DISTRIBUTION OF RAPTORS IN THE CITY METROPOLITAN, NAIROBI, KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree or any other award in any other University

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DEDICATION

This thesis is dedicated to my family; especially my mother who supported and encouraged me through my studies and field work. Your encouraging words helped me through the many long hours in the field and at the university. To my brother John for the kind and unwavering support whenever I needed back up.

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ABSTRACT

Diurnal raptors are a great group of birds to use for environmental monitoring. Being at the top of the food chain, raptor populations indicate the health of an ecosystem in general and show gradual trends as occasioned by environmental changes. Nairobi is a fast-developing urban metropolis and its development has led to reduction of green spaces in most places where there were forests and woodlands. This study was developed to help quantify the importance of urban forests by using diurnal raptors as indicators of forest value. Line transects were conducted in three large forest blocks within the greater Nairobi metropolitan; namely Karura Forest, Ngong Road Forest and Thogoto Forest. A metropolitan road transect was also developed to overlap the three study forests and then incorporate all the major development zones around the city. These transects were used to count all diurnal raptors seen or heard and then comparisons were computed to quantify the differences between the three forests individually. Secondly, the three forests as one single block, were compared against the city metropolitan. The study identified 15 diurnal raptor species in the three urban forests. The Shannon diversity index results showed that Thogoto Forest had the highest raptor diversity index (Shannon) at 1.08, followed by Ngong Road Forest Sanctuary at 1.05 and the lowest was Karura Forest at 1.03. However, the Analysis of Variance (ANOVA) results queried on the diversity indices showed that the indices were not statistically significant. Therefore, despite each forest having some species that did not occur in the other two forests; the three urban forests did not differ significantly in the numbers of species represented. Species encounter rates were computed per 100 kilometres to check for differences in species abundances across the three forests. A chi-square test of independence was done to examine the relation between species encounter rates across the three urban forests. The results showed that; species that were more abundant in one forest, were not as abundant in the other forests. When the three forests were compared against the metropolitan area; the urban forests had a significantly higher diversity mean score than the metropolitan area. This meant that the urban forests had more raptor species represented than the general metropolitan. Diurnal raptor abundances were also compared between the urban forests and the metropolitan area; and it turned out that those species that were more likely to be encountered in the forests were not as likely to be encountered in the greater metropolitan region. The months of March and April recorded the highest raptor numbers in the three forests with June recording the lowest numbers. In the metropolitan the months of March, April and May recorded the highest raptor numbers while December recorded the lowest numbers. This study showed that the existence of urban forests has an effect on diurnal raptor species diversity and abundance in the greater Nairobi area.

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ACRONYMS AND ABBREVIATIONS

CBD	Central Business District
FF	forest-specialists (species)
F	forest generalists (species)
f	forest visitors (species)
GPS	Global Positioning System
H'	Shannon-index of diversity
IUCN	International Union for Conservation of Nature and Natural Resources
SPSS	Statistical Package for the Social Sciences
UN	United Nations
UNEP	United Nations Environment Programme
χ^2	Chi-square

CHAPTER ONE

1 INTRODUCTION

1.1 Background

1.1.1 Nairobi and urban forests

The capital city of Kenya, Nairobi, was established in 1899. At its inception, it started as a railway supply depot (Iwatani and Wanjiku, 2010). Urbanization is a global trend that is transforming many natural habitats into anthropogenic pockets. Nairobi has been continually expanding both in infrastructure and human population and even faster in the past decade (Wachira, 2017a).

Urban forests are very crucial to the conservation of birds especially in areas where forest habitats are changing regularly (Dranzoa, 1990; Wachira, 2017b). Nairobi has many small forest blocks, of varying sizes and protection levels. This study focused on three of these small forest blocks; namely Karura Forest (located on the Northern end of Nairobi County, between Limuru Road and Kiambu Road), Ngong Road Forest Sanctuary (located near the Nairobi CBD, between Ngong Road and the Southern Bypass) and Thogoto Forest, also called Dagoretti Forest (located on the Western boundary of the Nairobi County, along Dagoretti Road). Several measures have been taken to improve the urban forests of Nairobi. Fencing, of varying extent, has been done in Karura Forest and Ngong Road Forest Sanctuary. In Karura Forest, Friends of Karura Forest (FKF- the local Community Forest Association) undertook a project that reintroduced the Mount Kenya Guereza (*Colobus guereza kikuyuensis*), a species of Colobus Monkey presumed to have been present in the forest in the past (Fundi and Mariotte, 2016). Of the three study forests, Karura (gazetted as a forest reserve in 1932) is the most famous among the local public and is a good example of successful community-based participatory forest management (Croze, 2016). Before the forest was transformed, it suffered immense destruction by poachers and especially those cutting *Muhugu* (*Brachylaena huillensis*) trees for wood carving (Croze, 2016). Thogoto Forest still remains unfenced to date, although regular security patrols are performed by the Kenya Forest Service Rangers.

1.1.2 Diurnal raptors

Kenya has seventy nine (79) species of diurnal birds of prey (raptors); as recognized by the country's birds' checklist (Bird Committee, 2019). These species are divided into four main families; namely Family *Sagittariidae*, Family *Accipitridae,* Family *Falconidae* and Family *Pandionidae*. Two of these families are represented by single species in the country; namely Family *Sagittariidae*: Secretarybird *Sagittarius serpentarius,* Family *Pandionidae*: Western Osprey *Pandion haliaetus*.

The other two families have multiple species occurring in Kenya. In Kenya, Family *Falconidae* has eighteen (18) species of Kestrels and Falcons; such as African Pygmy Falcon *Polihierax semitorquatus,* Lesser Kestrel *Falco naumanni*, Common Kestrel *Falco tinnunculus*, Greater Kestrel *Falco rupicoloides*, Red-necked Falcon *Falco chiquera*, Red-footed Falcon *Falco vespertinus* and Amur Falcon *Falco amurensis*. Family *Accipitridae* is the largest family of diurnal raptors; and there are fifty nine (59) species occurring in Kenya. It is comprised of Hawks (such as African Cuckoo Hawk

Aviceda cuculoides, Bat Hawk *Macheiramphus alcinus*, Dark Chanting Goshawk *Melierax metabates* and Eastern Chanting Goshawk *Melierax poliopterus*), Vultures (such as Palm-nut Vulture *Gypohierax angolensis*, Egyptian Vulture *Neophron percnopterus*, White-headed Vulture *Trigonoceps occipitalis*, Hooded Vulture *Necrosyrtes monachus* and White-backed Vulture *Gyps africanus*), Buzzards (such as European Honey Buzzard *Pernis apivorus*, Mountain Buzzard *Buteo oreophilus*, Long-legged Buzzard *Buteo rufinus* and Augur Buzzard *Buteo augur*), Eagles (such as Short-toed Snake Eagle *Circaetus gallicus*, Beaudouin's Snake Eagle *Circaetus beaudouini*, Crowned Eagle *Stephanoaetus coronatus*, Martial Eagle *Polemaetus bellicosus* and Tawny Eagle *Aquila rapax*), Kites (such as Black-shouldered or Black-winged Kite *Elanus caeruleus*, African Swallow-tailed or Scissor-tailed Kite *Chelictinia riocourii* and Black Kite *Milvus migrans*), and Harriers (such as Western Marsh Harrier *Circus aeruginosus*, African Marsh Harrier *Circus ranivorus*, Pallid Harrier *Circus macrourus* and Montagu's Harrier *Circus pygargus*).

Diurnal raptors offer vital ecosystem services, helping to regulate populations of their prey species, including crop pests, and for vultures, consuming carcasses rapidly to prevent the spread of diseases (Wachira, 2017a). Diurnal raptors are faced with many dangers in their natural habitats (Thomsett, 2011). This is mainly due to their low numbers, relatively large territorial ranges and direct anthropogenic persecution; where they are shot for meat, ornamental bones and archery feathers (Noss *et al.*, 1996; Thiollay, 2006; Thomsett, 2011).

Most of the regions in Africa are less studied, and the local diurnal raptor populations and trends are poorly documented (Thiollay, 2006; Thomsett, 2011; McPherson *et al.*, 2016). Moreover, past studies on the distribution of diurnal raptors have focused on few popular and highly protected wildlife areas; like national parks and pristine forests (Shultz, 2002; Thomsett, 2011; McPherson *et al.*, 2016). This may provide a biased opinion as to the current distribution and status of these species; as well as the perceived dangers they face. This calls for more studies from all corners of the continent, to reveal the real continental picture of these species' status across their entire ranges (Thomsett, 2011). It is also paramount for new studies to shift from the norm of studying pristine habitats and protected areas. Sound Scientific knowledge from more disturbed habitats, such as urban areas and unprotected forests will help inform future conservation policies for diurnal raptors.

1.2 Statement of the problem

The value of Nairobi's forests to human existence and the general ecosystem balance is very significant (Wachira, 2017a). However, most of Nairobi's forest blocks have been degraded over the past decades, suffering massive biodiversity losses (Croze, 2016; Wachira, 2017a). Further, Nairobi is transforming rapidly with pressure to build multi-lane highways, by-passes, wind mills, power lines to new homes, and the new Standard Gauge Railway (Wachira, 2017a). Habitat loss is the most significant threat to biodiversity globally (Munyekenye, 2006).

Thomsett (2011) detailed the main threats facing raptors in Kenya and Africa in general. These include direct habitats loss, where nest sites and feeding areas are reduced significantly. Persecution and direct hunting is also a considerable threat to raptors. Nairobi has had these same problems, and the local raptors are faced with similar challenges. For raptors to survive, they need pristine habitats. Nairobi’s raptors need the urban forests, for them to breed and feed.

In the past, most Nairobi’s forests have been heavily degraded, by illegal loggers and game-meat poachers (Croze, 2016; Wachira, 2017a). Local conservation managers ought to protect these urban forests against further encroachment by poachers, illegal loggers and unplanned developments. With the increasing urbanization and habitat conversion, the need to conserve and sustain indigenous wildlife populations is proving more urgent (McPherson *et al.*, 2016). McPherson *et al.* (2016) suggested that optimal integration of wildlife habitats into urban sprawl is a possible way of ensuring species are not lost during urban development. It is, however, a considerable challenge for Scientists to comprehensively prove the value or ecological importance of urban forests.

1.3 Justification

One suitable way to justify the conservation of urban forests to the forest managers, county management and other stakeholders is by profiling their ecological importance. This calls for more studies that will quantify the ecological value of these urban forests using a reliable set of indicators.

The success or failure of different bird populations points to the state of the habitat where they occur (Munyekenye 2006; McPherson *et al.*, 2016). This means that if a certain bird population is successful, the habitats is favourable. The richness and composition of avifauna in a given forest can give an indication of the overall value of that forest for the conservation of biological diversity (Bennun *et al.*, 1996). Critical to note, in many parts of the World, environmental change, as well as the impacts of habitat alteration (and sometimes, restoration), are accurately assessed by monitoring avian communities; since birds are easy to count, observe and identify (Pomeroy, 1992; Furness and Greenwood, 1993). Surveys on birds can be made in a fraction of the time and expense required for most other faunal groups' studies aimed at the same outputs (Pomeroy, 1992).

Diurnal raptors occupy the top of the food chain in Nairobi city; and thus they are a reliable indicator for the health condition of the various urban ecosystems (Munyekenye, 2006; Thomsett, 2011; McPherson *et al.*, 2016; Wachira, 2017a). Diurnal raptors vary significantly in forests of different quality, as well as in the anthropogenic metropolitan space (Bennun *et al.*, 1996). The presence of large diurnal raptors (for example Crowned Eagles), in urban areas, indicates a substantial prey base (such as smaller birds, reptiles, rodents and mammals) and adequate forest cover to establish successful nesting territories (McPherson *et al.*, 2016). The presence of many breeding pairs of large diurnal raptors, in urban areas, also indicates an absence of persecution by humans (McPherson *et al.*, 2016). Studying their distribution within the greater Nairobi will help unlock critical aspects on the ecological value of urban forests.

This study helped to evaluate the ecological status of urban forests in the greater Nairobi using diurnal raptors as indicators; as suggested in Pearson (1995). The study focused on establishing the distribution of diurnal raptors within the greater Nairobi. There have not been previous similar studies in the greater Nairobi region, focusing on the objective this study addressed. Therefore, this study addressed a research gap in the study area. Through results obtained from this study, sustainable urban forest management structures were recommended to all stakeholders working towards safeguarding these urban forests.

1.4 Research Questions

i) What are the differences in the diurnal raptor diversity across the three urban forests (Karura, Thogoto and Ngong Road Sanctuary) of the greater Nairobi?

ii) What are the differences in the diurnal raptor abundance across the three urban forests (Karura, Thogoto and Ngong Road Sanctuary) of the greater Nairobi?

iii) What are the differences in diurnal raptor distribution between urban forests and the metropolitan of the greater Nairobi?

1.5 Hypotheses

i) Diurnal raptor diversity is not dependent on forest type or management strategies.

ii) Diurnal raptor abundance is not dependent on forest type or management strategies.

iii) Existence of urban forests has no significant effect on diurnal raptor distribution.

1.6 Objectives

1.6.1 General Objective

To assess the role of urban forests in the distribution of diurnal raptor populations in the greater Nairobi.

1.6.2 Specific Objectives

i) To compare the diurnal raptor diversity across three urban forests (Karura, Thogoto and Ngong Road Sanctuary) of the greater Nairobi.

ii) To compare the diurnal raptor abundance across three urban forests (Karura, Thogoto and Ngong Road Sanctuary) of the greater Nairobi.

iii) To establish differences in diurnal raptor distribution between urban forests and the metropolitan of the greater Nairobi.

1.7 Significance and anticipated output

The study helped generate scientifically-sound knowledge about urban raptors that will better inform conservation policies that Kenya Forest Service, Wildlife Research and Training Institute and Kenya Wildlife Service were lacking. Ngong Road Community Forest Association, Thogoto Forest Community Conservation Association and Friends of Karura Forest are developing and regularly updating management plans for their respective forests. Data from this study will add critical knowledge to the required measures of conserving these top avian predators and their habitats. In the long-term, findings generated from this study will be utilized in the development of single species action plans and threat assessments for raptors by The Peregrine Fund and the IUCN. This study has given direction to decisions makers on where roads, railway lines, power lines, wind farms and other industry may be built; without affecting the ecosystem balance. This will, in turn, progressively transform Nairobi as a model green city that has a National Park at its doorstep where one can see predators like lions and now avian predators like Crowned Eagles.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Diurnal raptors and their Biology

Raptors are birds of prey, characterised by having keen vision, strong, hooked bills and strong, sharp talons on their feet (del Hoyo *et al.*, 1994). Raptor species have reversed sexual dimorphism, where unlike many other birds, females are larger than males (Clark and Davies, 2018). Further, males have a different toned call from females; where males have a higher pitched tone (Thomsett, 2011; Clark and Davies, 2018). Some species also have colour variations between males and females. Juveniles and Immature birds are usually differently plumaged from the adults. Large raptors depend on thermals rising from the earth surface to fly. These thermals help them create lift for their proportionately heavy bodies. Smaller raptors will often power their flight with strong wingbeats (Zimmerman *et al.,* 1999; Stevenson and Fanshawe, 2003; Clark and Davies, 2018).

Breeding raptor pairs often engage in aerial display flights. These flights and aerial displays are often combined with loud calls, mainly used for advertising territories (Zimmerman *et al.,* 1999; Stevenson and Fanshawe, 2003; Thomsett, 2011). Raptors build medium to large stick-made nests, with the larger species building, the larger sizes (Tarboton, 2001; Clark and Davies, 2018). Some birds of prey however, do not build their own nests; but instead utilise old nests from other birds e.g. Falcons. Some falcons also choose to nest on edges of buildings and natural cliff faces. Human-made nest boxes are also a key nesting site for many birds of prey (Clark and Davies, 2018).

Raptors are all dependent on meat-based diets; where they choose different sources of nutrition from species to species. Most diurnal raptors will hunt their own prey, with prey size being dependent on the raptor species, age, gender, yearly cycles (such as breeding season or migration season) and seasons (Thomsett, 2011; Clark and Davies, 2018). Prey hunting techniques vary across species and genera; and these include ambush mammalian hunters like Crowned Eagles; ground-based termite hunters like Steppe Eagles (*Aquila nipalensis*); and aerial bird-predators like the Lanner Falcon (*Falco biammicus*); with most diurnal raptors preying on more than one prey species. A large group of diurnal raptors will scavenge readily when an opportunity arises (Zimmerman *et al.,* 1999; Stevenson and Fanshawe, 2003; Clark and Davies, 2018).

Conventionally, vultures are the group of diurnal raptors considered to be scavengers. However, field observations have proven than a big proportion of other diurnal raptors also scavenge either on natural carrion from wild habitats or on road kill along urban settlements. Non-vulturine diurnal raptor species known to readily scavenge include the Tawny Eagle (*Aquila rapax*), which often associates with vultures and mammalian scavengers around carrion in the wild; and the Black Kite (*Milvus migrans*), which often scavenges road kills (Clark and Davies, 2018).

One raptor is also a keen consumer of plant parts; that is the Palm-nut Vulture (*Gypohierax angolensis*), which often feeds on palm nuts around coastal lowlands and dry countryside. The Palm-nut Vulture is however not an exclusive vegetarian; and they often scavenge dead fish along water shores and road-kill carrion. Palm-nut Vultures also kill live prey such as crabs, small turtles, molluscs, insects, rodents and nestling birds (Clark and Davies, 2018).

Raptor habitats differ considerably from species to species. Most species will often associate with certain habitat types based on their feeding and breeding Biology. Some species are more eclectic in terms of their habitats choices; tending to occupy virtually any available habitat, for example Black Kite (*Milvus migrans*) that survives well even in urban areas (Zimmerman *et al.*, 1999; Thomsett, 2011; Clark and Davies, 2018). These eclectic species will often have higher survival chances than the more selective species. Some diurnals raptors will be present only in specific habitat types; such as forest-dependent raptors like the Cassin's Hawk-Eagle (*Aquila africana*) which occurs in lowland and submontane tropical rainforests (Clark and Davies, 2018). Urban habitats are now increasingly becoming a preferred habitat for many diurnal raptor species (McPherson *et al.*, 2016; Wachira, 2017a). As McPherson *et al.* (2016) explains, we are likely to see increased use of urban habitats by both small and large raptor species; with the continued human developments and habitat conversions.

Some species of diurnal raptors migrate following varying migration patterns across the globe and at different times of the year. Some of the common migration patterns exhibited by raptors include Palearctic migration, where raptors migrate to the Northern latitudes in the summer months (April to September) mainly for breeding e.g. Steppe Eagle (*Aquila nipalensis*). Another common migration pattern exhibited by diurnal raptors is altitudinal migration; where highland species move to lower altitudes during cold months (mainly July) and vice versa e.g. Rufous-breasted Sparrowhawk (*Accipiter* *rufiventris*). According to Clark and Davies (2018); intra-African migrations are also common among diurnal raptors; with some species breeding in certain regions of the continent then migrating to other regions for a couple of months e.g. Wahlberg's Eagle (*Aquila wahlbergi*). Some raptors however, do not make any migrations locally or globally; such as the Crowned Eagle as explained in Thomsett (2011).

2.2 Diurnal raptors and their status in forests

Urban raptors contribute greatly to the global populations of their species (McPherson *et al.*, 2015; McPherson *et al.*, 2016; Kenya Bird Map, 2020). Many of the Kenyan raptor species are known to be widely distributed, with some few species being endemic to selective habitats (Lewis and Pomeroy, 1989; Kenya Bird Map, 2020). Some follow their prey and exist in habitats hosting adequate prey species and numbers. Prey abundance and availability can influence breeding performance in raptors; thus it plays a key role in raptor distributions (Virani and Harper, 2009).

There are several families of raptors represented by different diurnal species of Nairobi (Britton, 1980; Wachira 2017a). Nairobi is considered a great place for diurnal raptors with a huge, varied composition of species. Some exhibit preference of certain sites across the metropolitan while some migrate each day locally in synchronised diurnal movements (Wachira, 2017b).

Thomsett (2011) noted that for the last few decades, protected areas such as forests and parks have secured the populations of diurnal raptors. These protected habitats will continue to offer a home to diurnal raptors; so as long as they are allowed to remain in existence and in good condition. In his studies, Thomsett (2011) noted that 27 diurnal raptor nests/ territories that were present in the late 1970s plummeted to only 3 nests/ territories in the following decade and they were all gone in the next decade.

Bennun *et al.* (1996) detailed the forest birds of Kenya and Uganda into three categories namely: - the forest-specialists (FF species), the forest generalists (F species) and the forest visitors (f species). In the paper, it details, FF and F species, but not f species, are dependent on forests. The forest-dependent birds, especially the forest specialists, are less widespread than forest visitors. Kenya has 335 forest birds in total.

Further, the proportion of FF, F and f species and their relative abundance in an area will shift according to changes in the forest structure (Bennun *et al.*, 1996). This aspect can be compared across different forests to show forest structure and quality. Surveys done in two adjacent parts of the Trans-Mara Forest, where the two had undergone differing intensities of logging showed that species composition was similar in the two sites. However, when compared, the densities of many FF species were higher in the less-disturbed location; and a similar result was observed in Kakamega Forest (Bennun and Waiyaki, 1992a; Bennun and Waiyaki, 1992b). Forest specialists' species are more likely to be threatened with extinction than forest generalists or forest visitors' species, mainly because forest specialists have smaller ranges and lower adaptability (Bennun *et al.*, 1996). According to Bennun *et al.* (1996), the proportion of species that are threatened or near-threatened rises with the degree of forest-dependence expressed by the species; FF species being the most threatened.

2.3 Nairobi urban forests, status and their current utilization; with specific overview of Thogoto Forest, Karura Forest and Ngong Road Forest Sanctuary

Urban forests help to offset the effects of anthropogenic development by providing ecological benefits such as filtering air and water pollution, providing habitat for species and maintaining forest cover that will protect watersheds (Dranzoa, 1990; Munyekenye, 2006). Social values of urban forests include being used as spiritual sites, sanctuaries and recreation areas for urban dwellers (Mangat, 2015; Croze, 2016). Economic benefits include raising revenue through tourism, research and providing raw materials for medicine and construction industries.

The increasing threats to forests have made it possible for the birds that live in them to receive greater attention as documented in Bennun *et al.* (1996). There is a catastrophic loss of forest species and other bio-diversity; with little or no functioning actions in existence that would mitigate these losses. Kenya is fortunate to be one of the few countries in Africa with very sound wildlife and forest policies; with the only gap being on implementation of the same (Thomsett, 2011; Wachira, 2017a; Wachira, 2017b). According to Bennun *et al.* (1996), the number of FF species can be used as an initial measure of a forest's relative conservation importance- a feature that is very critical in Nairobi’s forests.

Fortunately, Nairobi as the wildlife capital of the World hosts a great set of natural forests that have survived many years. These natural forests are boosted by several hectares of plantation forests; mainly composed of *Eucalyptus spp.*, *Araucaria spp.*, *Cupressus spp.*, and *Grevillea robusta* (Kenya Forest Service, 2016a; 2016b; 2016c).

All of the three study forests have developed strategic and participatory forest management plans to enable the local communities to manage these resources sustainably (Kenya Forest Service, 2016a; 2016b; 2016c). The plans have identified a number of programmes that are progressively being implemented in the forests. These programmes include Eco-tourism activities, infrastructure development and forest ecosystem business development (such as apiary). These plans are implemented jointly between the Kenya Forest Service (KFS) and the local Community Forest Associations (CFAs). These Community Forest Associations include Thogoto Forest Community Conservation Association (TFCCA), Friends of Karura Forest Community Forest Association (FKF) and Ngong Road Forest Association (NRFA).

The respective participatory management plans for each forest have clearly documented the threats and conservation challenges facing these forests. The three forests have very similar threats and challenges; that is deforestation, wildlife poaching, pressure from urban developers, susceptibility to fires during the dry season, invasive species like *Lantana camara* and dumping of waste inside the forests. However, each Community Forest Association has, working with the Kenya Forest Service, initiated certain measures to counter these threats. These measures include awareness creation among the local community members, tree planting or reforestation, removal of invasive species by physical harvesting, increased research programmes and improved community waste collection by private companies (Kenya Forest Service, 2016a; 2016b; 2016c).

The forests in the greater Nairobi area are fortunate to have governance and protection status seldom afforded any other forest in Kenya; other than those forests that are protected in well managed Kenya Wildlife Service national parks (Wachira, 2017a; Wachira, 2017b). During his field work, Thomsett (2011) observed the presence of dead timber on the Nairobi forests' floor, antelope droppings, minimal livestock present, minimal snaring evidence and comparatively low human disturbance. This is unlike other forests in the rest of Kenya; where firewood harvesting and livestock grazing are a common scene.

Nairobi forests have also proven to be a great habitat for nesting diurnal raptors; with many nests recorded in forests of varying size and quality (Thomsett, 2011; Wachira 2017a; Wachira, 2017b; Clark and Davies, 2018). Most raptors, especially large species like Crowned Eagles, exhibit high nest site fidelity. This implies that there are some unique factors that they prefer in these sites and which may hold the key explanation to their continued survival. Once these are identified and documented, they will hopefully inform future policy and developmental decisions' making (McPherson *et al.*, 2016).

2.3.1 Thogoto Forest

Thogoto Forest occupies a land area of 764 ha. The forest is composed predominantly of exotic plantations; occupying 711 ha of the forest area. The exotic species include *Eucalyptus spp*. covering 694 ha, *Grevillea robusta* covering 4 ha and *Cupressus lusitanica* covering 13 ha. Indigenous species in the forest cover an area of 53 ha. These indigenous species include *Acokanthera schimperi, Albizia gumnifera, Brachylaena* *huilensis, Calondedrum capense, Croton megalocarpus, Juniperus procera, Markhamia lutea, Osyris lanceolata, Podocarpus latifolia, Teclea nobilis* and *Waburgia ugandensis.* (Kenya Forest Service, 2016a).

2.3.2 Karura Forest

Karura Forest covers an area of 1041.3 ha and is divided into two blocks; that is Karura (including Mazingira, where the field work occurred; that is 797.3 ha) and Sigiria. The forest has a sizeable plantation covering 461 ha. The plantation is comprised of species such as *Araucaria cunninghamii, Eucalyptus saligna*, *Eucalyptus globula*, *Brachylaena huillensis*, *Grevillea robusta*, *Cupressus torulosa* and *Cupressus lusitanica*. The indigenous trees cover an area of 257 ha. This area is comprised of species such as *Olea europeae var. africana, Croton megalocarpus, Warburgia ugandensis, Brachyleana huillensis, Uvaridendron anisatum, Markhamia lutea*, *Teclea nobilis, Juniperus procera, Craebean brownii*, *Newtonia buchananii, Salvadora persica, Ficus thonningii*, *Trichilia emetica, Calondendrum capense* and *Dombeya goetzenii.* Additionally, there are 43.5 ha of degraded indigenous forest that have not been stocked. A further 72.2 ha have been replanted with indigenous trees and are managed. Another 45.8 ha have been planted but have not been managed in any way (Kenya Forest Service, 2016b).

2.3.3 Ngong Road Forest Sanctuary

Ngong Road Forest covers an area of 1,224.4 ha; comprising of two blocks; that is Miotoni Section to the North West and the Racecourse and Kibera section to the South East (this covers 702 ha and the field work took place in this block). The area of forest covered by plantations is 393.45 ha. This plantation is made up of species such as *Eucalyptus spp., Pinus spp., Cupressus spp., Croton spp.* and *Cordia spp.* The indigenous trees cover 670.4 ha. This section is composed of species such as *Brachylaena hutchinsii, Croton megalocarpus, Olea chrispophylla*, *Maba abyssinica, Calodrendum capense*, *Warbugia ugadensis* and *Drypetes battiscombei* (Kenya Forest Service, 2016c).

2.4 General threats to raptors and population declines

Habitat loss is the major threat to raptors in any given ecosystem globally (Munir *et al.*, 2010; Thomsett, 2011; Donázar *et al.*, 2016). Larger species of raptors are less adaptable to habitat change, as compared to smaller species (Chace and Walsh, 2006). The most-threatened areas, by habitat loss and conversion, are the productive areas. These include the best fertile lands around the highlands and wetlands of Kenya; as well as the prime grasslands that provide best real estate grounds. Thomsett (2011) mentions that only high education as well as a new ethical world order, focused on principled restraint by humans to limit our full population potential, can intervene. As true as this may be, there is evidently less effort being placed to reverse habitat loss; with increasing demand on land each seen day (UNEP, 2010; UN-Habitat, 2012). Owino *et al.* (2008), notes that tropical forests are certainly being degraded and destroyed more rapidly due to human activities.

An increasing human population is a major threat to raptors in Nairobi; and a big contributor to habitat loss (Wachira, 2017a). By Kenya's independence in 1963, Nairobi city had a population of 350,000 people. Today, over 3.138 million people occupy the 696.1 square kilometres of the modern Nairobi (UNEP, 2010; UN-Habitat, 2012). Kenya’s population was 5.5 million people in the year 1955; but the current population stands at over 47 million today. The urban and rural populations of Kenya are projected to equal by the year 2050; with a population of over 80 million people (Thomsett, 2011). According to Thomsett (2011), the unfortunate reality is that wildlife is expected to actually parallel these human-population changes with proportional declines; thus the more humans increase, the more wildlife decreases.

Climate change is a major threat to raptors. Urban Heat Island effects are a key climatic feature of cities, after vegetation has been cleared. The resultant higher temperatures of large urban areas compared to their surroundings are easily observed in all major cities (Collins *et al.*, 2000; Kalnay and Cei, 2003).

Poisoning is another key threat to diurnal raptors in Kenya and Africa as a whole. In recent past, poisoning cases have been related to human-wildlife conflicts and poaching. Most poisoning incidents in Kenya are a result of pastoral community’s retaliation after their livestock has been attacked by mammalian carnivores e.g. Spotted Hyena (*Crocuta*

crocuta), African Lion (*Panthera leo*), and other large predators (Ogada and Keesing, 2010).

Poaching, human persecution and trade in raptor body parts is another major threat to species populations across the entire African continent (The Peregrine Fund, 2017). Some are used in the fetish markets and others are sold to be used in the zoos or amusement parks in exotic regions. A major cause of population decimation in these export trades is the fact that most trapped wild birds die before reaching their aimed destination; thus demanding more captures from the wild. Some raptors get targeted by poachers or local farmers in fear of livestock predation; where some large eagles are known to kill sheep and goats; with smaller raptors preying on chickens (Thomsett, 2011; Wachira, 2017a). Thomsett (2011) recorded a Crowned Eagle that was killed by a Kenyan resident for killing a domestic cat. Poaching also affects diurnal raptors in another sphere, when humans compete with eagles for mammalian prey. According to Thomsett (2011) Crowned Eagles, in Ololua Forest, were observed to change their menu as forest prey species were lost to poaching and, or, were largely replaced by more open savannah species. The change from diurnal prey species such as antelopes and diurnal hyraxes; to nocturnal prey species such as genets, galagos and mongooses. The diet change was forced upon the Crowned Eagles as poaching and disturbance wiped out the diurnal prey species. Further to this diet change, the Crowned Eagles struggled to breed successfully for a decade; and then later ended up becoming only an occasional and non-breeding visitor to the forest patch; showing just how much poaching of mammalian prey can affect raptor distribution.

Waste and pollution are also a key threat to raptors and their habitats (UNEP, 2010). Nairobi generates over 2,000 tons of garbage per day, and this is dumped undesirably in the open environment or selectively in designated dumpsites, where it is often managed in an unsustainable manner (UNEP, 2010). Urban areas show enhanced levels of bioaccumulation of heavy metals in birds and studies have shown this to be true for an array of species (Swaileh and Sansur, 2006; Hofer *et al.*, 2010; Kekkonen, 2011; Bichet, 2013). Raptors, with them being at the top of the food chain, are in more danger from this kind of pollution.

Another major and emerging threat to raptors, is power lines and telecommunication infrastructure (Clark and Davies, 2018; Van Rooyen and Ledger, 1999). With the ongoing developments in Nairobi, there are more power generation projects being set up. This is aimed at meeting the demand for power in the city (Wachira, 2017a). Being large-bodied and with their large wingspans, birds of prey tend to have longer response time when they encounter a flight-path obstacle (Clark and Davies, 2018).

Severe declines in raptor numbers have been observed in different parts of Kenya (Munir *et al.*, 2010). Ogada and Keesing, 2010 noted, over a three-year period in a protected area in central Kenya, that raptor numbers declined by more than 40% per year. This is an alarming rate for these top members of the food chain. In the study, scavenging birds accounted for most of the decline among the raptors; and their sightings decreased by 70% during the three years survey period. Similar trends in raptor declines were observed in the Mara ecosystem of Southern Kenya by Munir *et al.* (2010).

Raptor species' extinctions and extirpations from certain regions continue to be a reality each day. Most of the birds that have been extirpated from Kenya's wild habitats are forest birds. The relatively reasonable way to save diminishing raptor populations is by creating local capacity; to use raptors as indicator species and thus secure environmental services; through conservation of forests and water catchment areas (Thomsett, 2011).

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Study Area

3.1.1 Introduction

The study was run in the greater Nairobi region, which encompasses areas of Nairobi County and partial sections of the modern Kiambu County (as shown on figure 3.1). Nairobi is averagely at Latitude: 1°16′59″ S and Longitude: 36°49′00″ E. The altitude averages 1684 m. February, the hottest month in Nairobi, and averages at 21°C. July is the coldest month at averagely 17°C. The wettest month is April, averaging rainfall amounts of 130mm. The study was sub-divided into two main sections: - a) the urban forests, and b) the general metropolitan of the greater Nairobi.

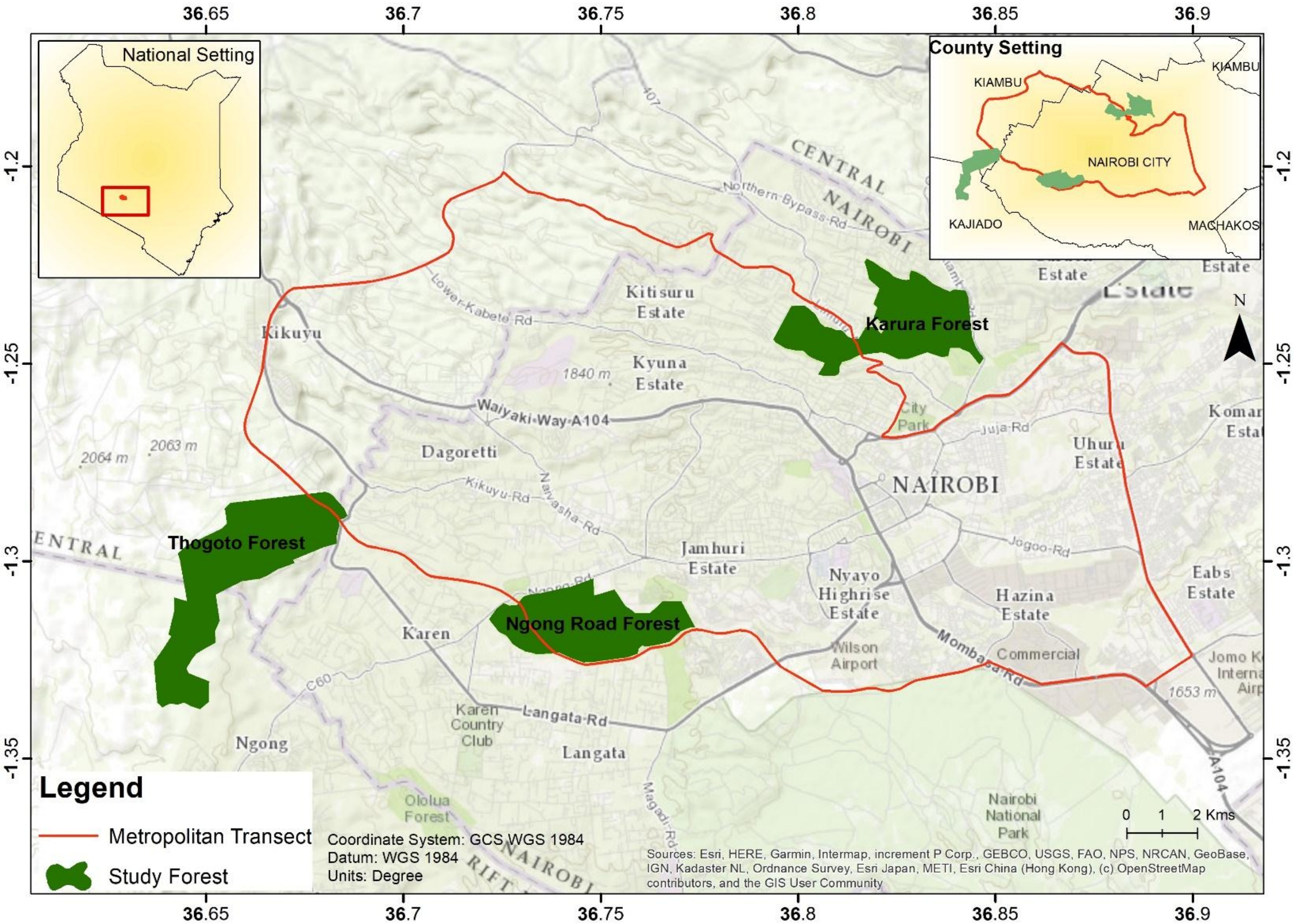


Fig 3.1: Map of the greater Nairobi area showing the study forests and the urban metropolitan transect

3.1.2 The urban forests studied

The study worked in three urban forests: - Karura Forest (797.3 ha, fully fenced and at 1,667 m average altitude); Ngong Road Forest Sanctuary (702 ha, partially fenced and at 1,791 m average altitude); Thogoto Forest (764 ha, not fenced and at 1,951 m average altitude). All the study forests are directly managed by the Kenya Forest Service; with input and participation of the relevant Community Forest Associations (Government of Kenya, 2005).

At the time of the field work, Karura Forest was fully managed and utilised in non-consumptive economic activities only; that is bee keeping, eco-restaurant, events (like weddings), meetings or conferencing, team building activities, outdoor sports and eco-tourism. Ngong Road Forest Sanctuary was also fully managed and only utilised in non-consumptive economic activities; that is outdoor sports, horse racing, events (like weddings), meetings or conferences and eco-tourism. Thogoto Forest was also fully managed with its utilisation including consumptive harvesting of exotic trees, pre-dominantly *Eucalyptus spp*. under the Plantation Establishment and Livelihood Improvement Scheme (PELIS) program (rotational farming and tree growing practised in commercial forests); as detailed by KEFRI, 2014. Thogoto Forest had minor levels of other economic activities, with tourism being low and also occasional horse riding activities.

The three forests were selected based on these criteria:- a) all three forests fall within the greater Nairobi area; b) all three forests are managed by the same government parastatal;

c) the three forests represented the best variation among forests management categories within the urban Nairobi (Karura Forest being fully fenced, Thogoto Forest being totally unfenced, Ngong Road Forest being the intermediate with partial fencing) d) the three forests represented varying degrees of utilisation on the scales of consumptive and non-consumptive economic activities.

3.1.3 The metropolitan transect

The second segment of the study focused on the greater metropolitan. This involved a transect across the main suburbs of Nairobi, covering all major roads and cardinal points of the compass around the city (as shown on figure 3.1). The 80 kilometres-long transect was plotted using Google Maps, touching these landmarks:- Cabanas Bus Stop, Gitaru, Kihara-Gachie-Karura Road, Muthaiga and GSU Headquarters. These locations were joined into a loop, that allowed a comprehensive transect including all habitation types of Nairobi; that is affluent neighbourhoods around Karen and Muthaiga; rural farmlands or highlands around Gitaru and Muguga; slums and less affluent areas around Kibera and Wangige; industrial areas around Mombasa Road and Embakasi; and medium class estates around Eastlands and Langata.

3.2 Study design

3.2.1 Sample area and size

The Significance Criterion (P –Value) for the study was set at 0.05 or 5 percent. Since the study required a representation of urban forests in the greater Nairobi, a minimum forest size of 700 ha was deemed as a necessary criterion to allow enough an area for adequate raptor sightings. In each forest, 4 transects were used to cover all available habitats. The city transect line was set at 80 kilometres to allow a sample of all available settlement types within the greater Nairobi area.

3.2.2 Sampling design

The study employed a combined stratified and purposeful sampling design. This allowed the study areas to be divided into equal sections based on the distinct ecological characteristics; for comprehensive data collection.

Stratified sampling was used to allow equal representation of urban forests within the study area. The forests of Nairobi were all broken down into size area, current economic uses and conservation status. Each of the three strata of forest types we represented equally allowing the final decision to study the three forests; that is Karura Forest, Thogoto Forest and Ngong Road Forest Sanctuary. In this sampling design, transects were aligned within all the habitat types in the three forests. In the greater metropolitan, stratified sampling was applied to design a route that represented all the economic zones of Nairobi; that is industrial areas, rural farmlands, slums, medium-class estates and affluent estates.

Purposeful sampling was also used in the study. The known and existing Scientifically-proven characteristics of diurnal raptors were employed to select the most productive areas within the study sites. To allow maximum data and to account for all variants; the field work was conducted from December 2016 to July 2017. This allowed for sampling that cut across two seasons (dry season and rainy season). This purposeful design also allowed the study to factor in another major aspect of diurnal raptors; that is raptor migrations (Palearctic and Intra-African); and this was well represented in the studied months. Purposive sampling also allowed for sampling time to be based on best activity times for diurnal raptors; that is most birds of prey start soaring as from 1000hrs when there are warm thermals rising from the ground to aid their lift and effective flight. This allows the diurnal raptors, with heavy bodies to conserve energy by flying rather effortlessly across the sky.

3.2.3 Selection of forest sampling sites

Four transects of one kilometre each were established in each forest. Transects were averagely five hundred metres apart to reduce individual mixing of birds and establish independence of bird populations. Transects were randomly selected along existing forest paths to cover all habitats within the forests. Random grid codes (selected by throwing four dice cubes) were picked on a printed map of each forest, after which they were stretched along the forest maps to cover the habitats evenly and form transects.

3.2.4 Counting diurnal raptors in the forests

Transects were covered on foot by two people (each scanning the opposite side of the line, using professional Vortex 8x42 Binoculars pairs). Bird identification was done in the field, using field guide books; that is Zimmerman *et al.*, 1999; Stevenson and Fanshawe, 2003. Bird calls were identified and confirmed through the digital version of Stevenson and Fanshawe, 2003. The counters walked at an average speed of two kilometres per hour. The birds were recorded, based on the distance from the transect line, as distance 1 (50 metres), 2 (50-100 metres), 3 (100-250 metres), 4 (250-500 metres), 5 (over 500 metres) and 0 (birds that flew over the transect line).

Transects counts were conducted from 1000hrs to account for large raptors that depend on thermals to fly. Transects were done on three days per week, with each of the three forests taking one separate day; to ensure similarity in field work timings. Transects routes were alternated to have the first transect from the previous week covered last in the following week; for maximum uniformity across the forest habitats. Starting points on each transect line were also alternated to have the ending point of any transect being the starting point in the following week’s survey. This allowed for even time sampling of the different forest sections.

Each raptor sighted or heard was identified, aged, photographed (where possible) and GPS coordinates taken (using Garmin eTrex20 GPS Receivers). Further, the team estimated the distance, from the transect lines, of all birds seen or heard by use of a Range Finder (Insight 400XL).

3.2.5 Counting diurnal raptors in the metropolitan

A monthly road transect of the greater Nairobi metropolitan area was conducted, covering a looping circuit. The road transect covered 80 kilometres and was conducted in a vehicle travelling at averagely 20km/hr. Transects were done every mid-month Saturday from December to June. Surveys started at 0900hrs. The starting time was pre-determined to favour raptor activity, as many large raptors depend on thermals for flight and only start flying after the earth surface has warmed up.

However, urban areas (developed metropolitan zones) warm faster than forests, due to presence of more heat absorbing and reflecting surfaces; that is road surfaces, roofing surfaces, humans and contribution from automobiles. Urban spaces also lack cooling processes such as those served by evapo-transpiration in the intact forests. Thus, the metropolitan surveys started one hour earlier that the respective forest line transects.

Similar variables as those taken during forest line transects were recorded for each raptor sighted; that is species identification, GPS coordinates and distance from the transect.

3.3 Data process and analysis

Data cleaning was done using Office 2019 Microsoft Excel software. Using this software, tables were generated to represent all 142 raptor sightings recorded from the forest transects. The same table computation was used for the 831 raptor sightings recorded on the monthly road transects. The tables included all variables recorded on the field data sheets; that is species, number of individuals, activity, height from the ground, age, sex and GPS waypoint.

The detailed quantitative data collected in the study was analysed using the Statistical Package for Social Sciences (SPSS). Variables, including means and percentages were computed for the quantitative data. Results, after computation, were presented using frequency distribution tables, bar graphs and pie charts.

EstimateS Version 9.1.0 software was used to establish biodiversity statistics from the data collected. Further the raptor sightings were analysed for two variables; that is frequencies and percentages of a) activity frequencies, b) distance from the transect, c) height from the ground, d) age, e) colour morphs, and f) sex. A species accumulation curve or collectors curve of all the species sighted in the forests was computed using EstimateS; so as to determine the cumulative number of raptor species recorded as a function of sampling effort during the forest transects; and further the same for the metropolitan transect. Using EstimateS biodiversity statistics were computed for the data to measure singletons and uniques in the entire study sample.

The Shannon-index of diversity (H') was calculated to determine raptor species diversity for the three different forests. The same index was used to compare species diversity between urban forests and the metropolitan. The formula for Shannon-index of diversity is shared below:-

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

Where *S* is the total number of species and *pi* is the frequency of the i^{th} species.

Using Analysis of Variance (ANOVA), the mean Shannon diversity indices for the three forests were then compared to find out whether there were significant differences in raptor diversity across the three urban forests. The null hypothesis was rejected 5% significance level.

For raptor species abundance analysis; the first step was to determine the species encounter rates. This was computed per one hundred kilometres; using SPSS software. The same software was used to compute raptor sightings across the various study months, to test for variations over time.

A chi-square test of independence was done, at P-value 0.05, to examine the relation between species encounter rates across the three urban forests. A chi-square test of independence was also run, at P-value 0.05, to examine the relation between species encounter rates in urban forests and the metropolitan region. The chi-square test formula is shared below:-

$$\chi_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

Where:

c = degrees of freedom

O = observed values

E = expected values

Further, the chi-squared test allowed the computation of commonality of selected species in each of the various forests in relation to the other sister-forests.

The same data treatment done for the three urban forests was done for the metropolitan transect. This allowed for the classification of the metropolitan data as a single set and the three urban forests combined as the second set. An independent samples T-test analysis was used to determine if there were significant differences in raptor diversities between urban forests and the metropolitan.

CHAPTER FOUR

4 RESULTS

4.1 Differences in the diurnal raptor diversity across three urban forests (Karura, Thogoto and Ngong Road Sanctuary) of the greater Nairobi

4.1.1 Sample size and field characteristics

The total forest surveys yielded 142 raptor sightings. The study was conducted using line transect surveys in three urban forests of the greater Nairobi. As shown in Figure 4.1, Karura Forest yielded the highest number of raptor sightings at 47.2% which represents 67 sightings. Ngong Road Forest Sanctuary was second with 34.5% which represents 49 raptor sightings. Thogoto Forest had the least number of raptor sightings at 18.3% representing 26 sightings.

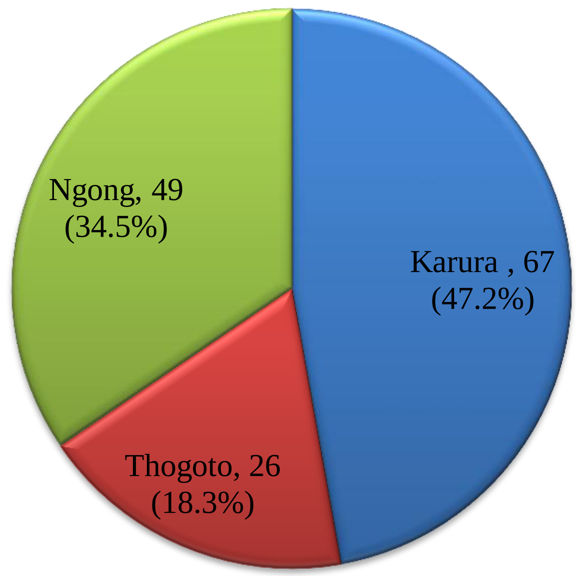


Figure 4.1: Raptor sightings per forest during forest transects

No raptor mortality incident was recorded during the entire forest survey.

Table 4.1: Mortality of raptor sightings during forest transects

	Frequency	Percent
Alive	142	100.0
Dead	0	0.0

During the survey, the team recorded the raptor activities and classified them as either: fighting, nesting, perched, soaring or mixed activity. As shown in table 4.2, the highest number of individuals were seen soaring (74.6%); with the lowest number of individuals seen fighting (1.4%). This data helped the team get an estimate of the daily energy and time budget of the raptor community in Nairobi during the study.

Table 4.2: Raptor activity when sighted during forest transects

Raptor activity	Frequency	Percent
Fight	2	1.4
Mixed Activity	9	6.3
Nesting/Nest	10	7.0
Perched	15	10.6
Soaring	106	74.6
Total	**142**	**100.0**

The raptors sighted were ranked according to the distance from the transect lines, where the team was walking. The categories included <50m, 50-100m, 100-250m, 250m-500m and >500m. All birds seen flying overhead or crossing the transect line were recorded as distance 0 or fly over. Of these categories, birds seen <50m were the highest in number, recording 60 raptor sightings. This represented 42.3% of all raptor sightings. The lowest number was birds seen >500m which recorded one sighting. This represented 0.7% of all raptor sightings recorded. Table 4.3 details the distances of the raptors from the transect line.

Table 4.3: Raptor distance from transect when sighted during forest transects

Distance from transect	Frequency	Percent
Fly over	29	20.4
Less than 50m	60	42.3
50-100m	27	19.0
100-250m	19	13.4
250-500m	6	4.2
More than 500m	1	0.7
Total	**142**	**100.0**

The raptors were also detailed according to their height from the ground. This was grouped into three major cohorts; that is 1-50m, 50-200m and >200m. Sixty five sightings representing 45.8% were recorded at 1-50m height. 50-200m height had 62 sightings, representing 43.7%. The lowest number was recorded at >200m, where only 15 sightings were recorded, representing 10.6%. Figure 4.2 shows the detailed comparisons in height.

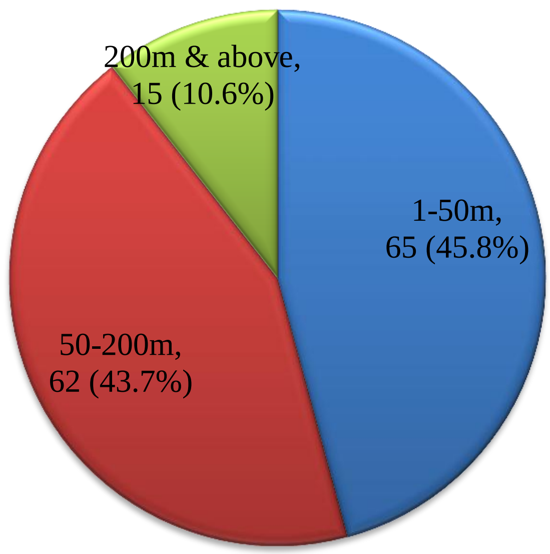


Figure 4.2: Raptor height from the ground when sighted during forest transects

The raptors seen during the study were aged, where sufficient aging details were observed. These details included the colour or plumage of the individual seen, the body size and season of year. The aging categories or groups applied included adult, immature, juvenile and mixed group. Adults were the most abundant, as shown on table 4.4. The adults represented 96.5% of all sightings. This included 137 adult sightings during the forest surveys.

Table 4.4: Age groups of the raptors seen during forest transects

Age group	Frequency	Percent
Adult	137	96.5
Adult &Juvenile	1	0.7
Immature	2	1.4
Mixed group	2	1.4
Total	**142**	**100.0**

Colour morphs in birds of prey is a common field identification feature, and the study recorded all the birds seen, where colour morph was of significant note. One of the diurnal raptor species seen that manifests two colour morphs is the Augur Buzzard *Buteo augur* which can have a dark morph or a white morph. These colour morphs are illustrated below with images:-

Plate 1: Colour morphs on the Augur Buzzard *Bueto augur* (left two images are the white/ common morph; right two images are the dark/ uncommon morph)

Birds that have two or more known colour morphs were recorded under the morph displayed by the individual seen. The morphs recorded included dark morph, white morph and normal morph for species that have a common morph. Species that have only one colour morph, or those species that never display different morphs were recorded as "No response", to indicate that no unique morphs were expected nor seen. Of the two major significant morphs; that is dark and white; the white morph manifested more prominently than the dark morph. The former had six sightings, while the latter had two sightings. Table 4.5 has the detailed breakdown of the morph representation from the observed birds.

Table 4.5: Colour morphs recorded for raptors seen during forest transects

Morph of the raptors	Frequency	Percent
No known morphs in the species	133	93.7
Dark	2	1.4
Normal	1	0.7
White	6	4.2
Total	**142**	**100.0**

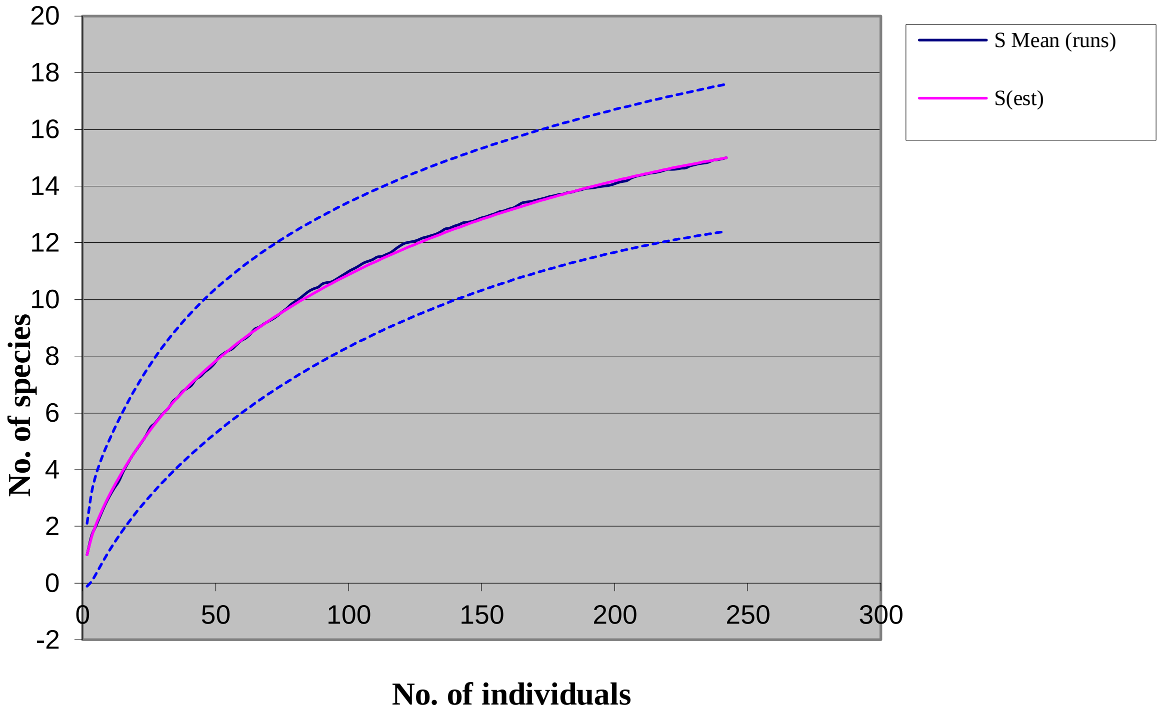
In all birds of prey, sexual dimorphism is a major factor, where females are larger than males. For some birds of prey sexual differences manifest in form of colour or plumage. During the study, some birds were accurately identified to the sex as either males or females. However, in some sightings, depending on the details that were available, the birds could not be sexed satisfactorily. Of the ones where sex was determined, males equalled females; with each gender representing three sightings. Table 4.6 details the raptor sightings and their sex scores.

Table 4.6: Sex of the raptors seen during forest transects

Sex of the raptors	Frequency	Percent
Unidentified	135	95.1
Female	3	2.1
Male	3	2.1
Male & Female	1	0.7
Total	**142**	**100.0**

4.1.2 Raptor species composition in the urban forests

A species accumulation curve (collectors curve) was plotted to determine the cumulative number of raptor species recorded as a function of sampling effort, that is, number of individuals collected or cumulative number of samples (Figure 4.3).



Key: **S Mean =** Species observed

S (est) = Estimated number of species in the sample

Figure 4.3: Species accumulation curve for diurnal raptors observed in the three urban forests

The study identified fifteen (15) raptor species in the three urban forests (Karura, Thogoto and Ngong Road Sanctuary). Out of the 15 raptor species, 12 were of least concern, 1 was near threatened, 1 was vulnerable and 1 was endangered. The raptor species are detailed in table 4.7 with their IUCN RedList status (Birdlife International, 2016a; 2016b; 2016c; 2016d; 2016e; 2016f; 2016g; 2016h; 2016i; 2017a; 2017b; 2018a; 2018b; 2019a; 2019b).

Raptor species	IUCN RedList status	Forest dependence status
1) Black Kite	Least concern	f
2) Crowned Eagle	Near threatened	FF
3) Long-crested Eagle	Least concern	f
4) Augur Buzzard	Least concern	f
5) African Cuckoo-Hawk	Least concern	F
6) African Goshawk	Least concern	F
7) Great Sparrowhawk	Least concern	F
8) Tawny Eagle	Vulnerable	f
9) Ayres's Hawk-Eagle	Least concern	F
10) Steppe Buzzard	Least concern	f
11) African Fish Eagle	Least concern	f
12) Steppe Eagle	Endangered	f
13) Lanner Falcon	Least concern	f
14) Amur Falcon	Least concern	f
15) Wahlberg's Eagle	Least concern	f

Table 4.7: Raptor species seen in the three forests with their IUCN RedList and forest dependence status

4.1.3 Raptor species diversity across the three urban forests

Shannon Diversity index was used to calculate raptor species diversity for the three different forests. The Shannon-Wiener's diversity index allows identification of the degree of habitat heterogeneity, based on the proportional abundance of all species within a community. The results for this analysis are shown on figure 4.4:-

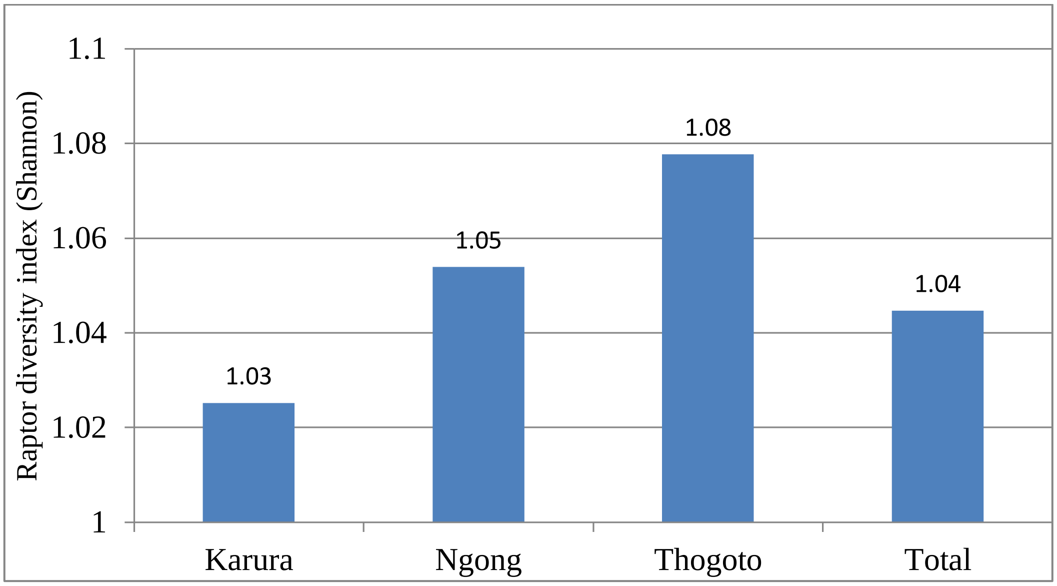


Figure 4.4: Shannon diversity indices for the raptor species seen in each of the three urban forests

The Shannon diversity index results showed that Thogoto Forest had the highest raptor diversity index (Shannon) at 1.08, followed by Ngong Road Forest Sanctuary at 1.05 and the lowest was Karura Forest at 1.03.

Using Analysis of Variance (ANOVA), the mean Shannon diversity indices for the three urban forests were then compared to find out whether there were significant differences in raptor diversity across the three urban forests. The test yielded a significance value of 0.242. Results, as shown in Table 4.8, revealed that there were no significant differences in Shannon diversity indices for the three forests.

Table 4.8: ANOVA results for mean Shannon diversity indices from the three urban forests

Forest	N*	Mean	Std. Dev.	ANOVA Statistics				
				Sum of squares		df	F	p
Karura	67	1.03	0.19	***Between***	0.058	2		
Ngong	49	1.05	0.08	***Within***	2.802	139		
Thogoto	26	1.08	0.06	***Total***	**2.860**	**141**	1.435	0.242
Total	**142**	**1.04**	**0.14**					

***Represents number of raptor sightings per forest**

Consequently, the first null hypothesis was not rejected. This stated that: - Diurnal raptor diversity is not dependent on forest type or management strategies. This means, therefore, that the three urban forests did not differ in the numbers of species represented.

4.2 Differences in the diurnal raptor abundance across three urban forests (Karura, Thogoto and Ngong Road Sanctuary) of the greater Nairobi

In order to quantify species abundances, the encounter rates per raptor species were calculated and weighted by the size (length in kilometres) of each sampling sector; that is urban forest. Species encounter rates were obtained by computing the number of raptors observed per 100 kilometers. The computation of size ensured that species sightings were not overshadowed by the sizes of each forest; thus allowing uniformity in data comparison. During the study, the total distance covered for each of the three forests was 40km. Table 4.9 shows the raptor species encounter rates for the three forests.

Table 4.9: Raptor species encounter rates (per 100km) for the three urban forests

Species	Karura	Thogoto	Ngong	Total
Black Kite	235	103	113	451
Augur Buzzard	5	10	15	30
Crowned Eagle	15	0	30	45
Long-crested Eagle	15	0	3	18
Great Sparrowhawk	10	3	0	13
Ayres's Hawk-Eagle	0	3	3	6
Steppe Buzzard	0	8	3	11
Lanner Falcon	3	5	0	8
African Cuckoo-Hawk	0	0	8	8
Tawny Eagle	0	0	3	3
African Goshawk	0	0	5	5
African Fish Eagle	0	0	5	5
Steppe Eagle	3	0	0	3
Amur Falcon	0	3	0	3
Wahlberg's Eagle	0	3	0	3
Total	286	138	188	612

χ^2value = 168.863; df = 28; sig.= 0.000

A chi-square test of independence was run, at P-value 0.05, to examine the relation between species encounter rates across the three urban forests. The relation between these variables was significant, $P<0.0001$. This means that the three forests differed significantly in their raptor abundances. This further means that those species that were more abundant in one forest were not as abundant in the other two forests.

The Black Kite and Augur Buzzard occur in all the three forests, with the Black Kite being the most abundant raptor in all the habitats. The Black Kite was more common in Karura Forest, with an encounter rate score of 235 sightings per 100km. This differed from Thogoto and Ngong Road Forests, which had encounter rate scores of 103 and 113, respectively. The African Cuckoo-Hawk was more common in Ngong Road Forest with an encounter rate score of 8. The same species was completely absent from Karura and Thogoto Forests. The Lanner Falcon was more common in Thogoto Forest with an encounter rate score of 5. The same species scored encounter rates of 3 and 0, in Karura Forest and Ngong Road Forest, respectively. The African Fish Eagle was more common in Ngong Road Forest with an encounter rate score of 5, but was absent in both Thogoto and Karura Forests.

Consequently, the second null hypothesis was rejected and its alternate accepted that: - Diurnal raptor abundance is dependent on forest type or management strategies.

4.3 Differences in diurnal raptor distribution between urban forests and the metropolitan of the greater Nairobi

The third objective was to determine the differences in diurnal raptor distribution between urban forests and the metropolitan of the greater Nairobi. This involved considering the three forests as a single unit and comparing them against the metropolitan area.

The measure of diurnal raptor distribution was cumulated by an assessment of both the raptor diversity and raptor abundance; between the two study cohorts; that is the three combined urban forests versus the metropolitan area.

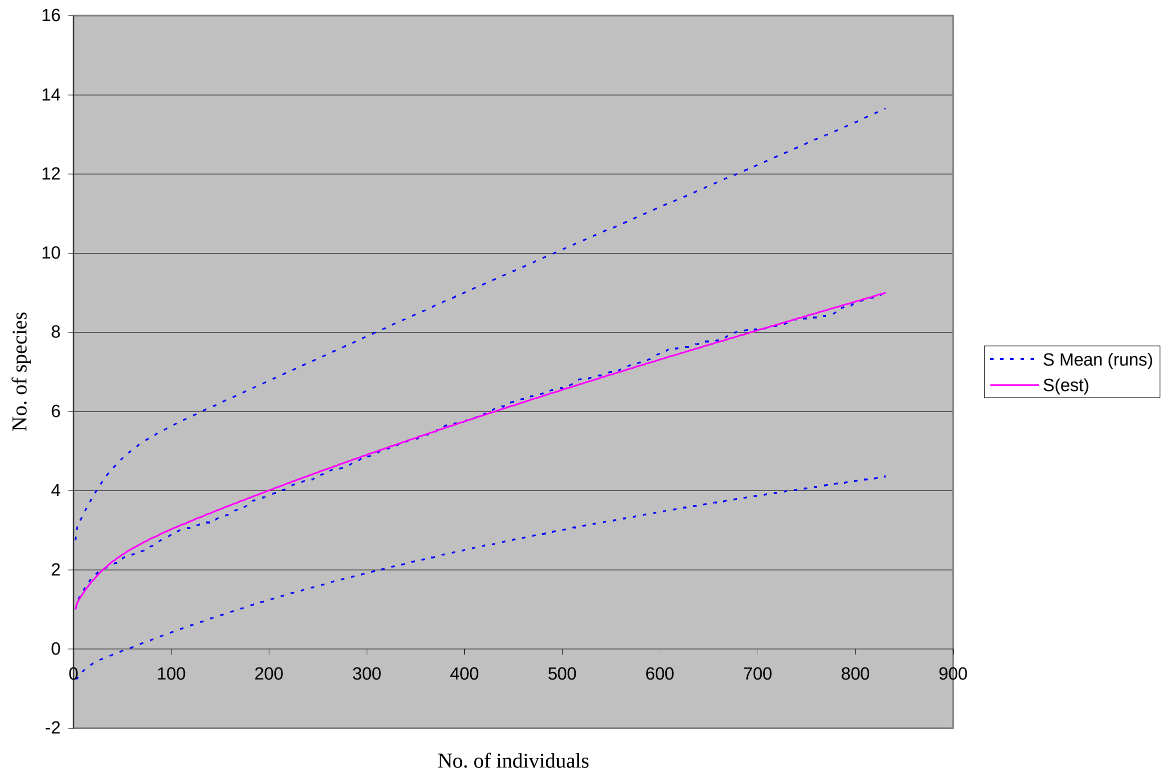
4.3.1 Raptor species composition in the Metropolitan area

In the Nairobi Metropolitan region, nine (9) raptor species were identified during the study; accounting for 831 raptor individuals. Out of the nine raptor species, 7 (77.8%) were of least concern, 1 (11.1%) was near threatened and 1 (11.1%) was critically endangered. The raptor species are detailed in table 4.10 with their IUCN RedList status (BirdLife International, 2016b; BirdLife International, 2016f; BirdLife International, 2016g; Birdlife International, 2016j; BirdLife International, 2017b; BirdLife International, 2018b; Birdlife International, 2018c; BirdLife International, 2019a; Birdlife International, 2019c).

Table 4.10: Raptor species seen in the Nairobi metropolitan with their IUCN RedList and forest dependence status

Raptor species	IUCN RedList status	Forest dependence status
1) Black Kite	Least concern	f
2) Crowned Eagle	Near threatened	FF
3) Augur Buzzard	Least concern	f
4) European Honey Buzzard	Least concern	F
5) African Black-shouldered Kite	Least concern	f
6) Steppe Buzzard	Least concern	f
7) African Fish Eagle	Least concern	f
8) White-backed Vulture	Critically endangered	f
9) Lanner Falcon	Least concern	f

A species accumulation curve (collectors curve) was plotted to determine the cumulative number of raptor species recorded as a function of sampling effort, that is, number of individuals collected or cumulative number of samples (Figure 4.5). This analysis also showed the numbers of singletons and uniques in the data set.



Key: **S Mean =** Species observed

S (est) = Estimated number of species in the sample

Figure 4.5: Species accumulation curve for diurnal raptors observed in Nairobi Metropolitan

4.3.2 Raptor species representation across the three urban forests

Using EstimateS Version 9.1.0 software, biodiversity statistics were computed for the data; that is forest transect raptor sightings.

Results indicated that there were four singletons in the data set, meaning that there were four raptor species represented by a single individual each. These included the following species:-

1. Tawny Eagle
2. Steppe Eagle
3. Amur Falcon
4. Wahlberg's Eagle.

There were four Uniques in the data set, which is an indication that four raptor species occurred only in one sample each. This means that these four species tended to occur in groups. They were thus only seen at one spot (the entire group), per species, during the entire study. The species include:-

1. Wahlberg's Eagle: - where one adult individual was recorded flying in Thogoto Forest on 16th June, 2017 at 1102hrs.

2. Amur Falcon: - where one adult individual was recorded flying in Thogoto Forest on 21st April, 2017 at 0942hrs.

3. Steppe Eagle: - where one adult individual was recorded flying in Karura Forest on 3rd April, 2017 at 1159hrs.

4. Tawny Eagle: - where one immature individual was recorded flying in Ngong Road Forest Sanctuary on 8th March, 2017 at 1102hrs.

4.3.3 Raptor species representation in the metropolitan area

Results of biodiversity analysis using EstimateS Version 9.1.0 indicated that there were five singletons in the data set, which means that there were five raptor species represented by a single individual each. These included the following species:-

i. White-backed Vulture
ii. African Black-shouldered Kite
iii. European Honey Buzzard
iv. Steppe Buzzard
v. Lanner Falcon,

Further, there were six Uniques in the data set, an indication that six raptor species occurred only in one sample each; and which further implies that the species tended to occur in groups (recorded at a single spot per group, and once only in the entire study period). These species included the following:-

i. African Crowned Eagle: - where two adult individuals were recorded flying on 17th December, 2016 at 1106hrs.

ii. Steppe Buzzard: - where one adult individual was recorded flying on 17th December, 2016 at 1050hrs.

iii. European Honey Buzzard: - where one adult individual was recorded flying on 17th December, 2016 at 1106hrs.

iv. African Black-shouldered Kite: - where one adult individual was recorded flying on 18th February, 2017 at 1029hrs.

v. Lanner Falcon: - where one adult individual was recorded flying on 15th April, 2017 at 1113hrs.

vi. White-backed Vulture: - where one adult individual was recorded flying on 18th February, 2017 at 1037hrs.

4.3.4 Monthly Raptor Distribution in the Urban Forests

The study analysed the distribution of raptors across the study period; that is field months. The main focus was to establish if there were observable differences between raptor numbers across the various months. The total number of individuals for each raptor species in each month was computed. This was further compared to the number of field days that were recorded in the stated month, so as to get the individuals seen per month, in relation to sampling effort. This produced the value indicated as the “per-day” score for each species in each month. This score means that if any field day was done in the forest, the team would record that number of individuals of that species. Table 4.11 has the details of the individuals-seen-per-day per species.

Table 4.11: Monthly raptor distribution in the three urban forests (showing the individuals-seen-per-day scores)

	February (3)		March (5)		April (6)		May (7)		June (6)		July (1)		
	To tal	Per-day	To tal	Per-day	To tal	Per-day	To tal	Per-day	To tal	Per-day	To tal	Per-day	To tal
Black Kite	12	4	43	8.6	62	10.33	46	6.57	9	1.5	8	8	180
Crowned Eagle	2	0.67	4	0.8	2	0.33	7	1	3	0.5	0	0	18
Long-crested Eagle	1	0.33	2	0.4	0	0	2	0.29	1	0.17	1	1	7
Augur Buzzard	4	1.33	2	0.4	2	0.33	1	0.14	3	0.5	0	0	12
African Cuckoo-Hawk	3	1	0	0	0	0	0	0	0	0	0	0	3
African Goshawk	1	0.33	0	0	1	0.17	0	0	0	0	0	0	2
Great Sparrowhawk	0	0	1	0.2	2	0.33	0	0	2	0.33	0	0	5
Tawny Eagle	0	0	1	0.2	0	0	0	0	0	0	0	0	1
Ayres's Hawk-Eagle	0	0	1	0.2	0	0	1	0.14	0	0	0	0	2
Steppe Buzzard	0	0	2	0.4	2	0.33	0	0	0	0	0	0	4
African Fish Eagle	0	0	1	0.2	0	0	0	0	1	0.17	0	0	2

Steppe Eagle	0	0	0	0	1	0.17	0	0	0	0	0	0	1
Lanner Falcon	0	0	0	0	3	0.5	0	0	0	0	0	0	3
Amur Falcon	0	0	0	0	1	0.17	0	0	0	0	0	0	1
Wahlberg's Eagle	0	0	0	0	0	0	0	0	1	0.17	0	0	1

**the number of survey days per month is indicated in brackets*

The average raptor individuals-seen-per-day were cumulated for each month. Later, each month was compared against the other months to show individuals-seen-per-day changes across the study period. The averages were calculated by summing the total number of birds per day, then dividing by the number of days. Figure 4.6 shows the details.

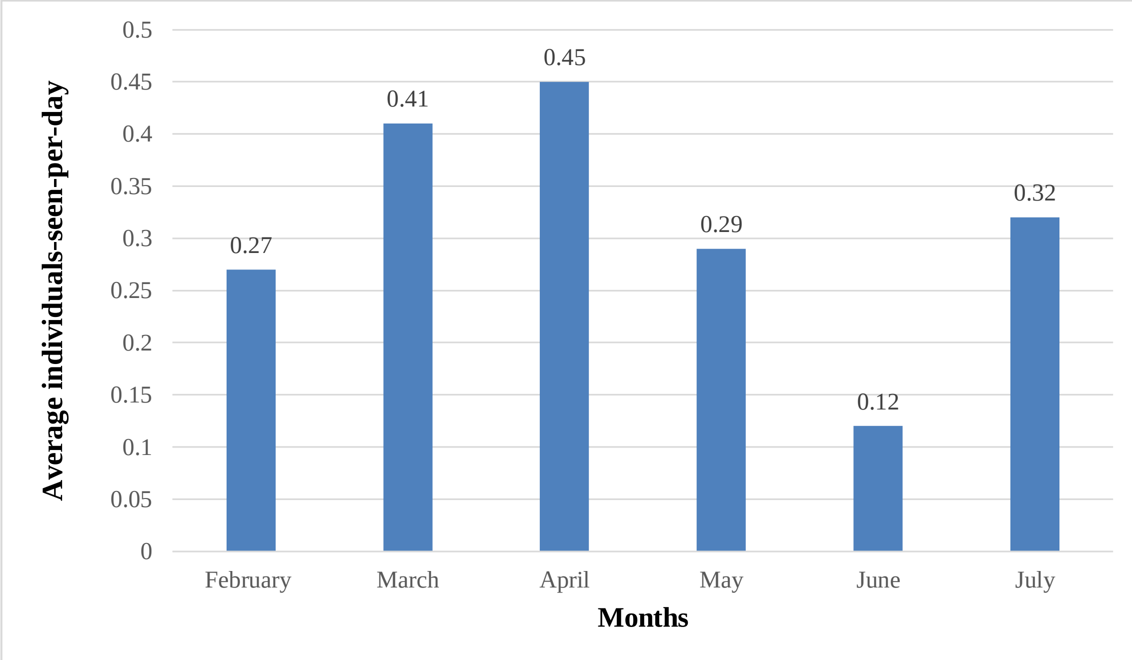


Figure 4.6: Average monthly variations of individuals-seen-per-day in the three urban forests combined

From the results, the month of June recorded the lowest raptor individuals across the three urban forests. This was followed by the month of February. The months of May and July followed closely. The months of March and April recorded the highest raptor numbers.

4.3.5 Monthly Raptor Distribution in the Metropolitan

The study further computed similar statistics, as those done for the urban forests, for the raptor sightings obtained from the metropolitan surveys. The objective was again to determine the raptor numbers across the various months when the study was conducted. Table 4.12 has the details:

Table 4.12: Monthly raptor distribution in the urban metropolitan (showing the individuals-seen-per-day scores)

Per-day scores	Dec	Jan	Feb	March	April	May	June
Black Kite	64	95	121	141	140	127	102
Steppe Buzzard	1	0	0	0	0	0	0
European Honey Buzzard	1	0	0	0	0	0	0
Crowned Eagle	2	0	0	0	0	0	0
Augur Buzzard	0	6	6	2	5	5	6
African Black-shouldered Kite	0	0	1	0	0	0	0
White-backed Vulture	0	0	1	0	0	0	0
African Fish Eagle	0	0	0	1	3	0	0
Lanner Falcon	0	0	0	0	1	0	0

The average of raptor individuals-seen-per-day were cumulated for each month. Later, each month was compared against the other months to show individuals-seen-per-day changes across the study period. Figure 4.7 shows the details.

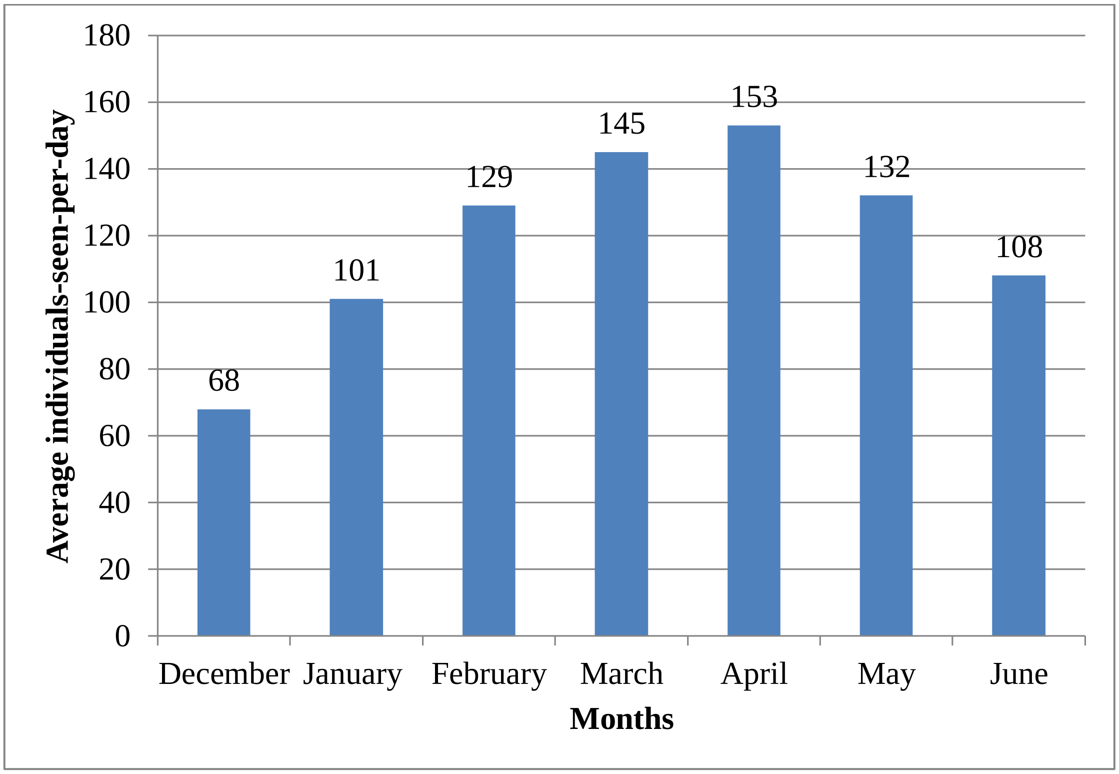


Figure 4.7: Average monthly variations of individuals-seen-per-day in the urban metropolitan

From the data, the month of December recorded the lowest raptor numbers across the urban metropolitan at a score of 68. This was followed by the month of January at 101, June at 108 and February at 129. The months of March, April and May recorded the highest sightings scoring 145, 153 and 132, respectively.

4.3.6 Raptor diversity differences between urban forests and the metropolitan

In order to establish whether there were significant differences in the raptor diversity between urban forests and the metropolitan of the greater Nairobi, Shannon Diversity index was used to calculate raptor species diversity for the two regions. The Shannon

Diversity index results show that urban forests had a higher raptor diversity index (Shannon) at 1.04; while the metropolitan had lower raptor diversity index (Shannon) at 0.24. Figure 4.8 shows the indices' comparisons:

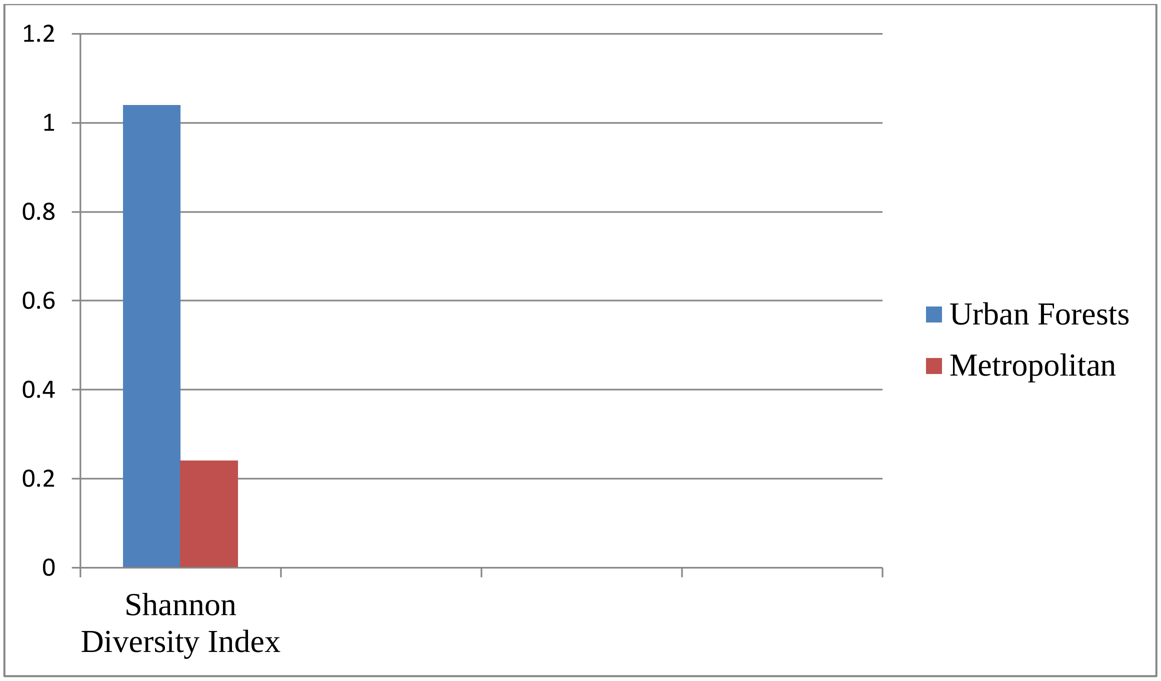


Figure 4.8: Shannon diversity indices for the urban forests versus the metropolitan

Further, independent samples t-test was used to compare Shannon Diversity indices for the Nairobi Metropolitan region and the urban forests. The results are shown on table 4.13:

Table 4.13: T-test results for mean Shannon diversity indices between the metropolitan and the urban forests

Study Site	N*	Mean	Std. Dev.	t	df	Sig.
Urban forests	142	1.04	0.14			
Metropolitan	451	0.24	0.02	117.361	591	.000
Total	**593**	**0.43**	**0.35**			

***Represents number of raptor sightings**

The t-test results showed that the three urban forests (Karura, Thogoto and Ngong Road Sanctuary) had a higher diversity index (M = 1.04, SD = 0.14) than the larger Nairobi Metropolitan (*M* = 0.24, *SD* = 0.02), *t*(117.361), *p* = 0.000. The P-value for this analysis was set at 0.05; where the samples analysed yielded a P-value of 0.000. This indicated that there were significant differences between the two compared variables.

The results indicate that the urban forests had a significantly higher diversity mean score than the metropolitan area, meaning that the urban forests had more raptor species represented than the general metropolitan.

Consequently, the third null hypothesis was rejected, and its alternate accepted, that: - Existence of urban forests has an effect on diurnal raptor species diversity in the greater Nairobi area.

4.3.7 Raptor species abundance in the urban forests versus the metropolitan

A total of 1,073 raptor individuals of 18 different species were recorded during the entire study. The three most common species' sightings were Black Kite (90.4% of total), Augur Buzzard (3.9% of total) and Crowned Eagle (1.9% of total). The other species were represented by less than one per cent of the total raptors recorded.

The metropolitan had the highest number of raptor individuals recorded at 831. Among the urban forests, Karura Forest had the highest raptor sightings at 114, followed by Ngong Road Forest Sanctuary at 74. Thogoto Forest had the least sightings at 54. Table 4.14 has the detailed species numbers per site:

Table 4.14: Number of raptor sightings observed in each site

Species	Karura	Thogoto	Ngong	Metrop.	Total
1. Black Kite	94	41	45	790	970
2. Crowned Eagle	6	0	12	2	20
3. Long-crested Eagle	6	0	1	0	7
4. Augur Buzzard	2	4	6	30	42
5. African Cuckoo-Hawk	0	0	3	0	3
6. African Goshawk	0	0	2	0	2
7. Great Sparrowhawk	4	1	0	0	5
8. Tawny Eagle	0	0	1	0	1
9. Ayres's Hawk-Eagle	0	1	1	0	2
10. Steppe Buzzard	0	3	1	1	5
11. African Fish Eagle	0	0	2	4	6
12. Steppe Eagle	1	0	0	0	1
13. Lanner Falcon	1	2	0	1	4
14. Amur Falcon	0	1	0	0	1
15. Wahlberg's Eagle	0	1	0	0	1
16. European Honey Buzzard	0	0	0	1	1
17. African Black-shouldered Kite	0	0	0	1	1
18. White-backed Vulture	0	0	0	1	1
Total	**114**	**54**	**74**	**831**	**1073**

The quantification of species abundances was then done by measuring the encounter rates per species. These were as well calculated and weighted by the size (length in kilometres) of each sampling sector. Species encounter rates were obtained by computing the number of raptors observed per 100 kilometers. During the study, the total distance covered for the Greater Nairobi Metropolitan was 560km. Table 4.15 shows the species encounter rates for the four study sites:

Table 4.15: Species encounter rates (per 100km) for the study sites

Species	Karura	Thogoto	Ngong	Metropolitan
1. Black Kite	235.0	102.5	112.5	141.1
2. Crowned Eagle	15.0	0.0	30.0	0.4
3. Long-crested Eagle	15.0	0.0	2.5	0.0
4. Augur Buzzard	5.0	10.0	15.0	5.4
5. African Cuckoo-Hawk	0.0	0.0	7.5	0.0
6. African Goshawk	0.0	0.0	5.0	0.0
7. Great Sparrowhawk	10.0	2.5	0.0	0.0
8. Tawny Eagle	0.0	0.0	2.5	0.0
9. Ayres's Hawk-Eagle	0.0	2.5	2.5	0.0
10. Steppe Buzzard	0.0	7.5	2.5	0.2
11. African Fish Eagle	0.0	0.0	5.0	0.7
12. Steppe Eagle	2.5	0.0	0.0	0.0
13. Lanner Falcon	2.5	5.0	0.0	0.2
14. Amur Falcon	0.0	2.5	0.0	0.0
15. Wahlberg's Eagle	0.0	2.5	0.0	0.0
16. European Honey Buzzard	0.0	0.0	0.0	0.2
17. African Black-shouldered kite	0.0	0.0	0.0	0.2
18. White-backed Vulture	0.0	0.0	0.0	0.2
Mean raptor encounter rate	**15.8**	**7.5**	**10.3**	**8.3**

For deeper comparisons between the species encounter rates in the metropolitan area versus the forests; the three urban forests were merged and considered as one unit. This was then compared against the metropolitan area, as the second unit. From the results obtained, it was observed that the species encounter rate was highest for the Black Kite in urban forests (at 150 individuals per 100km) followed by the same raptor species in the larger Metropolitan region (141.1 individuals per 100km). Table 4.16 details these results:

Table 4.16: Species encounter rates for urban forests versus Metropolitan

Species	Urban forests	Metropolitan	Total
1. Black Kite	150.0	141.1	291.1
2. Crowned Eagle	15.0	0.4	15.4
3. Long-crested Eagle	5.8	0.0	5.8
4. Augur Buzzard	10.0	5.4	15.4
5. African Cuckoo-Hawk	2.5	0.0	2.5
6. African Goshawk	1.7	0.0	1.7
7. Great Sparrowhawk	4.2	0.0	4.2
8. Tawny Eagle	0.8	0.0	0.8
9. Ayres's Hawk-Eagle	1.7	0.0	1.7
10. Steppe Buzzard	3.3	0.2	3.5
11. African Fish Eagle	1.7	0.7	2.4
12. Steppe Eagle	0.8	0.0	0.8
13. Lanner Falcon	2.5	0.2	2.7
14. Amur Falcon	0.8	0.0	0.8
15. Wahlberg's Eagle	0.8	0.0	0.8
16. European Honey Buzzard	0.0	0.2	0.2
17. African Black-shouldered Kite	0.0	0.2	0.2
18. White-backed Vulture	0.0	0.2	0.2
Total	**148.6**	**201.6**	**350.2**

χ^2 value = 35.971; df = 14; sig.= 0.001

A chi-square test of independence was run, at P-value 0.05, to examine the relation between species encounter rates in urban forests and the metropolitan region. The relation between these variables was significant, χ^2 (14, N=350.2) = 35.971, p=0.001. This means that those species that were more likely to be encountered in the forests were not as likely to be encountered in the greater metropolitan region. Consequently, the third null hypothesis was rejected and its alternate accepted that: - Existence of urban forests has an effect on diurnal raptor species abundance in the greater Nairobi area.

CHAPTER FIVE

5 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Differences in the diurnal raptor diversity across three urban forests (Karura, Thogoto and Ngong Road Sanctuary) of the greater Nairobi

One aspect of raptor diversity is the family composition; in relation to diet. Kenya hosts a great number of diurnal raptors, but not all species depend on the same diet. Scavenging species seemed to be particularly low from the study findings and this further implies their increased threat level, as many areas continue to become more urbanized. Ogada and Keesing (2010); observed that in central Kenya raptor numbers steadily decreased annually by over 40% per year. However, the groups of scavenging birds decreased more than the other raptors; showing a 70% decrease in sightings over the study period of three years. In Nairobi, scavenging birds were virtually absent in all the three forests; with only one partial scavenging diurnal raptor recorded. The Black Kite, despite being a great hunter and often seen catching its own prey, such as domestic fowl; will readily scavenge on carrion when a chance arises (Zimmerman *et al.*, 1999; Clark and Davies, 2018). The specific name of the resident race *parasitus* refers to the habit of stealing food from other birds, a common trait among Nairobi birds (Clark and Davies, 2018).

By grouping all raptors seen across the three urban forests under the categories suggested by Bennun *et al.* (1996); the study revealed that Karura Forest and Ngong

Road Forest Sanctuary are the only forests that had FF species; with one (1) species each. Ngong Road Forest Sanctuary had the highest number of F species, with three (3) species. This was followed closely by Thogoto Forest with two (2) species. Karura Forest had the least number of F species, with only one (1) species. Thogoto Forest and Ngong Road Forest Sanctuary both had six (6) f species; with Karura Forest having five (5). This observation matched clearly with the conclusions made by Bennun *et al.* (1996).

According to Bennun *et al.* (1996); the number of FF species is reliable and initial measure of a forest's relative conservation importance. From the results obtained in the Nairobi study, it clearly shows that the forests that had more indigenous sectors dominated in the numbers of FF species. Thogoto Forest, being almost an entirely exotic and planted forest, had no FF species recorded during the study (Kenya Forest Service, 2016a; Kenya Forest Service, 2016b; Kenya Forest Service, 2016c).

Bennun *et al.* (1996) further detailed that FF and F species are dependent on forests. However, the f species are not dependent on forests. From the Nairobi study, Ngong Road Forest Sanctuary led in the combined FF and F species; with four (4) species. Karura Forest and Thogoto Forest, both tied at two (2) species. This means that when the total forest-dependent species' lists are tallied (FF plus F species per forest); again the three forests do not show a consistent difference in species numbers.

From the study, it was clear that Thogoto Forest had the highest raptor diversity index (Shannon) at 1.08, followed by Ngong Road Forest Sanctuary at 1.05 and the lowest was Karura Forest at 1.03. However, upon the application of Analysis of Variance

(ANOVA), the mean Shannon diversity indices for the three urban forests revealed that there were no significant differences in Shannon diversity indices. This clearly showed that diurnal raptor diversity is not dependent on forest type or management strategies, across the greater Nairobi. Even though the three individual forests differed in the raptor species represented, this difference was not statistically significant.

Eduardo *et al*. (2007) and Thiollay (1996) noted that the largest diurnal raptors disappeared in disturbed areas that were formerly covered by more native forests in South-Eastern Brazil and the Andes, respectively. This was observed in Thogoto Forest, where the FF and F species were encountered less regularly than in Ngong Road Forest. A good portion of Thogoto Forest has been converted from indigenous native forest to plantation Eucalyptus forest.

5.2 Differences in the diurnal raptor abundance across three urban forests (Karura, Thogoto and Ngong Road Sanctuary) of the greater Nairobi

After the species encounter rates were obtained by computing the number of raptors observed per 100 kilometers; both in the urban forests and the general metropolitan. The chi-square test of independence indicated that the three forests differed significantly in their raptor abundances. Therefore, it means that some species were more abundant in one of the forests, than in the other two forests.

The Black Kite, an f species, was significantly more common in Karura Forest, with an encounter rate score of 235 sightings per 100km. This differed from Thogoto and Ngong

Road Forests, which had encounter rate scores of 103 and 113, respectively. This is likely to me linked to the species ecological preferences, where it prefers urban areas with readily available dumping sites for scavenging and occasional hunting. The species has been observed to hunt domestic fowl as well, and these are more readily available near human habitation (Zimmerman *et al.*, 1999; Stevenson and Fanshawe, 2003; Clark and Davies, 2018). Karura Forest is the most proximal to the Nairobi city centre, followed by Ngong Road Forest; while Thogoto Forest was the farthest. This geographical positioning matched perfectly with the species abundance scores.

According to studies analysed by Chace and Walsh (2006); they support the supposition that diurnal raptors that specialize in eating small prey, including insects, have a strong ability to colonize urban habitats and environments. Black Kites are known to hunt small prey species including small mammals, fish, birds, reptiles and insects (Clark and Davies, 2018). Chace and Walsh (2006) further noted that small mammalian human-commensals often respond well to urban environments; and in turn, the raptors that feed on them also respond positively.

The African Cuckoo-Hawk, an F species, was significantly more common in Ngong Road Forest with an encounter rate score of 8. Ngong Road Forest also proved to host the highest number of FF and F species, combined. Being the forest with the largest tract of indigenous trees, the study results match perfectly with the deductions by Bennun *et al.* (1996). The same species was completely absent from Karura and Thogoto Forests.

The Lanner Falcon, an f species, was significantly more common in Thogoto Forest with an encounter rate score of 5. The same species scored encounter rates of 3 and 0, in

Karura Forest and Ngong Road Forest, respectively. Being a species associated with more open habitat, it is likely to choose forests that have less indigenous-closed-canopies; that is Ngong Road Forest (Bennun *et al.*, 1996; Zimmerman *et al.*, 1999; Stevenson and Fanshawe, 2003; Clark and Davies, 2018).

The Nairobi study matched well with the deductions by Bennun *et al.* (1996) regarding relative abundances of forest birds. According to Bennun *et al.* (1996); the shifts in proportion or relative abundance of various FF and F species can be effectively used to assess the effects and success of forest management on different bird communities. In the study conducted in the Trans-Mara forests, it was clear that all forests had undergone varying levels of disturbance; but still the species composition was the same. However, species densities differed significantly across the various forests; particularly of the FF species (Bennun and Waiyaki, 1992a). According to Bennun *et al.* (1996); this shift in the relative densities of the FF species versus the other species categories has been proven to be consistent across East Africa; as forest disturbance is observed. In the Nairobi study it was clear that the FF Crowned Eagle was more abundant in Ngong Road Forest and Karura Forest as opposed to Thogoto Forest. Ground truthing expeditions and reports from forest rangers and management teams proved that there were two breeding territories in Karura Forest and Ngong Road Forest for Crowned Eagles. However, Thogoto Forest has no breeding territory; although there is a nearby nesting pair in the Kibiku Forest block; South of Thogoto Forest.

5.3 Differences in diurnal raptor distribution between urban forests and the metropolitan of the greater Nairobi

5.3.1 Forest dependence

The same forest dependence scales used by Bennun *et al.* (1996) were compared between the three forests, as one unit, versus the general metropolitan. From the Nairobi study, the urban forests and the metropolitan both tied at the total number of FF species; with each having one (1) species only. This was the African Crowned Eagle, a relatively well-studied forest species (Brown, 1971a; Chittenden and Myburgh, 1994; del Hoyo *et al*, 1994; Ferguson-Lees and Christie, 2001; Hockey *et al*, 2005; Thomsett, 2011). For F species, the urban forests had a higher record, with four (4) species. The metropolitan had only one (1) F species. Under the f category, the forests had higher numbers with ten (10) species; while the metropolitan had seven (7) species.

Based on the conclusions made by Bennun *et al.* (1996); the urban forests clearly had a higher combined FF and F species; with five (5) species total. This is compared to the metropolitan that had only two (2) species in the combined FF and F categories. Since FF and F species are dependent on forests, unlike the f species; it therefore means that forest-dependent species in the greater Nairobi require the urban forests for them to survive. Evidently, if it were not for these urban forests, five (5) of Nairobi's forest-dependent diurnal raptor species would not thrive in the city.

The observations made in the study matched with Bennun *et al.* (1996). The study results showed that the three urban forests (Karura, Thogoto and Ngong Road Sanctuary) had a higher diversity index than the metropolitan. These results indicate that the urban forests had more raptor species represented than the general metropolitan. This clearly proved that the existence of urban forests has an effect on diurnal raptor species diversity in the greater Nairobi area. Further, the comparison between species encounter rates in urban forests and the metropolitan region showed that: - those species that were more likely to be encountered in the forests were not as likely to be encountered in the greater metropolitan region. Consequently, the third null hypothesis was rejected and its alternate accepted that:- Existence of urban forests has an effect on diurnal raptor species abundance in the greater Nairobi area.

A study by Eduardo *et al.* (2007) conducted in Brazil; showed that forests and related forested habitats hosted more raptor species than open habitats; with 17 versus 12 raptor species, respectively. In that study there were 9 species that occurred only in forests. In the study conducted in Brazil, the abundance of diurnal raptors was observed to be equal in both urban areas and the semi-natural areas. However, species richness was lost in the urban areas (Eduardo *et al.,* 2007). Further, according to Eduardo *et al.* (2007), urbanization led to a loss of one-third of diurnal raptors.

According to Pomeroy *et al.* (2015); protected areas played a big role in the existence of vultures across Uganda. This was proven by the fact that five scavenging species from their study were detected 4-6 times more frequently in protected areas than in non-protected areas. Two species of scavenging birds were further only recorded in protected areas. This goes to further explain that indeed Nairobi's urban forests do play a key role in the existence of diurnal raptors; by virtue of the fact that they are protected. Because the study by Pomeroy *et al.* (2015) visited protected areas of varying sizes and status; it further proves that diurnal raptors do require protected habitats to thrive, regardless of the level and intensity of protection. Land use demarcations at various localities played a role in the encounter rates observed by Pomeroy *et al.* (2015). This trend was repeated in Nairobi; where over the many years of urbanisation, forests have been reduced to developed and agricultural areas. A similar study by Shaw *et al. (*2019) also noted the same variations; whereby they noted that the expansion of agricultural land across the sub-Saharan Africa will in turn reduce the population of raptor species. Farmlands also proved to have lower species richness than contiguous forestland around New Jersey (Bosakowski and Smith, 1997).

Bosakowski and Smith (1997); despite using different methods to study their population, observed that raptor species richness was correlated to wilderness size area. They observed that wilderness areas smaller than 1,000 ha did not host more than four raptor species; while wilderness areas between 1,000-8,000 ha would host four to eight raptor species (Bosakowski and Smith, 1997). Nairobi forests showed similar trends, hosting more raptor species than the general metropolitan area, despite there being several small green spaces across the city limits. This further proved that forest dependence among diurnal raptors goes beyond the presence of a green space; and accounts for the size of that green space as well.

Owino *et al.* (2008) conducted similar studies in coastal forests of Kenya using mist netting as a main method. Their observations were similar to the Nairobi study and also the work done by Bosakowski and Smith (1997). In coastal Kenya, there was a positive relationship between forest-dependent birds species richness and the overall forest patch sizes. Owino *et al.* (2008) thus concluded that forest patch sizes significantly influenced the total numbers of forest-dependent birds within coastal Kenya. This makes sense in the Nairobi study, where the three large urban forests are compared to smaller green spaces which were accounted for in the metropolitan surveys.

5.3.2 Monthly trends in diurnal raptor numbers and the role of rainfall seasons

Peak months in terms of raptor numbers recorded in the study matched with the peak rainy season. In the forest surveys, the months of March and April recorded the highest per-day raptor sightings scoring 11.4 and 12.67, respectively. The same pattern was repeated in the metropolitan survey; where the months of March and April recorded the highest raptor sightings scoring 145 and 153, respectively.

This is likely to be attributed to availability of adequate prey (Brown, 1966; Brown, 1971a). Many prey species often breed during the rainy season, including smaller passerine birds and mammalian prey species (Zimmerman *et al.*, 1999; Stevenson and Fanshawe, 2003; Kingdon, 2015). With the abundance of prey, many raptors will also tend to position their breeding seasons to coincide with the prey breeding seasons (Safriel, 2013). As documented by Safriel (2013), raptors in the Northern latitudes plan their breeding season in the short Summer season, to maximize food availability. Therefore, with Nairobi being along the Equator, the food peaks fall around the rainy seasons.

Ogada and Keesing (2010); hypothesised that the rapid declines observed in the scavenging species at the study site in Central Kenya; may have been due to lack of food. After analysing the mammalian herbivores in the area, Ogada and Keesing (2010) noted an increase in herbivores. This showed that lack of food may not have been the primary cause of declines in scavenging birds. However, in the Nairobi study, scavenging birds may be getting access to prey due to breeding small birds, which are known to breed during the rainy season. This is due to the Black Kites being partial scavengers; unlike the vulture species studied by Ogada and Keesing (2010). Only one vulture species was represented in the Nairobi data, a single African White-backed Vulture sighting from the metropolitan surveys.

Breeding seasons of raptor species may also play a role in the observed sightings; with some species remaining around the nests during the breeding season and thus reducing sighting opportunities (Clark and Davies, 2018). In Uganda, breeding seasons for scavenging species were observed to coincide around the months of November to February (Pomeroy *et al.*, 2015; Carswell *et al.*, 2005). Being located along the same latitude range and time zones, Kenyan species are also likely to fall within the same trends. This further explains a possibility of this breeding having inhibited raptor sightings around the Nairobi metropolitan during the months of November to February.

5.4 Conclusions

This study showed that indeed urban forests in Nairobi do differ in terms of the raptor species diversity they host. This can be attributed to the different management policies and strategies employed by each forest. A good example was shown by Thogoto Forest, where due to having a high percentage of Eucalyptus trees, there were fewer raptor species. However, this does not differ significantly from the other forests, as shown by the study. It therefore means that urban raptors need forests but all forest types are equally important.

In terms of abundance, forests with better management strategies and more indigenous trees hosted more raptors. This means that even though any forest within the city is good for raptor diversity, as shown above, for raptor numbers to increase, we need more indigenous trees.

When compared to the metropolitan, the urban forests performed better in species diversity and abundances. It therefore shows that, without these urban forests, Nairobi's raptors will not survive.

5.5 Recommendations

The study showed clearly that urban forests need more indigenous trees to continue hosting many raptors. This therefore calls for more afforestation within the urban forests, to increase the indigenous trees. Exotic trees should also be removed or reduced in the forests. In turn, indigenous trees can be planted on the same space.

In the same line, forests need to uphold the highest management strategies in order to host many more raptors. These strategies include fencing and ranger patrols. Human activities that are consumptive should also be reduced in the urban forests, such as logging and farming. This will allow the forests to thrive and continue to host urban raptors for many years.

Because forests host more species than the built metropolitan, the county government of Nairobi needs to designate more green spaces. These can include large forests like Karura, Thogoto and Ngong Road. They can also include smaller forests and patches of woodlands within the city.

5.5.1 Recommended further research for diurnal urban raptors

i. There is need to further study the nesting behaviour of urban raptors, to establish the nesting requirements, nesting success and fledgling dispersal mechanisms.

ii. More studies are required on the scavenging species of Nairobi, to establish if there are impacts of pollution, garbage disposal and poisoning in the metropolitan.

iii. Deeper single-species-oriented studies on the FF species of Nairobi will add critical scientific information that will advise forest management. It is a gap area in Nairobi that could yield new Scientific knowledge.

iv. There is an opportunity for increasing knowledge on the impacts of power lines and other electrical infrastructure on diurnal raptors. Nairobi, as a model green city that is constantly developing, forms a great study site for this work.

REFERENCES

Bennun L.A., Dranzoa C. and Pomeroy D. 1996. The forest birds of Kenya and Uganda. *Journal of East African History*, 85: 23-48.

Bennun L.A. and Waiyaki E.M. 1992a. Using birds to monitor environmental change in the Mau Forests. Research Reports of the Centre for Biodiversity, National Museums of Kenya: Ornithology 2.

Bennun L.A. Waiyaki E.M. 1992b. An ornithological survey of Kakamega Forest. Research Reports of the Centre for Biodiversity, National Museums of Kenya: Ornithology 4.

Bichet C., Scheifler R., Coeurdassier M., Julliard R., Sorci G. and Loiseau C. 2013. Urbanization, trace metal pollution, and malaria prevalence in the House Sparrow. *PLoSONE* 8: e53866. doi: 10.1371/journal.pone.0053866

Bird Committee. 2019. Checklist of the Birds of Kenya. FIFTH EDITION. Nairobi. Nature Kenya — the East Africa Natural History Society.

BirdLife International. 2016a. *Lophaetus occipitalis*. The IUCN Red List of Threatened Species 2016: e.T22696134A93546422. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22696134A93546422.en. Downloaded on 17 June 2020.

BirdLife International. 2016b. *Buteo augur*. The IUCN Red List of Threatened Species 2016: e.T22732019A95040751. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22732019A95040751.en. Downloaded on 17 June 2020.

BirdLife International. 2016c. *Aviceda cuculoides*. The IUCN Red List of Threatened Species 2016: e.T22694944A93480370. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22694944A93480370.en. Downloaded on 17 June 2020.

BirdLife International. 2016d. *Accipiter tachiro*. The IUCN Red List of Threatened Species 2016: e.T22727697A95230244. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22727697A95230244.en. Downloaded on 17 June 2020.

BirdLife International. 2016e. *Accipiter melanoleucus*. The IUCN Red List of Threatened Species 2016: e.T22695673A93522165. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22695673A93522165.en. Downloaded on 17 June 2020.

BirdLife International. 2016f. *Haliaeetus vocifer*. The IUCN Red List of Threatened Species 2016: e.T22695115A93490143. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22695115A93490143.en. Downloaded on 17 June 2020. 84

BirdLife International. 2016g. *Falco biarmicus*. The IUCN Red List of Threatened Species 2016: e.T22696487A93567240. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22696487A93567240.en. Downloaded on 17 June 2020.

BirdLife International. 2016h. *Falco amurensis*. The IUCN Red List of Threatened Species 2016: e.T22696437A93561051. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22696437A93561051.en. Downloaded on 17 June 2020.

BirdLife International. 2016i. *Hieraaetus wahlbergi*. The IUCN Red List of Threatened Species 2016: e.T22696072A93543119. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22696072A93543119.en. Downloaded on 17 June 2020.

BirdLife International. 2016j. *Pernis apivorus*. The IUCN Red List of Threatened Species 2016: e.T22694989A93482980. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22694989A93482980.en. Downloaded on 17 June 2020.

BirdLife International. 2017a. *Hieraaetus ayresii* (amended version of 2016 assessment). The IUCN Red List of Threatened Species 2017: e.T22696103A111817606. https://dx.doi.org/10.2305/IUCN.UK.2017-1.RLTS.T22696103A111817606.en. Downloaded on 17 June 2020.

BirdLife International. 2017b. *Buteo buteo* (amended version of 2016 assessment). The IUCN Red List of Threatened Species 2017: e.T61695117A119279994. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T61695117A119279994.en. Downloaded on 17 June 2020.

BirdLife International. 2018a. *Aquila rapax*. The IUCN Red List of Threatened Species 2018: e.T22696033A131671001. https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22696033A131671001.en. Downloaded on 17 June 2020.

BirdLife International. 2018b. *Stephanoaetus coronatus*. The IUCN Red List of Threatened Species 2018: e.T22696201A129914678. https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22696201A129914678.en. Downloaded on 17 June 2020.

BirdLife International. 2018c. *Gyps africanus*. The IUCN Red List of Threatened Species 2018: e.T22695189A126667006. https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22695189A126667006.en. Downloaded on 17 June 2020.

BirdLife International. 2019a. *Milvus migrans* (amended version of 2016 assessment). The IUCN Red List of Threatened Species 2019: e.T22734972A155599376. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22734972A155599376.en. Downloaded on 17 June 2020.

BirdLife International. 2019b. *Aquila nipalensis* (amended version of 2017 assessment). The IUCN Red List of Threatened Species 2019: e.T22696038A155419092. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T22696038A155419092.en. Downloaded on 17 June 2020. 85

BirdLife International. 2019c. *Elanus caeruleus*. The IUCN Red List of Threatened Species 2019: e.T22695028A152521997. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T22695028A152521997.en. Downloaded on 17 June 2020.

Bosakowski T. and Smith D. 1997. Distribution and species richness of a forest raptor community in relation to urbanization. Journal of Raptor Research. 31(1):26-33.

Britton P.L. (ed.). 1980. Birds of East Africa. Nairobi. EANHS.

Brown L.H. 1966. Observations on some Kenya eagles. Ibis, 108, 531–572.

Brown L. 1971a. African birds of prey. Boston. Houghton Mifflin Company.

Carswell M., Pomeroy D., Reynolds J. and Tushabe H. 2005. The Bird Atlas of Uganda. Oxford, UK: British Ornithologists' Club & British Ornithologists' Union.

Chace J.F. and Walsh J.J. 2006. Urban effects on native avifauna. *Landscape and Urban Planning*, 74, 46-69.

Chittenden H. and Myburgh N. 1994. Observations at a Crowned Eagle nest. Birding in Southern Africa, 46(4), 112-114.

Clark W. S. and Davies R. 2018. African Raptors. London. Helm.

Collins J. P., Kinzig A., Grimm N. B., Fagan W. F., Hope D., Wu J. and Borer E. T. 2000. A new urban ecology. *American Scientist* 88: 416–425. doi: 10.1511/2000.5.416

Croze H. 2016. Karura Forest Much more than just a pleasant walk in the woods. Swara Magazine issue 4. East African Wild Life Society.

del Hoyo J., Elliott A. and Sargatal J. 1994. Handbook of the Birds of the World. Volume 2: New World Vultures to Guineafowl. Barcelona. Lynx Edicions.

Donázar J. A., Cortés-Avizanda A., Fargallo J. A., Margalida A., Moleón M., Morales-Reyes Z., Moreno-Opo R., Pérez-García J. M., Sánchez-Zapata J. A., Zuberogoitia I. and Serrano D. 2016. Roles Of Raptors In A Changing World: From Flagships To Providers Of Key Ecosystem Services. Ardeola 63(1), 181-234 86

Dranzoa C. 1990. Survival of forest birds in formerly forested areas around Kampala. MSC thesis. Makerere University.

Eduardo C., Carvalho A. and Marini M. A. 2007. Distribution patterns of diurnal raptors in open and forested habitats in south-eastern Brazil and the effects of urbanization. Bird Conservation International 17:367–380. doi: 10.1017/S0959270907000822.

Ferguson-Lees J. and Christie D.A. 2001. Raptors of the World. London. Helm Identification Guides, A & C Black Publishers.

Fundi P. and Mariotte C. 2016. Introducing the Colobus guereza to Karura Forest. Swara Magazine issue 4. Nairobi. East African Wild Life Society.

Furness R.W. and Greenwood J.J.D. (eds). (1993). Birds as monitors of environmental change. London. Chapman and Hall.

Government of Kenya. 2005. Forest Act. Special Issue Kenya Gazette Supplement No. 88 (Acts No. 7). Nairobi. Government Printer.

Hockey P.A.R., Dean W.R.J. and Ryan, P.G. 2005. Roberts birds of southern Africa. Cape Town. Trustees of the John Voelcker Bird Book Fund.

Hofer C., Gallagher F. J. and Holzapfel C. 2010. Metal accumulation and performance of nestlings of passerine bird species at an urban brownfield site. *Environmental Pollution* 158: 1207–1213. doi: 10.1016/j.envpol.2010.01.018

Iwatani Y. and Wanjiku E. 2010. A brief tour of the buildings of Nairobi. Nairobi. Yuko Iwatani.

Kalnay E. and Cei M. 2003. Impact of urbanization and land-use change on climate. *Nature* 423: 528–531. doi: 10.1038/nature01675

Kekkonen J. 2011. Evolutionary and conservation biology of the Finnish house sparrow. Academic dissertation, University of Helsinki, Finland, 28 pp.

Kenya Bird Map. 2020. Website (http://kenyabirdmap.adu.org.za/) accessed on 18th April 2020.

Kenya Forest Service. 2016a. Dagoreti Participatory Forest Management Plan (2016-2020). Nairobi. GOK.

Kenya Forest Service. 2016b. Karura Forest Strategic Management Plan (2016-2020). Nairobi. GOK.

Kenya Forest Service. 2016c. Ngong Road Participatory Forest Management Plan (2016-2020). Nairobi. GOK. 87

Kingdon J. 2015. The Kingdon Field Guide to African Mammals. Second Edition. London. Bloomsbury.

Lewis A. and Pomeroy D. 1989. A Bird Atlas of Kenya. Rotterdam. A.A. Balkema.

Mangat R. 2015. Allure of Oloolua. Daily Nation online Friday June 19 2015. Nairobi. Nation Media Group.

McPherson S. C. Brown M. and Downs C. T. 2015. Diet of the crowned eagle (Stephanoaetus coronatus) in an urban landscape: potential for human-wildlife conflict? Urban Ecosystems. DOI 10.1007/s11252-015-0500-6.

McPherson S.C., Brown M. and Downs C.T. 2016. Crowned Eagle nest sites in an urban landscape: Requirements of a large eagle in the Durban Metropolitan Open Space System. *Landscape and Urban Planning*, 146, 43-50.

Munyekenye F. B. 2006. Bird species richness and abundance in different forest types of Kakamega forest, western Kenya. MSc thesis. University of Nairobi.

Munir V., Kendall C., Njoroge P. and Thomsett, S. 2010. Major declines in the abundance of vultures and other scavenging raptors in and around the Masai Mara ecosystem, Kenya. Biological conservation: 746-753.

Noss R.F., Quigley H.B., Hornocker M.G., Merrill T. and Paquet P.C. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. *Conservation Biology*, 10, 949–963.

Ogada D. L. and Keesing F. 2010. Decline of raptors over a three-year period in Laikipia, central Kenya. *J. Raptor Res*. 44(2):129–135.

Owino A. O., Amutete G., Mulwa R. K. and Oyugi J. O. 2008. Forest patch structures and bird species composition of a lowland riverine coastal forest in Kenya. *Mongabay.com Open Access Journal - Tropical Conservation Science*. Vol. 1 (3) : 242-264.

Pearson D.L. 1995. Selecting indicator taxa for the quantitative assessment of biodiversity. Pp 75-80, in Hawksworth D.L. op cit.

Pomeroy D., Shaw P., Opige M., Kaphu G., Ogada D. and Virani M. 2015. Vulture populations in Uganda: using road survey data to measure both densities and encounter rates within protected and unprotected areas. Bird Conservation International. Vol. 25 (4): 399-414. https://doi.org/10.1017/S095927091400029X. 88

Pomeroy D.E. 1992. Counting Birds. AWF Technical Handbook Series no. 6. Nairobi. African Wildlife Foundation.

Safriel U. 2013. The evolution of Palearctic migration – the case for southern ancestry. *Israel Journal of Zoology*. 41. 417-431. 10.1080/00212210.1995.10688811.

Shaw P., Kibuule M., Nalwanga D., Kaphu G., Opige M. and Pomeroy D. 2019. Implications of farmland expansion for species abundance, richness and mean body mass in African raptor communities. Biological Conservation 235, 164–177.

Shultz S. 2002. Population density, breeding chrology and diet of crowned eagles Stephanoaetus coronatus in Tai National Park, Ivory Coast. Ibis, 144, 135–138.

Stevenson T. and Fanshawe J. 2003. Birds of East Africa. London. Christopher Helm.

Swaileh K. M. and Sansur R. 2006. Monitoring urban heavy metal pollution using the House Sparrow (Passer domesticus). *Journal of Environmental Monitoring* 8: 209–213. doi: 10.1039/B510635D

Tarboton W. R. 2001. A guide to the nests and eggs of Southern African birds. CapeTown. Struik.

The Peregrine Fund. 2017. Website (https://www.peregrinefund.org/explore-raptors) accessed on 19th April 2017.

Thiollay J-M. 2006. Large bird declines with increasing human pressure in savanna woodlands (Burkina Faso). *Biodiversity and Conservation,* 15, 2085–2108.

Thiollay J. M. 1996. Distributional patterns of raptors along altitudinal gradients in the Northern Andes and effects of forest fragmentation. J. Trop. Ecol. 12: 535–560.

Thomsett S. 2011. Simon Thomsett on the African Crowned Eagle. Available at: http://www.africanraptors.org/simon-thomsett-on-the-african-crowned-eagle-part-1/. 89

UNEP. 2010. Integrated Solid Waste Management Plan For Nairobi- Opening Remarks By Peter Aquah Deputy Director Regional Office For Africa. Nairobi. UNEP.

UN-Habitat. 2012. State of the World's Cities 2010/2011. Cities for All: Bridging the Urban Divide. London, Sterling, VA. 224 pp.

Van Rooyen C.S. and Ledger J.A. 1999. Birds and utility structures: Developments in southern Africa in Ferrer, M. & G. F.M Janns (eds) Birds and Power lines. Quercus: Madirid, Spain, pp 205-230.

Virani M. Z. and Harper D. M. 2009. Factors influencing the breeding performance of the Augur Buzzard Buteo augur in southern Lake Naivasha, Rift Valley, Kenya. *Ostrich* Vol. 80, Iss. 1.

Wachira W. 2017a. Role of raptors in urban ecosystem. Swara magazine January-March Issue. East African Wild Life Society.

Wachira. W. 2017b. Notes on the increasing use of urban nesting and roosting sites in Kenya: a nesting site for Yellow-billed Storks Mycteria ibis and Pink-backed Pelicans Pelecanus rufescens in Naivasha. *Scopus Journal*, 37(1), 24-27.

Zimmerman D.A., Turner D.A. and Pearson J.D. 1999. Birds of Kenya and Northern Tanzania. London. Christopher Helm.