at the sampling point. Individual woody species close to the point in each quarter was identified, height and point to individual distance determined. This was repeated for all the points. All the average distances for all five points were added and divide by five to find the overall distance of the trees in meters. For the average area each tree takes, multiplying the average distance in meters by itself was done.

3.2.4.2   Assessment of ground cover

The ground cover was recorded for all the 3 habitats and per transect for all the species along that transect. It was done at the same time for all transects. Ground cover was measured for both living and the dead plant materials. This was determined by random throws of a 30*30cm wire quadrat and making a visual assessment of the percentage of the quadrat cover by living and

dead plant material. Several locations at any one sampling site were sampled for ground cover and the percentage ground cover averaged.

3.2.4.3   Assessment of shrub density

Shrub density was estimated by usage of distance laser and height, diameter at breast height measuring tape, a 3m long polymerizing vinyl chloride measuring pole and pin flags for measuring the selected plots. It was carried out from one end of the transect as the starting point using the distance laser meter to explain the furthest edge. Pin flags were positioned at the edges. Shrubs in each of the plots formed were sampled. Shrubs with as a minimum of 50% of the base inside the plot were included. Shrubs beneath 5m in height were omitted.

3.2.4.4   Assessment of herb layer

The extent to which ground is covered by herbaceous plants is referred to as the herb layer and was determined by quantification of these herbs within the nominated regions in plots of 1m by1m plots connected unsystematically in each research region. All the present herbaceous plants within the selected plots were recorded.

3.3   Data Analysis

3.3.1   Rodent Species Diversity, Richness, Evenness and Abundance

Rodent species diversity, species richness, abundance and evenness were determined for the entire area sampled (all sampling sites combined), for separate sampling sites, vegetation type (forest, savannah, and riverine vegetation) and human disturbed sites (habitat edges, the adjacent

control sites, and the pristine park interior) using Simpson diversity index, Shannon Weiner diversity index, and the Brillouin diversity index.

Shannon-Wiener Index (H') is the most used diversity index in ecology and it quantifies the uncertainty associated with predicting a new taxon given number of taxa and evenness in abundances of individuals within taxa. Its defined using the following equation:

$$H' = \Sigma \left(\frac{ni}{N} \times ln \frac{ni}{N} \right)$$

Where - ni is the number of individuals of each of the i species and N is the total number of individuals at each site. Values of H' can range from 0 to 5 but typically range from 1.5 to 3.5.

The Shannon-Wiener Index assumes that the samples were collected randomly. The Brillouin Index (HB) is a modification of the Shannon-Wiener Index that is preferred when samples are likely not to have been sampled randomly. It is defined by the following equation:

$$H_B = \frac{lnN! - \Sigma ln\, ni!}{N}$$

Simpson's Index (λ) is the probability that two individuals drawn at random from an infinitely large community will belong to different species. It is more of a measure of dominance and as such weights towards the abundance of the most common taxa. Simpson's Index is usually expressed as the reciprocal (DS=1−λ) so that as a measure of diversity, higher values represent higher diversity. It is less sensitive to rare species than the Shannon-Wiener Index. Simpson's index ranges from 0 to 1 and it is defined by the following equations:

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$$\lambda = \sum \frac{ni\,(ni-1)}{N(N-1)}$$

$$D^s = 1 - \sum \frac{ni\,(ni-1)}{N\,(N(-1)}$$

These indices were calculated using the "vegan" package of the R statistical software (Oksanen *et al*., 2020). The differences in diversity across vegetation types, disturbance types and seasons was tested with the Hutcheson student t tests from the "ecolTest" package (Salinas and Ramirez-Delgado, 2021) in the R software for statistical computing.

3.3.2   Tree and shrub density, percent cover and dominance

The density of trees and shrubs, the percent herbaceous cover and the dominant plant species (i.e. those with ≥ 80% ground cover) were determined for each study site where rodents were sampled.

These habitat features were used to characterize their relationships with vegetation type and habitat disturbance by humans. Further, variation in tree and shrub densities as well as percent herbaceous cover were also used to test their direct influence on rodent community structure.

To characterize habitat variation in tree and shrub density, herbaceous cover, and dominant plant species in relation to vegetation type, and human disturbance, Principal Components Analyses (PCA) was used. PCA was used to classify vegetation type or habitat disturbance by plotting PCA scores in a two-dimensional bi-plot. PCA is a scaling procedure that reduces dimensions of complex multivariate data in this case shrub densities, tree densities, herbaceous cover and

dominant plant species and projects these reduced dimensions to a grouping variable to discern habitat classes and their important characteristics.

Additionally, differences in mean tree and shrub density between natural vegetation types and human disturbed areas were tested using Analyses of Variance (One-way ANOVA). Differences in herbaceous cover among vegetation types and disturbed and control sites were tested using Kruskal -Wallis tests. Principal components analyses were performed using the "vegan" package while ANOVA and Kruskal-Wallis tests were performed using the core R software (R Core Team, 2021).

To test the influence of habitat metrics such as tree and shrub density and herbaceous cover, vegetation type and habitat disturbance on rodent species richness, abundance and diversity, a Generalized Linear Model framework with a Poisson family and a log-link function was used. Rodent species richness, abundance, and diversity (Shannon Weiner diversity index) per site, were incorporated into the model as dependent covariates in three independent models.

Tree density, shrub density, herbaceous vegetation cover, vegetation type (Forest, Savannah, and Riverine vegetation), disturbance (disturbed, control and park) and season were used as independent covariates (predictor variables). Numeric variables particularly vegetation metrics were standardized to stabilize the variance of coefficients and to provide unbiased hypothesis testing.

Univariate analysis followed by multivariate analyses and model selection was performed. Model selection was attained by computing the coefficients of all possible simple and complex model combinations using the 'MuMIn' package in the R statistical software (Barton, 2020). The finest model was nominated based on Akaike Information Criteria (AIC); the most parsimonious or best model being one with a small AIC.

CHAPTER FOUR

4.0   RESULTS

4.1   Patterns of rodent diversity

Rodents were captured during 2700 trap nights, involving 20 traps per location for three nights each month over a three month period. Sixty five of these trap nights experienced defective traps or caught non-target species leaving 2635 effective trap nights available for target species. A total of 56 individual rodents were captured consisting of five species namely, *Hylomiscus* sp, *Lemniscomys striatus*, *Mus mus*, *Otomys tropicalis* and *Rattus rattus*. The most abundant species was *Lemniscomys striatus* (43%), followed by *Rattus rattus* (23%) and *Otomys tropicalis* (20%). The least abundant species was *Mus mus* (5%) and *Hylomiscus* sp (9%). Overall rodent diversity in Nairobi NP was low (Simpson = 0.7130102; Shannon Weiner = 1.40, Brillouin index = 1.27). Pielou's species evenness, J was moderate (0.44), indicating nearly average equity in species distribution (Table 1).

Rodent species richness varied across 15 sampling sites investigated in this study despite using identical trapping effort. No rodents were captured from four sites (Southern Bypass, Nangolomon Circuit, Lion dip, and Asian settlement) whereas the greatest number of rodents was captured at the David Sheldrick and the Nairobi tented camp site. More species were captured per site at (Club House, David Sheldrick and Nairobi Tented Camp sites) whereas the rest of the sites had only a single species captured (Ex1, Ex2, Hyena dam, Kingfisher, Athi basin, Bangla, and Nangolomon dam). The site with the highest diversity was Club House (DS = 0.56, H' = 0.95 and HB = 0.56) and Nairobi Tented Camp (DS = 0.57, H'= 0.94 and HB = 0.69). The

David Sheldrick site had a moderate species diversity (DS = 0.30, H'= 0.48 and HB = 0.40). The

rest had zero diversity.

Table 1: Variation in rodent diversity indices species richness, evenness and rodent abundance
by sampling site or location

SAMPLING LOCATION	SIMPSON (D^S)	SHANNON-WEINER INDEX (H')	BRILLOUIN INDEX (H$_B$)	SPECIES RICHNESS	PIELOU'S EVENNESS (J)	SPECIES ABUNDANCE
Asian Settlement	-	-	-	-	-	0
Athi Basin	0	0	0	1	-	1
Bangla	0	0	0	1	-	4
Club House	0.560	0.950	0.599	3	0.510	5
David Sheldrick	0.305	0.483	0.395	2	0.440	16
Ex1	0	0	0	1	-	3
Ex2	0	0	0	1	-	5
Hyena Dam	0	0	0	1	-	1
Kingfisher	0	0	0	1	-	6
Lion Dip	-	-	-	-	-	0
Mokoiyet	0	0	0	1	-	3
Nairobi Tented Camp	0.568	0.937	0.691	3	0.517	9
Nangolomon Circuit	-	-	-	-	-	0
Nangolomon dam	0	0	0	1	-	3
Southern Bypass	-	-	-	-	-	0
Grand Total	0.713	1.394	1.267	5	0.443	56

Forests had a higher species diversity, richness and abundance than either savannah or riverine vegetation, however, species evenness was similar between forest and savannah vegetation (Table 2). There was a statistically significant difference in Shannon Weiner diversity between forest vegetation and savannah (forest = 1.50, savannah = 0.54; Hutcheson t-statistic = 5.98, df = 21.27, P <0.0001) or riverine vegetation (forest = 1.50, riverine = 0.377; Hutcheson t-statistic = 4.68, df = 9.91, P = 0.0009). There was however, no difference in diversity between savannah and riverine vegetation (savannah = 0.540 and riverine = 0.377; Hutcheson t-statistic = 0.611, df = 14.03, P = 0.551).

Human disturbed sites or edges had a slightly higher Shannon Weiner rodent diversity index than the control sites (Table 2), but the difference was not statistically significant (edge = 1.145, control = 1.022; Hutcheson t-statistic = 0.91, df = 50.38, P = 0.370).

Table 2: Variation in rodent diversity indices, species richness, evenness and rodent abundance across vegetation types and disturbance categories

	SIMPSON (D^S)	SHANNON-WEINER INDEX (H')	BRILLOUIN INDEX (H_B)	SPECIES RICHNESS	PIELOU'S EVENNESS (J)	SPECIES ABUNDANCE
Vegetation						
Forest	0.754	1.500	1.313	5	0.469	35
Riverine	0.219	0.377	0.260	2	0.316	8
Savanah	0.355	0.540	0.435	2	0.512	13
Disturbance						
Control	0.612	1.022	0.881	3	0.558	23
Edge	0.640	1.146	0.990	4	0.461	29
Generally protected Area	0.375	0.562	0.347	2	0.541	4

4.2   Habitat variability and effects of human disturbance

The 15 sites sampled were classified into three vegetation types namely, Savannah (Asian Settlement, Bangla, Ex1, Kingfisher and Southern Bypass), Forest (Club House, David Sheldrick, Ex2, Nairobi Tented Camp, and Nangolomon Circuit) and Riverine (Athi Basin, Hyena Dam, Lion Dip, Mokoiyet, and Nangolomon Dam). These sites were also classified according to disturbance by humans into three groups: pristine vegetation, human disturbed site and a control for each human disturbed site. Edge or disturbed site consisted of (Asian Settlement, Athi Basin, Bangla, Club House, David Sheldrick, Mokoiyet and Southern Bypass), while the control sites consisted of (Ex2, Kingfisher, Lion Dip, Nairobi Tented Camp, Nangolomon Circuit, and Nangolomon Dam).

Principal component analysis of trees and shrub densities and herbaceous cover from 15 sites belonging to three vegetation classes resulted in three principal axes accounting for 100% of the variance with the first two axes responsible for about 93% of the variance. On the other hand, PCA results based on the dominant plant species in each sampling site produced 15 principal axes from the presence and absence of 31 plant species. Twelve of these principal components explained 100% of the variance with 6 principal components explaining 90% of the variance. Projecting vegetation types and habitat disturbance groupings on PCA axes revealed that vegetation types (Figure 4A & 4B) could be discriminated from habitat metrics but not human disturbance (Figure 4C & 4D).
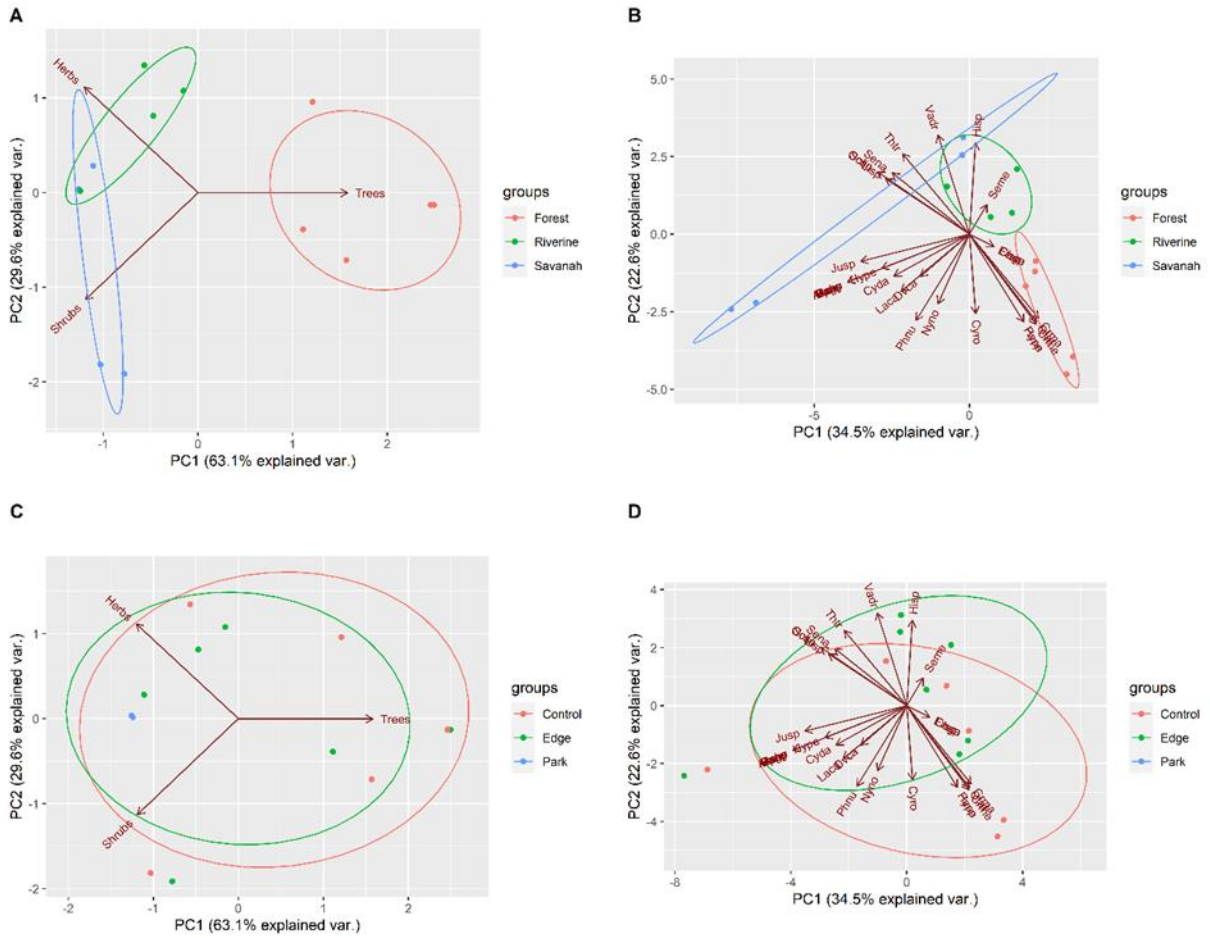
Figure 4: Principal component analyses bi-plots showing clustering of vegetation type (A, B) and human disturbance (C, D) using shrub density, tree density, and herbaceous cover (A, C) and species composition (B, D)

Analyses of Variance revealed that tree and shrub densities varied across vegetation types and habitat disturbance, but the variation was statistically significant for vegetation types but not between edges and controls (Table 3; Figure 5). Similarly, Kruskal-Wallis analyses revealed that median herbaceous cover variations were statistically significant across vegetation types but not across human disturbance gradient or categories (Table 3).

Table 3: The mean and median variation in vegetation metrics across vegetation types and human disturbance categories

Habitat classification	Vegetation metric	Mean ± SD	Median ± MAD	Kruskal-Wallis H	P value
	[A]				
Dry upland forest	Herbaceous cover	29.00 ± 34.35	15 ± 7.41		
Riverine vegetation	Herbaceous cover	93.2 ± 4.15	94 ± 5.93		
Savannah grassland	Herbaceous cover	68.8 ± 28.63	89 ± 1.48	7.757	0.0207
Dry upland forest	Shrub density	280 ± 268.33	400 ± 296.52		
Riverine vegetation	Shrub density	680 ± 414.73	600 ± 593.04		
Savannah grassland	Shrub density	1440 ± 517.69	1200 ± 296.52	10.17	0.0026
Dry upland forest	Tree density	194 ± 59.1	220 ± 44.48		
Riverine vegetation	Tree density	25 ± 35.36	0.00 ± 0.00		
Savannah grassland	Tree density	15 ± 22.36	0.00 ± 0.00	28.95	<0.0001
Disturbance	[B]				
Control	Herbaceous cover	57.17 ± 40.3	65 ± 43		
Edge	Herbaceous cover	62.14 ± 38.61	90 ± 8.9		
Generally protected area	Herbaceous cover	88.5 ± 0.71	88.5 ± 0.74	0.0902	0.9556
Control	Shrub density	700 ± 723.88	500 ± 593.04		
Edge	Shrub density	771.43 ± 647.34	600 ± 593.04		
Generally protected area	Shrub density	1200 ± 0.00	1200 ± 0.00	1.124	0.357
Control	Tree density	111.67 ± 116.05	100 ± 148.26		
Edge	Tree density	71.43 ± 76.96	50 ± 74.13		
Generally protected area	Tree density	0.00 ± 0.00	0.00 ± 0.00	0.451	0.648

Herbaceous cover varied significantly among the sampled habitat with the highest cover occurring in the riverine vegetation (93 %,) followed by savannah grassland at 68%. Shrub density and tree density were highly variable in controls compared to disturbed sites, but the differences were not statistically significant (Figure 5A - 5C). The herbaceous cover was higher in riverine and savannah vegetation compared to forests (Figure 5D), shrub density was highest in savannah and lowest in forest vegetation, but it was intermediate in riverine habitats (Figure 5E). Tree density was highest in forest vegetation as would be expected but was lower in savannah and riverine vegetation (Figure 5F).
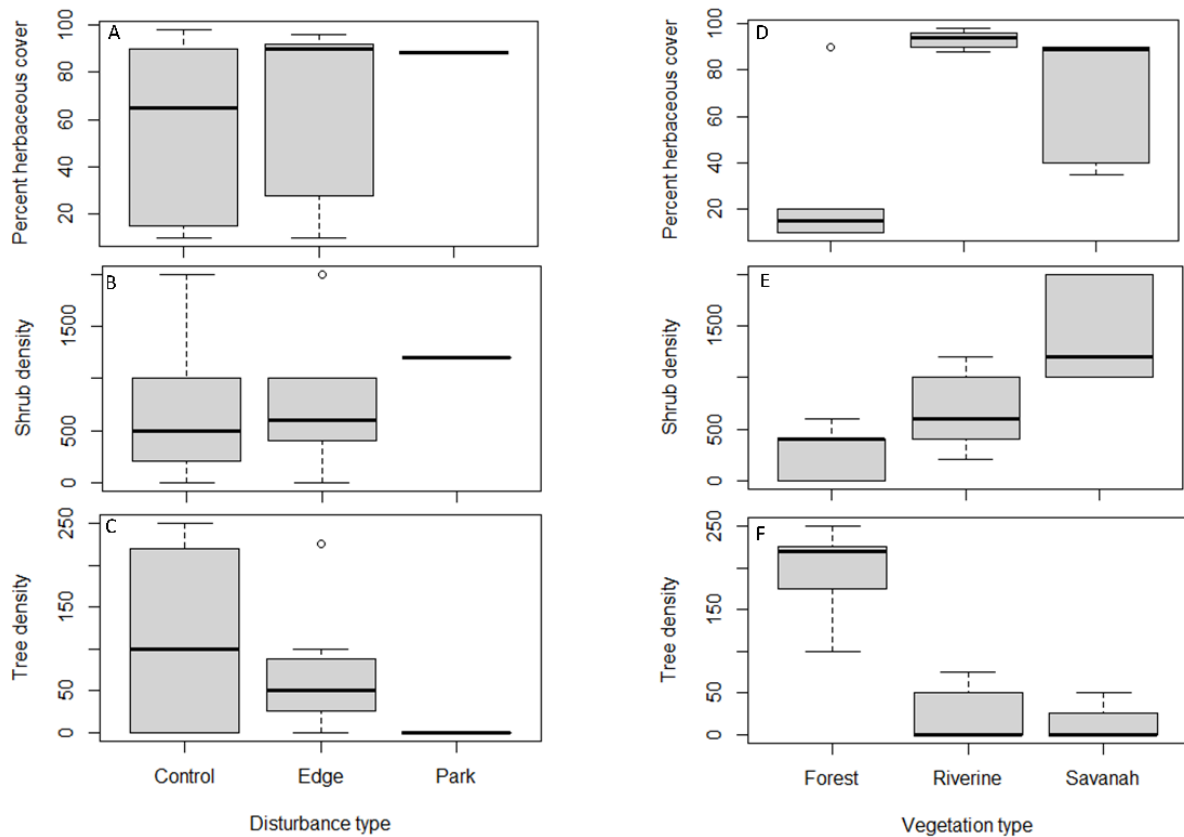
Figure 5: Boxplots showing the variation in herbaceous cover, shrub density, tree density with respect to habitat disturbance (A, B, C) and Vegetation type (D, E, F) in NNP

Dominant plant species composition also varied across vegetation types (Table 4). Savannah vegetation was dominated by *Themeda triandra* grass where it occurred in all the savannah sites as a dominant grass species. The forbs that dominated across all savannah vegetation sites included *Lippia* sp. *Ocimum suave* and *Solanum incanum* whereas the dominant tree species were *Searsia natalensis*, and *Vachellia drepanolobium*. For forest vegetation, the dominant tree species were different from those for savannah, and they included *Croton megalocarpus*, *C. macrostachys* and *Olea europaea subsp. cuspidata*, Riverine vegetation somewhat overlapped with savannah vegetation in terms of species composition. Riverine had *Themeda triandra* as a dominant grass species across most sites whereas *Searsia natalensis*, and *Vachellia drepanolobium* were widespread and dominant tree species (Table 4).

In terms of species restricted to a vegetation type, grasses, such as *Panicum* sp., *Chloris gayana*, and *Eragrostis* sp. were restricted to forest whereas *Croton megalocarpus*, *Olea europaea subsp. cuspidata* and *Croton macrostachyus* were restricted to forest vegetation. Species restricted to savannah included *Vachellia gerrardii* and *Balanites aegyptiaca* among trees and *Opuntia* sp and *Hyphaene* sp among shrubs and *Asparagus* sp, *Parthenium hysterophorus* and *Aspilia mossambicensis* among other herbs. No grass species was restricted into a savannah vegetation class. On the other hand, *Senegalia mellifera* was the only tree restricted to riverine vegetation.

There was limited conspicuous differentiation by plant species composition across habitat disturbance categories. The dominant species in the control sample sites for human disturbance included *Themeda triandra* and *Cyperus rotundus* among grasses, *Phyllanthus nummulariifolius* var. *capillaris* among shrubs and *Searsia natalensis*, *Vachellia drepanolobium*, *Olea europaea subsp. cuspidata* and *Croton macrostachyus* among the trees. Human disturbed habitats also had *Themeda triandra* as a dominant grass, *Lippia* spp as a dominant herb and *Searsia natalensis* as a

dominant tree. The plants dominating in the park were *Themeda triandra* of the grass species, *Lippia* sp., *Ocimum suave*, *Solanum incanum* and *Hibiscus* sp. from among herbs. *Searsia natalensis* and *Vachellia drepanolobium* were among the dominant species in the park as a pristine category (Table 4). In terms of species restricted to habitats, edge habitat controls had more restricted species including those that occurred in control sites *Cyperus rotundus*, *Chloris gayana*, *Eragrostis* sp among grasses, *Nymphaea nouchali*, *Hypenia* sp among the herbs and *Carissa spinarum* among the shrubs. Edge or disturbed habitats had *Hyphaene* sp., *Dovyalis caffra* and *Senegalia mellifera* as species restricted to that habitat. There were no species restricted to the human disturbed area and the pristine sites (Table 4).

Table 4: The percent distribution of dominant plant species in sites sampled by vegetation type and by disturbance type in NNP.

Plant classification			Vegetation			Disturbance		
Species	**Abbre1**	**Growth form**	**Forest %**	**Riverine %**	**Savannah %**	**Control %**	**Edge %**	**Park %**
Themeda triandra	Thtr	G	20	80	100	67	57	100
Cyperus rotundus	Cyro	G	40	20	20	67	0	0
Cynodon dactylon	Cyda	G	20	20	40	17	43	0
Panicum sp	Pasp	G	40	0	0	33	0	0
Chloris gayana	Chga	G	20	0	0	17	0	0
Eragrostis sp	Ersp	G	20	0	0	17	0	0
Lippia sp	Lisp	H	0	40	100	17	57	100
Ocimum suave	Ocsu	H	0	40	100	33	43	100
Solanum incanum	Solin	H	0	40	100	33	43	100
Hibiscus sp	Hisp	H	0	40	40	0	29	100
Justicia sp	Jusp	H	0	20	40	33	14	0
Aspilia mossambicensis	Asmo	H	0	0	40	17	14	0
Nymphaea nouchali	Nyno	H	20	0	20	33	0	0
Asparagus sp	Assp	H	0	0	40	17	14	0
Parthenium hysterophorus	Pahy	H	0	0	40	17	14	0
Hypenia sp	Hypa	H	40	0	0	33	0	0
Hyphaene sp	Hype	S	0	0	20	0	14	0
Phyllanthus nummulariifolius	Phnu	S	40	20	40	67	14	0
Lantana camara	Laca	S	40	0	40	33	29	0
Opuntia sp	Opsp	S	0	0	40	17	14	0
Dovyalis caffra	Dvca	S	20	0	20	0	29	0
Carissa spinarum	Casp	S	20	0	0	17	0	0
Searsia natalensis	Sena	T	20	60	100	50	57	100
Vachellia drepanolobium	Vadr	T	0	80	80	50	43	100
Croton megalocarpus	Crme.	T	80	0	0	33	29	0
Olea europaea subsp. Cuspidate	Olaf	T	80	0	0	50	14	0
Croton macrostachyus	Crma	T	80	0	0	50	14	0
Vachellia gerrardii	Vage	T	0	0	40	17	14	0
Balanites aegyptiaca	Baae	T	0	0	40	17	14	0
Senegalia mellifera	Seme	T	0	20	0	0	14	0

[1]Abbrev is abbreviations of species names as used in the PCA biplot

4.3   Effects of vegetation, human disturbance and seasonality on rodent community structure

Univariate Generalized Linear Models revealed that the abundance of rodents in this study was influenced by season, vegetation type, vegetation metrics (density and cover) but not human disturbance (Table 5). The best multivariate model however, indicated that rodents were abundant in the wet season compared to the dry season, and abundance was also positively associated with increased tree and shrub densities (Table 5, Appendix 1).

Table 5: Univariate models and the best multivariate model explaining rodent abundance in Nairobi National Park

	ESTIMATE	STD. ERROR	Z VALUE	PR(>|Z|)	AIC
UNIVARIATE MODELS					
INTERCEPT	0.385	0.163	2.356	0.0185	
TREE DENSITY	0.667	0.128	**5.208**	0.0000	119.0
INTERCEPT	1.253	0.169	7.411	0.0000	
RIVERINE CF. FOREST	-1.476	0.392	**-3.766**	0.0002	
SAVANNAH CF. FOREST	-0.990	0.325	**-3.049**	0.0023	127.8
INTERCEPT	-0.143	0.277	-0.516	0.6059	
WET SEASON CF. DRY SEASON	1.196	0.317	**3.779**	0.0002	129.9
INTERCEPT	0.480	0.153	3.144	0.0017	
HERBACEOUS COVER	-0.537	0.138	**-3.899**	0.0001	130.9
INTERCEPT	0.577	0.140	4.11	0.0000	
SHRUB DENSITY	-0.325	0.154	**-2.109**	0.0350	142.0
INTERCEPT	0.651	0.209	3.12	0.0018	
EDGE CF. CONTROL	0.078	0.279	0.278	0.7809	
PARK CF. CONTROL	-0.651	0.542	-1.201	0.2298	146.6
BEST MODEL					
INTERCEPT	-0.403	0.296	-1.361	0.1736	
WET SEASON CF. DRY SEASON	1.168	0.317	**3.69**	0.0002	
TREE DENSITY	0.873	0.184	**4.732**	0.0000	
SHRUB DENSITY	0.326	0.190	1.715	0.0864	104.0

Variation in rodent species richness was positively and strongly associated with high tree density (Table 6). The percentage herbaceous cover in all habitats sampled and seasonal changes were not significant factors influencing rodent density. Multivariate model selection indicated that there was no better model to explain changes in rodent density than a univariate tree density model (Table 6, Appendix 2). The bivariate model that included vegetation type and intercept also explained rodent species richness in NNP (Appendix 2).

Table 6: Univariate models that best explained rodent species richness in NNP. The tree density-rodent density model yielded marginally significant results.

	ESTIMATE	STD. ERROR	Z VALUE	PR(>|Z|)	AIC
INTERCEPT	-0.348	0.225	-1.550	0.1210	
TREE DENSITY	0.397	0.195	2.037	**0.0417**	66
INTERCEPT	-0.331	0.222	-1.493	0.1355	
HERBACEOUS COVER	-0.362	0.208	-1.740	0.0818	66.9
INTERCEPT	0.182	0.289	0.632	0.5280	
RIVERINE CF. FOREST	-0.876	0.532	-1.645	0.1000	
SAVANNAH CF. FOREST	-0.693	0.500	-1.386	0.1660	68.4
INTERCEPT	-0.511	0.333	-1.532	0.1250	
WET SEASON CF. DRY SEASON	0.442	0.427	1.034	0.3010	68.9
INTERCEPT	-0.271	0.210	-1.294	0.1960	
SHRUB DENSITY	-0.110	0.221	-0.498	0.6190	69.7
INTERCEPT	-0.288	0.333	-0.863	0.3880	
EDGE CF. CONTROL	0.047	0.450	0.104	0.9180	
PARK CF. CONTROL	0.000	0.667	0.000	1.0000	72

Univariate linear regression model selection using AIC revealed that the best model for species diversity estimated using Shannon-Weiner index (Table 7), Brillouin index (Table 8) or Simpson index (Table 9) was vegetation type. Specifically, forest vegetation had higher species diversity than either savannah or riverine vegetation.

Table 7: Univariate models for Shannon-Weiner Index of rodent species diversity

	ESTIMATE	STD. ERROR	T VALUE	PR(>|T|)	AIC
INTERCEPT	0.592	0.138	4.292	0.0026	
RIVERINE CF. FOREST	-0.592	0.195	**-3.035**	0.0162	
SAVANNAH CF. FOREST	-0.592	0.211	**-2.810**	0.0229	7.4
INTERCEPT	0.215	0.099	2.182	0.0570	
TREE DENSITY	0.232	0.104	**2.241**	0.0518	10.4
INTERCEPT	0.215	0.110	1.954	0.0825	
SHRUB DENSITY	-0.173	0.116	-1.497	0.1686	12.9
INTERCEPT	0.215	0.120	1.802	0.1050	
HERBACEOUS COVER	-0.094	0.125	-0.748	0.4740	14.7
INTERCEPT	0.234	0.208	1.126	0.2930	
EDGE CF. CONTROL	0.052	0.279	0.188	0.8560	
PARK CF. CONTROL	-0.234	0.360	-0.650	0.5340	16.4

Table 8: Univariate models for Brillouin Index for rodent species diversity

	ESTIMATE	STD. ERROR	T VALUE	PR(>|T|)	
INTERCEPT	0.422	0.094	4.484	0.0020	-1.06
RIVERINE CF. FOREST	-0.422	0.133	**-3.171**	0.0132	
SAVANNAH CF. FOREST	-0.422	0.144	**-2.936**	0.0188	
INTERCEPT	0.153	0.066	2.336	0.0443	1.46
TREE DENSITY	0.176	0.069	**2.553**	0.0310	
INTERCEPT	0.153	0.076	2.009	0.0754	4.77
SHRUB DENSITY	-0.126	0.080	-1.576	0.1494	
INTERCEPT	0.153	0.084	1.830	0.1010	6.83
HERBACEOUS COVER	-0.063	0.088	-0.722	0.4890	
INTERCEPT	0.173	0.145	1.189	0.2680	8.53
EDGE CF. CONTROL	0.026	0.195	0.134	0.8970	
PARK CF. CONTROL	-0.173	0.252	-0.687	0.5120	

Table 9: Univariate models for the Simpson index of rodent species diversity

	ESTIMATE	STD. ERROR	T VALUE	PR(>|T|)	AIC
INTERCEPT	0.358	0.082	4.361	0.0024	-4.0
RIVERINE CF. FOREST	-0.358	0.116	-3.083	0.0150	
SAVANNAH CF. FOREST	-0.358	0.125	-2.855	0.0213	
INTERCEPT	0.130	0.059	2.222	0.0534	-1.0
TREE DENSITY	0.142	0.061	2.312	0.0460	
INTERCEPT	0.130	0.066	1.973	0.0799	1.6
SHRUB DENSITY	-0.105	0.069	-1.522	0.1623	
INTERCEPT	0.130	0.072	1.814	0.1030	3.4
HERBACEOUS COVER	-0.057	0.075	-0.754	0.4700	
INTERCEPT	0.142	0.125	1.137	0.2880	5.2
EDGE CF. CONTROL	0.031	0.168	0.185	0.8580	
PARK CF. CONTROL	-0.142	0.216	-0.657	0.5300	

On the other hand, the best overall model selected after evaluating all simple and complex multivariable models (Appendix 3-5) was a univariate model with diversity positively influenced by tree density (Table7, Table 8). Human disturbance had no influence on diversity estimated using the Shannon-Weiner diversity index (Table 6), Brillouin index (Table 7) or Simpson index (Table 8).

CHAPTER FIVE

5.0 DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Patterns of rodent diversity

The *Lemniscomys striatus* is one of the commonest rodents in the savannah grassland, and cultivated areas. It is appearing that *L. striatus* is both a habitat and altitudinal generalist, having previously been recorded in coastal and inland forests, savannah and also montane ecosystems in East Africa. *L. striatus* has been recorded in Kakamega forests and in the Kenyan coastal forests (Mortelliti and Boitani, 2006; Canova and Fasola, 2000), while in Mabira forest, Uganda, *L. striatus* dominated depleted habitats compared to intact or regenerating patches (Ssuuna *et al.,* 2020). Among the Miombo belt of South Africa, *L. striatus* is more prominent outside the protected areas, especially in cultivated edges (Caro *et al.,* 2001). It therefore suffices to suggest that *L. striatus* is highly adaptable to disturbed habitat conditions and probably has the ability to exploit various vegetation mosaics, which probably made it to thrive and become dominant in NNP. Disturbances can be described as conditions that encourage modifications in change of resource availability, systems structures and reduce species competition (Vera and Rocha 2006, Hall and Miller, 2012).

The NNP has five rodent species, of which three are native (*L. striatus*, *Otomys tropicalis*, *Hylomyscus* sp.) while two are invasive/exotic commensal species (*Mus mus,* and *Rattus rattus).* Rodents in the genus *Mastomys* are the most common and widespread in East and Central Africa and it is important to note their absence in NNP. The *L. striatus* (striped grass mouse) is the most widespread and abundant rodent in the entire park and accounted for 44.6% (25/56) of all the individuals captured in the study period. Although *L. striatus* occurred across the vegetation

types, the Pielou's species evenness, J was moderate (0.44) indicating nearly average equity in species distribution.

Being an urban protected area, and a park within an expanding capital city, NNP is under intense anthropogenic disturbance, which ranges from encroachment to massive infrastructural developments, such as the construction of the Mombasa – Nairobi standard gauge railway line. In addition, the park has recreational sites, such as camping, entertainment facilities and residential areas for staff and Animal orphanage. Further, these edge conditions in NNP, especially the human settlements, are responsible for the introduction and maintenance of the two exotic synanthropic species in the park (Banks and Smith, 2015).

It suffices to suggest that *L. striatus, O. tropicalis* and *Hylomyscus* sp are natural remnant species of the NNP because there are no previous publications on rodent species diversity in NNP. The only report on rodent species in a location closest to NNP was at Embakasi plains where out of 4, 320 night-traps, only *Mastomys coucha* and *Crocidura fumosa* were ensnared (Hartman, 1966). Both *L. striatus* and *O. tropicalis* have been found to co-occur in Mt. Kenya at comparable elevations of 1700 m a.s.l. (Musila *et al.,* 2019).

This study reports *Hylomyscus* spp (wood mice) in NNP, which is an unexpected range for the genus because they are expected to be montane specialists. It is known that *H. endorobae* and *H. kerbispeterhansi* are distributed across montane and lowland rainforests in tropical Africa, including Mt. Kenya and Mt. Elgon (Happold, 2013; Nicolas and Colyn, 2003; Musila *et al.,* 2019), while *H. denniae* are endemic to the Mau escarpment (Demos *et al.,* 2014). Recent surveys and the application of genetic tools have discovered more species within the genus (Nicolas *et al.,* 2020) and it is likely that the *Hylomyscus* sp in NNP could be a distinct species.

Species richness of rodents is highly variable across the African landscapes and among the disjointed networks of protected areas. The present study recorded five species, which is more or less comparable to species richness across African ranges. The species richness at Katavi National Park and Mikumi National Park both in Tanzania, recorded five and 21 species, respectively (Caro *et al.,* 2001; Venance, 2009) while Nechisar National Park, Ethiopia, had 20 species (Workeneh *et al.,* 2011). At Laikipia rangeland, which is more comparable to NNP in regard to vegetation types, species richness ranged from 5 - 7 (Webala *et al.,* 2006) and *L. Striatus* is a common species in both Laikipia and NNP. Misfires or non-target species being caught reduced the chance of getting a target species.

The pattern in abundance and diversity at NNP, where higher rodent abundance and diversity concentrated in human settled areas or disturbed areas (edge habitats), suggests that anthropogenic impacts define the distribution of rodents and may select rodent species that could adapt in disturbed patches. According to Jeffrey (1977), the clearing of forests and replacing the patches with domestic housing and cultivation increases the diversity and abundance of rodents.

Vegetation structure and anthropogenic stressors may act in concert to influence the resilience, distribution, and diversity of a small mammal community (Venance, 2009; Byrom *et al.,* 2015). Most of the anthropogenic activities at NNP were in the forest habitat explains the pattern in which higher rodent diversity, richness, abundance occurred in the forest compared to savannah vegetation types. There was a statistically significant higher Shannon-Weiner diversity in the forest than savannah patches of NNP. Olayemi and Akinpelu, (2008) observed a similar pattern in Nigeria, where Shannon-Weiner Index was higher in the forest (H = 1.68) compared to derived Savanna (H = 0.97). This pattern is consistent with observations at Mikumi National Park, Tanzania, Bwindi Impenetrable National Park and Kibale National Park, both in Uganda

where the evergreen forest showed the highest species diversity, compared to the Savanna woodlands (Kasangaki *et al.,* 2003; Isabirye-Basuta and Kasenene 1987; Venance, 2009). It is posited that evergreen forests provide several microhabitats and support a variety of food resources which may offer nest sites and cover to different small mammal species (Isabirye-Basuta and Kasenene 1987; Kasangaki *et al.,* 2003).

Lemniscomys striatus was nearly ubiquitous in NNP, a pattern observed in Nigeria in which this species displayed comparable distribution and occurred in both the forest and derived savanna patches (Olayemi and Akinpelu, 2008). Although *L. striatus* was widespread at the NNP, the Simpson diversity index, which measures the evenness of taxon presence in a community was higher in the forest ($\lambda = 0.754$) than in the savanna ($\lambda = 0.355$), and shows that rodent community in the forest vegetation is more diverse.

Overall, rodent abundance and diversity is usually lower in protected areas than outside, with abundance driven by *L. striatus, Mastomys natalensis,* and *Rattus rattus* (Caro *et al.,* 2001).

5.2   Habitat variability and effect of human disturbance

This objective describes the extent of variation of the habitats at the NNP using vegetation metrics (tree density, shrub density, herbaceous cover, and dominant plant species). NNP is within the extensive Savanna biome, which covers half of the sub-Sahara Africa (Scholes and Archer, 1997). Generally, Savannas are characterized by an open woody canopy with a continuous layer of herbaceous vegetation, which are modulated by disturbance and environmental factors, primarily amount of rainfall, rainfall seasonality, fire and herbivory (Lehmann *et al.,* 2014).

The forest was defined by trees, the savanna by shrubs while the riverine was characterized by the herbaceous cover. At the forest or woodland, which was once part of the Langata forest, the *Acacia* sp. tree and *Themeda* sp. grassland covers approximately 40% of the park and the riverine vegetation which runs along River Mbagathi and Athi River basin.

It was observed that Savanna and forest had specific dominant species, while the riverine vegetation had comparable tree species. The savanna vegetation was characterized by the dominant grass species of *Themeda triandra*, herbs *Solanum incanum*, *Lippia* sp., and *Ocimum suave,* and trees, *Searsia natalensis* and *Vachellia drepanolobium*. In contrast, the dominant trees in the forest vegetation were *Croton megalocarpus, C. macrostachys* and *Olea europaea subsp. cuspidata*. Over the past 50 years, the dominant species in the savanna and forest of NNP has undergone tremendous changes. The Savanna vegetation was dominated by *Acacia drepanolobium* which were 2.5 m high (Goldsmith and Harrison 1967). In the present study, it was noted that the occurrence of *Acacia* species in the park is did not have a great significance to rodents' abundance in relation to vegetation type.

Croton megalocarpus has persisted over the past half a century as a dominant species in the forest vegetation (Goldsmith and Harrison 1967), as the present study indicated its dominance in the forest vegetation. However, tree species such as *Diospyros abyssinica*, *Vepris* spp; *Brachylaena hutchinsii* (Goldsmith and Harrison, 1967) which were previously dominant in the forest vegetation of the NNP is no longer significant and indicates significant spatial and temporal changes in the vegetation structure. Even though tree density, herbaceous cover and shrub density also varied across disturbed/edge sites, there was no statistical difference, which suggests that these vegetation matrices did not define disturbed sites. It was also noted that the disturbed sites could not be differentiated by a specific plant species.

In summary, the results show that tree density, shrub density, herbaceous cover, and dominant plant species define habitat variability in the natural vegetation types but not among the disturbed habitat types in NNP.

5.3   Effects of vegetation, human disturbance and seasonality on rodent community structure

In the present study, it was observed that rodent abundance, species richness and diversity were variable in time and space. It is postulated that multiple biophysical factors, such as predator risks and avoidance opportunities, intra-and inter-species competitions, resource quantity and quality, especially the availability of water and food, influence rodent community composition, richness, abundance and diversity (Willig *et al.,* 2003). The rodent abundance was influenced by season, vegetation type and vegetation metrics (density and cover). The rodents at NNP were abundant in the wet season compared to the dry season. This pattern is consistent with rodent communities across Africa (Massawe *et al.,* 2011). Availability of rainfall is highly correlated with the reproduction of small mammals in Africa (Happold, 1974; Afework and Leirs, 1997), particularly with breeding and population dynamics of several rodent species (Leirs *et al.,* 1992; Leirs *et al.,* 1996). This study established that abundance was also associated with density and cover, especially tree density. Massawe *et al.,* (2011) explains this phenomenon by stating that rainfall *per se*, may not induce rodent reproduction, however, rainfall enhances habitat productivity on which rodents depend on and thus density fluctuations often correspond with rainfall patterns. Therefore, rainfall may influence vegetation height and abundance, hence the resulting cover, which are components of suitable habitat for rodents (Bakker *et al.,* 2009). Less vegetation cover increases predation risk, reduces food quality and advances negative

competition which eventually affects population performance (Keesing, 1998; Flowerdew and Ellwood, 2001; Vroni, 2007).

This study also established that abundance was positively associated with increased tree and shrub densities. At the NNP, the high abundance of rodents in areas with increased trees and shrubs, may depict rodent's preference for patches with ample food and security. Spatial distribution of rodents in a landscape is determined by rodent intrinsic factors and ecological factors, as each species responds differently to habitat structural variability (Gentili *et al.,* 2014).

Although rodent abundance was higher around human settlements and habitat edges compared to non-disturbed areas in NNP, the results indicated that human disturbance, *per se*, did not influence rodent abundance. It is likely, that vegetation type, in this case, forest vegetation, has a significant impact on rodent abundance. The anthropogenic effect is thought to increase the abundance of small mammals (Men *et al.,* 2015). Moreover, it is postulated that the clearing of forests and replacing the patches with domestic housing and cultivation increases the diversity and abundance of rodents (Jeffrey, 1977). Results of this study appear to disentangle the effect of anthropogenic activities and the effect of the habitat type where such human activities occur.

It was observed that at the NNP, rodent species richness increased as tree density increased, which means the rodents preferred this type of habitat, probably for security and sufficient food (Keesing, 1998; Flowerdew and Ellwood, 2001; Vroni, 2007). In some conditions, it has been observed that human cleared patches attract more rodent richness. For instance, in Kakamega forest, increased species richness was linked to their proximity to cleared patches and forest edges (Mortelliti and Boitani, 2006). A more ideal situation compares species richness in an

intact, regenerating, and depleted patches of Mabira forest. Rodent species richness was higher in regenerating patch compared to intact and least in depleted patch (Ssuuna *et al.,* 2020).

In the present study, the Shannon-Weiner index, Brillouin index, or Simpson index, all concurred that species diversity was influenced by vegetation type at the NNP. The results established that rodent diversity increased as tree density increased. In contrast, human disturbance did not influence rodent diversity at the NNP. Human activities are expected to reduce shrub cover and negatively influence rodent diversity (Men *et al.,* 2015).

There was limited conspicuous differentiation by plant species composition across habitat disturbance categories. Results are concurred with those of Garcia *et al.,* (2012), and suggest that rodents cannot distinguish the specific plant composition of each vegetation type but can distinguish forested and open areas.

5.4   Conclusion and recommendations

5.4.1   Conclusion

- The null hypothesis for the study was rejected

- The rodents at the Nairobi National Park, comprised three indigenous murid species and two exotic species.

- *Lemniscomys striatus*, was the dominant species at the NNP, can serve as a bio-indicator species for monitoring the ecological integrity of NNP.

- The overall rodent diversity and abundance in NNP was low while evenness was moderate, indicating nearly average equity in species distribution.

- Habitat metrics could discriminate the vegetation types but not human disturbance.

- Abundance of rodents was influenced by season, vegetation type, vegetation metrics (density and cover) but not human disturbance.

- The habitat matrices (density and cover) sufficiently determined the vegetation types as forest, savanna and riverine. Therefore, because tree density and herbaceous cover were statistically significant ($P<0.05$) in defining the vegetation types, the null hypothesis is rejected.

- The habitat matrices failed to statistically differentiate ($P> 0.05$) disturbed and control areas of the park, thus null hypothesis is not rejected.

- The vegetation types influenced species diversity, while rodent species richness was only positively associated with higher tree density. The abundance of rodents was influenced by season, vegetation type, vegetation metrics (density and cover) but not human disturbance. Therefore, because of the statistically significant effect ($P<0.05$) of season, vegetation type, and habitat metrics, the null hypothesis is rejected.

5.4.2 Recommendations

- It is important to monitor the spatial and temporal dynamics of *Lemniscomys striatus* because it appeared to have spread widely in the park.

- More research should be carried out to establish habitat changes along the park boundaries and around residential areas because there is a risk of invasion by exotic plant species.

- Investigations should also be carried to determine the effects of domestic solid waste disposal by people close to or inside the park boundaries because the solid waste can encourage invasion by small rodents into and out of the park.

- A survey should be conducted to establish whether feral cats in search of rodents gain access to the park through the porous areas of its boundary.

- Further studies should be carried out to determine the roles of small predators in the population dynamics of rodents in protected areas, and how this is likely to contribute to biodiversity conservation in African savanna.

REFERENCES

Afework, B. and Leirs, H., (1997). Population ecology of rodents of maize fields and grassland in central Ethiopia. *Belgian Journal of Zoology (Belgium)*.

Auffray, J. C., Renaud, S. and Claude, J. (2009). Rodent biodiversity in changing environments. Rodent Biodiversity Human Health and Pest control in changing environments. *Natural Science,* **43**:83-93.

Avenant, N., (2003). The potential utility of rodents and other small mammals as indicators of ecosystem 'integrity'of South African grasslands. *Wildlife Research*, *38*(7), pp.626-639.

Bakker, E. S., Olff, H., Boekhoff, M., Gleichman, J. M. and Berendse, F. (2004). Impact of herbivores on Nitrogen cycling: contrasting effects of small and large species. *Oecologia,* **138** (1): 91-101.

Banks, P.B. and Smith, H.M., 2015. The ecological impacts of commensal species: black rats, Rattus rattus, at the urban–bushland interface. *Wildlife Research*, **42**(2):86-97.

Barton, K. (2020). MuMIn: Multi-Model Inference. R package version 1.43.17.

Batzli, G. O. and Pitelka, F. A. (1970). Influence of meadow mouse population on California Grassland. *Ecology*, **51:** 1027-1039.

Begon, M., Harper, J. L. and Townsend, C. R. (1987). Ecología, individuos, poblaciones y comunidades (M. Costa, Trans.). Ediciones Omega, S. A., Barcelona.

Bekele, A. (1996). Population dynamics of the Ethiopian endemic rodent, *Praomys albipes* in the Menagesha State. Forest. *Journal of Zoology,* **238:** 1-12.

Bestelmeyer, B.T., Goolsby, D.P. and Archer, S.R., 2011. Spatial perspectives in state-and transition models: A missing link to land management? *Journal of Applied Ecology*, **48**(3):746-757.

Bolger, T. D., Alberts, A. C., Sauvajot, R. M., Potenza, P., McCalvin C., Tran, D., Mazzoni, S. and Soule, M. E. (1997). Response of rodents to habitat fragmentation in coastal southern California. *Ecological Applications,* **7** (2):552-563

Bowman, J., Forbes, G. J. and Dilworth, T. G. (2001). Spatial and temporal patterns of an interrupting population of deer mice. *Journal of Mammalogy,* **82** (2):567-572.

Briani, D. C., Palma, A. R. T., Vieira, E. M. V. and Henriques, R. P. B. (2004). Post-fire Succession of Small Mammals in the Cerrado of Central Brazil. *Biodiversity Conservation,* **13:**1023-1037.

Byrom, A. E., Nkwabi, A. J. K. and Metzger, K. (2015). Anthropogenic stressors influence small mammal communities in tropical East African savanna at multiple spatial scales. *Wildlife Research,* **42:** 119–131.

Cameron, G. N. and Scheel, D. (2001). Getting warmer: effect of global climate change on distribution of rodents in Texas. *Journal of Mammalogy*, **82** (3): 652-680.

Canova, L. and Fasola, M. (2000). Small rodents along a ground-cover gradient in coastal Kenya. *Tropical Zoology*. **13** (2): 219-226.

Caro, T.M., 2001. Species richness and abundance of small mammals inside and outside an African national park. *Biological Conservation*, **98**(3):251-257.

Casula, P, Luiselli, L. and Amori, G. (2018). Which population density affects home ranges of co-occurring rodents? *Basic and Applied Ecology.***11**.002.

Cavia, R., Rubn, G. and Virginia, O. (2012). *Techniques to Estimate Abundance and Monitoring Rodent Pests in Urban Environments, Integrated Pest Management and Pest Control.* Current and Future Tactics.

Chen, J., Franklin, J. F. and Spies, T. A. (1993). Contrasting Microclimates among clear cut, edge, and interior of Old-Growth Douglas-Fir Forest. *Agricultural and Forest Meteorology*, **63:**219-237.

Chidumayo, E. N. and Gumbo, D. J. (2010). The dry forests and woodlands of Africa: managing for products and services. The Earthscan Forest Library London, UK, *Earthscan*.

Clark, J. E., Hellgren, E. C., Parsons, J. L., Jorgensen, E. E., Engle, D. M. and Leslie, D. M. (2005). Nitrogen outputs from faecal and urine deposition of small mammals: implications for nitrogen cycling. *Oecologia*. **144** (3): 447-455.

Converse, S. J., White, G. C., Farris, K. L. and Zack, S. (2006). Small Mammals and Forest Fuel Reduction: National-Scale Responses to Fire and Fire Surrogates. *Ecological Applications*. **16**(5):1717-1729.

Cramer, M. J. and Willig, M. R. (2002). Habitat heterogeneity, habitat associations and rodent species diversity in a Sand-Shinnery-Oak Landscape. *Journal 0f Mammalogy*. **83:** 743 - 753.

Delany, M. J. (1974). The ecology of small mammals. Edward Arnorld (Publishers) Ltd, London.

Demos, T. C., Agwanda, B. and Hickerson, M., (2014). Integrative taxonomy within the *Hylomyscus denniae* complex (Rodentia: Muridae) and a new species from Kenya. *Journal of Mammalogy* **95**: E1 - E15.

Deshmukh, I. (1986). Primary production of grassland in Nairobi National Park. *Journal of Applied Ecology*. **23**: 115-123.

Eagles, P. F. J., McCool, S. F. and Haynes, C. D. (2002). United Nations Environment Programme, World Tourism Organization, International Union for Conservation of Nature and Natural Resources. Sustainable tourism in protected areas: guidelines for planning and management. Gland, Switzerland: *IUCN—the World Conservation Union*.

Ernest, S. K., Brown, J. H. and Haskell, J. P. (2001). Regulation of diversity: maintenance of species richness in changing environments. *Oecologia.* **126** (3): 321-332.

Ewers, R. M. and Didham, R. K. (2006). Confounding factors in the detection of species responses to habitat fragmentation. *Biological Reviews of the Cambridge Philosophical Society*. **81** (1): 117–142.

Fagan W. E., Cantrell R. S. and Cosner, C. (1999). How habitat edges change species interactions. *American Naturalist*. **153:**165 –182.

Fiedler, L. A. (1994). Rodent pest Management in East Africa. *FAO plant production*. Bulletin 123.

Finney, S. K., Pearce-Higgins, J. W. and Yalden, D. W. (2005). The effect of recreational disturbance on an upland breeding bird, the golden plover, *Pluvialis apricaria*. *Biology of Conservation*. **121**: 53–63.

Fisher, J. T. and Wilkinson, L. (2005). Response of Mammals to Forest Fire and Timber Harvest. *Mammal Review*. **35** (1):51-81.

Flaspohler, D. J., Temple, S. A. and Rosenfield, R. N. (2001). Species-specific edge effects on nest success and breeding bird density in a forested landscape. *Ecological Applications*. **11**: 32–46.

Flowerdew J. R. and Ellwood S. A. (2001). Impacts of woodland deer on small mammal ecology. *Forestry.* **74**: 277-287.

Fogel, R. and Trappe, J. M. (1978). Fungus consumption (mycophagy) by small animals. *Northwest science,* **52:** 1-31

García, K. P., Zapata, J. C. O. and Aguayo, M. D. G. (2012). Assessing rodent community responses in disturbed environments of the Chilean Patagonia. Mammalia. *Mammalia* **77**(2)*:*2011-0134

Gascon, C., Lovejoy, T. E., Bierregaard, R. O., Malcom, J. R., Stouffer, P. C., and Vasconcelos, H. L. (1999). Matrix Habitat and Species Richness in Tropical Forest Remnants. *Biological Conservation,* **91:** 223-229.

Gashweiler, J. S. (1970). Further study of conifer seed survival in a western Oregon clear cut. *Ecology*, **51:** 849-854

Gentili, S., Sigura, M. and Boneri, L. (2014). Decreased small mammals species diversity and increased population abundance along a gradient of agricultural intensification. *Hystrix It. Journal of Mammalogy*. **25**(1):39-44.

George, S. L., and Crooks, K. R. (2006). Recreation and large mammal activity in an urban nature reserve. *Biology of Conservation.* **133**: 107–117.

Goldsmith, F.B. and CM. Harrison. 1976. Description and analysis of vegetation. In: SP. Chapman (ed.), Methods in Plant Ecology. Blackwell, Oxford, UK. 85-156.

Greenwood, R. J. (1982). Nocturnal activity and foraging of prairie raccoons (*Procyon lotor*) in North Dakota. *American Midland Naturalist*, **107:** 238-43.

Grzimek, B. (1988). Grzimek's Encyclopedia of Mammals. McGraw-Hill, Inc. Muncher, West Germany. **2:**318-24.

Habrerie, O., Massol, F., Facon, B., Thevenoux, R., Hess, M., Ulmer, R., Pantel, J. H., Braschi,J., Amsellem, L., Baltora-Rosset, S., Tasiemski, A., Grandjean, F., Gibert, P., Chauvat, M., Affre, L., Thiébaut, G., Viard, F., Forey, E., Folcher, L., Boivin, T., Buisson, E., Richardson, D. M. and Renault, D. (2019). Biological Invasion Theories: Merging Perspectives from Population, Community and Ecosystem Scales. Preprints. 2019100327.

Halffter, G. (1998). A strategy for measuring landscape biodiversity. *Biology International* **36:** 3-17.

Hall, A. R. and Miller A. D. (2012). Diversity – disturbance relationships: frequency and intensity interact. *Biology Letters*. **8**: 768–771.

Happold, D. and Lock, J.M., (2013). The biotic zones of Africa. *Mammals of Africa*, *1*, pp.57-74.

Hartman, D. S. (1966). A June-July census of small mammals on the Athi plains; Kenya. *Journal of the East Africa Natural History Society and National Museum.* **26**: 2 (114).

Heil, L., Fernandez-Juricic, E., Renison, D., Cingolani, A. M. and Blumstein, D. T. (2007). Avian responses to tourism in the biogeographically isolated high Cordoba Mountains, Argentina. *Biodiversity and Conservation*. **16**: 1009–1026.

Hoffmann, A. and Zeller, U. (2005). Influence of variations in land use intensity on species diversity and abundance of small mammals in the Nama Karoo, Namibia. *Belgian Journal of Zoology*, **135** (suppl.): 91-96.

Isabirye-Basuta, G. and J.M. Kasenene. (1987). Small rodent populations in selectively felled and matured tracts of Kibale Forest, Uganda. Biotropica 19: 260–266.

IUCN. , (1996). Forest Cover and Forest Reserves in Kenya: Policy and Practice. Nairobi, Kenya.

Jeffrey, S. M. (1977). Rodent ecology and land use in western Ghana. Journal of Applied Ecology 14:741–755.

Johnson, M. D. and Horn, C. M. (2008). Effects of rotational grazing on rodents and raptors in a Coastal Grassland. *Western North American Naturalist.* **68:** 444-452.

Jones, C. G., Lawton, J. H. and Shachak, M. (1994). Organisms as ecosystem engineers. *Ecosystem management*. **69:**373–386.

Kangas, K., Luoto, Tomppo, E. and Siikamaki P. (2010). Recreation-induced changes in boreal bird communities in protected areas. *Ecological Applications*. **20**: 1775–1786.

Kasangaki, A., Kityo, R. and Kerbis, J. (2003) Diversity of rodents and shrews along an elevational gradient in Bwindi Impenetrable National Park, south-western Uganda. *African Journal of Ecology*, **41**(2):115-123.

Keesing F. (1998). Impacts of ungulates on the demography and diversity of small mammals in central Kenya. *Oecologia.* **116**: 381-389.

Kenya Indigenous Forest Conservation Programme, (KIFCON), (1994). A National Profile of Kenya's Indigenous Forests. Kenya Indigenous Forest Conservation Programme: Nairobi, Kenya. Unpublished Project Report.

Kerley, G. I. H., Whitford, W. G. and Kay, F. R. (2004). Effects of pocket gophers on desert soils and vegetation. *Journal of Arid Environments.* **58:** 155-166.

Kingdon, J. (1974). East African mammals: an atlas of Evolution in Africa. *Vol. II Academic Press*, London.

Kingdon, J. (1997). *The Kingdon Field Guide to African Mammals*. London: Academic Press.

Koprowski, J. L. (2005). The response of tree squirrels to fragmentation: a review and synthesis. *Animal Conservation*. **8:** (4) 369–376.

Krohne, D. T. and Burgin, A. B. (1990). The scale of demographic heterogeneity in a population of *Peromyscus leucopus*. *Oecologia*. **82** (1): 97-101.

Lara, M. C., Patton, J. L. and Da Silva, M. N. F. (1996). The Simultaneous Diversification of South American Echimyid Rodents (Hystricognathi) Basedon Complete Cytochrome *b* Sequences. *Molecular Phylogenetics and Evolution*. **5** (2): 403–413.

Larson, C. L., Reed, S. E., Merenlender, A. M. and Crooks, K. R. (2016). Effects of Recreation on Animals Revealed as Widespread through a Global Systematic Review. *Plos one* **11**(12): e0167259.

Laurance, W. F. (1994). Rainforest fragmentation and the structure of small mammal communities in tropical Queensland. *Biological Conservation*. **69:** 23-32.

Laurance, W. F. and Yensen, E. (1991). Predicting the impacts of edge effects in fragmented habitats. *Biological Conservation*. **55**: 777–792.

Laurance, W. F., Goosem, M. and Laurance, S. G. W. (2009) Impacts of Roads and Linear Clearings on Tropical Forests. *Trends in Ecology and Evolution,* **24:** 659-669.

Lehmann, C.E., Anderson, T.M., Sankaran, M., Higgins, S.I., Archibald, S., Hoffmann, W.A., Hanan, N.P., Williams, R.J., Fensham, R.J., Felfili, J. and Hutley, L.B. (2014). Savanna vegetation-fire-climate relationships differ among continents. *Science*, **343**(6170):548 552.

Leirs, H., Verhagen, R., Verheyen, W., Mwanjabe, P. and Mbise, T. (1996). Forecasting rodent outbreaks in Africa: An ecological basis for Mastomys Control in Tanzania. *Journal of Applied Ecology* **33**: 937–943.

Lentic, M. and Dickman, C. R. (2005). The responses of small mammals to patches regenerating after fire and rainfall in the Simpson Desert, central Australia. *Austral Ecology.* **30:** 24 - 39.

Losos, E., Hayes, J., Phillips, A., Wilcove, D. and Alkire, C. (1995). Taxpayer-Subsidized Resource Extraction Harms Species. *BioScience*. **45**: 446–455.

Makundi, R. H., Massawe, A. W., Mulungu, L. S. and Katakweba, A. (2009). Diversity and population dynamics of rodents in farm-fallow mosaic fields in Central Tanzania. *African Journal of Ecology* **48**: 313–320.

Massawe, A. W., Mulungu, L. S., Makundi, R. H., Dlamini, N., Eiseb, S. J., Kirsten, F., Mahlaba, T., Malebane, P., Maltitz, E. V., Monadjem, A., Taylor, P., Tutjavi, V. and Belmain, S. R. (2011). Spatial and temporal population dynamics of rodents in three geographically different regions in Africa: Implication for ecologically-based rodent management. *African Zoology*. **46**: 393-405.

Massawe, A. W., Rwamugira, W., Leirs, H., Makundi, R. H. and Mulungu, L. S. (2007). Do farming practices influence population dynamics of rodents: A case study of the multimammate field rats, *Mastomys natalensis*, in Tanzania. *African Journal of Ecology.* **45:** 293-301.

Matlack, G. R. (1993). Microenvironment variation within and among forest edge sites in the eastern United States. *Biological Conservation.* **66**: 185–194.

Maxson, S. J. and Oring, L. W. (1978). Mice as a source of egg loss among ground-nesting birds. *Auk*, **95:**582-84.

Men, X., Guo, X., Dong, W., Ding, N. and Qian, T. (2015). Influence of human disturbance to the small mammal communities in the forests. *Journal of Forestry,* **05** (01):1-9.

Mitchell, K. (2007). Department of Mathematics and Computer Science Hobart and William Smith Colleges, Geneva, Switzerland. *Quantitative Analysis by the Point-Centered Quarter Method*.

Morrison, M.L. (1986). Bird populations as indicators of environmental change. In *Current ornithology*. Springer, Boston, MA. 429-451.

Mortelliti, A. and Boitani, L. (2006). Patterns of rodent species diversity and abundance in a Kenyan relict tropical rainforest. *Forest Diversity and management*. **15**: 365-380.

Mukinzi, I., Katuala, P. G. B., Kennis, J., Gambalemoke, M. and Kadange, N. (2005). Preliminary data on the biodiversity of rodents and insectivores (*Mammalia*) in the periphery of Kisangani (D.R. Congo). *Belgian Journal of Zoology*. **135:** 133-140.

Mulligan, M. and Parks, K. E. (2010). On the relationship between a resources based measure of geodiversity and broad scale biodiversity patterns. *Biodiversity and Conservation.* **19:**2751–2766.

Mundia, C. N, and Aniya, M. (2005). *International journal of remote sensing*. **26** (13): 2831-2849.

Musila, S., Monadjem, A., Webala, P. W., Patterson, B. D., Hutterer, R., De Jong, Y., A., Yvonne A., Butynski, T., Mwangi, G., Chen, Z. Z., and Jiang, X. L. (2019). An annotated checklist of mammals of Kenya. *Zoological Research*. **40** (1):3–52.

Nedbal, M. A., Honeycutt, R. L. and Schiltter, D. A. (1996). Higher-level systematic of rodents (Mammalia, Rodentia): Evidence from the mitochondria 125rRNA Gene. *Journal of Mammalian Evolution*, **3**: 201-226.

Ng'ang'a, J. K. (1992.) The climate and meteorology of Nairobi Region, Kenya. *African Urban Quarterly*, **7** (1):6-23.

Nicolas, V. and Colyn, M. (2003). Seasonal variations in population and community structure of small rodents in a tropical forest of Gabon. *Journal of Zoology* **81**: 1034-1046.

Nowak, R. M. (1999). Walker's Mammals of the World. 6th Edition. The John Hopkins University Press, London.

Odhiambo, R. O., Makundi, R. H., Leirs, H. and Verhagen, R. (2008). Demography, reproductive biology and diet of the bushveld Gerbil Tatera Leucogaster (Rodentia: Gerbillinae) in the lake Rukwa Valley, South-Western Tanzania. *Integrative Zoology.* **3**: 31–37.

Ogega, O. M. (2019). Exploring the Future of Nairobi National Park in a Changing Climate and Urban Growth. *The Geography of Climate Change Adaptation in Urban Africa.*

Ogutu, J.O., Piepho, H.P., Reid, R.S., Rainy, M.E., Kruska, R.L., Worden, J.S., Nyabenge, M. and Hobbs, N.T., 2010. Large herbivore responses to water and settlements in savannas. *Ecological Monographs*, **80**(2):241-266.

Oksanen, J. F., Guillaume B., Michael F., Roeland K., Pierre L., Dan M., Peter R. Minchin, R. B. O'Hara, Gavin L. Simpson, P., Solymos, M., Henry, H., Stevens, E. S. and Helene, W. (2020). Vegan: Community Ecology Package. *R package version* **2:**5-7.

Olayemi, A., Obadare, A., Oyeyiola, A., Fasogbon, S., Igbokwe, J., Igbahenah, F., Ortsega, D., Günther, S., Verheyen, E. and Fichet-Calvet, E., (2018). Small mammal diversity and

dynamics within Nigeria, with emphasis on reservoirs of the Lassa virus. *Systematics and Biodiversity*, **16**(2):118-127.

Pardini, R., Marques de Souza, S., Braga-Neto, R. and Metzger, J. P. (2005). The role of forest structure, fragment size and corridors in maintaining small mammal abundance and diversity in an Atlantic forest landscape. *Biological Conservation.* **124:** 253-266.

Pohlman, C. L., Turton, S. M. and Goosem, M. (2007). Edge Effects of Linear Canopy Openings on Tropical Rain Forest Understory Microclimate. *Biotropica*, **39:** 62-71.

Price, P. W., Westoby, M., Rice, B., Atsatt, P. R., Fritz, R. S., Thompson, J. N. and Mobley, K. (1986). Parasite mediation in ecological interactions. *Annual Review of Ecology and Systematics*, **17:**487–505.

R Core Team. *R: A Language and Environment for Statistical Computing* (R Foundation for Statistical Computing, Vienna, Austria, 2021).

Rand, T. A., Tylianakis J. M. and Tscharntke T. (2006). Spill over edge effects: the dispersal of agriculturally subsidized insect natural enemies into adjacent natural habitats. *Ecology Letters.* **9:**603–614.

Ranta, E., Kaitala, V., Lindstrom J. and Linden H. (1995). Synchrony in population dynamics. Proceedings of the royal society of London. Series B: *Biological Sciences.* **262** (1364):113-118.

Reed, S. E., Merenlender, A. M., and Adina, M. (2008). Quiet, non-consumptive recreation reduces protected area effectiveness. *Conservation Letters*. **1**: 146–154.

Riffell, S. K., Gutzwiller, K. J., and Anderson, S. H. (1996). Does Repeated Human Intrusion Cause Cumulative Declines in Avian Richness and Abundance? *Ecological Applications.* **6**:492- 505.

Rogala, J. K., Hebblewhite, M., White, C. A., Coleshill, J. and Musiani, M. (2011). Human activity differentially redistributes large mammals in the Canadian Rockies national parks. *Ecology and Society.* 16.

Ross, F. C. (1983). *Introductory Microbiology*. Charles E. Merril Publishing Co. Ohio, USA.

Salinas, H. and Ramirez-Delgado, D. (2021). Ecological Test: Community Ecology Tests R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Sauvajot, R. M. (1995). Conservation science in fire-prone natural areas. Brushfires in California: Ecology and Resource Management. *International Association of Wildland Fire, Fairfield, WA.* 11-20.

Scholes, R.J. and Archer, S.R. (1997). Tree-grass interactions in savannas. *Annual review of Ecology and Systematics*. 517-544.

Schonewald-Cox, C. and Buechner, M. (1992). Park protection and public roads. *Conservation biology*. 373-395.

Seber, A. F. (1992). A review of estimating animal abundance II. *International statistical Review*. 129-166.

Simon, N. P. P., Stratton, C. B., Forbes, G. J. and Schwab, F. E. (2002). Similarity of Small Mammal Abundance in Post-Fire and Clear cut Forests. *Forest Ecology and Management.* **165:**163-172.

Smirnov, V. S., and Tokmakova, S. G. (1971). Preliminary data on the influence of different numbers of voles upon the forest tundra vegetation, *Annales Zoologici Fennici.* **8:**154 156.

Ssuuna, J., Makundi, R. H., Isabirye M., Sabuni, A. C., Babyesiza W. S. and Mulungu, L. S. (2020). Rodent species composition, relative abundance, and habitat association in the Mabira Central Forest Reserve, Uganda. *Journal of Vertebrate Biology*. **69**:2.

Steven, R. and Castley, J. G. (2013). Tourism as a threat to critically endangered and endangered birds: global patterns and trends in conservation hotspots. *Biodiversity of Conservation*. **22**: 1063–1082.

Tattersall, F. H., Macdonald, D. W., Hart, B. J., Johnson, P., Manley, W. and Feber, R. (2002). Is habitat linearity important for small mammal communities on farmland? *Journal of Applied Ecology.* **39** (4):643-652.

Tews, J., Brose, U., Wichmann, M. C. and Schwager, M. (2004). Animal species diversity driven by habitat heterogeneity/diversity: The importance of keystone structures, influence of human disturbance to the small mammal communities in the forests. *Journal of Biogeography.* **31**(15):79-92

Torre, I. and Díaz, M. (2004). Small Mammal Abundance in Mediterranean Post-Fire Habitats: A Role for Predators? *Acta Oecologica.* **25:**137-143.

Utrera, A., Duno, G., Ellis, B. A., Salas, R. A., De Manzione, N., Fulhorst, C. F., Tesh, R.B. and Mills, J. N. (2000). Small mammals in agricultural areas of western Llanos of Venezuela: Community structure, habitat associations, and relative densities. *Journal of Mammalogy* **81** (2):536–548.

Van-Andel, J., Bakker, J. P. and Snaydon, R. W. (1987). Disturbance in grasslands. Causes, effects and processes. *Dordrecht: Junk.* 316.

Venance, J. (2009). Small mammal communities in the Mikumi national park, Tanzania. Hystrix It. *Journal of Mammalogy.* **20:** 91–100.

Vera, C. C. F. and Rocha, C. F. D. (2006). Habitat disturbance and small mammal richness and diversity in an Atlantic rainforest area in south eastern Brazil. Braz. *Journal of Biology.* **6:** 983–990.

Vieira, E. M. (1999). Small Mammal Communities and Fire in the Brazilian Cerrado. *Journal. Zoology.* **249:**75-81.

Vroni R. (2007). Forage competition between livestock and Mongolian Pika (Ochotona Pallasi) in southern Mongolian Mountain Steppes. *Basic and Applied Ecology.* **8**: 147-157.

Wato, Y.A., Wahungu, G.M. and Okello, M.M., 2006. Correlates of wildlife snaring patterns in tsavo west national park, kenya. *Biological conservation*, **132**(4):500-509.

Webala P. W., Muriuki G., Lala F. and Bett, A. (2006). The small mammal community of Mukogodo Forest, Kenya. *African Journal of Ecology.* **44**:363-370.

Willan, K., Contrafatto, G., Meester, J. A., Taylor, P. J., Robert, M. A. and Baker, C. M. (1992). Genetic variation in the African rodent subfamily Otomyinae (muridae). *Cytogenetic and Genome Research.* **59** (4): 293-299.

Willig, R., Kaufman, M. and Stevens, D. (2003) Latitudinal gradients of biodiversity: pattern, process, scale and synthesis. *Annual Review of Ecology, Evolution, and Systematics.* **34:** 273–309

Wilson, E. D. and Reeder, D. E. (2005). Mammal species of the world: a taxonomic and geographic reference. *Johns Hopkins University Press.*

Wolff, J. O. and Sherman, P. W. (2007). *Rodent Societies: An Ecological and Evolutionary Perspective*. Chicago: The University of Chicago Press.

Workeneh, S., Bekele, A. and Balakrishnan, M., (2012). Species diversity and abundance of small mammals in Nechisar National Park, Ethiopia. *African Journal of Ecology*, **50**(1):102-108.

Yahner, R. H. (1988). Changes in wildlife communities near edges. *Conservation of Biology* **2:**333–339.

Young, H. S., McCauley, D. J., Dirzo, R., Nunn, C. L., Agwanda, B., Campana, M., Fleischer, R., Castillo, E. O., Salkeld, D., Lambin, E., Goheen, J. R., Palmer, T. M., Pringle, R. M.,Veblen, K. E. and Helgen, K. M. (2017). Interacting effects of land-use and climate on rodent borne pathogens in central Kenya. *Philosophical Transactions of the Royal Society B* 372, 20160116.

Zachary, M. H., Robert, A., McCleery, B. A., Collier, R. J., Fletcher, J., Nova J. S., Peter J. T. and Ara, M. (2013). Dynamic Edge Effects in Small Mammal Communities across a Conservation-Agricultural Interface in Swaziland. *Plos one*. **8**(9).

APPENDICES

Appendix 1: Model selection table for rodent species abundance

	cnd((Int))	dsp((Int))	cnd(Dst)	cnd(scl(Hrb	cnd(scl(Shr	cnd(scl(Tre	cnd(Ssn)	cnd(Vgt_ty	df	logLik	AICc	delta	weight
30	-1.052	+	+		0.4895	1.195	+		6	-44.217	104.1	0	0.286
29	-0.4026	+			0.3259	0.8725	+		4	-48.001	105.6	1.51	0.134
25	-0.3675	+				0.6639	+		3	-49.405	105.7	1.65	0.125
26	-0.8212	+	+			0.8087	+		5	-47.039	106.6	2.49	0.082
27	-0.3914	+		-0.1891		0.5841	+		4	-48.529	106.7	2.57	0.079
31	-0.4458	+		-0.1878	0.3265	0.8204	+		5	-47.097	106.7	2.61	0.078
32	-1.034	+	+	-0.1301	0.4804	1.142	+		7	-43.852	106.8	2.71	0.074
57	-0.8269	+				0.9623	+	+	5	-47.8	108.1	4.01	0.038
28	-0.7945	+	+	-0.1471		0.7318	+		6	-46.574	108.8	4.71	0.027
59	-1.203	+		-0.2448		1.087	+	+	6	-46.605	108.9	4.78	0.026
58	-1.389	+	+			1.173	+	+	7	-45.408	109.9	5.82	0.016
61	-0.6723	+			0.1632	0.9558	+	+	6	-47.605	110.9	6.78	0.01
62	-1.145	+	+		0.4475	1.234	+	+	8	-44.195	111.2	7.16	0.008
60	-1.672	+	+	-0.2231		1.265	+	+	8	-44.577	112	7.92	0.005
63	-1.066	+		-0.2393	0.1418	1.088	+	+	7	-46.463	112	7.93	0.005
64	-1.409	+	+	-0.189	0.4038	1.32	+	+	9	-43.623	114.2	10.16	0.002
49	0.4855	+					+	+	4	-52.449	114.5	10.41	0.002
51	0.3351	+		-0.1549			+	+	5	-52.072	116.6	12.56	0.001
53	0.5793	+			0.1148		+	+	5	-52.348	117.2	13.11	0
14	-0.2796	+	+		0.4863	1.188			5	-52.415	117.3	13.24	0
19	-0.2681	+		-0.5279			+		3	-55.385	117.7	13.61	0
23	-0.2725	+		-0.4738	-0.1656		+		4	-54.636	118.9	14.79	0
13	0.3488	+			0.3282	0.8755			3	-56.055	119	14.95	0
50	0.3446	+	+				+	+	6	-51.823	119.3	15.21	0
9	0.3847	+				0.6665			2	-57.49	119.4	15.34	0
16	-0.2605	+	+	-0.1347	0.4762	1.132			6	-52.021	119.7	15.61	0
55	0.4088	+		-0.1437	0.07451		+	+	6	-52.031	119.7	15.63	0
15	0.3035	+		-0.1923	0.3277	0.82			4	-55.097	119.8	15.71	0
11	0.3586	+		-0.1946		0.583			3	-56.556	120	15.95	0
10	-0.05328	+	+			0.8063			4	-55.223	120	15.96	0
41	-0.1592	+				1.015		+	4	-55.848	121.3	17.21	0
43	-0.6017	+		-0.2714		1.16		+	5	-54.401	121.3	17.22	0
12	-0.02566	+	+	-0.1528		0.7257			5	-54.72	121.9	17.85	0
54	0.4895	+	+		0.2106		+	+	7	-51.512	122.1	18.03	0
52	0.2264	+	+	-0.133			+	+	7	-51.576	122.2	18.16	0
20	-0.371	+	+	-0.5274			+		5	-55.1	122.7	18.61	0
42	-0.6738	+	+			1.202		+	6	-53.562	122.8	18.69	0
45	-0.00612	+			0.163	1.009		+	5	-55.653	123.8	19.72	0
46	-0.4258	+	+		0.4424	1.258		+	7	-52.372	123.8	19.75	0
47	-0.4645	+		-0.2671	0.1465	1.165		+	6	-54.25	124.2	20.06	0
44	-1.009	+	+	-0.2485		1.313		+	7	-52.553	124.2	20.11	0
24	-0.387	+	+	-0.4812	-0.1655		+		6	-54.367	124.4	20.3	0
56	0.3776	+	+	-0.09857	0.1703		+	+	8	-51.385	125.6	21.54	0
48	-0.7436	+	+	-0.2152	0.3929	1.363		+	8	-51.647	126.2	22.06	0
21	-0.1856	+			-0.319		+		3	-60.63	128.2	24.1	0
33	1.253	+						+	3	-60.922	128.8	24.68	0
17	-0.1431	+					+		2	-62.969	130.4	26.3	0
35	1.08	+		-0.1728				+	4	-60.465	130.5	26.44	0
37	1.339	+			0.105			+	4	-60.836	131.3	27.19	0
3	0.4798	+		-0.5372					2	-63.43	131.3	27.22	0
7	0.4763	+		-0.483	-0.1637				3	-62.692	132.3	28.22	0
22	-0.2052	+	+		-0.2788		+		5	-60.148	132.8	28.71	0
34	1.112	+	+					+	5	-60.296	133.1	29	0
18	-0.1167	+	+				+		4	-61.839	133.3	29.19	0
39	1.141	+		-0.1635	0.06064			+	5	-60.437	133.4	29.29	0
36	0.976	+	+	-0.1498				+	6	-59.99	135.6	31.54	0
38	1.251	+	+		0.2015			+	6	-60.01	135.7	31.59	0
4	0.3872	+	+	-0.5356					4	-63.185	136	31.88	0
8	0.3722	+	+	-0.489	-0.1637				5	-62.461	137.4	33.34	0
40	1.115	+	+	-0.1178	0.1539			+	7	-59.832	138.8	34.67	0
5	0.5769	+			-0.3249				2	-69.008	142.5	38.37	0
1	0.6242	+							1	-71.441	145	40.94	0
6	0.5587	+	+		-0.2849				4	-68.539	146.7	42.59	0
2	0.6506	+	+						3	-70.312	147.5	43.46	0

Appendix 2: Model selection table for rodent species richness

Model sn	cnd((Int))	dsp((Int))	cnd(Dst)	Herbaceou	Shrub_Den	Tree_densi	Season	Vegetation	df	logLik	AICc	delta	weight
9	-0.3481	+				0.3967			2	-30.976	66.4	0	0.158
3	-0.3312	+		-0.362					2	-31.457	67.4	0.96	0.098
25	-0.5819	+				0.3935	+		3	-30.477	67.9	1.48	0.075
13	-0.3728	+			0.2695	0.5669			3	-30.5	67.9	1.53	0.074
1	-0.2657	+							1	-32.982	68.1	1.71	0.067
11	-0.3616	+		-0.1744		0.3072			3	-30.706	68.3	1.94	0.06
19	-0.5636	+		-0.3571			+		3	-30.963	68.8	2.45	0.046
17	-0.5108	+					+		2	-32.435	69.3	2.92	0.037
33	0.1823	+						+	3	-31.214	69.4	2.96	0.036
29	-0.6049	+			0.2678	0.563	+		4	-30.009	69.6	3.22	0.032
7	-0.3309	+		-0.353	-0.03593				3	-31.441	69.8	3.41	0.029
27	-0.5927	+		-0.1711		0.3062	+		4	-30.218	70	3.64	0.026
5	-0.2714	+			-0.1097				2	-32.855	70.2	3.76	0.024
15	-0.3856	+		-0.1351	0.2399	0.4918			4	-30.334	70.3	3.87	0.023
10	-0.6794	+	+			0.5326			4	-30.338	70.3	3.88	0.023
49	-0.0628	+					+	+	4	-30.666	70.9	4.54	0.016
37	0.4636	+			0.3484			+	4	-30.789	71.2	4.78	0.014
41	-0.3206	+				0.3841		+	4	-30.872	71.3	4.95	0.013
23	-0.5633	+		-0.3481	-0.03587		+		4	-30.947	71.5	5.1	0.012
21	-0.5151	+			-0.1073		+		3	-32.313	71.5	5.15	0.012
35	0.01881	+		-0.1637				+	4	-31.057	71.7	5.32	0.011
14	-0.8072	+	+		0.356	0.7953			5	-29.636	71.8	5.38	0.011
4	-0.472	+	+	-0.4195					4	-31.242	72.1	5.69	0.009
26	-0.9171	+	+			0.5314	+		5	-29.835	72.2	5.77	0.009
31	-0.6156	+		-0.132	0.2389	0.49	+		5	-29.85	72.2	5.8	0.009
12	-0.6662	+	+	-0.1849		0.4323			5	-30.065	72.6	6.23	0.007
2	-0.2877	+	+						3	-32.976	72.9	6.48	0.006
53	0.22	+			0.3548		+	+	5	-30.227	73	6.56	0.006
57	-0.523	+				0.3597	+	+	5	-30.364	73.2	6.83	0.005
45	-0.03983	+			0.3787	0.4113		+	5	-30.383	73.3	6.87	0.005
51	-0.2095	+		-0.152			+	+	5	-30.529	73.6	7.16	0.004
43	-0.5556	+		-0.1862		0.43		+	5	-30.642	73.8	7.39	0.004
30	-1.045	+	+		0.3558	0.795	+		6	-29.136	73.9	7.53	0.004
39	0.3474	+		-0.09421	0.3136			+	5	-30.738	74	7.58	0.004
20	-0.7071	+	+	-0.4152			+		5	-30.747	74	7.6	0.004
34	0.07976	+	+					+	5	-30.914	74.3	7.93	0.003
18	-0.5328	+	+				+		4	-32.428	74.5	8.06	0.003
16	-0.7921	+	+	-0.1352	0.3262	0.7156			6	-29.487	74.6	8.23	0.003
28	-0.903	+	+	-0.182		0.4331	+		6	-29.571	74.8	8.4	0.002
8	-0.4768	+	+	-0.4063	-0.05896				5	-31.202	74.9	8.51	0.002
6	-0.317	+	+		-0.1203				4	-32.839	75.3	8.88	0.002
61	-0.2394	+			0.3817	0.3848	+	+	6	-29.868	75.4	8.99	0.002
59	-0.7313	+		-0.1726		0.4007	+	+	6	-30.165	76	9.59	0.001
55	0.123	+		-0.08109	0.3244		+	+	6	-30.189	76	9.63	0.001
42	-0.7127	+	+			0.5613		+	6	-30.256	76.2	9.77	0.001
47	-0.2416	+		-0.133	0.341	0.4541		+	6	-30.266	76.2	9.79	0.001
50	-0.1654	+	+				+	+	6	-30.366	76.4	9.99	0.001
38	0.3572	+	+		0.4076			+	6	-30.388	76.4	10.03	0.001
24	-0.712	+	+	-0.4022	-0.05905		+		6	-30.708	77.1	10.67	0.001
32	-1.03	+	+	-0.1326	0.3267	0.7172	+		7	-28.994	77.1	10.68	0.001
22	-0.5605	+	+		-0.1177		+		5	-32.297	77.1	10.7	0.001
36	-0.1004	+	+	-0.1891				+	6	-30.73	77.1	10.72	0.001
46	-0.4853	+	+		0.5179	0.6634		+	7	-29.462	78	11.62	0
58	-0.9248	+	+			0.5439	+	+	7	-29.749	78.6	12.19	0
63	-0.4111	+		-0.1174	0.347	0.4217	+	+	7	-29.777	78.6	12.25	0
54	0.113	+	+		0.4126		+	+	7	-29.828	78.7	12.35	0
44	-0.9884	+	+	-0.2254		0.6213		+	7	-29.958	79	12.61	0
52	-0.331	+	+	-0.1783			+	+	7	-30.2	79.5	13.09	0
40	0.2553	+	+	-0.08503	0.366			+	7	-30.354	79.8	13.4	0
62	-0.6994	+	+		0.5198	0.6473	+	+	8	-28.951	80.8	14.36	0
48	-0.6723	+	+	-0.1335	0.4652	0.7018		+	8	-29.363	81.6	15.19	0
60	-1.177	+	+	-0.213		0.5989	+	+	8	-29.482	81.8	15.42	0
56	0.02762	+	+	-0.07282	0.3768		+	+	8	-29.802	82.5	16.07	0
64	-0.8635	+	+	-0.1205	0.4721	0.6813	+	+	9	-28.869	84.7	18.34	0

Appendix 3: Model selection table for Shannon Weiner diversity Index

	(Int)	Dst	Herbaceou	Shrub_Den	Tree_Dens	Vegetation	df.	logLik	AICc	delta	weight
9	0.2154				0.232		3	-2.223	13.9	0	0.298
17	0.5924					+	4	0.301	14.1	0.19	0.271
1	0.2154						2	-4.661	14.8	0.95	0.186
5	0.2154			-0.1731			3	-3.439	16.3	2.43	0.088
3	0.2154		-0.09379				3	-4.33	18.1	4.21	0.036
19	0.7293		0.1817			+	5	1.902	18.2	4.32	0.034
11	0.2154		0.01641		0.2396		4	-2.211	19.1	5.21	0.022
13	0.2154			-0.01846	0.219		4	-2.213	19.1	5.22	0.022
21	0.7736			0.2018		+	5	1.074	19.9	5.98	0.015
25	0.7815				-0.1682	+	5	0.85	20.3	6.43	0.012
7	0.2154		-0.07031	-0.163			4	-3.213	21.1	7.22	0.008
2	0.2342	+					4	-4.206	23.1	9.2	0.003
23	0.9817		0.2102	0.2572		+	6	3.683	25.6	11.76	0.001
10	0.1511	+			0.2405		5	-2.065	26.1	12.26	0.001
27	1.012		0.2121		-0.2315	+	6	3.348	26.3	12.43	0.001
15	0.2154		0.01328	-0.01367	0.2285		5	-2.206	26.4	12.54	0.001
6	0.2372	+		-0.1553			5	-3.241	28.5	14.61	0
4	0.2298	+	-0.06033				5	-4.082	30.2	16.29	0
29	0.8787			0.1664	-0.1217	+	6	1.372	30.3	16.38	0
18	0.5355	+				+	6	0.562	31.9	18	0
12	0.1495	+	0.02617		0.2505		6	-2.036	37.1	23.2	0
14	0.1502	+		0.003092	0.243		6	-2.065	37.1	23.26	0
8	0.2333	+	-0.05347	-0.1531			6	-3.126	39.3	25.38	0
31	1.153		0.2283	0.2103	-0.1777	+	7	4.745	41.8	27.97	0
20	0.6725	+	0.2444			+	7	3.337	44.7	30.78	0
22	0.7336	+		0.2593		+	7	1.832	47.7	33.79	0
26	0.7461	+			-0.1804	+	7	1.142	49	35.17	0
16	0.1447	+	0.03025	0.0158	0.2644		7	-2.03	55.4	41.52	0
24	0.9867	+	0.3044	0.3671		+	8	9.03	69.9	56.06	0
28	1.111	+	0.3214		-0.3382	+	8	7.351	73.3	59.42	0
30	0.8147	+		0.2227	-0.09343	+	8	1.992	84	70.14	0
32	1.227	+	0.3457	0.2886	-0.2374	+	9	14.586	168.8	154.95	0

Appendix 4: Model selection table for Brillouin index

	(Int)	Dst	Herbaceou	Shrub_Den	Tree_Dens	Vegetation	df	logLik	AICc	delta	weight
9	0.1533				0.1757		3	2.27	4.9	0	0.373
17	0.4215					+	4	4.528	5.6	0.72	0.26
1	0.1533						2	-0.726	7	2.06	0.133
5	0.1533			-0.1261			3	0.614	8.2	3.31	0.071
19	0.5243		0.1364			+	5	6.543	8.9	4.03	0.05
11	0.1533		0.02208		0.1859		4	2.32	10	5.14	0.029
13	0.1533			-0.00403	0.1729		4	2.271	10.1	5.24	0.027
3	0.1533		-0.06343				3	-0.417	10.3	5.37	0.025
21	0.537			0.1286		+	5	5.199	11.6	6.71	0.013
25	0.4977				-0.06772	+	5	4.714	12.6	7.68	0.008
7	0.1533		-0.04622	-0.1194			4	0.818	13	8.14	0.006
2	0.1728	+					4	-0.267	15.2	10.31	0.002
23	0.6905		0.1552	0.1695		+	6	8.344	16.3	11.42	0.001
10	0.1092	+			0.1841		5	2.422	17.2	12.27	0.001
15	0.1533		0.02306	0.004291	0.1893		5	2.321	17.4	12.47	0.001
27	0.6623		0.1512		-0.1129	+	6	7.295	18.4	13.52	0
6	0.175	+		-0.1143			5	0.814	20.4	15.48	0
4	0.17	+	-0.03954				5	-0.158	22.3	17.43	0
29	0.5669			0.1185	-0.03464	+	6	5.249	22.5	17.61	0
18	0.3867	+				+	6	4.737	23.5	18.64	0
12	0.1076	+	0.02768		0.1946		6	2.497	28	23.12	0
14	0.1058	+		0.01164	0.1932		6	2.43	28.1	23.25	0
8	0.1725	+	-0.03448	-0.1129			6	0.914	31.2	26.28	0
31	0.7624		0.1628	0.1498	-0.0745	+	7	8.756	33.8	28.93	0
20	0.4876	+	0.18			+	7	8.117	35.1	30.21	0
22	0.5122	+		0.1643		+	7	5.808	39.7	34.83	0
26	0.4686	+			-0.07013	+	7	4.918	41.5	36.61	0
16	0.09965	+	0.03443	0.0261	0.2176		7	2.534	46.3	41.38	0
24	0.6947	+	0.2196	0.242		+	8	14.187	59.6	54.74	0
28	0.7187	+	0.2206		-0.1785	+	8	10.435	67.1	62.24	0
30	0.5184	+		0.1615	-0.00707	+	8	5.809	76.4	71.49	0
32	0.8023	+	0.238	0.2069	-0.1062	+	9	16.349	165.3	160.41	0

Appendix 5: Model selection table for Simpson's diversity Index

	(Int)	Dst	Herbaceou	Shrub_Den	Tree_Dens	Vegetation	df	logLik	AICc	delta	weight
9	0.1302				0.1422		3	3.51	2.4	0	0.311
17	0.3581					+	4	6.012	2.6	0.23	0.277
1	0.1302						2	0.945	3.6	1.2	0.171
5	0.1302			-0.1054			3	2.205	5	2.61	0.084
19	0.4408		0.1097			+	5	7.668	6.7	4.25	0.037
3	0.1302		-0.05676				3	1.282	6.9	4.46	0.034
11	0.1302		0.01096		0.1472		4	3.525	7.6	5.21	0.023
13	0.1302			-0.00992	0.1352		4	3.518	7.6	5.22	0.023
21	0.4643			0.1183		+	5	6.761	8.5	6.07	0.015
25	0.4619				-0.09231	+	5	6.475	9	6.64	0.011
7	0.1302		-0.04246	-0.09926			4	2.435	9.8	7.39	0.008
2	0.142	+					4	1.406	11.9	9.45	0.003
23	0.5896		0.1265	0.1516		+	6	9.432	14.1	11.73	0.001
10	0.09087	+			0.1479		5	3.673	14.7	12.24	0.001
15	0.1302		0.00947	-0.0065	0.1419		5	3.528	14.9	12.53	0.001
27	0.6		0.1268		-0.1302	+	6	8.955	15.1	12.68	0.001
6	0.1438	+		-0.0947			5	2.404	17.2	14.78	0
4	0.1393	+	-0.03658				5	1.532	18.9	16.53	0
29	0.52			0.09952	-0.06454	+	6	6.994	19	16.6	0
18	0.3241	+				+	6	6.276	20.4	18.04	0
12	0.08989	+	0.01667		0.1542		6	3.708	25.6	23.18	0
14	0.08988	+		0.003413	0.1505		6	3.674	25.7	23.24	0
8	0.1414	+	-0.03239	-0.09336			6	2.522	28	25.55	0
31	0.684		0.1365	0.1257	-0.09797	+	7	10.337	30.7	28.25	0
20	0.4067	+	0.1474			+	7	9.155	33	30.61	0
22	0.4406	+		0.1524		+	7	7.513	36.3	33.9	0
26	0.4389	+			-0.09841	+	7	6.76	37.8	35.4	0
16	0.08634	+	0.01969	0.01168	0.1644		7	3.717	43.9	41.49	0
24	0.5926	+	0.1829	0.2172		+	8	14.932	58.1	55.73	0
28	0.6558	+	0.1912		-0.1923	+	8	12.776	62.4	60.04	0
30	0.4804	+		0.1344	-0.04591	+	8	7.621	72.8	70.35	0
32	0.7259	+	0.2058	0.1737	-0.1317	+	9	19.594	158.8	156.4	0

Appendix 6: field images

a). Sherman trap destroyed by a Rhino in one of the transects in NNP

b). Sherman trap that caught a snake, (Naja nigricollis) in NNP

c). Ground view of a laid Sherman trap in one of the transects in NNP

d). Ground view of Riverine habitat in NNP

e). Ground view of edge habitat in an area overgrazed by cattle in NNP