The ecology and conservation of Mackinder's eagle owls (*Bubo capensis mackinderi*) in central Kenya in relation to agricultural land-use and cultural attitudes

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ABSTRACT

The loss of habitat to agriculture is a worldwide problem for biodiversity conservation. One species that has seemingly been able to adapt to the conversion of forests to farmlands is Mackinder's eagle owl (*Bubo capensis mackinderi*), which inhabits highland areas, but little is known of its ecology, especially outside of protected areas. This study examined the impact of agricultural practices and farmer's attitudes on the foraging and population ecology of the Mackinder's eagle owl in central Kenya. Owl territories were monitored monthly from June 2004- October 2006 for signs of occupancy, breeding activity, mortality and to collect data on food resources. Nest site characteristics were measured for all known nests. Because previous studies showed an affinity for rodents, small mammals were trapped monthly using mark-recapture methodology. In each territory, the type and amount of farm crops were measured each month and farmers were interviewed about their knowledge and beliefs about owls. Mackinder's eagle owls in central Kenya lived at extremely high density 0.87 owl pairs/km^2. This density was high compared to other populations of Mackinder's eagle owl and to Eurasian eagle owl (*Bubo bubo*) populations in Europe. Breeding success was 48% over three years and this compared well with other species of eagle owl inhabiting human-disturbed areas. All nests and roosts were located in river valleys, and all successful nest sites were located on cliffs or other inaccessible rocky terrain. Nest sites were located adjacent to farms, which provided for both open hunting and an abundance of prey. Breeding activity was concentrated after the rainy seasons and this was likely linked to prey availability after the rains. Agricultural activities generally had a positive effect on rodent populations. Small mammal trapping results revealed that rodents were over 14 times more abundant in farms than in adjacent grassland habitat. This population of Mackinder's eagle owl had a very catholic diet and consumed mostly mammalian prey species including hares, giant rats, root rats, grooved-tooth rats and small rodents. Small rodents accounted for almost half of the owls' diet and when their numbers increased, owls responded by consuming more of them, indicating the importance of farming activities to this population of owls. Other populations of eagle owl inhabiting human-disturbed areas had diet widths positively related to levels of habitat disturbance. This result supported optimal foraging theory that more productive environments have predators with more specialized diets, while patchy environments have generalist predators. The ecology of this population of Mackinder's eagle owls was heavily influenced by human agricultural activities, which generally had a positive effect on their population. Farming activities changed rapidly both within and between seasons as plots were small and neighbouring farmers planted various crops at different times of the year and this was enhanced by irrigation in some areas. Year-round availability of forage within farms had a positive effect on owl prey species, some of which increased relative to the type and amount of crops found in farms. However, 57% of owl injuries and mortalities that occurred were related either directly or indirectly to human activities. Cultural prejudices against owls remain the biggest threat to this population's long-

term persistence. Farmer education was shown to play a significant role in overcoming negative beliefs about owls. Because Mackinder's eagle owls are highly adaptable to anthropomorphic landscape changes, largely due to their adaptability as food generalists, they are one of the few top predators remaining in this highly disturbed agricultural system. However, populations within agricultural areas remain especially vulnerable to negative human attitudes towards owls due to their close association with human activities.

DEDICATION

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CHAPTER 1: INTRODUCTION

1.1 *Introduction*

Kenya is fortunate to have one of the most diverse avian assemblages of any country in the world. With over 1,000 species, Kenya is a world-leader in terms of the numbers of bird species that can be found within its borders. This avian diversity is largely a result of extreme elevational differences resulting in the diversity of habitats found within Kenya. From the eastern-most reaches of the Congo-Guinean rainforest in western Kenya, volcanic highland massifs, plateaus and forests reaching over 2000 m, large expanses of semi-arid savanna, alkaline Rift Valley Lakes, coastal forest and northern deserts, Kenya has a diversity of habitats unmatched by most other countries, especially for its size (~586,600 km^2 or about the size of the U.S. state of Texas).

Despite being known for its abundant wildlife and spectacular landscapes, Kenya is facing a growing pressure on its natural habitats. Most of the current environmental threats in Kenya can be linked to human overpopulation in the limited area of the country suitable for human settlement. This overpopulation has led to deforestation, overgrazing, expanding agriculture, urbanization and pollution (Zimmerman et al. 1996). Kenya's forests have been particularly hard hit, with just 1.7% of land currently under forest cover (Singh 2001). Many forests have been cleared for agricultural production by small-scale farmers, which accounts for >80% of Kenya's economic activities (Bennun & Njoroge 1999).

The loss of habitat to agriculture is a worldwide problem for biodiversity conservation. For birds, habitat loss is considered the most significant risk to species persistence on a global scale (Owens & Bennett 2000), and there is strong evidence linking the rate of habitat loss to species extinctions (Brooks et al. 1997). Agricultural encroachment and habitat clearance are the major threats to priority sites for avian conservation in Africa (Fishpool & Evans 2001). In addition to land fragmentation, other deleterious effects of agricultural expansion on birds and their prey include increased use of pesticides and fertilizers, reduction of field margins necessary for cover and nest sites, and increased erosion due to poor farming practices. Eighty-one percent of avian species breeding in cultivated areas of southern Europe are classified as Species of European Conservation Concern: and 76% of them have shown recent population declines (Suarez et al. 1997). The barn owl (*Tyto alba*) has been in decline throughout much of its range largely as a consequence of loss of foraging habitat resulting from agricultural intensification (Askew et al. 2007; Colvin 1985). In Africa, the potential for agricultural landscapes to harbour a varied flora and fauna is poorly known (Soderstrom et al. 2003). Practical initiatives to address this potential threat depend upon understanding the ecology of species occupying fragmented agricultural landscapes, and attempting to resolve conflicts generated by human land-use by working directly with local communities.

In Kenya, one species that has seemingly been able to adapt to the conversion of forests to farmlands is Mackinder's eagle owl (*Bubo capensis mackinderi*). Inhabiting highland areas and known mostly from protected areas such as Mt. Kenya, Aberdare and Mt. Elgon National Parks, scattered, small populations of this species exist in unprotected areas in Kenya. Little is known of the ecology of this owl, especially outside of protected areas. There have been only two previously published studies on this species in Kenya, both from officially protected or otherwise secure areas (Rodel et al. 2002; Sessions 1972).

This study examined the impact of agricultural practices and farmer's attitudes on the foraging and population ecology of the Mackinder's eagle owl in central Kenya. Field research was conducted on an unprotected population of these owls that breed adjacent to and forage in agricultural fields in a densely settled area in the Kenyan highlands.

1.2 *Owls in a cultural context within Africa*

The study and existence of owls outside of protected areas in Africa has been greatly hindered by cultural taboos against owls in most communities. A widely held belief in most African cultures is that the sight or sound of an owl brings misfortune and even death. Thus an owl settling on a hut was traditionally regarded as a messenger of death among the Xhosa of South Africa (Godfrey 1941). In Malawi, more than 90% of respondents interviewed about their knowledge of owls connected owls with bad luck, witchcraft, and death (Enriquez & Mikkola 1997). The placement of a wooden spike at the apex of the traditional African round hut in East Africa has its origins in the belief that if an owl lands on your house someone inside will die. The wooden spike prevented owls from using the spot as a perch during their nighttime activities (M. Ogada, pers.comm.). The cultural taboo against owls remains very strong even today as most Africans will not tolerate the presence of owls in their communities and they are either chased away or killed by stoning. This strong antagonism towards owls is often prevalent irrespective of residents' education levels (D. Ogada, pers. obs.). These negative superstitions about owls are contributing to the unnecessary killing of owls in Africa (Enriquez & Mikkola 1997), and as human populations continue to expand, owls in unprotected areas are increasingly threatened with extinction. Large and medium-sized owls appear to be most at risk from direct human persecution (D. Ogada, pers. obs.). This is because the larger owls, in particular the eagle owls, produce calls that sound most like what most people associate with the call of an owl. Their deep hoots are more easily recognized as a call of an owl by the untrained ear and have been described as a forbidding sound in the dead of night (Brown 1970). Small African owls, such as scops owls and various species of owlets, e.g. red-chested or pearl-spotted, produce high frequency, rapid whistles or clicks, which are less likely to be recognised as owl calls and this makes them less vulnerable to human persecution.

Apart from the taboos against owls, they also remain little-studied due to the difficulty in locating them and observing their nocturnal behaviour, and therefore remain some of the least-known birds in Africa (Brown 1970). Despite this, owls are near or at the top of the food chain in most terrestrial habitats. This means that they are more at risk to adverse environmental conditions such as habitat degradation, pollution and climate change making them good indicators of ecosystem changes and anthropogenic disturbances (Newton 1979). Furthermore, sites occupied by top avian predators have been shown to have higher biodiversity levels and hold greater densities of individual birds and butterflies than control sites (Sergio et al. 2006). The presence of owls may not only benefit overall biodiversity levels, but farmers as well, as owls are overwhelmingly beneficial to man because they consume a large number of rodent and insect pests (Brown 1970).

1.3 *The Eagle Owls*

Owls in the genus *Bubo* include 20 species of horned owl, eagle owl and fishing owl. They are a cosmopolitan group that range throughout every continent except Australia and Antarctica, and are characterized as large, heavy owls with prominent ear tufts and powerful talons (Konig et al. 1999). They occupy nearly all available habitats, from rainforests to boreal forests, deserts and mountain tops, the only necessary feature being a few trees or rocky outcrops to provide cover for roosting and nesting (Burton 1973).

A few members of this genus are among the most well-studied owls in the world. These include the Great Horned Owl (*B. virginianus*) of the Americas and the Eurasian Eagle Owl (*B. bubo*). Within Africa, this group comprises some of the best-studied owls (*B. lacteus, B. africanus* and *B. capensis*), as well as some of least-studied owls (*B. leucostictus, B. poensis,* and *B. shelleyi*) (Konig et al. 1999).

Congeners most similar to *B. capensis* within Africa include spotted (*B. africanus*), Verreaux's (*B. lacteus*) and Usambara (*B. vosseleri*) eagle owls. Usambara eagle owl is known from the Usambara Mountains in Northeastern Tanzania, but may be endemic to the wider Eastern Arc Mountain range (see Stanley et al. 2002). This species has been little-studied, but is known to inhabit evergreen forest and forested borders of tea plantations between 200 and 1500 m (Zimmerman et al. 1996), where it feeds on a range of prey including bats, shrews, small rodents and probably birds, reptiles, amphibians and arthropods (Brown 1970; Burton 1973; Konig et al. 1999; Stanley et al. 2002). Verreaux's eagle owls are widespread inhabitants of wooded savanna, most common in riverine habitats where they typically nest in tall trees (Brown 1970; Konig et al. 1999). They range up to 3000 m and eat mostly medium-sized mammals including young monkeys, warthog piglets, hedgehogs, springhares, hares, hyraxes and ground squirrels (Konig et al. 1999). Spotted eagle owls are the most common eagle owls in Africa. They occur up to 2100 m in most habitats including, open or semi-open woodland, savanna, rocky hillsides, semi-deserts and suburban gardens (Konig et al. 1999; Tarboton & Erasmus 1998).

Numerically, spotted eagle owls consume more invertebrate than vertebrate prey. However, vertebrate prey forms the bulk of their diet (Hockey et al. 2005).

In Kenya, there is little overlap in the ranges of Verreaux's, spotted and Mackinder's eagle owls. Verreaux's eagle owls do not roost or nest on the ground and therefore prefer an entirely different habitat type from that of Mackinder's eagle owls. Spotted eagle owl is ecologically most similar to Mackinder's eagle owl. Both species prefer open, rocky habitat, eat a wide variety of mostly mammalian prey, roost comfortably on the ground, and easily adapt to human settlements (Dean 1978; Demeter 1982; Fry et al. 1988; Hockey et al. 2005; Konig et al. 1999; Nel 1969). However, Mackinder's eagle owl is segregated from the spotted eagle owl by altitude, with the latter occurring only up to 2100 m (Lewis & Pomeroy 1989).

Southern African populations of *B. c. mackinderi* and *B. c. capensis* overlap in range with spotted eagle owls, but the smaller size of the spotted eagle owl restricts it to smaller prey, thus limiting the competition between species (Brain 1981). A comparison of prey weights for spotted, Mackinder's and Cape eagle owls is shown in Table 1.

Table 1. Comparison of mammalian prey weights for *B. africanus, B. c. mackinderi* and *B. c. capensis*. Measurements are in g.

Species	Country	Prey weight range	Mean prey weight	Source
B. africanus	Ethiopia	2 - 500	45. 0	Demeter 1982
B. africanus	South Africa	6 - 150	47.7	Dean 1978
B. africanus	Namibia	20 - 53	28.0	Nel 1969
B. africanus	Namibia	12 – 150	41.2	Tilson & LeRoux 1983
B. c. capensis	South Africa	6 – 4060	203.1	Allan 1995
B. c. mackinderi	Zimbabwe	50 - 4500	1638.3	Tarr & Tarr 1991
B. c. mackinderi	Zimbabwe	50 – 2700	1404.2	Steyn & Tredgold 1977
B. c. mackinderi	Zimbabwe	60 - 4500	1586.0	Gargett & Grobler 1976
B. c. mackinderi	Kenya	7 – 2500	142.7	Rodel et al. 2002
B. c. mackinderi	Kenya	5 - 5075	585.4	This study

1.4 *Mackinder's eagle owl taxonomy*

Mackinder's eagle owl is one of two subspecies of the nominate Cape eagle owl (*B. c. capensis*), with a discontinuous distribution from Zimbabwe to Kenya (Fig. 1). The name Mackinder's eagle owl refers only to the specific subspecies *B. c. mackinderi*. It should be noted that in some published literature, reports and guides this subspecies is sometimes referred to by the common name Cape Eagle Owl. For purposes of clarity of this manuscript, the three subspecies will be referred to as follows:

Mackinder's eagle owl – *B. c. mackinderi*

Cape eagle owl – *B. c. capensis*

The third subspecies lacks a common name – *B. c. dillonii*

The most significant populations of Mackinder's eagle owl occur in Zimbabwe and Kenya. Within Mozambique a population is known from the Chimanimani Mountains (Jackson 1973). In Malawi, a specimen was collected from the Dedza highlands in 1950 and there is a reliable sight record from Mount Mulanje (Dowsett-Lemaire & Dowsett 2006). The species may exist in Tanzania on Mounts Kilimanjaro and Olosirwa, but these records are yet to be confirmed (Zimmerman et al. 1996). Although it has not been recorded in Uganda, it may occur on Mount Elgon as it has been recorded from the Kenyan-side of Mount Elgon (Carswell et al. 2005).

Due to its affinity for the highlands, local populations are generally small and scattered throughout high peaks and rocky valleys. The nominate race, *B. c. capensis* occurs in South Africa, Lesotho, Namibia, southern Angola and possibly Swaziland (Hockey et al. 2005). The other subspecies, *B. c. dillonii* is known to occur only in the highlands of Ethiopia and Eritrea (Benson & Stuart Irwin 1967), and little is known about its natural history or ecology. Due to differences in the morphology and vocalizations of the three subspecies, combined with their allopatric populations, there is a current debate about whether they should be classified as separate species (Table 2) (Goodwin 2001).

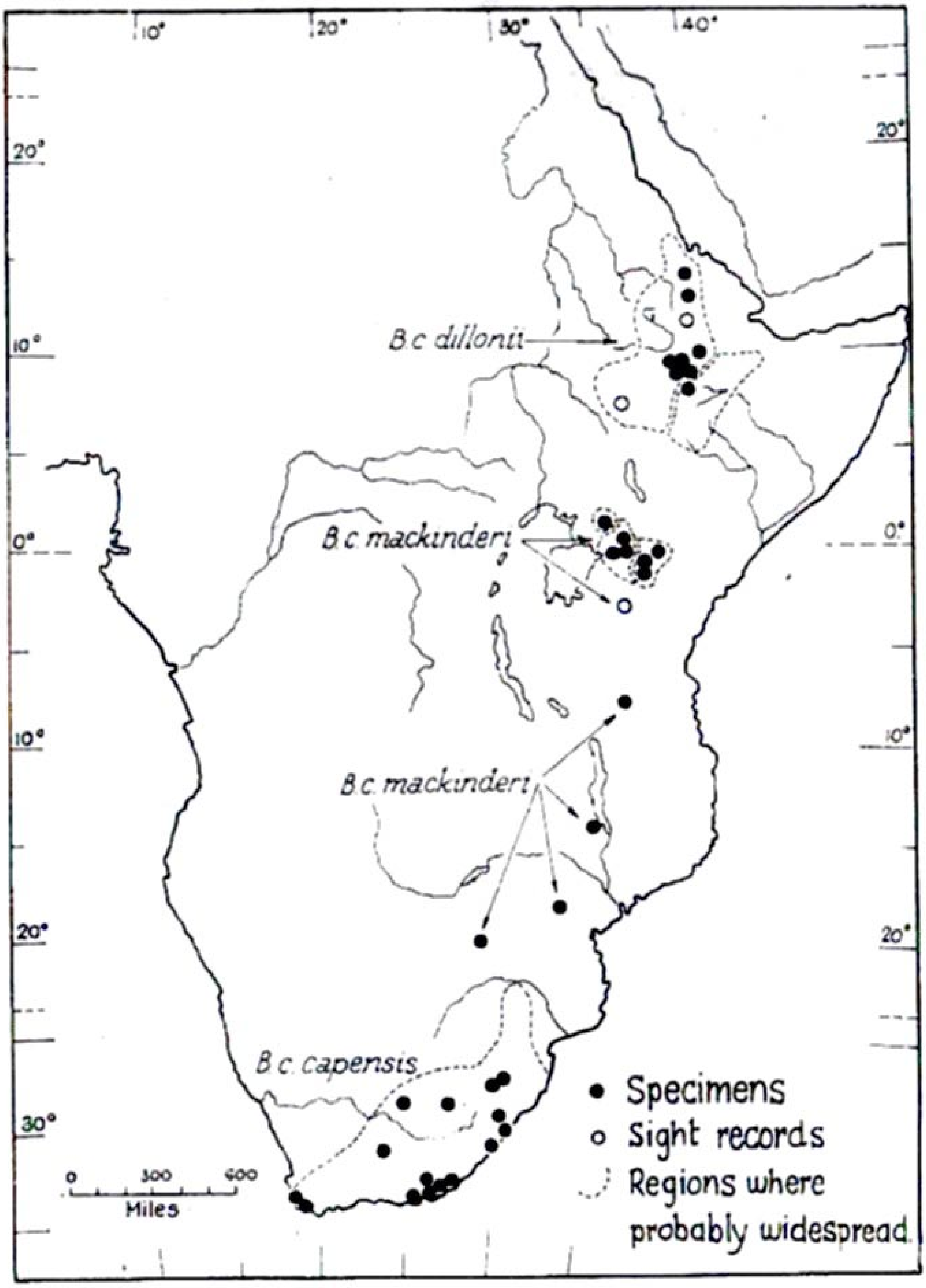


Figure 1. Distribution of *Bubo capensis.* From Benson & Irwin 1967

Table 2. Comparison of wing and tail measurements between three *B. capensis* subspecies. Measurements are in mm. Data from Benson & Irwin 1967 unless otherwise noted.

	Wing	Tail
B. c. mackinderi		
Male (n = 8)	375-402	184-205
Female[1,2] (n = 7)	406-428	200-240
B. c. dillonii		
Male (n = 7)	341-391	175-208
Female (n = 19)	380-413	181-241
B. c. capensis		
Male (n = 8)	330-357	155-215
Female[3] (n = 22)	362-392	169-240

[1] one specimen from this study
[2] Jackson 1973
[3] Martin & Pepler 1977

1.5 *Literature review*

Of the three subspecies, *B. c. mackinderi* has been the most studied. The majority of the published studies are from Zimbabwe and provide scientific data on diet, population density, breeding biology and habitat requirements (Gargett 1978; Gargett & Grobler 1976; Steyn & Tredgold 1977; Tarr & Tarr 1991). There have been two published papers on the Kenyan population. Sessions (1972) published a very informative descriptive paper on Mackinder's eagle owls inhabiting his farm in west-central Kenya. Though based solely on his own observations, experiences and knowledge of the owls, Sessions' work is the most extensive and thorough single publication on the Mackinder's eagle owl to date. A recent scientific study by Rodel et al. (2002) examined the owls' diet on Mt. Kenya, while Allan (1995) compared the diet of the Cape eagle owl to Mackinder's eagle owl based on previously published literature. Most the remaining information published about Mackinder's eagle owls consists of brief reports and notes concerning single breeding attempts, vocalizations, breeding biology, distribution and diet based on pellet analysis or field observations (Brooke 1973; Cotterill 1992; Gargett 1977a, b, 1983; Jackson 1973; Jones 1992; Rutledge 1986; Snell 1981; Snell 1979; Taylor 1987).

Benson & Irwin (1967) published the only account of the distribution and systematics for the three subspecies. It remains the only publication concerning *B. c. dillonii* apart from descriptions of the type specimen and early reports from collectors.

Published information on *B. c. capensis* consists largely of notes and reports about distribution records, diet, vocalizations and breeding biology (Brown 1987; Clinning 1980; Daugherty 1981; Gamble 1979; Grobler 1980, 1982; Martin 1983; Martin & Pepler 1977; Mathews & Scott 1980; Steyn 1982; Steyn & Myburgh 1983; Swanepoel 2003; Walter et al. 1986). Surprisingly, there is only one scientific study concerning the diet of this subspecies from southern Africa (Allan 1995).

1.6 *Mackinder's Eagle Owl Biology*

Mackinder's eagle owl is a relatively large eagle owl (46-61cm) with orange eyes, a brown, blotchy chest and feathered tarsi and toes (Fig. 2). It is intermediate in size between Verreaux's eagle owl (*B. lacteus*) and the spotted eagle owl (*B. africanus*). It is mainly nocturnal, but occasionally active after sunrise and before sunset (Konig et al. 1999). This owl prefers open habitats and never penetrates far into forests (Sessions 1972).

Within Kenya, Mackinder's eagle owl is known from four national parks, Mt. Kenya, Mt. Elgon, Aberdares and Hell's Gate. In unprotected areas, current or historical records of the owl exist from Mau Plateau, Kikopey escarpment and the surrounding areas of the Ngobit-Nakuru-Gilgil-Naivasha region, Kikuyu escarpment, Eburru and high elevation areas of Samburu and Laikipia Districts (Benson & Stuart Irwin 1967, Lewis & Pomeroy 1989, Zimmerman et al. 1996; D. Ogada pers. obs.; S. Thomsett, pers. comm.).

In Kenya, the owl is not known to nest below 1900 m (Sessions 1972; Taylor 1987). However, in Zimbabwe it regularly nests at elevations between 1300-1500 m (Gargett 1978). Mackinder's eagle owl prefers to nest either on the ground or on cliffs in rocky areas. There is only one published record of this species nesting in a tree (see Sessions 1972). Breeding can occur during any month of the year, but in Kenya all previous breeding attempts have been recorded only during the months of July-March (Sessions 1972; Taylor 1987). The owls lay from 1-3 white eggs asynchronously. Incubation is by the female only and chicks hatch after 34-38 days. As with many owls, the chicks wander from the nest before they can fly, usually from 30- 45 days. Flight begins around 70 days and they are cared for until 6 months of age (Konig et al. 1999).

Figure 2. Photograph of female Mackinder's eagle owl (*Bubo capensis mackinderi*)

Mackinder's eagle owls have a very catholic diet, but the majority (>90%) consists of mammals (Rodel et al. 2002). There have been a number of studies and reports of the diet of this owl from Kenya and Zimbabwe (Allan 1995; Brooke 1973; Coe & Foster 1972; Cotterill 1992; Gargett 1978; Gargett & Grobler 1976; Rodel et al. 2002; Rutledge 1986; Sessions 1972; Steyn & Tredgold 1977; Tarr & Tarr 1991; Young & Evans 1993), and all long-term studies have found that despite the range of prey species taken by this owl, only 1-2 prey species constitute >75% of the owl's diet (Gargett & Grobler 1976; Rodel et al. 2002; Tarr & Tarr 1991). So despite this owls' adaptability to catching a wide variety of prey items, it generally preys on one or two of the most abundant mammalian species at a given locality.

Sessions (1972) describes two common vocalizations of the adult Mackinder's eagle owl as a resonant hoot and a short bark, both sexes making either sound. The owl makes a long 'doooooo' before leaving to hunt in the evening and while hunting it makes either a double note 'hu-hoooooo', or less-often a triple note 'hu-hoooooo-hu'. The alarm call is a sharp 'wak wak' like the bark of a jackal. The nestlings hunger call is a whining 'kleeeee kleeeee' and when alarmed they hiss (Sessions 1972).

1.7 *Conservation status*

The Cape eagle owl, considered as a single race without subspecies, is not listed on the IUCN's Red Data List of globally-threatened species (The IUCN Species Survival Commission 2006). Within Kenya, *B. c. mackinderi* is listed as a regionally-vulnerable species where it occurs within important bird areas (Bennun & Njoroge 1996), whereas the South African *B. c. capensis* is not regarded as being of conservation concern (Hockey et al. 2005). The global conservation status of *B. capensis* would certainly be negatively affected if the subspecies *B. c. capensis, B. c. mackinderi* and *B. c. dillonii* were elevated to species status, as the global range and populations of the three species would be significantly reduced.

1.8 *Project background*

The study built upon initial work conducted on this population of Mackinder's eagle owls over the past ten years by local farmer and conservationist, Paul Muriithi. Paul's initial interest in wildlife began in secondary school and he soon became interested in the owls inhabiting his families' farm. He began by making regular observations of the owls to learn more about their behaviour and movements. It was during this time that he witnessed local boys stoning a pair of owls nesting at a quarry. Only one owl survived. This experience inspired him to learn more about the owls so he could educate locals about their importance. Soon thereafter a couple of foreign birding tourists stopped by the roadside to inquire if anyone could show them the owls. It was from this initial request to view the owls that Paul started his small-scale owl tourism business, in which he shows tourists the hard-to-locate owls in return for a small fee, which he divides between the local farmers whose land he accesses to view the owls. Paul began the owl tourism venture in 1997 and during the past ten years the impacts of owl tourism on the communities' perception of owls has been overwhelmingly positive. Obviously the farmers enjoy the extra income earned from owl tourists, but throughout the years Paul has taught them about the ecological importance of owls and many of the farmers now have a basic understanding of owl biology. Due to this knowledge, the owls inhabiting the farms, especially those frequented by tourists, are protected by the local farmers. If a farmer new to the area undertakes farming practices harmful to the resident pair of owls this is immediately reported to Paul who then educates the newcomer about owls and their ecological importance and an owl-friendly solution is found to remedy the threat. However, it should be mentioned that not all owl territories can logistically accommodate tourists, therefore the threat to owls from the local human population varies amongst territories.

1.9 *Study objectives and rationale*

This study had three main objectives:

1) To develop a basic understanding of the foraging and population ecology of Mackinder's eagle owls in highly fragmented agricultural landscapes
2) To better understand human attitudes and cultural beliefs about owls, particularly within a farming community

3) To develop a longer-term strategy for owl conservation in fragmented agricultural landscapes

Specific objectives and rationale of the study were:

1) **To assess measures of population stability including, nest site dispersion, breeding density, nest site choice, productivity and mortality, and the degree to which population processes are influenced by agricultural practices**

The ultimate role of any conservation project is to understand the long-term stability and threats to the study population or area. Long-term survival of a population cannot be assessed without understanding the stability of the breeding population. This can be achieved by measuring both the potential rate of breeding and the actual rate. The potential rate of breeding for owls is influenced by nest site dispersion and choice, and by breeding density. Dispersion is concerned with the spacing between nests and the movements of individual birds, which tells of the social organization within populations (Newton 1979). Nest site choice can potentially limit breeding rates if available nest sites are few and range in quality (Newton 1979). This is of particular importance for owls because they do not build their own nests. Breeding density as measured by the number of pairs in a given area is closely linked to dispersion, and often determined by limiting resources, chiefly food and nest sites (Newton 1979). The actual rate of breeding is measured by breeding success or population productivity. This is calculated in terms of the proportion of territorial pairs that lay eggs, rear young, and successfully fledge offspring. The two resources most important to sustain a breeding population are food and nest sites (Newton 1979), and these are easily manipulated with anthropomorphic changes in habitat. Examination of the effects of agricultural land-use practices, through changes in owl diet and rates of breeding success, on owls would show the extent that this population of owls is influenced by and potentially susceptible to farming activities. Comparisons of breeding success between this population and protected populations will yield insights into the long-term stability of this population of Mackinder's eagle owls living in close proximity to humans.

2) **To investigate feeding ecology, especially in reference to farming activities**

Mackinder's eagle owls primarily consume small mammals (Rodel et al. 2002). Some small mammal species readily adapt to anthropomorphic changes and can respond with a dramatic increase in their population sizes (Stoddart 1979). The influence of these anthropomorphic changes, via farming practices, on small mammal populations can have cascading effects on small mammal predators such as owls. The functional response of owls to changes in prey abundance can have community-level effects, for predators and prey, as well as for competitors. It is relatively straightforward to study owl diet by collecting pellets regurgitated at known roost sites. Prey species can then be identified from the pellets using existing reference collections, or molecular genetic markers. Pellet analysis and small mammal trapping data formed the basis for analyses of prey choice, factors that affect the distribution and availability of prey for owls, and the extent to which owls prey on species that are important crop pests.

3) **To interview farmers about their knowledge and cultural beliefs about owls**
Because owls are associated with negative taboos, their conservation in human-dominated landscapes is intimately tied to the local people's attitudes towards them. Human attitudes are generally formed on the basis of cultural beliefs, knowledge and experiences. Apart from gauging potential threats to owls, understanding human attitudes towards owls can assist in the conservation of owls by assessing the level to which education can overcome long-standing cultural beliefs. Farmers' attitudes towards owls were assessed via questionnaire. Analysis of this data, together with the ecological data was used to draw conclusions about the long-term sustainability and threats to this population and to identify conservation initiatives necessary for owl protection.

In addition to the objectives above, I also gathered morphological, vocal and genetic data towards the future evaluation of the taxonomic status of Mackinder's eagle owl.

This population of Mackinder's eagle owls offered a unique opportunity to study the ecology of this owl living within highly fragmented agricultural landscapes. The influence of human activities on raptor populations has generally been devastating (Brandl et al. 1985; Herremans & Herremans-Tonnoeyr 2001; Newton 1979; Thiollay 2006) . Although a few raptor species have shown considerable plasticity in adapting to human-altered landscapes (Marchesi et al. 2002a; Penteriani et al. 2002; Sergio & Bogliani 1999, 2000), the long-term stability of these populations is more intricately linked to human activities and may therefore, be more vulnerable to population-wide deleterious anthropomorphic changes.

CHAPTER 2: MATERIALS AND METHODS

2.1 *Description of study area*

Lying within Nyeri District in the highlands of Central Kenya, the study site is located in the foothills of the Aberdare Mountain range (Figs. 3 & 4). The Aberdare Mountains are fully protected as a national park, as is the surrounding Aberdare Forest. Most of the Aberdare Forest has only been well-protected for the last few years, as an electric fence has been gradually erected around its border to prevent human-wildlife conflict, mainly between elephants and farmers. Human settlement in many places extends right up to the fence itself. The study area begins from the fenced forest boundary at approximately 2600 m down the valleys through lower-lying communities to 1990 m.

The study area lies within unprotected, private land or government-owned land that has been taken over by permanent squatters. Human settlement is mostly in the form of small-scale farms, generally < 1 ha, and there are four villages within the study area. The density of human settlement varies from being very dense in communities adjacent to the forest boundary to relatively less-dense in lower elevation communities. Human settlement intensity mimics local rainfall patterns with the densest human settlement occurring at the highest elevations with the most rainfall. Due to this, farmers at higher elevations rely on rainfall to irrigate their crops, while those at lower elevations require diesel-powered pumps to irrigate their farms from adjacent streams and rivers. Therefore, most farms are located in the valleys and as close to water sources as possible. A typical owl territory consists of a cluster of many small farms owned or leased by different farmers. Most of the farmers' residences are >250 m from their farms on the plateaus that overlook the valleys. Therefore, few of the farms are inhabited by their owners. They are merely places the farmers, or their hired labourers, come to work during the day, but depart from in the evenings.

Figure 3. Map of Kenya showing location of study site within circle

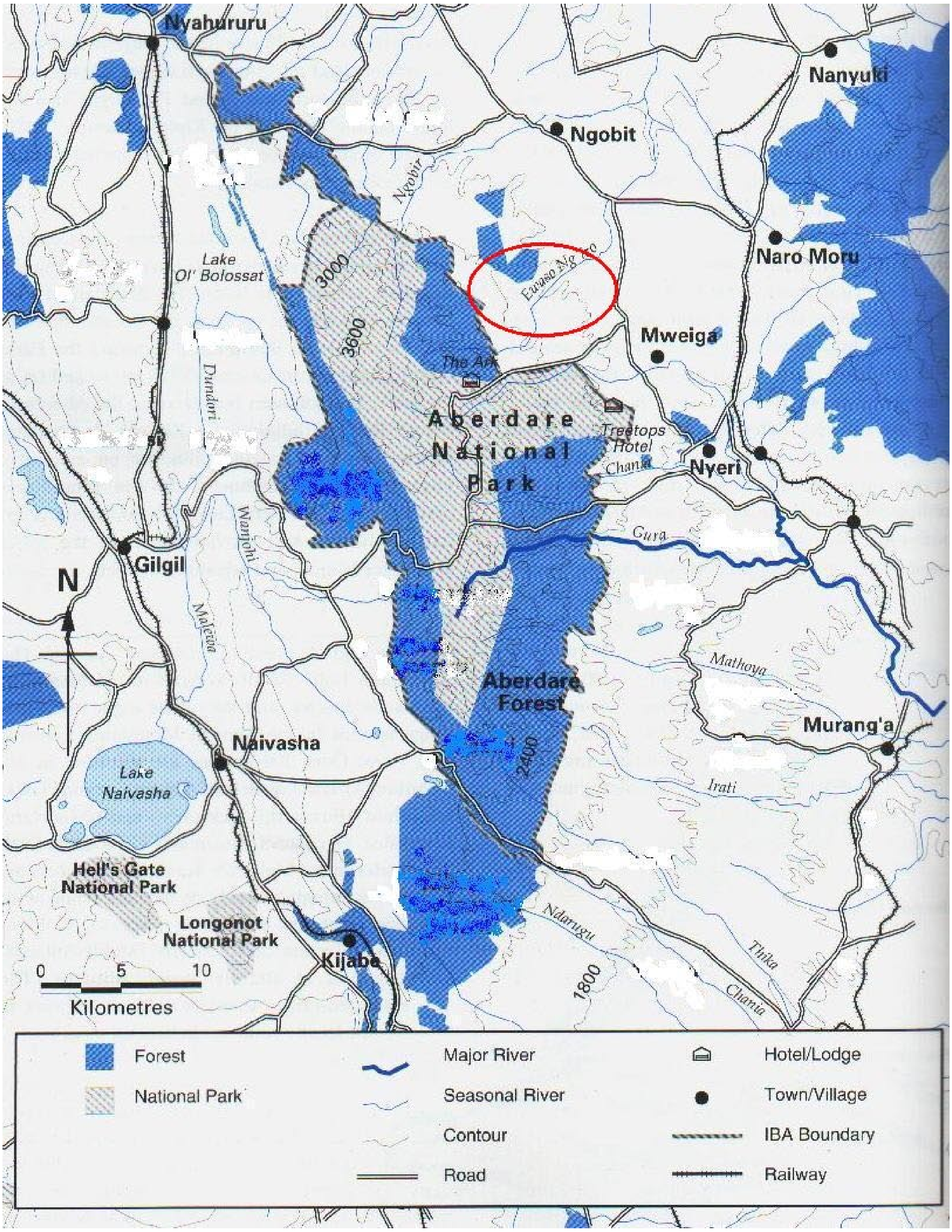


Figure 4. Map of Aberdare Mountain range showing location of study area within circle. Map adapted from Bennun & Njoroge, 1999

Farms are for both subsistence and commercial agriculture. Commercial crops are usually sold in nearby trading centres and are occasionally transported to larger towns and cities, including Nyeri and Nairobi. Approximately 40% of farms within owl territories exist on land owned by the Kenya Government, which is being farmed, and in many cases inhabited, by farmers and their families illegally (P. Muriithi, pers. comm.). These squatters have migrated to the area due to overcrowding and a lack of available farmland in their ancestral home areas. Due to lack of government enforcement and an inability by the government to address issues of landless peasants, many former government forests have suffered a similar fate. Apart from the obvious issues of deforestation, another serious issue with squatters is an attitude of 'take everything you can get, while you can get it', which results in stripping the land of all its available natural resources as quickly and thoroughly as possible. Therefore, these farms lie on severely degraded, treeless landscapes with little regard to the environmental consequences of deforestation, erosion and watershed pollution as the squatters never know when the government may intervene to remove them.

Most homesteads own small numbers of livestock - cattle, sheep and goats – with most households owning five head of livestock or less (D. Ogada, P. Muriithi, pers. obs.). However, as most of the land is under cultivation or being converted to farms, livestock increasingly compete for grazing pasture in steep and fragile riverine habitats. This has resulted in high levels of degradation within riparian and upland areas.

The topography of the study area consists of many adjacent valleys with permanent small streams and rivers at their base that drain from the Aberdare Mountains. Historically, the area was a mixed *Podocarpus latifolius* forest (Beentje 1990). Today however, there are very few, small (<1 ha), remnant patches of indigenous forest left. The hillsides now consist of farms and bushy grassland with few trees above 5 m remaining (Fig. 5). The only exceptions to this are riparian areas that have retained some large, indigenous trees, mostly *Ficus sp.,* because fig trees are revered in the local Kikuyu culture. Interspersed within the steep river valleys are infrequent rocky cliffs that are now well exposed due to the deforestation.

Figure 5. View of a typical Mackinder's eagle owl territory within the study area. The nest site is located within the circle. A small river runs at the bottom of the valley adjacent to the farms.

The main forbs in cultivated areas are *Amaranthus sp., Datura stramonium* and *Urtica massaica.* Grass and forbs in uncultivated areas include *Themeda triandra, Indigofera sp., Commelina sp, Solanum sp.* and *Aloe spp.* The major agricultural crops are beans, maize, potato, tomato, peas, onions and cabbage.

The climate ranges from cool and wet at higher elevations, to warm and semi-arid at the lowest elevations. Temperatures vary with elevation, but mid-day temperatures are generally between 22-28˚C. At higher elevations frosts are common during the coldest months of July and August. January and February are the hottest months of the year. Rainfall averages 600-1000 mm per year (Fig. 6). June and July are the driest months (x^2 = 37.7 mm, range: 10.5 - 73.0 mm). Most rainfall is concentrated in the months of March, April, May, November and December. There is considerable spatial and temporal heterogeneity of rainfall.

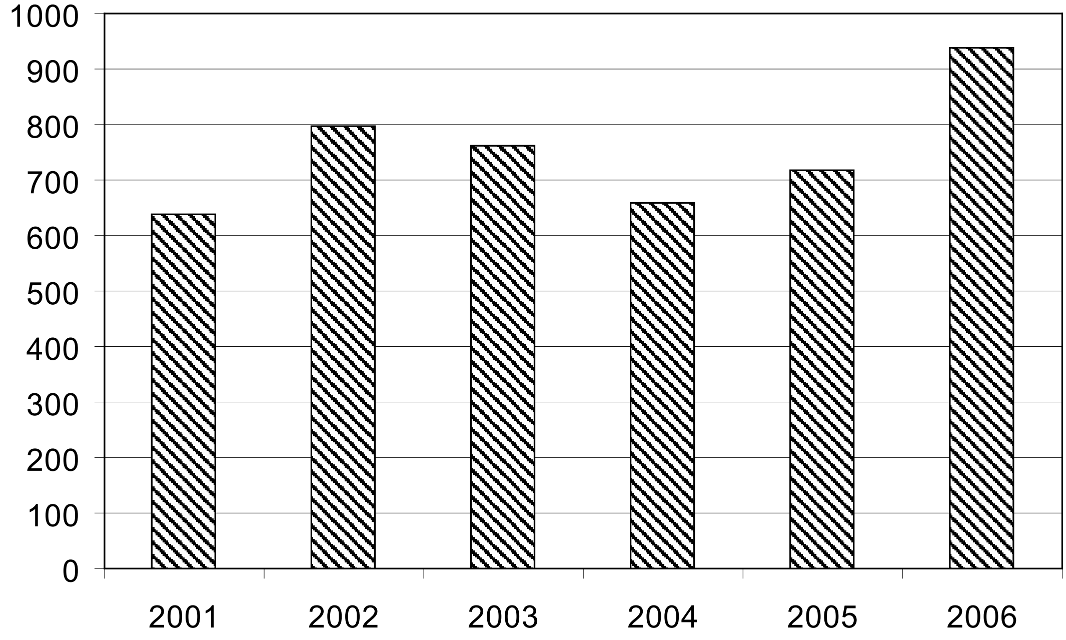


Figure 6. Annual rainfall (mm) 2001-06 measured at nearby Solio Ranch. Data courtesy of E. Parfet.

Mammalian species known from the study area include colobus monkey (*Colobus guereza*), rock hyrax (*Procavia johnstoni*), tree hyrax (*Heterohyrax spp.*), African clawless otter (*Aonyx capensis*), bushbuck (*Tragelaphus scriptus*), suni (*Neotragus moschatus*), scrub hare (*Lepus saxatilis*), genet (*Genetta* sp.), black-tipped mongoose (*Herpestes sanguineus*), crested porcupine (*Hytrix cristata*), crested rat (*Lophiomys imhausi*), ochre bush squirrel (*Paraxerus ochraceus*), numerous murid rodents, and domestic cattle, sheep and goats.

The avifauna is diverse and includes common generalists, as well as forest-dependent, highland species. Common species include bronze sunbird (*Nectarinia k. kilimensis*), baglafecht weaver (*Ploceus baglafecht*), common bulbul (*Pycnonotus barbatus*), speckled mousebird (*Colius striatus kikuyuensis*), red-eyed dove (*Streptopelia semitorquata*) and domestic chickens. Highland specialists include Hartlaub's turaco (*Tauraco hartlaubi*), cinnamon-chested bee-eater (*Merops oreobates*), Shelley's francolin (*Francolinus shelleyi uluensis*), Jackson's widowbird (*Euplectes jacksoni*), African black duck (*Anas sparsa leucostigma*) and olive pigeon (*Columba livia*). The commoner raptors are augur buzzard (*Buteo a. augur*), black-shouldered kite (*Elanus c. caeruleus*), African harrier-hawk (*Polyboroides t. typus*), long-crested eagle (*Lophaetus occipitalis*), lanner and peregrine falcons (*Falco biarmicus* & *F. peregrinus minor)* and the migrant Montagu's harrier (*Circus pygargus*). Other species of owl known from the study area are the African wood owl (*Strix woodfordii nigricantior*) and the African grass owl (*Tyto capensis*).

Other fauna observed in riparian areas include the freshwater crab (*Potamonautes neumannii*), the non-native Louisiana red swamp crayfish (*Procambarus clarkii*) and the Mascarene rocket frog (*Ptychadena mascareniensis*).

2.2 *Study site limitations*

Although Mackinder's eagle owl is mainly nocturnal, fieldwork was conducted during the day due to security concerns regarding personal safety. During the initial year of fieldwork, security was marginally better, which allowed for fieldwork, mainly tape recording of owl vocalizations, to be conducted until dusk. However, during the second and third years of the study heightened security problems in the region meant that fieldwork had to be completed by one hour before dusk so that I could travel to my base during daylight hours.

Scientific research on vertebrates often necessitates the marking of individuals within a population for studies of behaviour, population biology and physiology (Boitani & Fuller 2000). Although it would have added valuable population biology data, individual owls in this study were not marked. There were two reasons for this. First, as previously mentioned, the security situation prevented fieldwork at night when owls are active and could be trapped. The second reason was local attitudes towards owls that could threaten the population's survival. Although most people living in the vicinity of an owl territory knew of the presence of owls, they usually did not know the locality of nest sites. Nest sites are particularly vulnerable because eggs may be collected for traditional medicines and chicks may be captured to sell as pets. It was possible to ring owl chicks while they were in the nest; however, this activity causes a lot of disturbance around the nest site because adult owls will try to defend their young by vocalizing loudly near the intruder. This draws a lot of attention to the nest site, which can compromise the safety of the young because locals, especially young boys, can learn where the nest site is and subsequently return to capture or kill the young. As this is a small population of owls, jeopardizing any owls or their offspring for a relatively small amount of additional data was not deemed a justifiable risk.

2.3 *Data Collection Methods*

2.3.1 *Owl territory and nest surveys*

Like all owls, Mackinder's eagle owl is extremely well-camouflaged, making visual detection very difficult. Tips from farmers, who did not mind the presence of owls, provided the most valuable information for detecting new owl territories. After confirming new territories, the farmer who provided information was given a small monetary reward. Searches for new owl territories were also conducted by searching appropriate cliff habitats for the most obvious signs of owl occupancy - whitewash. Call-playback surveys, which are a commonly used field method for detecting owls, were not used because they could not be conducted at night when owls are most likely to respond and initial tests of the responsiveness of this species to call-playback were not encouraging. Although individual owls were not ringed for positive identification, new territories could be distinguished from existing, neighbouring territories by locating adjacent pairs during the same day. This could be easily accomplished because the owls roosted during the daytime and would only fly short distances if disturbed. Owl territories were digitally marked using a GPS from either the nest site, if known, or the cliff on which the owls were regularly seen roosting if nest site locations were unknown. Density of owl territories was determined by measuring the overall area surveyed divided by the total number of owl territories.

Owl territories were visited monthly from June 2004 – December 2006 to determine the presence or absence of the breeding pair, collect pellets and check for any signs of breeding activity. As the breeding season for this species was unknown and previous work by Sessions (1972) and P. Muriithi (unpub data) indicated the owls could breed in any month during the year, territories had to be checked monthly. New nest sites were very difficult to locate. Searches for new nests began if there was a continual presence of only one owl at the territory (i.e. the male, as the female would be hidden at the nest location), or the female vocalized from an area where a new nest could likely be. Timing of nest searches was aided in subsequent years by knowing the month(s) the pair bred in previous years. Any signs of potential or actual breeding activity were recorded including daytime vocalizing, nest location, development stage (i.e. egg, nestling, fledgling, post-fledgling) and approximate age of nestlings. Clutch size was difficult to determine for most nesting attempts due to either discovering the nest too late or inaccessibility of the nest site. Owls were never intentionally flushed from a nest to determine clutch size due to the human presence around owl territories. Determination of egg-laying dates was established by back-dating from the estimated age of chicks seen in or near the nest. An incubation period of 36 days was used based on published reports (Konig et al. 1999; Sessions 1972; Steyn & Tredgold 1977). Age of chicks was approximated from photographs and descriptions from published reports (Gargett 1978; Konig et al. 1999; Steyn & Tredgold 1977; Tarr & Tarr 1991). The breeding activities of each pair were followed until the chicks fledged from the nest and whenever possible, the chicks were capable of flight. Owl chicks typically wander away from the nest before they are able to fly. This is an anti-predator defence, whereby the young will disperse from the nest site as soon as they are able to and hide under bushes, logs, etc. This increases the survival of individual nestlings as it is less likely a predator will locate all the dispersed young. For this reason, I refer to fledglings as those young who have left the nest, but are not yet able to fly. Post-fledglings are young that have left the nest and are flying.

Given the importance of human-caused mortality during the study, I attempted to locate and verify incidences of owl mortality and injury. During nest site checks, any signs of mortality were recorded and carcasses were collected for further study and DNA collection, if possible. Additional incidences of owl mortality and injury were discovered by reports from the public and I always tried to locate the carcasses and assess the cause of death. Incidences of mortality were included for some reports in which no carcass was found. These reports were verified as best as possible based on the credibility of the reporter and follow-up visits to the nest site.

Twenty-three different nest site characteristics were measured for all confirmed nest sites (n = 11). A few territories contained more than one nest site, but additional nests were located so close to previous ones that measurements did not differ. Characteristics measured included topographic features, landscape-level variables and signs of human activities. Measurements of nest height, cliff width and height, and distances to nearest water, farms and human habitation were made using a Bushnell Elite 1500 Rangefinder. Cliff aspect was measured using a compass. A Garmin 12 GPS was used for long distance measurements, including distances to nearest road, forest, grassland and neighbouring nests. A pre-marked stick was used to measure shrub heights. Visual approximations were made for percent vegetation cover and disturbance indexes. Disturbance indexes were based on an incremental scale, with 1 = low disturbance and 5 = high disturbance. Canopy height and density were measured in a 5 m radius located 10 m horizontal distance from the cliff base. A comparison between active nest sites and control sites could not be made due to the difficulty in locating enough control sites (i.e. non-nesting cliffs) in the study area and confirming that they had not previously been used for nesting.

2.3.2 *Dietary Studies*

Owl pellets and other prey remains were collected monthly from all known territories. Whole pellets were measured and weighed in the lab. All pellets were then dissected using forceps to extract bones, exoskeletons and feathers of prey items. These were then identified, wherever possible, to species-level using reference collections at the National Museums of Kenya and from the literature (Kingdon 1997; Rosevear 1969; Spawls et al. 2002; Zimmerman et al. 1996). Mammals and reptiles were identified based on dentition patterns, which for small mammals was aided by use of a handheld magnifying glass and a dissecting microscope. The majority of small mammals could only be identified to genus-level, due to a lack of information about species-level distributions in Kenya. Birds were identified by beak size and shape. However, few bird beaks were recovered, thus most birds could only be placed in the Class Aves. Invertebrates were identified to order-level by exoskeleton parts and quantified based on the number of body segments found. Only the minimum possible number of prey items were counted using skeletal parts for which the exact number of bones is known such as skulls, mandibles or other paired-bones (femurs, humerus, tibia, etc.). Bones such as ribs and vertebrae were generally not used for this analysis. Vertebrae were only useful if no other bones were present in the pellet and species identification was possible by using only vertebrae, e.g. for medium-sized mammals. This is not believed to produce a bias toward identifying more medium-sized than small mammals because there were no pellets in which only vertebrae of small mammals were found. Vertebrae-only pellets occurred only in larger-bodied species like hares and giant rats. To limit biases in diet assessment by use of only one method, prey samples were pooled to include analyses of both pellets and remains (Marchesi et al. 2002b). Percent biomass (%B) contribution to the diet was calculated as follows: %B = $(100\, p_i\, n_i) / \sum p_i\, n_i$, where p_i was the mean prey mass and n_i was the number of individuals of the *i*th species (Pardinas et al. 2005). Estimates of mean prey mass were taken from the literature and from actual weights of specimens trapped during the study. Prey mass for unidentified prey were estimated based on mean prey mass for the most closely-related identified taxon.

Mean prey weight is calculated by multiplying the total number of each kind of prey by the mean weight for that species, then summing these totals and dividing the sum by the total weight of prey individuals in the samples. However, this measure has potential problems. Frequencies of prey weights cannot be assumed to follow normal distributions and mean prey weight is also overly sensitive to very large or very small prey weights. These potential problems can be minimized by log-transformation of the mean weights of individual prey species prior to calculating the grand mean prey weight, which is then referred to as the geometric mean (Marti 1987). Geometric mean weight of prey was calculated as follows: GMWP = antilog $(\sum n_i \log p_i / \sum n_i)$, where n_i and p_i are described above. Estimates of GMWP did not include the prey weight of *Chameleo sp.* because it was unavailable and prey weights of insects, which were negligible. Only nests with ≥30 prey items, after removing *Chameleo sp.* and insects, were used in estimates of GMWP.

Diet breadth was measured using Levins' index (Levins 1968), DB = $1/ \sum p_i^2$, where p_i = proportion of the diet contributed by the *i*th taxon. Values from this index range from 1 to *n*, where *n* is the number of prey taxa in the diet. Prey categories were grouped to genus-level and unidentified small rodents and birds, and all insects were not included in calculations. Only nests with ≥30 prey items, after removing unidentified groups and insects, were used in estimates of diet breadth.

2.3.3 *Small mammal trapping*

Small mammals (<150 g) were trapped monthly from June 2004 – October 2006 on two replicates of two different habitats, or four trapping plots in total. Small mammals were not trapped during July 2006 due to logistical constraints. Treatments represented the two habitat types within the study area that the owls could use while foraging, farmland and bushed grassland. Forested habitat was not trapped because a review of previous studies of this species' diet shows they do not feed on any forest-dwelling species (Brooke 1973; Gargett 1978; Gargett & Grobler 1976; Rodel et al. 2002; Sessions 1972; Steyn & Tredgold 1977). While the habitat for small mammals on grassland remained relatively constant during two years of trapping, agricultural habitats were very dynamic. Agricultural lands were ploughed, planted, harvested and irrigated throughout the trapping period. As the agricultural sites consisted of small sections of leased farmland, farming activities there were irregular and not consistent throughout the block, but were representative of typical agricultural habitat for small mammals in the study area.

Four 70 m x 70 m plots were established in each of the two habitats with a minimum of 100 m spacing between plots. Trap stations were laid in a grid with 10 m spacing between stations. One Sherman live-trap (23.5 x 8.9 x 7.7 cm) was laid per station and baited with a mixture of peanut butter and oats. Traps were covered with vegetation to prevent captured animals from overheating during the day. Traps were open for three consecutive days and nights and checked before 9am and after 4pm. Captured individuals were identified, ear-tagged, sexed, weighed and their reproductive condition noted before release. Species too small to be ear-tagged, i.e. *Mus sp.*, *Crocidura sp.* and *Dendromus sp*. were marked using nail polish on different appendages to distinguish recaptured individuals within a single-trapping session. Nail polish was generally not effective in marking individuals between trapping sessions. Individuals of uncertain identification were measured using a standard protocol, including total length, length of head and body, tail length and weight (Stanley et al. 2005), and whenever possible photographs were taken. This information was taken to the National Museums of Kenya, Department of Mammalogy for further identification assistance.

2.3.4 *Influence of farming practices*

Farm crops within eight owl territories were assessed monthly from July 2005- October 2006 as to type and amount of crop production. Farm crops were not assessed during the month of July 2006. At each owl territory, crops in the farm(s) nearest to the nest site and of approximately 1 ha in area were measured using a Bushnell Elite 1500 Rangefinder and a measuring stick. Crops were measured as to type, area as a percentage of total area measured, height and general condition (flowering, fruiting, harvested or dead).

2.3.5 *Farmer interviews*

Interviews were conducted from October-December 2005 by an intern from the National Museums of Kenya, Department of Ornithology. All interviews were conducted one-on-one by the same interviewer, in the local Kikuyu language and lasted between 15 - 45 minutes. The interviewer translated answers from Kikuyu into English before recording them. The interviewer was new to the area and therefore, not known to the interviewees. The project field assistant approached potential interviewees either in their farms or outside their adjacent houses and asked them if they would consent to an interview about their farming practices and knowledge of owls. Between 2 and 11 farmers, whose farms comprised a portion of an owl pairs' territory, were interviewed at eight different territories.

Interview questions were designed to assess the farmer's knowledge of agricultural pests and of the role of owls as natural pest controllers and their potential benefit to farmers. In the first series of questions, farmers were asked demographic data including their age and sex, and historical data about their farms. Farmers were then asked about the major problems they faced in their work (i.e. financial, infrastructure, climate, etc.) and then they were asked specifically, which crop pests were problems on their farms. In the next series of questions, farmers were asked about six pest species or groups, which were also common owl prey. The six species or groups included the giant pouched rat, smaller 'rats', root rat, hare, weavers and mousebirds. Farmers were asked to what extent the six species were pests on their farm, what the pests were consuming, during which seasons they were problems, and what control methods they used. Farmers were then asked which chemicals they used to control pests and if they irrigated their farms and how often. Finally, farmers were questioned as to their knowledge and beliefs about owls, whether they knew about the Project Assistant, Paul Muriithi's work with owls and what were their impressions of his work. An expert in social science from a local university reviewed the questions from a cultural context to ensure their appropriateness and correct meaning prior to beginning interviews (see Appendix 1 for a full list of the interview questions). Occasionally, respondents did not fully answer all interview questions and therefore not all percentages of respondent's answers total 100 %.

2.4 *Statistical Analyses*

All tests are parametric unless otherwise noted. As necessary, data were tested for assumptions of normality and constant variance prior to running statistical tests. Where data did not meet test assumptions, they were arc-sin transformed prior to testing whenever possible. Simple linear regressions were run to compare dependent versus independent variables. Interview responses were compared with demographic data using Chi-squared tests. Analysis of variance was used to test for relationships between more than two groups. Post-hoc pairwise differences in means were evaluated using Bonferroni's post-hoc test. Statistics were performed using JMP 4.0.3. and Systat 9. Linear regressions were performed using SigmaPlot 4.0.

CHAPTER 3: RESULTS

3.1 *Owl nest sites*

In total 16 different owl nest sites were located within the study area by the conclusion of the 31-month study period (Fig. 7). Owl density was 0.87 owl pairs/km^2 within the study area. The closest sites were 1.02 km apart, and the furthest 5.60 km apart. Elevation of sites ranged from 1993 – 2595 m. Placement of sites followed prominent geographic features, as the centre of all nest sites was located within river valleys (mean distance from water = 48.6 m). Adjacent upland areas were used for foraging, but not for nesting or daytime roosting. All sites were located within 200 m of agricultural lands, with 58% being <20 m from an active farm (x^2= 49.1 m, range: 7-190 m). Other prominent landscape features included roads, houses and forests. Mean distances of owl nest sites to roads was 568.4 m, houses 295.6 m, and forests >1 km. The centre of one site was located <200 m from a major highway, which resulted in owl collisions with vehicles being a significant cause of mortality at this site throughout the study. Placement of sites showed little regard to human settlement patterns, as some sites were amidst densely populated, agricultural areas. Disturbance adjacent to nest sites was generally high, and largely attributed to livestock grazing and tree clearing.

3.2 *Nest characteristics*

This population of Mackinder's eagle owls nested primarily on cliffs, the exceptions being one nest located on the ground at the base of a cliff and two nests on the ground in steep, rocky areas (Table 3). Nests located on cliffs (n = 9) were generally mid-way up cliffs, as they had a mean distance of 14.7 m above the ground and 12.1 m from the top of the cliff. Nest aspects varied, with most facing a northwest direction and having a mean slope of 79.4˚. Cliff sizes varied: mean width was 123.2 m (range: 50-216 m) and mean height 30.3 m (range: 19-51 m). Verticality of cliffs ranged from being slightly overhung to sloped. Most nests were located either in caves or under or behind a covered ledge, but one nest was on an open ledge. Approximately half of each cliff was covered with vegetation (x^2 = 48 %), either hanging vegetation or plants growing from cliff ledges. Mean canopy height of trees and shrubs growing beneath cliffs was 2.5 m and canopy density averaged 5.3 trees and shrubs within a 5 m radius. Relationships between nest site characteristics and the number of fledglings produced or the number of successful nesting attempts were not significant (Table 4).

Table 3. Nest site characteristics and measures of productivity for 11 active Mackinder's eagle owl nests. Nest sites refer to map (Fig. 7)

Nest Sites	1 road	2 churc	3 home	4 junc	5 ngare	6 watu	7 euph	8 emb	9 upst	10 muth	11 willy	Mean
Elevation (m)	2099	2076	2410	2127	2089	2134	2075	2595	2074	1993	2137	2164.4
Substrate (1=cliff, 2=ground)	1	2	1	1	1	1	2	1	1	2	1	
Nest height (m)	17	0	9.2	4.5	13	2	13	15	42	0	17	12.1
Cliff aspect	307°NW	317°NW	141°SE	297°NW	322°NW	124°SE	263°SW	48°NE	173°SE	229°SW	317°NW	
Nest visible (1=yes, 2=no)	1	1	2	2	1	1	2	1	2	2	1	
Height from top of cliff to nest (m)	0	19	8	27	9	8	13	7	9	n/a	21	12.1
Height of cliff complex (m)	24	19	17.2	36	44	26	26	22	51	n/a	38	30.3
Width of cliff complex (m)	164	74	50	73	149	216	130	98	213	n/a	65	123.2
Verticality[a]	2	4	4	2	4	3	5	2	3	n/a	4	
Nest location[b]	4	4	2	1	2	1	1	2	2	4	1	
% vegetative cover on cliff	30	50	70	10	50	35	95	40	35	n/a	65	48.0
Nearest neighbour distance (km)	1.89	1.02	2.00	1.07	2.29	1.07	2.26	2.37	2.29	1.02	1.20	1.68
Average canopy height[c]	0	3.37	0	6.26	3.97	1.5	2	6	0	3.6	0.97	2.51
Average canopy density[d]	0	22	0	5	4	8	1	1	0	5	12	5.27
Distance to water (m)[e]	42	11	5	191	167	63	8	10	30	7	1	48.6
Distance to road (m)	154	420	374	491	1143	387	1000	500	753	741	290	568.4
Distance to agriculture (m)	9	15	15	84	190	71	12	10	7	10	117	49.1
Distance to human habitation (m)	315	394	184	471	270	177	371	103	73	716	178	295.6
Distance to grassland (m)	0	7	33	0	0	0	60	-	9	634	200	
Distance to forest (m)	1280	3140	225	2000	-	-	316	580	-	153	0	
Disturbance index[f]	3	2	5	1	1	5	5	5	5	1	1	3.1
Type of disturbance[g]	1	1	2	4	1	1	3	3	3	4	4	
Grazing pressure index[f]	4	2	2	3	2	5	3	2	5	1	1	2.7
No. of fledglings produced	2	1	2	2	3	2	3	1	0	0	2	1.6
% of successful nesting attempts	1	0.33	1	1	.67	1	1	1	0	0	1	

[a] 1=overhung, 2=>vertical, 3=vertical, 4=<vertical, 5=sloped

[b] 1=cave, 2=covered ledge or ground, 3=among rocks, 4=open ledge or ground

[c] average height (m) of all trees and shrubs within 5 m radius

[d] total number of trees and shrubs within 5 m radius

[e] all distances are nearest distances

[f] 1-5, 1=low, 5=high

[g] 1=livestock, 2=humans, 3=tree/vegetation cutting, 4=none

- indicates distance too great for measurement

Table 4. Linear regressions between nest site characteristics and measures of owl productivity.

	Number of fledglings produced	Number of successful nesting attempts
Elevation	$r^2 = 0.00$, $p = 0.98$	$r^2 = 0.22$, $p = 0.14$
Nearest neighbour distance	$r^2 = 0.04$, $p = 0.54$	$r^2 = 0.01$, $p = 0.73$
Cliff height	$r^2 = 0.02$, $p = 0.72$	$r^2 = 0.23$, $p = 0.16$
Cliff width	$r^2 = 0.02$, $p = 0.69$	$r^2 = 0.11$, $p = 0.35$
Nest height	$r^2 = 0.04$, $p = 0.55$	$r^2 = 0.04$, $p = 0.55$
Aspect	$r^2 = 0.12$, $p = 0.30$	$r^2 = 0.01$, $p = 0.83$
Canopy height	$r^2 = 0.00$, $p = 0.95$	$r^2 = 0.00$, $p = 0.91$
Canopy density	$r^2 = 0.01$, $p = 0.77$	$r^2 = 0.03$, $p = 0.58$
Distance to water	$r^2 = 0.16$, $p = 0.23$	$r^2 = 0.03$, $p = 0.63$
Distance to road	$r^2 = 0.03$, $p = 0.63$	$r^2 = 0.12$, $p = 0.29$
Distance to agriculture	$r^2 = 0.30$, $p = 0.08$	$r^2 = 0.05$, $p = 0.50$
Distance to human habitation	$r^2 = 0.12$, $p = 0.70$	$r^2 = 0.11$, $p = 0.33$

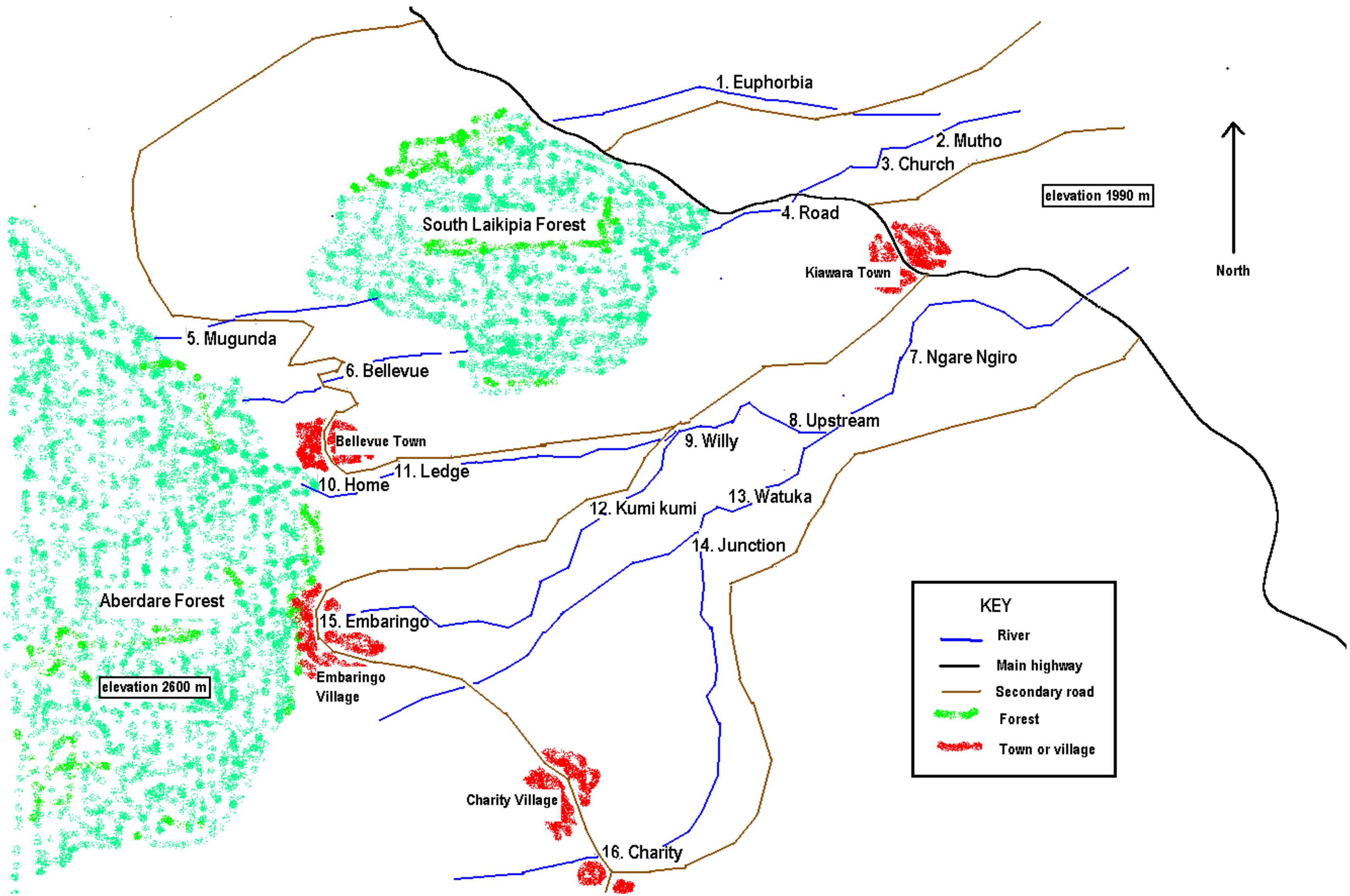
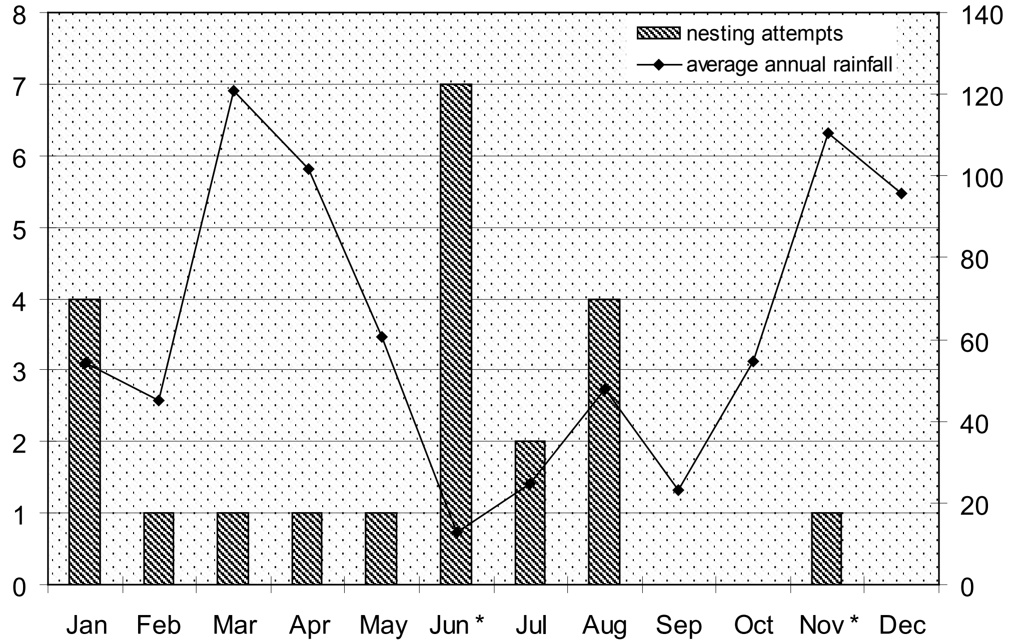


Figure 7. Map of 16 nest territories of Mackinder's eagle owls in central Kenya (Jun 2004- Dec 2006). Territories indicated by number

3.3 *Breeding activity*

Data includes breeding activity through August 2007. Evidence of breeding activity, i.e. egg-laying, was found or inferred by chick age in nine different months of the year (Fig. 8). There were three nesting attempts for which the start of breeding activity could not be determined. Breeding seasons followed rainfall patterns, with most breeding beginning at the end of the rainy seasons.

Figure 8. Number of breeding attempts (n = 23) by month as assessed by egg-laying dates compared to average annual rainfall (mm).



*one breeding attempt was a re-nesting following a failed earlier attempt

Of the five owl pairs whose territories were known throughout the study period, four pairs nested every other year regardless of whether or not they successfully fledged chicks during the previous attempt. Of 12 pairs whose breeding attempts were known for at least two years, only two pairs nested successfully in consecutive years. Owl pairs tended to nest in the same or adjacent months in successive years, especially if their previous nesting attempt was successful.

Clutch size was directly observed for only four of 25 breeding attempts and was two eggs in three nests and one egg in the other nest. Nests had 1-3 chicks per nest (n = 15), with most nests having one chick (n = 10). Four nests had 2 chicks each, and one nest had three chicks.

Productivity was determined for three consecutive years, 2004-06 (Table 5). Newly discovered nest sites that indicated successful hatching of chicks, i.e. many pellets and remains found at nest site, were assumed to have fledged one chick if no chick carcasses were found at the nest site. Nest sites for which the number of fledged chicks was known, were assumed to have the same number of young in the nest.

Table 5. Mean productivity of Mackinder's eagle owl nests (2004-06)

	2004	2005	2006	Mean
Number of pairs known	4	9	16	9.67
Number of breeding pairs	3	5	11	6.33
Number of successful pairs*	2	4	8	4.67
Percent of nests successful	67%	80%	73%	73%
Number of young	3	6	12	7.00
Number of young fledged	2	6	10	6.00
Number of young fledged/territorial pair	0.50	0.67	0.63	0.60
Number of young fledged/successful pair	1.00	1.50	1.25	1.25

* Number of breeding pairs that successfully fledged young

Only one nest site monitored throughout the study period had two failed nesting attempts. Both attempts produced young, but the young failed to fledge from the nest. In the first attempt, one chick and one egg were taken by pied crows (*Corvus albus*). In the second attempt, two chicks died before reaching two-weeks old and were apparently victims of an attack by safari ants. Both nests were located on the ground at the base of a cliff, the only nests to be placed in such an exposed location. This pair successfully raised a chick in late 2006 from a new nest located on the cliff wall.

3.4 *Owl mortality and injury*

A minimum estimate of owl mortality and injury rates per year was made based on the recovery of carcasses and injured owls, and credible reports from locals (Table 6). An average of 24% of chicks and 4% of adults were found dead per year.

Table 6. Minimum Mackinder's eagle owl mortality and injury rates (2004-06)

	2004	2005	2006	Mean
Number of territories checked	6	9	16	7.17
Number of adults known	13	20	34	15.17
Number of chicks known	5	6	12	5.67
Total number of owls known	18	26	46	20.83
Number of owls found injured	0	1	1	0.33
Number of chicks found dead	2	3	2	1.50
Number of adults found dead	1	2	2	0.83
Percent of owls found injured/ year	0%	4%	2%	1%
Percent of chicks found dead/year	40%	50%	17%	23%
Percent of adults found dead/year	8%	10%	6%	4%

Of 14 owls, both chicks and adults, found either injured or killed during the study, 57% were known to have been caused either directly or indirectly by human activities (Table 7).

Table 7. Causes of 14 cases of owl injury and mortality during study period

Cause of injury/mortality	# of owls affected
Vehicle collision	2
Intentional poisoning	3
Secondary poisoning	2
Capture of owl for sale	1*
Attacked by safari ants	2
Killed by pied crow	1
Flew into wire fence	1
Unknown cause	2

*one additional chick was captured for sale, but it was returned to the nest site uninjured

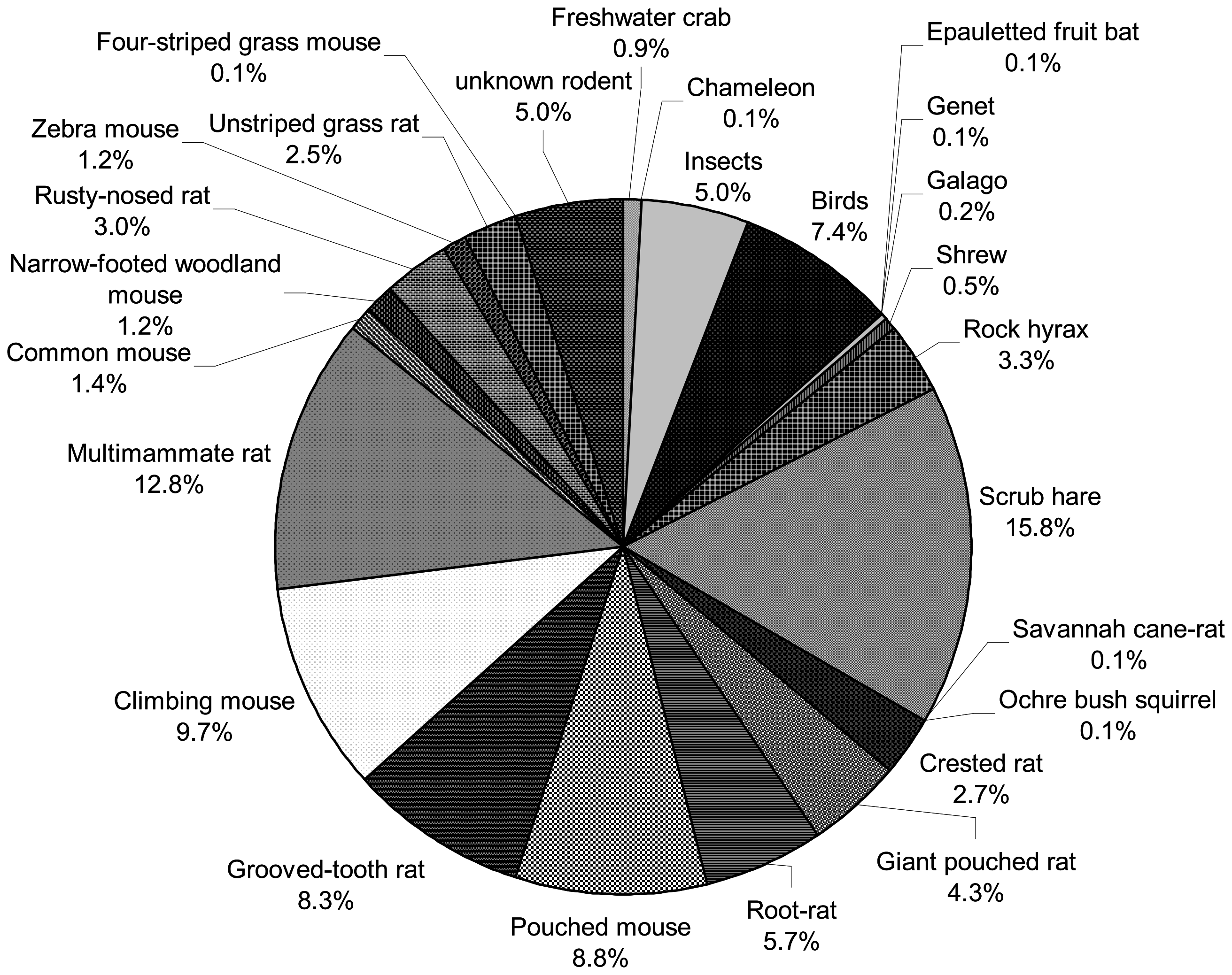
3.5 *Owl diet*

The owls captured and consumed a wide diversity of prey. A total of 1388 individual prey items consisting of 21 mammal species (87%), 7 bird species (7%), 1 reptile (0.1%), 1 crustacean (0.1%) and 3 insect orders (5%) were collected as pellets and prey remains from 16 nest territories (Fig. 9). Scrub hares (*Lepus saxatilis*) were the most common prey species (15.7%) and the only species to occur at all nest sites, followed by the multi-mammate rat (*Mastomys sp.*) (12.8%), and climbing mouse (*Dendromus sp.*) (9.7%). Small rodents (<120 g) made up 46% of the owl's prey. Insects, primarily from the orders Coleoptera and Orthoptera, accounted for 5% of the owl's prey, but a negligible proportion of prey biomass.

Mammals contributed 98.4% of prey biomass, birds 1.6%, and invertebrates and reptiles accounted for the remaining <0.1%. In terms of biomass, scrub hares (53.1%), rock hyrax (*Procavia sp.*) (19.9%) and giant pouched rats (*Cricetomys gambianus*) (10.3%) were the most important prey. Although scrub hares accounted for the most biomass, they were the most important prey item in only 58% of owl territories (n = 12). At territories where scrub hares were not the most important prey item by biomass, the most important prey items were similar large mammals, either rock hyrax or giant pouched rats. Small rodents accounted for <5% of prey biomass. Vertebrate prey mass ranged between 5 g (shrew) and 5075 g (cane rat).

Geometric mean weight of prey (GMWP) for individual territories ranged from 39.7 – 364.5 g (168.6 ± 24.2 g; x^2 ± SE) (Table 8). Estimates for diet breadth ranged from 3.11 – 8.60 (5.71 ± 0.5; x^2 ± SE). Diet breadth was related to nest site elevation ($r^2 = 0.36$, $p = 0.04$). However, one nest site (#15 Embaringo) was a strong outlier. This nest site had an extremely low value for GMWP (39.7 g), indicating that the diet of this pair consisted of a high abundance of small prey, mostly two species. This may reflect a relatively better habitat quality around this nest site compared with the others. If this outlier is removed the regression between diet breadth and elevation is very strong ($r^2 = 0.83$, $p < 0.0001$).

Figure 9. Prey species composition recovered from owl pellets (n = 151) and remains from 16 nest territories from Jul 2004 – Oct 2006



n = 1388 (Prey items)

Table 8. Prey items found in pellets and remains from 16 Mackinder's eagle owl nest territories. N refers to the number of prey items and %B is the percent biomass for that item. Prey mass of reptiles and insects were negligible and not included. Nest territories refer to those in Figure 1. Prey mass is given in grams for samples with n >30.

	Nest	1	Eup	2	Mut	3	Ch	4	Rd	5 Mug	6 Bel
Primates	Mass	N	%B	N	%B	N	%B	N	%B	N	
Otolemur sp.	760[1]										
Chiroptera											
Epomophorus sp.	65.8[2]	1	0.1								
Insectivora											
Crocidura spp.	5[3]					1		1			
Lagomorpha											
Lepus saxatilis	1750[4]	25	71.1	8	62.2	48	73.9	53	81.1	2	3
Rodentia											
Paraxerus ochraceus	93[4]	1	0.2								
Thryonomys gregorianus	5075[4]					1	4.5				
Lophiomys imhausi	755[4]							2	1.3		1
Dendromus sp.	7.75[3]	2	<0.1	5	0.2	1	<0.1	7	<0.1	7	5
Cricetomys gambianus	1235[4]	5	10.0			1	1.1	5	5.4	2	1
Saccostomus mearnsi	78.1[3]	29	3.7	21	7.3	32	2.2	23	1.6		
Otomys sp.	150[4]	1	0.2			16	2.1	4	0.5	2	2
Tachyoryctes sp.	220[4]	1	0.4			3	0.6				
Mastomys sp.	58.1[3]	7	0.7	1	0.3	9	0.5	7	0.4	2	2
Mus sp.	7.2[3]							2	<0.1		
Grammomys sp.	25.5[3]			1	0.1			2	<0.1		
Oenomys hypoxanthus	90[4]			1	0.4	26	2.1	4	0.3	1	1
Rhabdomys pumilio	35[4]										
Lemniscomys sp.	50.8[3]									1	3
Arvicanthis sp.	66[3]	5	0.5	2	0.6	11	0.6	3	0.2		
Small rodents unidentified	29.9[5]	9	0.4	4	0.5	12	0.3	7	0.2	3	1
Carnivora											
Genetta sp.	1650[6]										
Hyracoidea											
Procavia sp.	3100[7]	2	10.1	2	27.6	4	10.9	3	8.1		
Aves											
Vanellus melanopterus minor	166.5[8]	2	0.5			1	0.1				1
Francolinus sp.	498[9]										
Francolinus leucoscepus	631.5[9]										
Treron calva gibberifrons	200[10]										
Apus barbatus roehli	42[11]							1	<0.1		
Colius striatus kikuyuensis	52.5[12]					4	0.2	3	0.1		
Onychognathus tenuirostris theresae	126[13]										
Birds unidentified	96.7[14]	13	2.0	2	0.9	11	0.9	8	0.7	1	2
Reptilia											
Chameleo sp.											
Crustacea											
Potamonautes neumannii	10.3[15]									1	
Insects		20		3		2		4		4	
Total prey items		123		50		183		139		26	22
MGWP[16]			184.8		109.0		198.2		259.4		
Levin's diet breadth index			4.15		3.11		5.54		4.07		

Kingdon 1997; [2] Kingdon 1974b; [3] average weight from trapped specimens; [4] Kingdon 1974c; [5] average weight for small murid rodents (<60 g); [6] Kingdon 1977; [7] Kingdon 1974a; [8] del Hoyo et al. 1996; [9] del Hoyo et al. 1994 [10] del Hoyo et al. 1997; [11] del Hoyo et al. 1999; [12] del Hoyo et al. 2001; [13] Feare & Craig 1998; [14] average weight for small birds (<200 g); [15] Ogada 2007 [16] MGWP = geometric mean weight of prey

Table 8. continued

	Nest	7 Ng		8 Ups	9 Wil		10 Ho		11 Led	
Primates	Mass	N	%B	N	N	%B	N	%B	N	%B
Otolemur sp.	760[1]				1	2.5				
Chiroptera										
Epomophorus sp.	65.8[2]									
Insectivora										
Crocidura spp.	5[3]	1	<0.1							
Lagomorpha										
Lepus saxatilis	1750[4]	23	60.9	2	4	23.0	1	5.2	3	23.3
Rodentia										
Paraxerus ochraceus	93[4]									
Thryonomys gregorianus	5075[4]						1	15.0		
Lophiomys imhausi	755[4]	4	4.6		1	2.5	6	13.4	5	16.8
Dendromus sp.	7.75[3]	18	0.2				3	0.1	1	<0.1
Cricetomys gambianus	1235[4]	1	1.9		9	36.6	1	3.7	2	11.0
Saccostomus mearnsi	78.1[3]	17	2.0							
Otomys sp.	150[4]	1	0.2		2	1.0	7	3.1	5	3.3
Tachyoryctes sp.	220[4]	48	16.0	1						
Mastomys sp.	58.1[3]	69	6.1		8	1.5	5	0.9		
Mus sp.	7.2[3]	5	0.1						1	<0.1
Grammomys sp.	25.5[3]	6	0.2		1	0.1			2	0.2
Oenomys hypoxanthus	90[4]	1	0.1				3	0.8	1	0.4
Rhabdomys pumilio	35[4]									
Lemniscomys sp.	50.8[3]								5	1.1
Arvicanthis sp.	66[3]	6	0.6				1	0.2		
Small rodents unidentified	29.9[5]	10	0.5		2	0.2	4	0.4	5	0.7
Carnivora										
Genetta sp.	1650[6]									
Hyracoidea										
Procavia sp.	3100[7]	1	4.7		3	30.6	6	55.0	3	41.3
Aves										
Vanellus melanopterus minor	166.5[8]	4	1.0							
Francolinus sp.	498[9]				1	1.6	1	1.5		
Francolinus leucoscepus	631.5[9]									
Treron calva gibberifrons	200[10]									
Apus barbatus roehli	42[11]									
Colius striatus kikuyuensis	52.5[12]	1	0.1				1	0.2		
Onychognathus tenuirostris theresae	126[13]									
Birds unidentified	96.7[14]	6	0.9		1	0.3	2	0.6	4	1.7
Reptilia										
Chameleo sp.										
Crustacea										
Potamonautes neumannii	10.3[15]	1	<0.1				4	0.1	2	0.1
Insects		21			3		1		2	
Total prey items		244		3	36		47		41	
MGWP[16]			95.7			364.5		156.9		142.9
Levin's diet breadth index			5.14			5.06		8.60		8.33

Table 8. continued

	Nest	12 Ku	13	Wat	14	Jun	15	Em	16	Cty	Totals
Primates	Mass	N	N	%B	N	%B	N	%B	N	%B	N
Otolemur sp.	760				2	1.5					3
Chiroptera											
Epomophorus sp.	65.8										1
Insectivora											
Crocidura sp.	5		2	<0.1			2	<0.1			7
Lagomorpha											
Lepus saxatilis	1750	2	17	37.1	17	29.2	8	42.1	2	23.9	218
Rodentia											
Paraxerus ochraceus	93										1
Thryonomys gregorianus	5075										2
Lophiomys imhausi	755		3	2.8	9	6.7	3	6.8	3	15.5	37
Dendromus sp.	7.75		18	0.2	25	0.2	38	0.9	5	0.3	135
Cricetomys gambianus	1235		19	29.3	9	10.9	2	7.4	3	25.3	60
Saccostomus mearnsi	78.1										122
Otomys sp.	150		16	3.0	49	7.2	7	3.2	3	3.1	115
Tachyoryctes sp.	220		9	2.5	12	2.6	1	0.7	4	6.0	79
Mastomys sp.	58.1		3	0.2	38	2.2	23	4.0	3	1.2	177
Mus sp.	7.2				1	<0.1	10	0.2			19
Grammomys sp.	25.5		1	<0.1	2	0.1	2	0.2			17
Oenomys hypoxanthus	90						4	1.1			42
Rhabdomys pumilio	35						1	0.1			1
Lemniscomys sp.	50.8		3	0.2	2	0.1	2	0.3			16
Arvicanthis sp.	66				3	0.2			1	0.5	32
Rodents unidentified	29.9		2	0.1	2	0.1	13	1.2			74
Carnivora											
Genetta sp.	1650				1	1.6					1
Hyracoidea											
Procavia sp.	3100		6	23.2	12	36.6	3	28.0	1	21.2	46
Aves											
Vanellus melanopterus minor	166.5										8
Francolinus sp.	498										2
Francolinus leucoscepus	631.5						1	1.9			1
Treron calva gibberifrons	200		2	0.5							2
Apus barbatus roehli	42										1
Colius striatus kikuyuensis	52.5										9
Onychognathus tenuirostris theresae	126								1	0.9	1
Birds unidentified	96.7		8	1.0	9	0.9	7	2.0	3	2.0	77
Reptilia											
Chameleo sp.							1				1
Crustacea											
Potamonautes neumannii	10.3		1	<0.1	1	<0.1			2	0.1	12
Insects			3		2		3		1		69
Total prey items		2	113		196		131		32		1388
MGWP				199.7		142.9		39.7		129.0	
Levin's diet breadth index				7.23		6.40		5.21			

Whole pellets averaged 63.7 ± 1.4 mm length (range 37.5 – 107.3 mm) x 28.3 ± 0.5 mm width (range 20.4 – 38.2 mm) and had a mean dry weight of 10.3 ± 0.4 g (range 2.3 – 22.1 g) (x^2 ± SE, n = 151). But pellet weight varied with type of prey item (ANOVA: $F_{1,21} = 1.94$, $p = 0.01$) and by nest site (ANOVA: $F_{1,8} = 3.92$, $p < 0.01$, including only nest sites with >5 whole pellets). Pellets averaged 2.67 prey items per pellet. The number of prey items per pellet differed significantly between nest sites (ANOVA: $F_{1,11} = 4.21$, $p < 0.01$).

3.6 *Small mammal surveys*

Over 28 months and 16068 trap nights, a total of 432 small mammals were captured (2.7 % trap success), comprising 10 species (Table 9). Four species (*Mus sp., Mastomys sp., Lemniscomys sp. and S. mearnsi*) represented >90% of captures.

Table 9. Total number and percent of small mammal captures by species (Jun 2004 – Oct 06)

Species	No. of captures	% of captures
Mus sp.	107	24.8
Mastomys sp.	102	23.6
Lemniscomys sp.	98	22.7
Saccostomus mearnsi	86	19.9
Arvicanthis sp.	25	5.8
Dendromus sp.	6	1.4
Grammomys sp.	3	<1.0
Paraxerus ochraeus	2	<1.0
Crocidura sp.	2	<1.0
Otomys sp.	1	<1.0

Overall, small mammal abundance was very low. Agricultural habitat averaged 7.4 small mammals/ha and grassland habitat averaged 0.5 small mammals/ha. Human agricultural activities amplified the positive effects of rainfall on small mammal numbers (Fig. 10). Abundances of small mammals in grassland treatments remained extremely low throughout the study period, suggesting that owls foraged primarily in farms and not grassland areas.

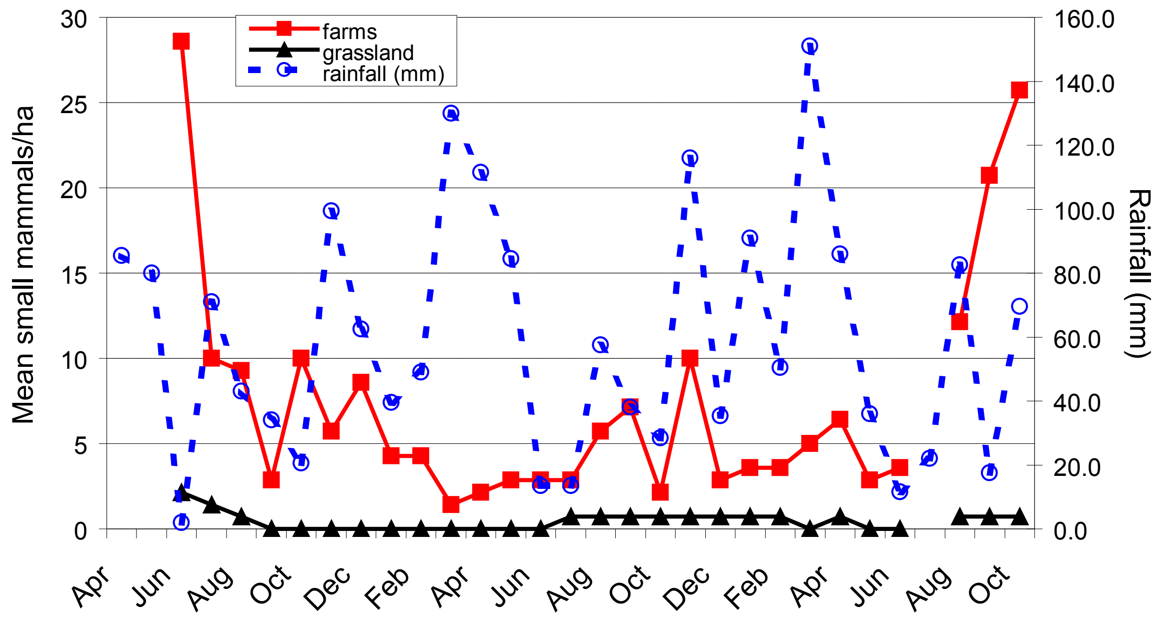


Figure 10. Mean number of small mammals per ha for two habitats (Jun 2004-Oct 06)

The percentage of small mammals in owl diet correlated positively with their relative abundance during monthly trapping and was an important determinant of owl diet composition (Fig. 11).

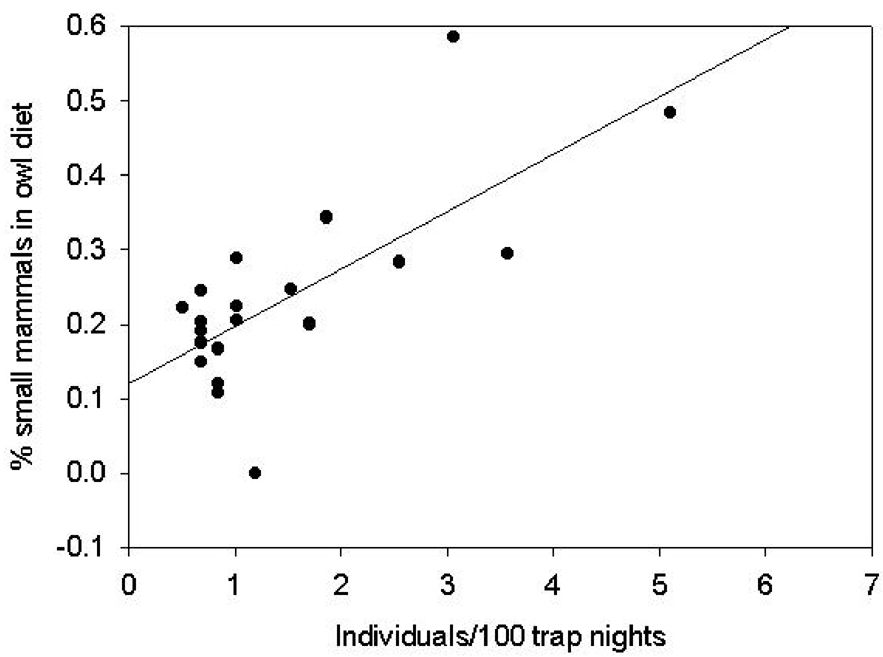
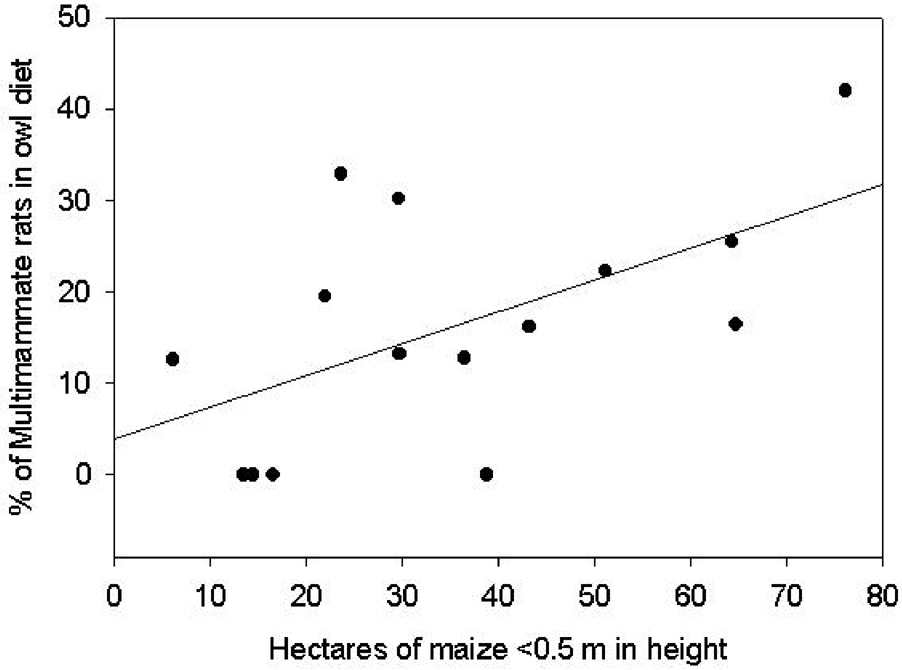
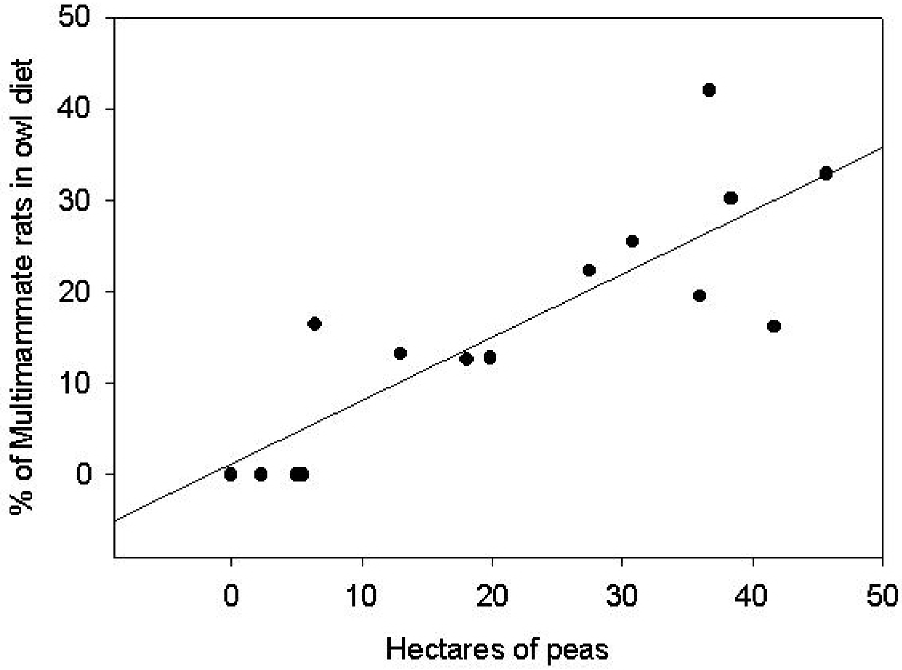


Figure 11. Regression between the monthly proportions (%) of small mammals in owl diet and their relative densities (individuals/100 trap nights during monthly trapping) ($r^2 = 0.52$, $p < 0.001$). The proportion of small mammals in the diet represents only those species trapped >5 times during monthly trapping, *Arvicanthis sp., Lemniscomys sp., Mastomys sp., Mus sp. and S. mearnsi* and for months with >5 individual prey items in owl pellets. Regression represents a 1-month lag between estimates of relative abundance from trapping to occurrence in the diet.

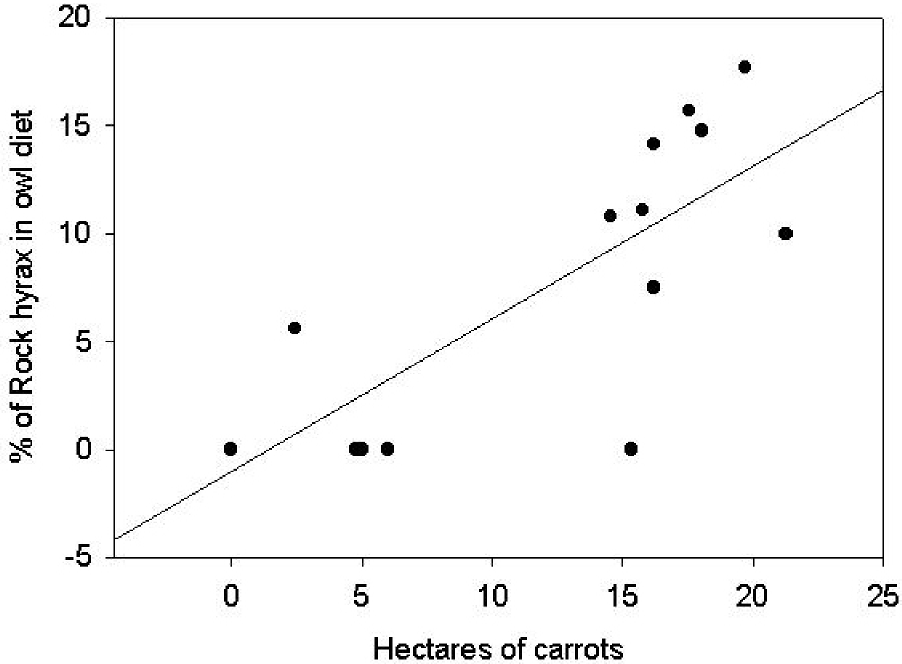
Farming activities affected owl diet through the selective planting of various crops. The total hectares of various crops correlated with the abundance of different prey species in owl diet (Fig. 12).



12a.



12b.



12c.

Figure 12. Regressions between the total hectares of three different farm crops and the proportion of two prey species in owl diet. Farm crops were measured at eight owl territories. The proportion of prey species in the diet is measured for the eight corresponding owl territories. Data were arc-sin transformed to meet test assumptions. 12a. ($r^2 = 0.32$, $p = 0.03$), 12b. ($r^2 = 0.71$, $p < 0.001$), 12c. ($r^2 = 0.63$, $p <0.001$)

3.7 *Farmer interviews*

A total of 72 interviews was conducted at eight owl territories, with 2-11 interviews conducted per territory. Only one farmer refused to be interviewed. Respondents were 33% female and 67% male and ranged in age from 17 – 86 years (Fig. 13). Although farmers were not asked their education level, only one farmer was obviously illiterate and one semi-literate, the rest were either literate or very-literate. The mean number of years they had cultivated their farm was 7.9 years. The majority of the land (73%) had been cleared by the respondents prior to being cultivated.

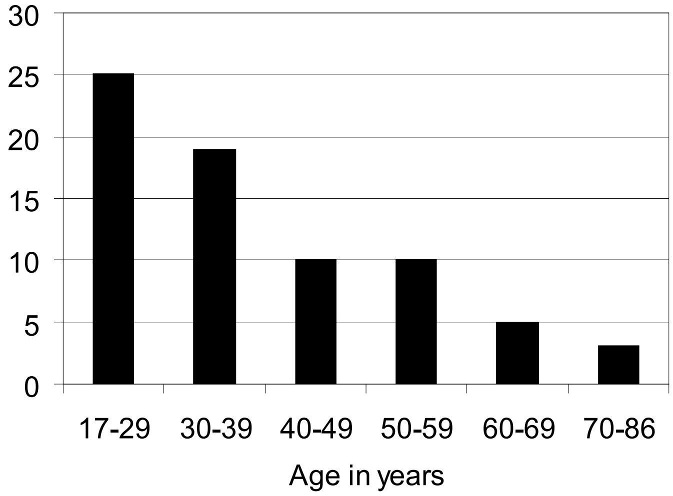


Figure 13. Number of respondents per age category (age x^2 = 38.9, SE = 1.7, n = 72)

Farmers identified the major problems they faced as pests (97%), followed by a lack of farm inputs (fertilizer, seeds, irrigation) due either to high prices or unavailability (90%) (Table 10).

Table 10. Major problems faced by farmers. Respondents were allowed multiple answers.

Problems faced by farmers	# responding
Pests	70 (97%)
Lack of inputs	65 (90%)
Low market prices	61 (85%)
Drought	60 (83%)
Lack of transport	22 (31%)
Poor soils	10 (14%)
Floods	2 (3%)

Farmers were asked to identify major agricultural pests by group (insect, bird and mammal). For insects and birds, only 2-3 species or groups accounted for most crop damage. But farmers identified a much larger range of species or groups of mammal pests (Table 11). Antelope, which included bushbuck and duiker, were the most commonly reported mammal pest. Rats, which included all rat-like small mammals were the second most commonly reported mammal pest. Porcupines, monkeys and hares were also significant crop pests.

Table 11. Specific agricultural pests as identified by farmers. Respondents were allowed multiple answers.

Specific pest by group	# responding
Insects	
Cut worm	71 (99%)
Aphids	66 (92%)
Red spider mite	42 (58%)
Moths	12 (17%)
Thrips	2 (3%)
Boll worm	1 (1%)
Leaf miners	1 (1%)
Locust	1 (1%)
Beetles	1 (1%)
Birds	
Mousebirds	70 (97%)
Weavers	62 (86%)
Francolin	5 (7%)
Waxbills	3 (4%)
Bulbuls	3 (4%)
Blue-eared starling	2 (3%)
Mammals	
Antelopes (bushbuck, duiker)	60 (83%)
Rats	53 (74%)
Porcupine	40 (56%)
Monkeys (Syke's, colobus)	38 (53%)
Hare	38 (53%)
Hyrax	7 (10%)
Root rat	2 (3%)
Otter*	2 (3%)
Wild pig	2 (3%)
Zebra	1 (1%)

*Farmers complained otters were eating maize. This has also been reported in neighbouring Laikipia District.

When asked about six specific pest species or groups, most farmers knew of the pest species or group (Table 12). Of the six, mousebirds, weavers, small rats and hares were the most often indicated as being a problem for farmers.

Table 12. Farmer's responses to questions about six agricultural pests. Numbers indicate farmers answering 'yes'

		It's a problem in your farm…		
Group or Species	Do you know this pest?	Not a problem	Not often	Often
Giant pouched rat	60 (83%)	35 (59%)	11 (19%)	13 (22%)
Small rats	72 (100%)	9 (13%)	15 (21%)	46 (66%)
Root rat	66 (92%)	48 (75%)	9 (14%)	7 (11%)
Hare	72 (100%)	6 (8%)	23 (32%)	42 (59%)
Weavers	71 (99%)	2 (3%)	13 (18%)	56 (79%)
Mousebird	72 (100%)	2 (3%)	3 (4%)	67 (93%)

Farmers listed a range of crops and plant parts targeted by the six agricultural pests (Table 13). Overall, according to farmers, maize and beans were the crops that attracted the most bird and mammal pests. Although onions were widely planted, they were the only crop not mentioned as being the target of any of the six pest species. Amongst bird pests, weavers targeted primarily maize, while mousebirds were a generalist pest that consumed many different crops. There was little consensus amongst farmers as to which seasons were the worst for the different pests.

The most common control measures for all the pests were either to do nothing, or to physically chase the pests from farms. Trapping and pesticide use were common control methods for rodents. Plastic tapes (cassette or video tape) were used to create noise and scare away bird pests.

Table 13. Food preferences, active seasons and control measures for six agricultural pests. Numbers indicate positive farmer responses. Crops are listed in decreasing amounts of hectares planted throughout the study area.

	Giant pouched rat	Small rats	Root rat	Hare	Weavers	Mousebird
Food preferences						
Crop or plant part consumed						
Maize	19 (43%)	56 (47%)	7 (10%)	7 (6%)	58 (76%)	37 (20%)
Cabbage		2 (2%)	1 (1%)	11 (9%)		7 (4%)
Potato	12 (27%)	9 (8%)	8 (11%)	1 (1%)		
Beans	8 (18%)	29 (24%)	1 (1%)	45 (38%)	1 (1%)	37 (20%)
Peas	1 (2%)	2 (2%)		2 (2%)		12 (6%)
Tomato	1 (2%)	5 (4%)	1 (1%)	1 (1%)	1 (1%)	41 (22%)
Carrots		4 (3%)		2 (2%)	1 (1%)	4 (2%)
Sugarcane	3 (7%)					
Peppers						2 (1%)
Wheat			1 (1%)	4 (3%)	4 (5%)	1 (1%)
Millet/sorghum					3 (4%)	
Sweet potato		1 (1%)	4 (6%)	1 (1%)		
Roots			6 (8%)			
Leaves				30 (26%)	1 (1%)	7 (6%)
Flowers					2 (3%)	24 (13%)
Active seasons						
Dry	2 (10%)	18 (31%)	1 (7%)	14 (23%)	10 (16%)	18 (26%)
Wet	4 (20%)	16 (28%)	2 (14%)	7 (25%)	1 (2%)	5 (7%)
All	8 (40%)	17 (29%)	5 (36%)	29 (48%)	4 (5%)	20 (29%)
When food is available	6 (30%)	7 (12%)	2 (14%)	3 (5%)	46 (72%)	25 (36%)
Control measures						
Does nothing	11 (52%)	29 (46%)	5 (31%)	39 (59%)	18 (27%)	15 (21%)
Uses traps	3 (14%)	6 (10%)	6 (38%)	7 (11%)		
Chase away	7 (33%)	4 (6%)	1 (6%)	13 (20%)	34 (51%)	38 (54%)
Scarecrow		1 (2%)		2 (3%)	3 (4%)	3 (4%)
Kills			1 (6%)			
Use pesticide		18 (29%)	2 (13%)			1 (1%)
Tapes*					11 (16%)	13 (19%)
Floods holes			1 (6%)			
Uses mud**					1 (1%)	
Uses dogs				3 (5%)		
Clears weeds		5 (8%)		1 (2%)		
Doesn't know what to do				1 (2%)		

* Cassette or videotapes are unwound from their cartridges and strung horizontally between trees and over crops as tightly as possible. Wind blowing through the tapes creates a low rumbling sound that scares away birds.

** Mud is smeared on cobs to support the husk and create an additional barrier to the kernels

The majority of farmers (81%) said they use chemical treatments to control agricultural pests. However, most used chemicals to control common insect pests (cut worms, aphids, red spider mites). Only 21% of farmers used pesticides to control mammals or birds.

Most farmers (55%) irrigate their farms between 1-4 times per week. Forty-two percent of farmers never irrigate their farms and 6% irrigate sporadically depending on the weather.

When questioned about their knowledge of owls, 100% of respondents replied that they knew about the owls living in the area; including 65% who responded that they had seen or heard owls. More than half of respondents (75%) could correctly name at least one type of owl prey species. The remaining 25% of respondents either didn't know what owls eat (24%) or answered incorrectly (1%) (Table 14). Neither age group, nor gender influenced whether a person could correctly name an owl prey item (age group: $\chi^2 = 4.67$, df = 4, p = 0.32; gender: $\chi^2 = 1.41$, df = 1, p = 0.23).

Table 14. Response to the question, 'Do you know what owls eat?'

Prey item	# responses (%)
Rats	33 (28%)
Rabbits	31 (26%)
Birds	11 (9%)
Snake	9 (8%)
Hyrax	3 (3%)
Crab	1 (1%)
Worms	1 (1%)
Don't know	28 (24%)

Most farmers (61%) knew Project Assistant, Paul Muriithi as a member of the community. But 67% of respondents didn't know about his work with owls, 21% responded that his work with owls was 'okay or fine' and 13% responded his work with owls was 'impressive'. Significantly more respondents who knew Paul could correctly name an owl prey item ($\chi^2 = 5.41$, df = 1, p = 0.02).

When asked, 'What does your community believe about owls?', 76% of respondents said the owls' cry causes death and 6% said 'owls cause death'. A further 10% of respondents said owls are a bad omen. The remaining 8% of respondents replied that they had heard about their communities' beliefs about owls, but did not elaborate further.

Farmers were then asked, 'What do you think about owls?', a majority (68%) responded that they didn't believe in the taboos about owls and of those, 76% responded that owls are 'just like any other bird', but 6% said they are 'weird' birds or that they didn't like the looks of them. Only 26% of respondents said they believe in the taboos about owls and of these, 26% responded that they are ‘weird’ birds or that they didn’t like the looks of them. A final 4% responded that owls are ‘weird’ birds, but didn’t elaborate further. There was no correlation between a respondents’ age or knowing Paul and their beliefs in taboos against owls, but significantly more women than men believed in the negative taboos associated with owls (age group: $\chi^2 = 0.85$, df = 4, p = 0.93; know Paul: $\chi^2 = 0.02$, df = 1, p = 0.87; gender: $\chi^2 = 3.68$, df = 1, p = 0.05).

Finally, farmers were asked if they perceived a benefit from living with owls. Only 20% responded positively about owls, despite the fact that the majority knew that owls eat agricultural pests (Table 15). The majority of respondents had a neutral feeling toward owls (44%). Thirty percent of respondents thought owls were bad and 14% didn’t know. Whether or not respondents knew Paul had a significant effect on how they felt about owls ($\chi^2 = 17.66$, df = 3, $p < 0.001$). More respondents who knew Paul answered that owls were ‘good’ or a benefit to them. The more knowledgeable respondents were about owl diet, the more likely they were to respond that owls were ‘good’ for them ($\chi^2 = 22.65$, df = 3, $p < 0.0001$). Of the farmers who did not know what owls eat, none answered that owls were ‘good’ for them, while the majority who knew what owls eat answered that owls were ‘good’ for them.

Table 15. Response to the questions, ‘Do you think the presence of owls is good or bad for you? Why? Total is above 100% because 6 respondents answered in more than one category

Response	# responses (%)
Owls are good because…	
Eat pests	14 (20%)
Warn of things to come	1 (1%)
Owls are neutral because….	
Don’t disturb farm or my work	16 (23%)
No opinion, doesn’t see goodness or badness of owls	15 (21%)
Owls are bad because….	
Cause death	16 (23%)
Doesn’t like sound	5 (7%)
Doesn’t know	10 (14%)

CHAPTER 4: DISCUSSION

4.1 *Justification*

There have been few in-depth studies of Mackinder's eagle owl and most of these were published over 20 years ago (Gargett 1978; Sessions 1972). Previous studies of this owl have focused exclusively on populations within protected or large, privately-owned landholdings. This is the first study to assess the effects of human activities and attitudes on a population of Mackinder's eagle owls living in a completely unprotected, fragmented habitat.

4.2 *Comparison to other eagle owl species*

Due to the lack of published information on this species, it is necessary to supplement the existing comparative data with studies of ecologically similar eagle owl species.
Existing data for similar African eagle owls, *B. c. capensis, B. africanus* and *B. lacteus* is limited, but comparisons can be made for diet and nest site characteristics. Too little is known about *B. c. dillonii* and *B. vosseleri* for valuable comparison.

The Eurasian eagle owl (*Bubo bubo*) is very similar to Mackinder's eagle owl and is most likely a very close relative. Although it lives in the more temperate climates of Europe, Asia and North Africa, studies of the Eurasian eagle owl can provide a good comparison because of the similarities in natural history and ecology to Mackinder's eagle owl. Like Mackinder's eagle owl, the Eurasian eagle owl has been shown to be extremely adaptable to landscape changes and often lives in close proximity to human activities (Marchesi et al. 2002a). It generally inhabits a similar ecological niche in the more temperate zones. Both species are similar in size and appearance, with the Eurasian eagle owl being slightly larger (Konig et al. 1999). Both species also occupy similar habitat types, preferring rocky valleys and slopes often near human settlements, and they hunt in open areas. These owls feed primarily on small to medium-sized mammals, but exhibit a very catholic diet that includes many types of both vertebrate and invertebrate prey (Marchesi et al. 2002a; Papageorgiou et al. 1993). *B. bubo* is one of the most intensively studied owls in the world and though known mostly from Europe, studies of this owl provide a valuable basis for comparison with other eagle owl species throughout the world.

Like the Eurasian eagle owl, the Great horned owl *B. virginianus* has also been extensively studied throughout its range in the Americas. It is considered the geographical and ecological counterpart to the Eurasian eagle owl (Houston et al. 2007) and therefore similar in natural history and ecology to Mackinder's eagle owl.

4.3 *Population density and productivity*

Although Mackinder's eagle owls are not common throughout Kenya, this study has shown that they are capable of living at high population densities within suitable highland habitat. This population lived at extremely high density, about twice the density of another population in Kenya at approximately the same latitude (Sessions 1972) and 100-fold the density of a population in Zimbabwe (Gargett 1978). Although raptor pairs in less productive areas are generally spaced further apart than pairs in more productive areas (Hustler & Howells 1990), the Zimbabwe population was in a protected area and mean prey sizes were 1586 g compared to 585 g in this study. Therefore, the large difference in population density between pairs in Zimbabwe and this study may be related to the average size of prey species. Larger prey species live and breed less abundantly than smaller prey species (Newton 1979) and the differences in population density may be a reflection of this.

Population density is regulated by two important resources, breeding sites and food, whichever one is in shorter supply. Evidence that nest sites could limit breeding densities in birds of prey below the level that food would permit are of two types: 1) breeding pairs are scarce or absent in areas where nesting sites are scarce or absent, but which seem otherwise suitable; and 2) the provision of artificial nest sites is sometimes followed by an increase in breeding density (Newton 1979). Owl breeding sites within the study area were restricted to the availability of suitable cliffs, as all known nest sites were centred on a cliff or steep, rocky ground and few cliffs that did not contain breeding pairs were found. That this population nested almost exclusively on cliffs or steep, rocky ground is attributable to the close proximity of nest sites to human activities. Though many species of eagle owl may readily inhabit human-altered landscapes, they require breeding sites free from human interference to successfully raise young. The only nest site that was located on an accessible patch of open ground during this study did not produce fledglings during two successive attempts, although Mackinder's eagle owls have been shown to nest successfully and preferentially on the ground in areas relatively free from human interference (Sessions 1972). Further evidence that nest sites were limiting for this population is the existence of a surplus population that was unable to breed until one of the territory holders was removed. This occurred twice during the study when two successive females from the same nest site were killed by vehicle collisions and were replaced by 'floating' females after 82 and 27 days respectively. The females were presumed to be floaters and not females that moved from a neighbouring territory because most of the neighbouring territorial pairs were breeding at the time.

Table 16. compares breeding density, nearest neighbour distances and breeding success for four species of eagle owl. Breeding density was higher for Mackinder's eagle owls in Kenya than for Mackinder's eagle owls elsewhere or for other species' of eagle owl. Mackinder's eagle owl densities in Kenya were significantly higher than for Eurasian eagle owl or Great horned owl (ANOVA: $F_{1,4}=11.51$, $p = 0.001$; Bonferroni post-hoc; MEO vs. EEO, $p <0.001$, MEO vs. GHO, $p = 0.007$). This may be partially as a result of higher productivity levels in the tropics versus temperate latitudes. High breeding density resulted in low nearest neighbour distances for the Mackinder's eagle owl population in this study. Breeding success and productivity

measurements for Mackinder's eagle owls in this study were lower compared to most other eagle owl populations, but were closely related to the breeding success of eagle owls in disturbed habitats (Table 17). Disturbed habitats were related to human-interference, which is likely the highest at this study site than at any of the other sites, due to lifestyle differences in rural Kenya compared to more-developed nations. The majority of Kenyans earn their living directly from the land, usually through small-scale agriculture supplemented by raising livestock. This type of land-use means that you will find people almost everywhere at anytime amidst the rural Kenyan landscape.

Previous estimates of Mackinder's eagle owl productivity have only been reported by Gargett (1978). She reported owl reproductive success in terms of the number of young/pair/year and it was not possible based on her published data to deduce breeding success or the mean number of fledged young per territorial, breeding or successful pair. For seven owl pairs in a protected area in Zimbabwe, Gargett (1978) reported 10 owlets reared in 26 pair-years (the cumulative total of the number of breeding owl pairs added for the number of years of study) a reproductive success of 0.38 young/pair/year. The owls in this study produced 23 owlets in 31 pair-years, or 0.74 young/pair/year, thus almost double the productivity of the owls in the Zimbabwe study. The low productivity and population density of Mackinder's eagle owls in Zimbabwe suggests that the habitat in the Matopos is not optimal for these owls. One suggestion for low productivity in the Matopos is low rainfall (Tarr & Tarr 1991), which could negatively effect prey abundance, in comparison to Mackinder's eagle owl populations in Kenya where annual rainfall averages are higher (Table 18). Although my study site had only marginally more rainfall, some farms were irrigated, which artificially boosted primary production and likely lead to the increase of small mammals in farms compared to adjacent grassland habitats. Therefore, areas of high rainfall and elevation may be important factors for the success of this species, especially in unprotected areas. Another factor that could be limiting the Zimbabwe population is high predation rates. In the Matopos, owls and especially their eggs likely suffer greater predation rates due to the increased number of natural predators including mongoose, civet, genet and ground hornbill. In my study site only one species of mongoose and genet were known. However, owl mortality related to human causes is high at the study site and may offset any losses to natural predators that occur in Zimbabwe.

The high breeding density and relatively high productivity rates for this population raise a number of questions about the ecology of tropical systems. Specifically, do the ecological effects of agriculture play an increased role in tropical systems? This may occur because -- 1) agriculture is more intensive in the tropics as it occurs year-round and irrigation may magnify this, and 2) land adjacent to farms is more degraded from livestock, so farms become disproportionally productive habitats for those species that can adapt to intensive agriculture.

Table 16. Density, nearest neighbour distance (NND) and productivity for four species of eagle owl (adapted from: Marchesi et al. 2002a)

						Mean number of fledged young per			
Species	Country	Approximate Lat, Long[a]	Density[b] (n)	NND (km) (n)	Breeding success[c] (n)	Territorial pair (n)	Breeding pair (n)	Successful pair (n)	Reference
B. bubo	France	43°47'N, 004°51'E	16.00 (32)	1.4 (32)	74 (50)	1.44 (50)		1.95 (37)	Bergier and Badan 1979 in Marchesi et al. 2002a
B. bubo	France	43°48'N, 005°22'E	15.30 (59)	1.8 (59)	92 (347)		1.63 (347)	1.83 (306)	Penteriani et al. 2002 in Marchesi et al. 2002a
B. bubo	France	44°00'N, 003°30'E	0.44 (22)					1.89 (9)	Cochet 1985 in Marchesi et al. 2002a
B. bubo	France	43°17'N, 003°26'E	1.47 (25)		87 (107)	1.73 (107)		1.99 (93)	Defontaines & Ceret 1990 in Marchesi et al. 2002a
B. bubo	Germany		8.00 (8)	4.4 (36)			1.17 (98)	1.59 (37)	Mebs 1972 in Marchesi et al. 2002a
B. bubo	Spain	42°00'N, 002°30'E	5.71 (40)	2.4 (40)			2.04 (62)	2.30 (54)	Beneyto & Borau 1996 in Marchesi et al. 2002a
B. bubo	Spain	38°00'N, 001°30'W	2.00 (142)	4.6 (19)		1.70 (55)	2.90 (42)		Martinez et al. 1992 in Marchesi et al. 2002a
B. bubo	Austria	48°20'N, 015°45'E		2.4		0.99	1.30	2.00 (703)	Frey 1992 in Marchesi et al. 2002a
B. bubo	Switzerland	46°25'N, 010°00'E	0.92 (30)	6.5 (18)	92 (50)	1.32 (50)		1.80 (46)	Haller 1978 in Marchesi et al. 2002a
B. bubo	Sweden			8.5 (29)	40 (219)	0.60 (219)	0.90 (145)	1.60 (87)	Olsson 1979 in Marchesi et al. 2002a
B. bubo	Czech Rep.	49°30'N, 017°00'E	1.16 (50)	4.3 (81)	41 (231)	0.62 (231)	1.24 (115)	1.96 (73)	Kunstmuller 1996 in Marchesi et al. 2002a
B. bubo	Italy	46°04'N, 11°08'E	1.82 (24)	3.5 (169)	49 (160)	0.89 (160)	1.81 (21)	1.81 (79)	Marchesi et al 2002a
B. virginianus	USA		17.00 (12)		81 (28)		1.95 (28)	2.36 (24)	Data from Frank & Lutz 1997
B. virginianus	USA		8.02 (13)				1.28 (60)		Data from Adamcik et al. 1978
B. africanus	South Africa	24°57'S, 28°33'E	5.8 (2)						Mendelsohn 1989
B. c. mackinderi	Zimbabwe	20°20'S, 28°24'E	1.23 (8)	2.2 (8)					Gargett 1978
B. c. mackinderi	Kenya	00°33'S, 36°55'E	50.00 (10)[d]						Sessions 1972
B. c. mackinderi	Kenya	00°11'S, 04°48'E	114.94 (16)	1.0 (16)	48 (29)	0.60 (29)	0.92 (19)	1.25 (14)	This study

[a]National Geospatial-Intelligence Agency (2007)
[b]Number of pairs/100 km^2
[c]Percentage of territorial pairs raising at least one chick until fledging
[d]Estimation of territory size based on approximation of distances between land features and between nest sites

Table 17. Breeding success for three species of eagle owl in undisturbed vs. disturbed habitats

Species	Country	Breeding success[a] (n)	Habitat type	Reference
B. virginianus	USA	81 (28)	Grassland & wetland	Frank & Lutz 1997
B. bubo	Germany	53 (674)	Forest & agriculture	Dalbeck & Heg 2006
B. bubo	Italy	49 (160)	Woodland, cultivation, grassland, urban areas	Marchesi et al. 2002a
B.c. mackinderi	Kenya	48 (29)	Intensive agriculture	This study

[a]Percentage of territorial pairs raising at least one chick until fledging

Table 18. Average annual rainfall (mm) for Mackinder's eagle owl study sites

Country	Area	Rainfall	Reference
Kenya	Mau Narok	1000	Sessions 1972
Kenya	This study	752	This study
Zimbabwe	Matopos	630	Gargett 1978

4.4 *Nest site characteristics*

This unprotected Aberdare Highland population of Mackinder's eagle owls bred almost exclusively on cliffs or elevated rocky areas. Two attempts at nesting on the ground were unsuccessful. In Mau Narok, Kenya, Sessions (1972) found most of the pairs he studied nested on the ground and through his experiences concluded that Mackinder's eagle owl is by preference a ground-nester. Human interference in ground nests of unprotected populations may be causing adaptation toward exclusive use of cliff nesting sites. In this study, owls nested mid-way up cliffs, which offered protection from both people and goats from both above and below. In protected areas in southern African, the owls are known to breed on cliffs, rocks or on the ground in areas of open bare granite and well-wooded gullies (Gargett 1978; Steyn & Tredgold 1977). Cape eagle owls in South Africa are similarly ground-nesters, usually at the base of rocks in mountainous country, but are also known to nest on buildings in large cities (Fry et al. 1988; Grobler 1980). Spotted eagle owls nest in a wider-range of sites that include old trees, quarries, on the ground, in haystacks, nest boxes and on buildings (Tarboton & Erasmus 1998). Where spotted and Cape eagle owls occupy the same area, spotted eagle owls have generally nested at lower elevations than Cape eagle owls (Grobler 1980).

All nests and roosts in my study area were located in river valleys, but foraging occurred both in valleys and adjacent uplands, which had high levels of human activity. Apart from providing optimum nesting habitat, river valleys also offered a daytime refuge from human activities concentrated in upland areas. Although some river valleys had small numbers of remnant trees, the owls preferred open areas with few trees for nesting. Nest sites were located adjacent to farms, which provide for both open hunting and an abundance of prey. Human activities heavily impacted the area surrounding nest cliffs, but owls continued nesting as long as the nest site itself was free from disturbance. European eagle owls in Italy showed similar nest site preferences, nesting closer to villages and human-altered habitat than random sites (Marchesi et al. 2002a). Spotted and Cape eagle owls also tolerate high levels of human activity in the vicinity of their nest sites.

Sessions (1972) mentions that Mackinder's eagle owl nests were always within a stone's throw of water. Similarly all *B. b. ussuriensis* nests in Mongolia and *B. bengalensis* nests in Tamilnadu, India were located <50 m from water (R. Yosef, pers. comm., A. Arvind, pers. comm.). Nests in this study averaged 50 m from water. However, all nest cliffs were in river valleys. Therefore, nest sites located near water were likely a coincidence of the owls' nesting in river valleys, as opposed to any need for the owls to nest near water. In India, *B. bengalensis* nested in similar rocky valleys (A. Arvind, pers. comm.). Owls are not known to drink water, but obtain necessary fluids from their prey (Brown 1970). The freshwater crab was the only prey species that inhabits rivers and the owls rarely consumed it. However, given the diversity of eagle owl populations known to nest in close association to water, it may be more than a mere coincidence. One possibility is that riparian habitat provides better cover and food for owl prey, so that prey is disproportionally more abundant near water sources. Although nest sites in Zimbabwe were are only associated with water after heavy rains confined to the summer months (Gargett 1978), the Matopos area is not a productive area for Mackinder's eagle owls and perhaps the lack of permanent water contributed to its low productivity.

4.5 *Breeding seasonality*

This study showed breeding activity was concentrated after the rainy seasons. Given that most raptors breed only when food is most readily available (Newton 1979), breeding seasonality is likely linked to prey availability after the rainy seasons. Prey species such as multi-mammate rats exhibit reproductive seasonality that is strongly related to rainfall patterns (Leirs et al. 1994). Although prey productivity as measured by small mammal trapping did not consistently follow rainfall patterns (Fig 10), trapping was not done for larger, important prey species such as hares and large rodents. Figure 10. shows small mammals were most abundant in two years (2004 & 2006) following the April-May rains. In 2005, only a small increase in small mammal numbers followed periods of heavy rainfall. The reason for this is unclear, but may be as a result of regular irrigation in farms preferred by small mammals in this study. Leirs et al. (1994) found that breeding seasonality in multi-mammate rats may be triggered by new vegetation, which has a stimulatory effect on reproduction. In an irrigated system, new vegetation is constantly sprouting, whether it is the newly planted crop or opportunistic weeds. The supply of year-round water via irrigation may be altering reproductive cycles of resident species. Despite this, the owls may breed seasonally because prior to irrigation, small mammal populations showed breeding seasonality more closely related to rainfall patterns. Also, given the diversity of owl prey, other prey species that range outside of farms (eg. hares, large rodents, birds) may exhibit breeding seasonality related to rainfall patterns. Although there is no evidence for a breeding season for *Otomys* sp. and *Lepus saxatillis*, and too little information is known of the breeding season for *Lophiomys imhausi*, *Cricetomys gambianus* and *Procavia* sp. are seasonal breeders (Kingdon 1974c). *Tachyoryctes splendens* breeds during the rainy season (Kingdon 1974c).

Breeding attempts for Mackinder's eagle owl in Kenya are shown in Figure 14. Within Kenya, the species can be found breeding at any time during the year, but this is largely dependent on local rainfall patterns.

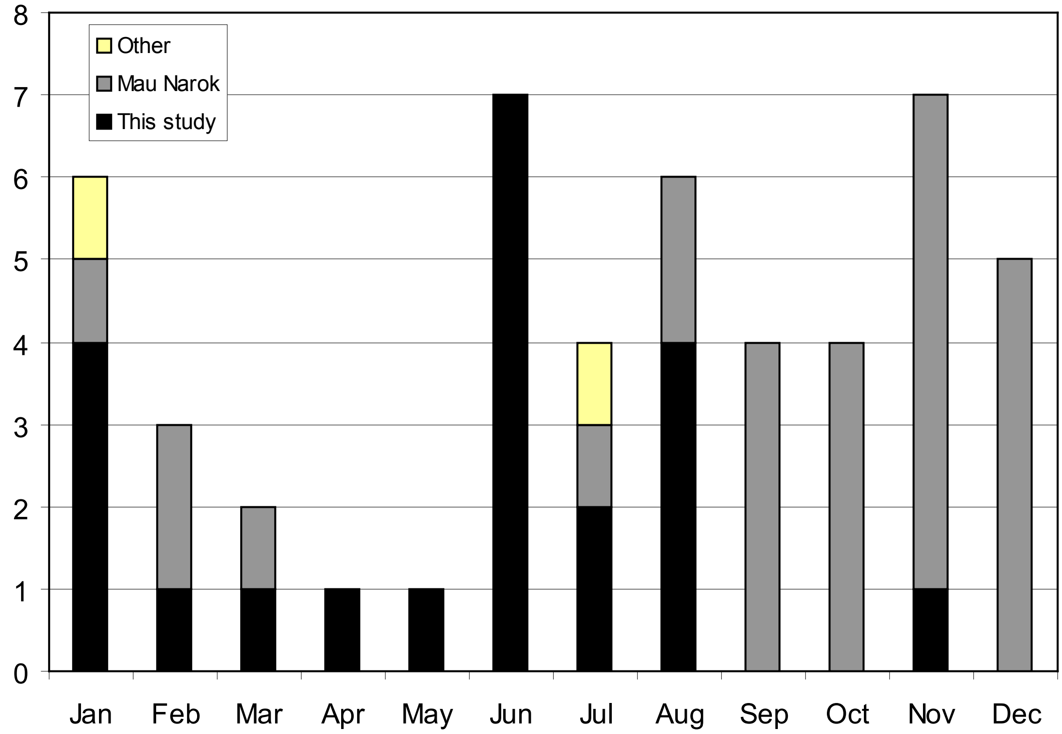


Figure 14. Mackinder's eagle owl breeding attempts in Kenya. Mau Narok is the population studied by Sessions (1972). Other refers to one attempt near Lake Elementaita (Taylor 1987) and one on Mt. Kenya (Praed & Grant 1952 in Sessions 1972).

Sessions (Sessions 1966) noted rainy periods in Mau Narok occur in Apr/May, heaviest in Jul/Aug and again in Nov/Dec. It follows that Mackinder's eagle owls in Kenya breed most often following rainy seasons when food is most available. In Zimbabwe, Mackinder's eagle owls breed during May-July, which follows the periods of heavy rain during the summer months of Nov-Apr (Gargett 1978; Steyn & Tredgold 1977; Tarr & Tarr 1991). Further, Tarr & Tarr (1991) noted that low rainfall in the Matobo Hills, Zimbabwe over a period of years had an influence on the decline in Mackinder's eagle owl breeding attempts.

4.6 *Breeding cycle*

Sessions (1972) noted a number of pairs showing a tendency to breed at 10-11 month intervals, which was rare during this study. The majority of owls in this study bred every other year. The reason for this difference may be related to prey productivity as influenced by rainfall amounts. Annual rainfall for Mau Narok was 1041 mm (Sessions 1966) compared to 751 mm for this study site. Prolonged parental care, as has been recorded for Crowned Eagles in Kenya (Brown 1970), can limit breeding to every second year. The period of parental care within a species can vary as Crowned Eagles in Kenya have been found to have a longer post-fledging period than in southern Africa. Crowned eagles in Kenya breed every second year, as opposed to every year in some pairs in southern Africa (Brown 1966 in Newton 1979; Fannin & Webb 1975 in Newton 1979). However, two pairs of Mackinder's eagle owls from this study did breed in consecutive years, so it is unlikely that the period of parental care is the reason for biennial breeding in this population.

4.7 *Population density and food*

Evidence for a link between density and food in areas where nest sites are not limiting is circumstantial, and based on the following: 1) an overall trend for large raptor species, which depend on large, sparse prey species to breed at lower density than small raptor species, which depend on small, numerous prey species; 2) regional differences in breeding density within species that are associated with regional differences in food; 3) annual fluctuations in food; and 4) sudden and long-term changes in breeding density that are associated with sudden and long-term changes in food (Newton 1979).

Regional differences in prey size are linked to differences in elevation, with Mackinder's eagle owl populations at the highest elevations taking the smallest prey and populations at the lowest elevations taking the largest prey. Presumably this trend could be linked to similar differences in breeding density, as larger prey is of higher energetic value to eagle owls than smaller prey. Penteriani et al. (2002) provides evidence for such a link between prey size and breeding density. They showed that eagle owl pairs with a diet based largely on high-value foods (i.e. rabbits and rats) bred earlier and produced large broods, showing an increase in breeding-effective numbers, even though the eagle owl is an opportunistic hunter with the highest degree of diversity and food-niche breadth value among owls (Penteriani et al. 2002). However, if this trend in prey size were linked to breeding density as suggested above, then it would be expected that Mackinder's eagle owls living at low elevation would have the highest breeding densities, i.e. populations in Zimbabwe should have the highest breeding densities if nest sites are not limiting. Gargett (1978) provided evidence that nest sites in Zimbabwe were not limiting when she mentioned searching 17 other possible nest sites without finding any breeding owls. Despite this, Mackinder's eagle owl densities in Zimbabwe were 100-fold lower than those in this study, suggesting that another external factor may be influencing owl densities in this study.

A recent study has shown that populations of the Eurasian eagle owl *B. bubo* living in relatively low-elevation, highly human-altered landscapes had higher densities, lower mean nearest neighbour distances and a similar mean number of fledged young per successful pair compared to populations in slightly human-altered landscapes (Marchesi et al. 2002a). Evidence from this study is suggestive of a possible similar trend for the Mackinder's eagle owl in Africa, whereby effects of human activities (i.e. farming on rodent numbers) are having a positive effect on owl breeding density and productivity, both of which were higher in this study than for the population in a protected area in Zimbabwe.

4.8 *Rodents and agriculture*

Human agricultural activities generally had a positive effect on rodent populations. Small mammal trapping results revealed that rodents were over 14 times more abundant in farms than in adjacent grassland habitat. That this trend persisted throughout almost 2 ½ years of trapping indicates the importance of irrigated farmland to increases in rodent abundances. Irrigation facilitates the growing of crops throughout the year, which are nutritious food sources for rodents and are likely a key factor in determining rodent numbers (Taylor & Green 1976). While rodent populations on farms responded positively to increases in rainfall, rodent populations in adjacent grasslands did not increase with increasing rainfall levels. This indicates that rodent populations in grasslands are being held at low levels and are unable to respond to seasonal changes in food abundance brought about by rainfall. Grassland areas were continually grazed by livestock, which can compete with rodents for food (Keesing 1998) and reduce vegetative cover (Saetnan & Skarpe 2006).

Small mammals were only trapped using Sherman traps, which biased results towards those species <120 g. Because of the diversity of owl diet, all prey species could not be sampled. Small mammals <120 g were chosen for sampling because they represented almost half of owl diet and they are relatively easy to sample compared to prey such as hares, which are best sampled at night.

A range of prey species including hares, giant rats, root rats, grooved-tooth rats and small rodents were important determinates of the diet composition of Mackinder's eagle owls. Small rodents accounted for almost half of the owls' diet and when their numbers increased, owls responded by consuming more of them, indicating the importance of farming activities to this population of owls. Farming activities, specifically the growing of certain crops, were linked to increases in two prey species in the owls' diet. An increase in the total hectares of maize, peas and carrots led to a corresponding increase in the numbers of multi-mammate rats and rock hyrax remains found in owl pellets. Presumably prey species are attracted to the easy food source offered by crops and move in relation to the distribution of maturing crops. Movements of *Mastomys erythroleucus* have been linked to maize crop phenology in the Kenyan Rift Valley (Odhiambo et al. 2005). The ability of owls to show a functional response to different farming practices illustrates the importance of human activities on community structure and especially predator-prey relationships in this agricultural system. Adaptation to intensive agriculture also reduces competition for food resources between owls and other predators, which are less adaptable to human disturbance. Known competitors to Mackinder's eagle owl in the study area were few but included black-tipped mongoose, genet, augur buzzard and African wood owl. Snakes also occurred but were only seen twice during the study period, so presumably their numbers were very low.

4.9 *Owl diet*

This population of Mackinder's eagle owls had a very catholic diet as is common for eagle owl populations worldwide. Unique to this population however, was the lack of specialization on one or two prey items as is widely mentioned in the literature on eagle owl diet and more so for Mackinder's eagle owls in particular (Brown 1970; Gargett & Grobler 1976; Marchesi et al. 2002a; Rodel et al. 2002; Sessions 1972). Gargett & Grobler (1976) reported Mackinder's eagle owl diet in the Matopos, Zimbabwe to be 99.4% mammals with the remaining <1% a combination of birds, invertebrates and reptiles. The majority of the prey (75%) consisted of two species, Natal red rock hare and hyrax (Fig. 15a). Mackinder's eagle owl diet on Mt. Kenya consisted of 97.4% mammals and <3% birds (Rodel et al. 2002). Groove-toothed rats comprised the majority of owl prey (Fig. 15b).

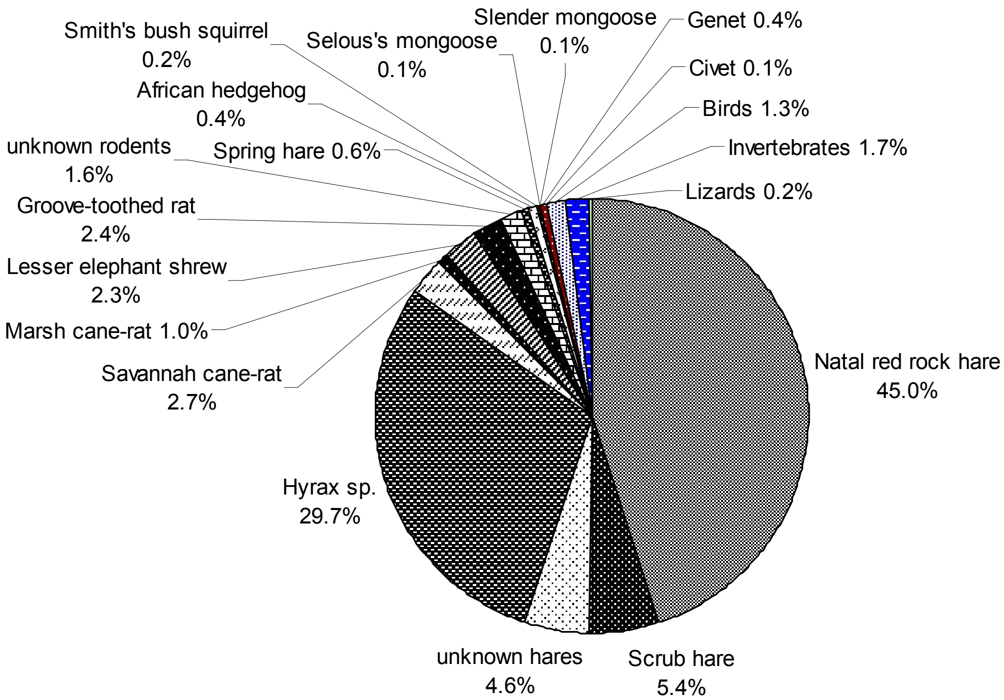


Figure 15a. Prey species composition for Mackinder's eagle owl pellets and skulls collected from breeding sites in the Matopos, Zimbabwe (Gargett & Grobler 1976). n = 925

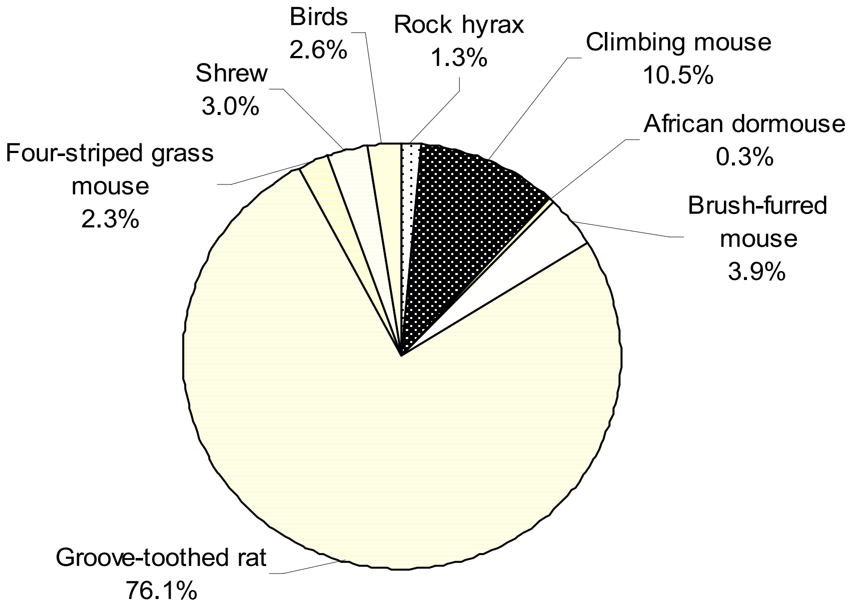


Figure 15b. Prey species composition for Mackinder's eagle owl pellets collected from four valleys on Mt. Kenya (Rodel et al. 2002). n = 305

Table 19. shows a comparison between diet breadth and human disturbance levels for 10 eagle owl studies. Diet breadth was positively related to human disturbance levels ($r^2 = 0.77$, $p < 0.001$).

Table 19. Habitat description, disturbance index and diet breadth as measured by Levin's index for three species of eagle owl. Disturbance based on relative measures as described for each study site (1 = little disturbance, 5 = high disturbance). Diet breadth values range from 1 to *n*, where *n* is the number of prey taxa in the diet.

Species	Diet breadth index *	Disturbance index	Habitat description	Reference
B. africanus	1.84	1	nature reserve	Dean 1978
B. africanus	2.27	1	desert vlei	Nel 1969
B. africanus	1.84	1	national park	Tilson & LeRoux 1983
B.c. mackinderi	2.32	1	national park	Tarr & Tarr 1991
B.c. mackinderi	2.95	1	national park	Gargett & Grobler, 1976
B.c. mackinderi	1.68	1	national park	Rodel et al 2002
B.c. capensis	6.31	2	private grasslands	Allan 1995
B. bubo	2.81	3	uncultivated & pasturelands	Hiraldo et al. 1975
B. bubo	6.79	4	woodland & cultivation	Marchesi et al 2002a
B.c. mackinderi	9.37	5	densely populated agricultural area	This study

* computed using mammal and bird prey only

These results support one of the predictions of optimal foraging theory that more productive environments have predators with more specialized diets, while patchy environments will have generalist predators (MacArthur & Pianka 1966). This is because predators in patchy environments (where prey abundance is lower) have to spend more time searching for prey and cannot afford to be choosy once they locate it, thus they tend to be generalists. The findings of this study support this prediction because the owls in this study inhabit a very patchy environment that is a mix of farms, villages and grassland areas interspersed with riverine woodland habitat. This is in contrast to studies of eagle owl diet undertaken in protected areas, where diet width is narrow and owls specialize on 1-2 prey species.

Diet and food availability are often closely linked with breeding rates or productivity. In the absence of human factors, much of the variation in the breeding rate of a species can be related to variation in food supply (Newton 1979). A lack of long-term data for this population precluded assessing the effects of food availability on breeding rates. However, there are a number of reasons to suspect that food availability had little influence on breeding rates for this population. Diet width was narrower in lower elevation territories, but there was no correlation between territory elevation and the number of fledglings produced as might be expected if food availability were affecting breeding rates. Food shortage is often a pre-disposing factor in nest desertions and other failures (Newton 1979), but in this population all nest desertions were known to be caused by either human interference or natural predation. The breeding success of this population (48%) is more likely to be influenced by direct and indirect human activity than by food limitation.

4.10 *Owl mortality*

The majority of owl injuries and mortalities were related directly or indirectly to human causes. Mortality related to human causes was a major consequence of the owls living adjacent to farms and other human activities and has been associated with increased risk of mortality in other species of eagle owl, notably the Eurasian eagle owl (Marchesi et al. 2002a; Martinez et al. 2006). Incidences of collisions with vehicles, while serious, involved only one owl territory and were not a serious threat to the larger population. Intentional and secondary poisonings of owls are the biggest threats to this population. The case of intentional poisoning was perpetrated by one family and involved one brood of three owl chicks, but it highlights the impact even a single malicious person can have on a small population like this. Nevertheless, the greatest threat to owls in this population is likely due to secondary poisoning, especially as more land in marginal areas is cleared for farming and farmers increasingly use desperate, ill-advised tactics to produce a profitable harvest. Increasingly this involves the use of highly toxic pesticides to kill mousebirds and rodents that consume many different types of farm crops. Owls are poisoned when feeding on debilitated and dying individuals. During interviews, pests were identified as the biggest threat that farmers faced. Farmers specifically identified mousebirds, weaver birds and small rodents as the most problematic vertebrate pests and pesticides were the second most-common form of control measure for rodents. The use of chemical control measures was very common, although mostly for insect pests, and this attests to their easy availability in shops in rural areas. However, a few farmers we interviewed told us that they no longer use chemicals to kill vertebrate pests due to a number of reasons including:

1. Secondary poisoning of young boys herding livestock who unknowingly ate a tomato laced with pesticide
2. Cost of pesticide relative to hiring a young boy to chase pests away
3. Lack of effect because pesticide is only applied to a small number of fruits and pests can still attach untreated fruits

Observation of farming practices during fieldwork led to the conclusion that chemical controls for vertebrate pests are not a cost-effective means of pest control. A lack of knowledge of simple, yet cost-effective control measures led farmers to use chemicals in lieu of adopting better farm management practices. Farmer education on alternative forms of pest control would greatly benefit the local owl population. The effectiveness of farmer education in protecting the owl population was evident from the results of field interviews.

Educating farmers about owls was initiated by project assistant, Paul Muriithi many years prior to the start of the study. Farmer interviews showed that by knowing Paul, farmers were significantly more likely to know about owls and their prey, and those who knew what owls eat were significantly more likely to answer that owls were ‘good’ for them as farmers. This finding shows the significant impact one person can have when it comes to conservation education. Additionally, while the negative beliefs about owls are based on culturally transmitted superstitions, these results show that strong cultural traditions can be overcome through education.

CHAPTER 5: CONCLUSIONS

Though Mackinder's eagle owl is mostly known from small, protected populations within its scattered range, this study has shown that it is highly adaptable to anthropomorphic landscape changes and capable of living at high population densities within suitable habitat. This owl is very successful in exploiting habitats where few other large avian predators can maintain a viable breeding population. This is largely due to its adaptability as a food generalist that enables it to exploit a wide variety of prey items none of which are numerous due to the fragmented habitat in which they exist. In this sense, Mackinder's eagle owl is behaviourally and ecologically very similar to some populations of the Eurasian eagle owl.

In general, farming practices have benefited this population. Land clearance for agriculture has increased the foraging habitat available to Mackinder's eagle owls in this highland area. Compared to grassland areas, agricultural areas have higher rodent abundances and this has provided a prey base for the owls. However, human activities including pesticide use, vehicle traffic and illegal trade in owls are significant threats to this population. Human cultural prejudices against owls remain the biggest threat to this population's long-term persistence, but education can play a significant role in overcoming these negative beliefs about owls.

Although the stability of this population cannot be fully assessed without additional long-term data, an initial assessment based upon almost three years of breeding and mortality records suggests that the population is stable, possibly even increasing and is naturally limited only by availability of suitable cliffs for nesting. Due to the close proximity of owl territories to farming activities, the long-term stability of this population is closely linked to the education and attitudes of local farmers. Initial assessments of farmers' attitudes towards the owls show that with education, cultural taboos that encourage the killing of owls can be overcome. However, the small size of this population, its density, and proximity to human habitation renders it vulnerable to adverse conditions and human attitudes. At present the most likely threat to this population is through poisoning of farm pests that are also owl prey and this can best be averted through farmer education.

While this study only examined a small population of Mackinder's eagle owls in Kenya, some general conclusions about the long-term conservation of this species throughout Kenya can be drawn based on the findings of this study and the author's knowledge of other Mackinder's eagle owl populations in Kenya.

There is little reason to suspect that the long-term conservation of Mackinder's eagle owls in Kenya is under threat. There are two main reasons for this. First, the majority of the populations of this species in Kenya are known from highland areas, many of which are protected as national parks (e.g. Mt. Kenya, Aberdares, Mt. Elgon, Hell's Gate). This virtually eliminates the owls' greatest threat, that of human persecution. There are no known incidences of die-off of owls from these populations, so the threat of disease is currently unlikely. The second main reason for a lack of threat to these owls in Kenya is their adaptability to human-altered environments, which means that there will probably always be small, isolated populations existing outside protected areas. However, the long-term stability of these populations is more in doubt and is particularly susceptible to the attitudes of the local human population. It should be noted that the relatively tolerant attitudes of farmers towards owls interviewed during this study are quite unusual for Kenya and should not be construed as being the norm for farmers in other areas. Currently many of the populations outside protected areas exist on large-privately owned farms near the base of Mt. Kenya and the Aberdare Mountains and are therefore under little threat from humans. Unprotected populations are increasingly at risk from the pet trade, as chicks from these populations have been sold by the roadside as pets, most notably near Naivasha (C. Campbell-Clause, pers. comm.).

Finally, it should be noted that owls remain one of the most-threatened groups of birds in Kenya due to negative cultural beliefs about them. Therefore, conservation policy decisions should take this into account when assessing threats to owl populations. However, based on the results of this study, there appears to be no need to upgrade the protection status for the Mackinder's eagle owl in Kenya at this time.

CHAPTER 6: RECOMMENDATIONS

6.1 *Education*

Conservation education can go a long way in demystifying cultural taboos and would greatly benefit populations of this species and other owls living outside protected areas. In addition, educating farmers on good agricultural practices would be a win-win situation for both farmers and owls. Agricultural practices that focus on cost-effective means of boosting harvests without polluting the environment could have many positive effects for owls co-existing closely with humans.

6.2 *Further research*

Further research on this species in Kenya and throughout Africa should assess various aspects of this species' population ecology. Including,

1) Breeding rates in different habitat types. This information could then be used to predict the vulnerability of populations to various forms of land use.

2) Study of movement patterns and home range sizes. This would allow for a more thorough assessment of population sizes.

Additional funding that would enable this study to resume, would give much better insights into the long-term threats to the conservation of owls in agricultural areas. Likewise, a comparative study within Kenya between protected and unprotected habitats would be the best way to assess population threats.

There is also a need to assess the best survey methods for this species in protected areas. Although initial results of call-playback surveys were not encouraging, additional testing of this method should be undertaken because if most of these owls are ground-nesters in protected areas in Kenya, visual surveys to detect owl numbers would be extremely difficult. Finally, taxonomic and morphological study of the three *B. capensis* subspecies should be undertaken to assess their species-level status.

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Appendix 1. Farmer interview questions

1. How many years have you farmed this farm? What was the land like before you started farming it? (farm, bush, grassland)

2. What is the biggest problem you face with your farm? (low prices for crops, drought, pests, lack of transport, poor soils, input costs)

3. Which animal pests do you face? (insects, mammals, birds)

The following questions were asked for 6 known crop pests; root rats, giant rat, small rats, rabbits, weaver birds and mousebirds

Do you know it?
Have you seen it in your farm?
If yes, how often (not often, often, very often)
What is it that's in the farm that this animal is interested in?
Are there certain seasons that this pest is worse/better?
How do you deal with this animal if you find it in your farm?

4. Do you use any farm chemicals to control pests or have you in the past? If so, which ones and for controlling which pests?

5. How often do you water your farm?

6. Do you know about the owls that live around here? Seen or heard them? Do you know what they are eating?

7. Do you know Paul? What do you think about his work with owls?

8. What does your community believe about owls? What do you think about owls?

9. Do you think the presence of owls is good or bad for you? Why?