Habitat use of Long-crested Eagles in human-modified Landscapes of KwaZulu-Natal, South Africa

Machawe I. Maphalala

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INYUVESI YAKWAZULU-NATALI

ABSTRACT

Loss of natural habitats due to land use change is threatening biodiversity globally, a cause for concern given the resulting loss of essential ecosystem services. Conservation of biodiversity within human-modified landscapes has become a necessity to halt further loss of biodiversity. The Long-crested Eagle *Lophaetus occipitalis* is an example of a species that can be managed within human-modified landscapes because it occurs in such landscapes, and the protection of its habitat may benefit other species that use the same habitats. The present study aimed to quantify the habitat use of Long-crested Eagles in human-modified landscapes of KwaZulu-Natal Province, South Africa, at various spatial scales and to make recommendations for the conservation of this species in such environments. Biodiversity in KwaZulu-Natal is threatened by anthropogenic activities that include agriculture, timber plantations and built environment.

Between August 2016 and September 2017, twelve Long-crested Eagle adults were tagged with geographic positioning system (GPS) transmitters in the KwaZulu-Natal Province. Telemetry data from the tagged eagles were used to estimate sizes of home ranges and habitat selection within home ranges. Home ranges of males and females were 420 ± 180 ha (n = 5) and 315 ± 161 ha (n = 4), respectively, using the kernel density estimator method (h_{ref} 95%), and were not significantly different, suggesting similar ranging behaviour between sexes. The home range size of the eagles was relatively smaller than estimates reported from other parts of South Africa which may be an indication of high quality habitats for the species in KwaZulu-Natal Province. Home ranges in rural environments predominantly comprised of cropland (33%) and savanna (22%), whereas in suburban environments they comprised of settlements (34%) and exotic tree plantations (23%). In rural and suburban landscapes, the eagles positively selected for natural patches such as wetlands, natural forest, natural forest edge and savanna but avoided

exotic tree plantations. Long-crested Eagles nested and roosted in the natural forests available within their home ranges.

Road surveys were used to determine land cover variables associated with Long-crested Eagle site occupancy at the landscape scale. 'Cropland' was the only land cover variable associated with occupancy and was positively associated with the area of cropland ($\beta = 4.71 \pm 2.28$). Such results suggest that the apparent increase in abundance of Long-crested Eagles may be partly attributed to increase in cropland area. Although the influence of natural habitats was not significant at the landscape scale, it is less likely that the eagles selected territories based on the amount of cropland alone because they also needed nesting sites in addition to foraging habitats. Overall, Long-crested Eagles appear to be using edges of cultivated fields that have natural vegetation and hunting perches, and thus gaining improved access to prey. Natural patches of habitat add to the heterogeneity of agricultural landscapes making them more suitable for this species, as supported by the habitat preference observed within home ranges results. Wildlife friendly management of farms whereby natural habitats are retained appears to benefit Long-crested Eagles in agricultural landscapes.

Admission records from a specialist raptor rehabilitation centre in Pietermaritzburg were examined to identify common threats facing raptors in KwaZulu-Natal and determine factors that could be used to predict the outcome of rehabilitation. The major causes of admission to the rehabilitation centre were collision related injuries (52.1%), grounded birds (11.6%) and orphaned chicks (9.5%). Only the variable 'reason for admission' was a significant predictor of the outcome of rehabilitation. Raptors with no severe injuries such as orphaned chicks and grounded birds were more likely to have successful rehabilitation treatment than raptors suffering from collision injuries. In cases where triage is necessary, rehabilitation centres can make such decisions based on the nature of the injuries as this study has demonstrated that birds suffering from collision injuries were less likely to have successful rehabilitation.

In the wake of rapidly changing environments, conservation of biodiversity should not be left to protected areas alone, instead people should work together to make human-modified landscapes more habitable to wildlife. The presence of Long-crested Eagles on private properties should be an inspiration to do more to conserve wildlife.

PREFACE

The data described in this thesis were collected in KwaZulu-Natal, Republic of South Africa from February 2016 to June 2019. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Prof. Colleen T. Downs and co-supervisors, Prof. Ara Monadjem and Dr Keith L. Bildstein.

This thesis, submitted for the degree of Doctor of Philosophy in Science in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, School of Life Sciences, Pietermaritzburg campus, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

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Machawe I. Maphalala

July 2019

I certify that the above statement is correct and as the candidate's supervisor I have approved this thesis for submission.

…………………………..

Professor Colleen T. Downs
Supervisor
July 2019

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DECLARATION 1 - PLAGIARISM

I, Machawe Innocent Maphalala, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis.

Publication 1

Maphalala, M.I., Monadjem A., Bildstein K.L., McPherson S., Hoffman B. and Downs C.T. In prep. Ranging behaviour of Long-crested Eagles (*Lophaetus occipitalis*) in human-modified landscapes, South Africa

Author contributions:

MIM conceived paper with AM, KLB, SM, BH and CTD. MIM collected and analysed data, and wrote the paper. AM, KLB, SM, BH and CTD contributed valuable comments to the manuscript.

Publication 2

Maphalala, M.I., Monadjem A., Bildstein K.L., McPherson S., Hoffman B. and Downs C.T. In prep. Importance of native habitat patches for the persistence of Long-crested Eagles in human-modified landscapes.

Author contributions:

MIM conceived paper with AM, KLB, SM, BH and CTD. MIM collected and analysed data, and wrote the paper. AM, KLB, SM, BH and CTD contributed valuable comments to the manuscript.

Publication 3

Maphalala, M.I., Monadjem A., Bildstein K.L. and Downs C.T. In prep. Influence of anthropogenic land use changes on the occupancy of Long-crested Eagles in an agricultural-urban landscape mosaic

Author contributions:

MIM conceived paper with AM, KLB and CTD. MIM collected and analysed data, and wrote the paper. AM, KLB and CTD contributed valuable comments to the manuscript.

Publication 4

Maphalala, M.I., Monadjem A., Bildstein K.L., Hoffman B. and Downs C.T. In prep. Causes of admission to a raptor rehabilitation centre and factors that can be used to predict likelihood of release.

Author contributions:

MIM conceived paper with AM, KLB and CTD. MIM collected and analysed data, and wrote the paper. AM, KLB, BH and CTD contributed valuable comments to the manuscript.

Signed: ………………………………………………

Machawe I. Maphalala

July 2019

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I am very grateful for the privileged opportunity I have had for the past three and half years of living and studying in KwaZulu-Natal, I couldn't have picked better place to do this work! Therefore, I want to acknowledge God who made every circumstance and situation to lead to me being here (University of KwaZulu-Natal, (UKZN)), I realise that it was all on purpose. I would like to express my heartfelt gratitude to my main supervisor, Prof Colleen Downs, who welcomed me to her lab and provided all the support I needed to learn and grow. Thank you very much to my supervisor Prof Ara Monadjem who has trained me from my early years as an undergraduate student until now. Hawk Mountain Sanctuary will forever be dear to me, a place that fuelled my passion for raptors! From there came one of my supervisors, Dr Keith Bildstein who supported me even before we met face to face, thank you very much. I am very grateful to National Research Foundation, South Africa, UKZN and Hawk Mountain Sanctuary, USA, in collaboration with the Sperry Fund for sponsoring this work.

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CHAPTER 1

INTRODUCTION

1.1 Background

There is a growing consensus that protected areas alone cannot sufficiently conserve all biodiversity and that conservation within human-modified landscapes has not been explored enough (Chazdon et al. 2009; Ellis 2013; Kremen and Merenlender 2018). While conservation in protected areas is still essential, ignoring biodiversity loss in human-modified landscapes results in loss of essential ecosystem services (Perrings et al. 2006). Landscapes outside protected areas can be managed in such a way that they complement protected areas through the use of biodiversity-based techniques such as agroecological farming and ecosystem-based forest management (Kremen and Merenlender 2018). Instead of just focussing on only large, high quality and well-connected patches of natural vegetation in urban areas, urban conservation must also value small spaces, recognise unconventional habitats and use science to minimise the impacts of future urban development (Soanes et al. 2019). In short, every conservation opportunity in human-modified landscapes should be utilised if biodiversity conservation goals are to be achieved.

The use of human-modified habitats by raptors is becoming an important research subject to raptor biologists and conservationists. Partly this growing interest is due to the realisation that modified landscapes hold significant avian diversity, and that in reality not all biodiversity rich areas can be conserved as protected areas (Petit et al. 1999). Urbanised landscapes, which are extremely modified, and agricultural landscapes (modified to a lesser extent) are inhabited by a number of raptor species around the world. More studies are emerging that describe the adaptation strategies of raptors to human-modified habitats (Table 1.1). These studies highlight the importance of natural vegetation, heterogeneity and behavioural adaptability of the raptor species to novel resources (Table 1.1). Behavioural adaptability allows raptors to move into transformed areas that are suitable to them or persist in changing habitats (Dykstra 2018). Maintaining natural vegetation in human transformed environments enhances the availability of nesting sites for ground nesting raptors (Alves et al. 2014) and those that avoid using human structures for nesting such as Cooper's Hawks (*Accipiter cooperii*) (Stout and Rosenfield 2010). Natural grasslands have also been shown to be important foraging habitats for Lesser Spotted Eagles (*Clanga pomarina*) breeding in agricultural landscapes (Väli et al. 2017). Human-modified landscapes can be made more habitable to raptors (and biodiversity in general) under informed management practices.

Humans have a long history of persecuting birds of prey (Newton 1979). That said, only some humans have come to appreciate their role in the ecosystem, some of which benefit humans directly or indirectly. Because of their position at the top of the food chain, raptors are susceptible to environmental contaminants and therefore can be used as indicators of environmental health (Gómez-Ramírez et al. 2014; Movalli et al. 2018; Slabe et al. 2019). A well-known example is the severe decline of raptors because of the effects of dichlorodiphenyltrichloroethane (DDT) leading to collaborative efforts to ban its use in many countries (Newton 1979). Biomonitoring using raptors continues to date and contaminants being monitored include organochlorine compounds and heavy metal such as cadmium, zinc and lead (Pérez-López et al. 2008; Gómez-Ramírez et al. 2014; Garcia-Heras et al. 2018; Krüger and Amar 2018). Humans also benefit greatly from the scavenging behaviour of vultures which prevents the spread of diseases amongst facultative scavengers and eventually humans

(Markandya et al. 2008; Ogada et al. 2012a). In fact, a study in East Africa has shown that in absence of vultures (obligate scavengers), carcasses stay longer in the environment, increasing the chance of spreading diseases (Ogada et al. 2012b). Indeed, the decline of vultures in India as a result of diclofenac poisoning (Green et al. 2004; Oaks et al. 2004), was accompanied by an increase in the population of feral dogs (*Canis lupus familiaris*) which are a major source of rabies for humans (Markandya et al. 2008). Raptors also prey on many pest species and may therefore potentially be used to supress such pests (Vibe-Petersen et al. 2006; Paz et al. 2013; Donázar et al. 2016).

1.2 Raptors in human-modified landscapes: behavioural adaptations

Research on raptors in human-modified landscapes in North America and Africa has been dominated by urban and suburban studies in recent years and accipiters are the most studied group in these urbanised environments (Table 1.1). In the European continent there are disproportionately more farmland studies than urban raptor studies. Overall, a majority of the studies of raptors in human landscapes have been conducted in Europe (44%) and North America (26%), followed by Africa (21%) (Table 1.1).

1.2.1 Agricultural landscapes

Agricultural landscapes are mosaics of different land uses such as cultivated areas, tree plantations, pastures, human settlements, roads and patches of natural or semi-natural vegetation (Bennett et al. 2006). Farmland studies have shown that heterogeneous agricultural landscapes have a greater capacity to host more biodiversity than homogeneous landscapes including some raptor species (Anderson 2001; Benton et al. 2003; Michel et al. 2017). Agricultural areas may have abundant temporal food resource for rodent hunting raptors (Buij et al. 2013; Bobowski et al. 2014). The availability of hunting perches in agricultural areas (such as utility poles, utility poles crossbeams, utility wires and trees/shrubs) improves prey access for raptors through low energy demanding sit and wait foraging strategy (Meunier et al. 2000; Sheffield et al. 2001; Bobowski et al. 2014). Common Kestrels (*Falco tinnunculus*) and Long-eared Owls (*Asio otus*) appear to benefit from farmland management practices that maintain natural strips of vegetation together with freshly mown grasslands which increase prey visibility and accessibility (Aschwanden et al. 2005). For raptors, prey accessibility may have greater influence on habitat use than prey density (Arlettaz et al. 2010). Thus, the moderate clearing of dense vegetation in agricultural areas benefits open space foragers (Buij et al. 2014).

In agriculturally transformed habitats some raptors have more diverse diets than in natural areas, for example the Verreaux's Eagle (*Aquila verreauxii*) in Western Cape, South Africa (Murgatroyd et al. 2016a). Cardador et al. (2012) also observed that in areas of intense agriculture, Marsh Harriers (*Circus aeruginosus*) took higher percentage of small mammal prey and progressively increased their provisioning rates at nests whereas in the more natural area they switched to larger prey late in the season. Manmade structures such as abandoned buildings, nest boxes, bridges, metal pipes in fences and pylons can attract raptors to agricultural landscapes where nesting sites were limiting (Mainwaring 2015; Grande et al. 2018). A significant population of Martial Eagles (*Polemaetus bellicosus*) in South Africa nests in electricity pylons which suggests that the eagles perceive them as optimal nesting structures in such environments (Machange et al. 2005).

1.2.2 Urban landscapes

Urban landscapes can be considered as fragmented mosaics of industrial, residential and recreational areas and patches of natural vegetation (Dykstra 2018). For raptors, these environments have been described to have less predation pressure (Chace and Walsh 2006; Rebolo-Ifrán et al. 2017; Solaro 2018). Urban environments bring novel food and nesting resources for adaptable predators (Fleming and Bateman 2018). Human-provided food in urban (which includes suburban habitats hereafter unless otherwise stated) is thought to induce early laying in passerines because of improved body conditions of adults prior to laying (Chamberlain et al. 2009). Early nesting has also been recorded in urban raptors such as Cooper's Hawk (*Accipiter cooperii*), Crested Goshawk (*A. trivirgatus*) and Eurasian Kestrel (*Falco tinnunculus*), and it is likely to have been induced by the year-round availability of their avian prey (Boal and Mannan 1999; Sumasgutner et al. 2014b; Lin et al. 2015).

The human-provided food in urban areas attracts a lot of avian prey which in turn attracts raptors (Boal and Mannan 1999). As an adaptation to breeding in city centres, urban Eurasian Kestrels increased the amount of avian prey in their diet more than those breeding in less urbanised areas or suburbs (Sumasgutner et al. 2013). The diet of Crowned Eagles (*Stephanoaetus coronatus*) in the urban landscapes of KwaZulu-Natal consisted of significantly more avian prey than previously reported in more natural landscapes (McPherson et al. 2016a,b). The diet of Crowned Eagles nesting within patches of natural forests were found to consist of mainly mammals in north-eastern South Africa (Swatridge et al. 2014). Urban raptors also take advantage of nesting opportunities in nest boxes, ledges of buildings and other anthropogenic structures (Altwegg et al. 2014; Sumasgutner et al. 2014a). Tolerance to human presence is another trait that allows some raptors to occur in urban environments. In general, raptors in urbanised landscapes have less fear of humans than their counterparts in natural or rural areas (Solaro 2018). This is shown in the shorter flight initiation distance in urban areas (Díaz et al. 2013).

1.2.3 Consequences of raptors for living in human landscapes

Although some raptors species are considered to have adapted to living in close proximity to humans, such environments come with costs that may threaten their persistence (Marchesi et al. 2002). Some of these human-dominated habitats are not the high quality habitats they appear to be because the raptors that select them have reduced breeding success. Eurasian Kestrels breed in high densities in the city of Vienna possibly because of high availability of nesting sites in historic buildings (Sumasgutner et al. 2014b). However, these birds suffer high nest failure rates in the city centre because of the lack of their preferred mammal prey (Sumasgutner et al. 2014a, b). High nest failure rate was also observed in urban breeding Cooper’s Hawks which was due to high nestling mortality from trichomoniasis infection (Boal and Mannan 1999), because of feeding upon infected avian prey (Boal and Mannan 1999). Thus, attractive urban environments, from the perspective of high food supply, may become an ecological trap (Boal and Mannan 1999).

Human-dominated habitats are associated with anthropogenic related threats such as collisions (e.g. vehicular and window) and electrocutions on powerlines (Hager 2009; Thompson et al. 2013; Šálek et al. 2019). Raptors living in close proximity with humans are often in conflict with property owners who may be protecting their domestic stock or pets (McPherson et al. 2016a). Birds of prey are often persecuted in areas where they are perceived as predators of livestock or as competition for hunters of game (Donázar et al. 2016; Grande et al. 2018). Although urban areas have been described as areas of low persecution for raptors (Chace and Walsh 2006), illegal shooting of raptors still does take place and pose a serious threat (Cianchetti-Benedetti et al. 2016). Furthermore, farmland raptors may also get poisoned through the use of agricultural pesticides (Hughes et al. 2013; Grande et al. 2018). Poisoned carcasses in farms that were intended for mammalian carnivores also kills vultures and other scavenging raptors in Africa (Ogada 2014). Regardless of the human related threats in human-modified landscapes, some species appear to be doing well in these environments.

1.3 Study species

Figure 1.1. One of the Long-crested Eagles tagged for the study, photographed near Pietermaritzburg, South Africa. Photo: Machawe I. Maphalala, 2017

1.3.1 Description

The Long-crested Eagle (*Lophaetus occipitalis*) is an example of a species that is associated with human-modified habitats, and unlike many other raptors with populations that are declining in such environments, the population of this species is thought to be increasing (Ferguson-Lees and Christie 2001; BirdLife International 2016). It occurs in well-watered African savannas and secondary forests, from Senegal east to Ethiopia and southwards to Eastern Cape Province but rare in the drier western parts of Southern Africa (Brown et al. 1982) (Fig. 1.1, 1.2). Its global population is estimated to be in the upper tens of thousands (Ferguson-Lees and Christie 2001). Preferred habitats include woodland, forest edge and marshy areas with good lookout posts (Ferguson-Lees and Christie 2001; Oberprieler 2012). It usually perches prominently on trees, telephone or fence posts which are used to scout for prey in its hunting territory and most of its prey is caught on the ground and swallowed whole except for large prey (Ferguson-Lees and Christie 2001; Johnson 2005). Categories of prey taken are mammals, birds, reptiles, amphibians and insects but the most prevalent are small mammals especially vlei rat (*Otomys* spp.) (Steyn 1983; Ferguson-Lees and Christie 2001; Johnson 2005).

Adults and juveniles are similar in appearance, but juveniles may have shorter crests (Johnson 2005). The Long-crested Eagle is easy to distinguish from other eagles because of its long floppy crest feathers which are visible when perched and when in flight it shows white windows on its primaries and some black and white barring on its tail. General plumage colour is black or dark brown with predominantly white or brownish to black leggings. Both sexes look alike but generally birds with white feathers on their legs are thought to be males and those with darker feathers females (Hall 1991; Ferguson-Lees and Christie 2001).

1.3.2 Breeding

This species uses tall trees for nesting, including exotic trees, and the nests are placed on lateral branches or the main fork 7-45 m above ground (Ferguson-Lees and Christie 2001). Nesting trees could be located on the edge of a forest clump or plantation and more recently *Eucalyptus* trees are the most preferred (Steyn 1983). The breeding season of the Long-crested Eagle is not well defined like other raptors and may be influenced by prey availability but, at least in South

Africa, egg laying has been recorded mainly in the summer months with a peak in August-October (Johnson 2005). Pairs may make more than one breeding attempt even if the first attempt was successful (Hall 1992). Although they frequently construct new nests and may change nests often, they stay in the same general area. One or two eggs are laid at intervals of 2-3 days or longer and incubation takes 42 days. Males do most of the hunting and bring prey back to the females, which incubate most of the time (Steyn 1978; Hall 1979). Once the chick is well feathered the female assists with the hunting and food is brought in the crop (may also be carried in the bill or talons) and is regurgitated on to the nest, torn up for the young until they can feed on their own (Hall 1979). Territory sizes may vary according to local conditions, Long-crested Eagles however, are not aggressive towards their own species or other raptor species and have nested close to yellow-billed kites, *Milvus parasitus* (O'Donoghue 2002).

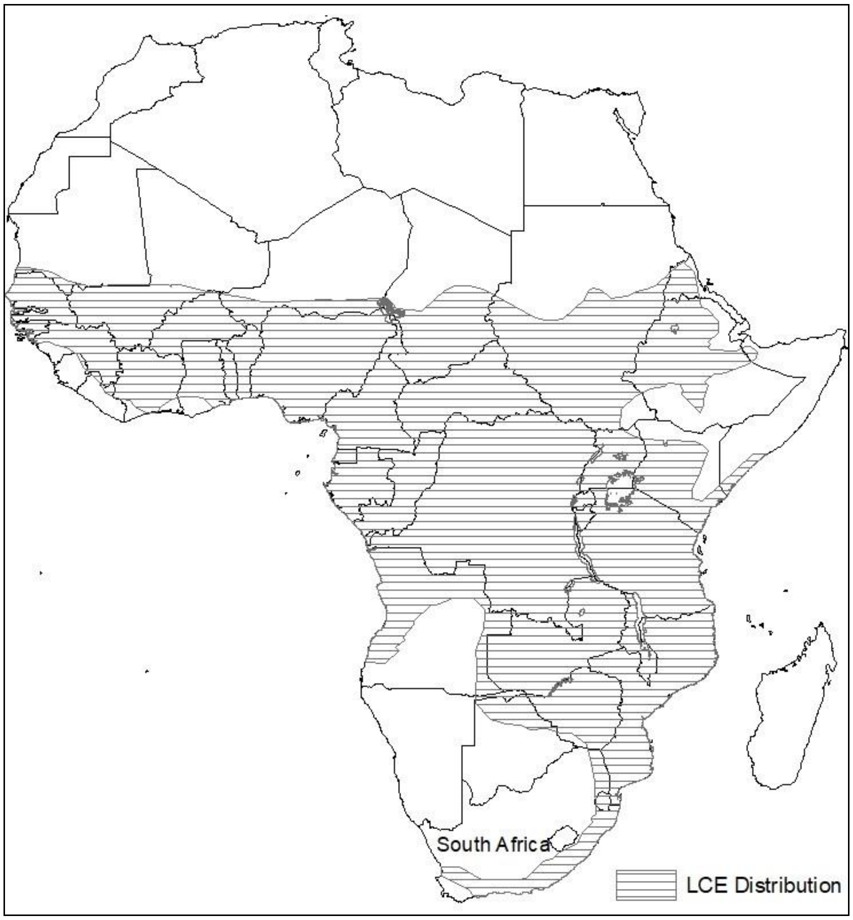

Figure 1.2. Long-crested Eagle range in Africa. Data sourced from IUCN website https://www.iucnredlist.org

1.4 Study area

The study area covered an area of about 10 500 km^2 and was located within KwaZulu-Natal Province, South Africa (Fig. 1.3). This province is located between latitudes 26^o S and 32^o S, and between longitudes 28^o E and 33^o E, (Fig. 1.3). The KwaZulu-Natal landscape consists of portions of grassland, savanna and Indian Ocean coastal belt biomes (Mucina and Rutherford 2006), and the most dominant land use is agriculture (sugar cane, orchards, commercial and subsistence crops and timber plantations or agroforestry) (Jewitt et al. 2015). The population of KwaZulu-Natal is the second largest in the country with 11.38 M people in 2018 (Statistics

South Africa 2018). This biodiversity rich province is experiencing loss of natural habitat due to anthropogenic transformation of the landscape (Jewitt et al. 2015).

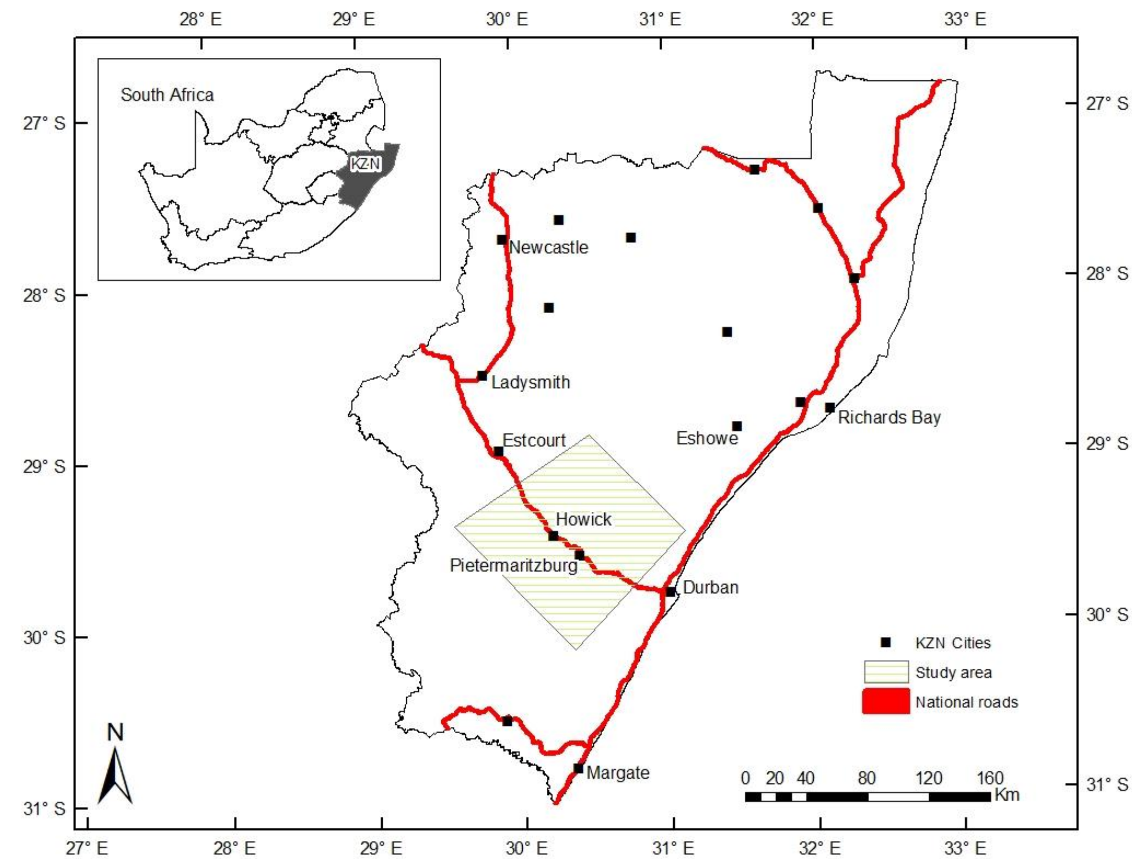

Figure 1.3. Location of the study area in the Midlands of KwaZulu-Natal (KZN) Province, South Africa. Insert: Location of KZN Province within South Africa.

1.5 Motivation of the study

While pristine habitats for wildlife are decreasing globally, human-modified habitats are on the increase (Boal 2018). Since these habitats are increasing at the expense of natural habitats, questions arise as to what would happen to the species that were originally using the area being transformed? More specifically, as the density of buildings and other humam infrastructure increase, will the birds continue to use the same territories and rely on remnants of natural patches or will they abandon their territories and move away from human residential areas? The answer to these questions will depend on the adaptability of the species under consideration. Because of their requirements for large high quality habitats and association with high biodiversity (Newton 1979; Sergio et al. 2005), raptors can be useful indicators of suitability of human-modified landscapes for wildlife. For example, Martial Eagles (*Polemaetus Bellicosus*) breeding on electricity pylons were reported to be suitable indicators of ecosystem health in the Karoo, South Africa (Machange et al. 2005). The habitat preference of raptors inhabiting human-modified or novel ecosystems can be used to advise management practices on vegetation structure that promotes the suitability of such habitats to animal wildlife (Martínez-Hesterkamp et al. 2018). The importance of urban green spaces for the persistance of Crowned Eagles in a suburban landscape has been revealed through a study of its home range (McPherson et al. 2019).

Since Long-crested Eagles are known to be associated with modified habitats, in particular agricultural landscapes, they can be used as a model species to study the suitability of such landscapes to animal wildlife. Management practices that promote the persistence of Long-crested Eagles in human-modified habitats will also benefit other species that use those habitats thus achieving conservation goals.

1.6 Aims and objectives

The overall aim of this study was to assess the use of human-modified landscapes by Long-crested Eagles in KwaZulu-Natal, South Africa. Specific objectives of the study were 1) to estimate home range size and describe movement patterns of male and female Long-crested Eagles in agricultural landscapes. Home ranges of breeding females were expected to be smaller because of incubation and brooding responsibilities. 2) To use telemetry to determine habitat preference of the eagles across a rural-suburban gradient. We expected them to show preference for open habitats such as savannas and forest edges because these eagles hunt from perches and therefore need areas with suitable perches overlooking an open area (Ferguson-Lees and Christie 2001). 3) To investigate the influence of landcover variables on site occupancy of Long-crested Eagles at a landscape scale level. Since this eagle preys on rodents, it was expected to be positively influenced by croplands. 4) To determine threats faced by raptors in the region from raptor admissions cases and make recommendations for raptor rehabilitation centres that treat rescued raptors.

1.7 Structure of the thesis

The main body of this thesis is organised as manuscripts prepared for publication in peer-reviewed journal articles. The first chapter (Chapter 1) is the Introduction which provides the literature review of the concepts covered in this study. The next four chapters (Chapter 2, 3, 4 and 5) are experimental chapters with each one covering a specific objective. Each chapter is formatted according to the journal it is intended to be submitted to. Because of this thesis format, a certain degree of repetition, especially in the methods section, was unavoidable. However, this is deemed to be of little concern as this format allows the reader to read each chapter separately without losing the overall context of the thesis. Chapter 2 investigated the ranging behaviour of Long-crested Eagles in human-modified landscapes and provides home range estimates of males and females. In chapter 3, habitat preference was investigated from telemetry data. Chapter 4 investigated the influence of land use type on the occupancy of Long-crested Eagles at landscape scale. Chapter 5 uses admission records to determine most prevalent raptor threats in the study area and investigates if information on the records can be used to predict the outcome of rehabilitation. Chapter 6 presents a summary of the findings and recommendations.

Table 1.1: Summary of recent diurnal raptor studies (2008-2019) in urban/suburban landscapes, agricultural landscapes and agroforestry plantations. Each species was considered as separate study.

Land use	**Common name**	**Latin**	**Region**	**Continent**	**Notes on behavioural adaptations**	**Reference**
Agriculture	Verreaux's Eagle	*Aquila verreauxii*	Western Cape, South Africa	Africa	Productivity and diet diversity was higher in agricultural than natural sites.	(Murgatroyd et al. 2016a; Murgatroyd et al. 2016b)
	Common Buzzard	*Buteo buteo*	France	Europe	Abundance decreased with reduction of hedgerows, woodlots, grasslands and prey abundance at landscape scale	(Butet et al. 2010)
	Common Buzzard	*Buteo buteo*	western Slovakia	Europe	Preferred alfalfa but avoided ploughed fields	(Nemček 2013)
	Ferruginous Hawk	*Buteo regalis*	Oklahoma, USA	North America	Compared to random sites, territories contained more sandsage habitat than cropland	(Wiggins et al. 2014)
	Swainson's Hawk	*Buteo swainsoni*	Oklahoma, USA	North America	Proportions of sandsage habitat influence reproductive success	(Wiggins et al. 2014)
	Marsh Harrier	*Circus aeruginosus*	North-eastern Spain	Europe	Uses ponds for breeding and hunts in surrounding crops	(Cardador et al. 2011)
	Marsh Harrier	*Circus aeruginosus*	Portugal	Europe	Occurrence positively associated with rice fields,	(Alves et al. 2014)

Land use	Common name	Latin	Region	Continent	Notes on behavioural adaptations	Reference
					saltmarshes and reed beds but negatively affected by road density and agricultural machinery during the breeding season	
	Lesser Spotted Eagle	*Clanga pomarina*	Estonia	Europe	Eagles preferred to breed close to managed agricultural biotopes and foraged on grasslands but avoided arable fields.	(Väli et al. 2017)
	Lesser Kestrel	*Falco naumanni*	Portugal	Europe	Cereal harvesting created high quality but ephemeral foraging habitats as cereals were converted into low quality stubbles.	(Catry et al. 2014)
	New Zealand Falcon	*Falco novaeseelandiae*	Marlborough, New Zealand	Island	Diet composition did not differ between native and vineyard habitats	(Kross et al. 2013)
	Peregrine Falcon	*Falco peregrinus*	Quebec, Canada	North America	Corn (Zea mays) and soybean (Glycine max) were used less during nestling period	(Lapointe et al. 2013)
	Common Kestrel	*Falco tinnunculus*	western Slovakia	Europe	Preferred alfalfa, corn fields, stubbles and fallow but avoided fallow	(Nemček 2013)
	Eurasian Kestrel	*Falco tinnunculus*	France	Europe	Abundance decreased with reduction of hedgerows, woodlots, grasslands and prey abundance at landscape scale but fall in abundance was not significant	(Butet et al. 2010)
Agroforestry	Northern Goshawk	*Accipiter gentilis*	North-western Spain	Europe	Preferred nesting in stands of high structural diversity	(Martínez-Hesterkamp et al. 2018)

Land use	Common name	Latin	Region	Continent	Notes on behavioural adaptations	Reference
					that included native species	
	Northern Goshawk	*Accipiter gentilis*	North-western Spain	Europe	Nested in structurally mature forest patches of high complexity	(García-Salgado et al. 2018)
	Northern Goshawk	*Accipiter gentilis*	North-western Spain	Europe	Nested preferably in mixed stands abundant in large exotic trees	(Martínez-Hesterkamp et al. 2018)
	Eurasian Sparrowhawk	*Accipiter nisus*	North-western Spain	Europe	Nested preferably in mixed stands abundant in large exotic trees and native species	(Martínez-Hesterkamp et al. 2018)
	Common Buzzard	*Buteo buteo*	North-western Spain	Europe	Nested preferably in mixed stands abundant in large exotic trees and native species	(Martínez-Hesterkamp et al. 2018)
	Hen Harrier	*Circus cyaneus*	Ireland	Europe	Preferred 2nd rotation pre-thickets, but may be suboptimal habitats	(Wilson et al. 2012)
	Merlin	*Falco columbarius*	Ireland	Europe	Nested in conifer plantations. Nests placed within 10 m of forest edge. Foraged in natural grassland	(Lusby et al. 2017)
	New Zealand Falcon	*Falco novaeseelandiae*	North Island, New Zealand	Island	Both males and females preferred edges between pine stands where stands less than 4 yr old bordered those greater than 19 yr old	(Seaton et al. 2013)
	New Zealand Falcon	*Falco novaeseelandiae*	North Island, New Zealand	Island	Falcons used open fields created by clearcutting	(Horikoshi et al. 2017)
	Red Kite	*Milvus milvus*	Northern Iberia	Europe	Mosaic of meadows and forests around nests	(Olano et al. 2016)
	African Crowned Eagles	*Stephanoaetus coronatus*	KwaZulu-Natal, South Africa	Africa	Eagles nesting in emerging habitats fed on rock hyraxes suggesting	(Malan et al. 2016)

Land use	Common name	Latin	Region	Continent	Notes on behavioural adaptations	Reference
					specialised feeding strategy	
Urban	Cooper's Hawk	*Accipiter cooperii*	Wisconsin, USA	North America	Breeding density increased with annual productivity (no. of young/laying pair)	(Stout and Rosenfield 2010)
	Cooper's Hawk	*Accipiter cooperii*	Washington, USA	North America	Positively responded to edges between deciduous mixed forest and light intensity urban land cover	(Rullman and Marzluff 2014)
	Cooper's Hawk	*Accipiter cooperii*	Tucson, USA	North America	Relatively small home ranges. Selected habitat consisted of large non-native trees and patches of natural vegetation.	(Boggie and Mannan 2014)
	Cooper's Hawk	*Accipiter cooperii*	Missouri, USA	North America	Occupancy positively influenced by woodland cover	(Hogg and Nilon 2015)
	Northern Goshawk	*Accipiter gentilis*	southern Finland	Europe	Higher brood size near urban areas suggesting more stable food and nesting conditions	(Solonen 2008)
	Black Sparrowhawks	*Accipiter melanoleucus*	Cape Town, South Africa	Africa	Home range sizes of males did not change between breeding and non-breeding seasons	(Sumasgutner et al. 2016)
	Black Sparrowhawks	*Accipiter melanoleucus*	Cape Town, South Africa	Africa	No evidence of negative effects of urbanization on health of nestling in urban areas	(Suri et al. 2017)
	Black Sparrowhawks	*Accipiter melanoleucus*	Cape Town, South Africa	Africa	High productivity in urbanised habitats early in the season, and late in the season, less urbanised habitats performed better	(Rose et al. 2017)
	Crested Goshawk	*Accipiter trivirgatus*	Taichung, Taiwan	Asia	Early laying dates in urban than rural	(Lin et al. 2015)

Land use	Common name	Latin	Region	Continent	Notes on behavioural adaptations	Reference
					population	
	Verreaux's Eagles	*Aquila verreauxii*	Johannesburg, South Africa	Africa	Switch from optimal rock hyrax to avian prey and supplemented food in urban environment	(Symes and Kruger 2012)
	Red-tailed Hawk	*Buteo jamaicensis*	Missouri, USA	North America	Occupancy positively influenced by woodland cover	(Hogg and Nilon 2015)
	Red-tailed Hawk	*Buteo jamaicensis*	Hartford County, USA	North America	Relatively small home ranges and multiple core areas associated with larger patches of green space	(Morrison et al. 2016)
	Peregrine Falcon	*Falco peregrinus*	Cape Town, South Africa	Africa	Population growth attributed to immigration and provision of nest boxes	(Altwegg et al. 2014)
	Peregrine Falcon	*Falco peregrinus*	Minnesota, USA	North America	High mate and nest-site fidelity and high female natal dispersal	(Caballero et al. 2016)
	Peregrine Falcon	*Falco peregrinus*	UK	Europe	High nesting success in urban areas probably driven by high prey availability	(Kettel et al. 2019)
	American Kestrel	*Falco sparverius*	Missouri, USA	North America	Occupancy positively influenced by grassland cover	(Hogg and Nilon 2015)
	Common Kestrel	*Falco tinnunculus*	Algeria	Africa	Relatively small home range and greater proportion of avian prey, i.e. rock dove chicks	(Kaf et al. 2015)
	Eurasian Kestrel	*Falco tinnunculus*	Vienna, Austria	Europe	High breeding densities in urban habitats but low breeding success due to lack of preferred prey (rodents)	(Sumasgutner et al. 2014a, b)
	Crowned Eagle	*Stephanoaetus*	Durban,	Africa	Diet consisted of	(McPherson

Land use	Common name	Latin	Region	Continent	Notes on behavioural adaptations	Reference
		coronatus	South Africa		rock hyrax and relatively high proportion of avian prey, i.e. Hadeda Ibis pulli. Selected for urban green space.	et al. 2016a,b; van der Meer et al. 2018)

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CHAPTER 2

Ranging behaviour of Long-crested Eagles (*Lophaetus occipitalis*) in human-modified landscapes, South Africa

Machawe I. Maphalala[1], Ara Monadjem[2], Keith L. Bildstein[3], Shane McPherson[1], Ben Hoffman[4] and Colleen T. Downs[1*]

1. *Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, Pietermaritzburg, South Africa*
2. *Department of Biological Sciences, University of Eswatini, Kwaluseni, Eswatini*
3. *Acopian Centre for Conservation Learning, Hawk Mountain Sanctuary, USA*
4. *Raptor Rescue, Pietermaritzburg, South Africa*

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* Corresponding Author: Colleen T. Downs

Email: downs@ukzn.ac.za

Tel: +27 (0)33 260 5127

ORCID: http://orcid.org/0000-0001-8334-1510

Other emails: machawe158@gmail.com; aramonadjem@gmail.com; keith.bildstein@gmail.com; shane.mcpherson@gmail.com; rescue@africanraptor.co.za

Running header: Ranging behaviour of Long-crested Eagles in human-modified landscapes

Abstract

The ranging behaviour of raptors in human-altered environments such as agricultural landscapes are becoming increasingly important for conservationists in the context of unprecedented high rates of anthropogenic land use change. In these transformed landscapes, habitat heterogeneity is important for the conservation of raptors as it provides them with non-substitutable resources such as foraging and breeding sites and thus influences their ranging behaviour. We studied the movement ecology Long-crested Eagles (*Lophaetus occipitalis*) fitted with geographic positioning system (GPS) transmitters in a human-modified landscape in KwaZulu-Natal Province, South Africa. Using the kernel density estimator (KDE) method (h_{ref} 95%), we estimated the home ranges of males and females to be 420 ± 180 ha (n = 5) and 315 ± 161 ha (n = 4) respectively and were not significantly different. Core areas (KDE h_{ref} 50%) were estimated to be 80 ± 38 ha and 39 ± 20 ha for males and females, respectively. Long-crested Eagles were relatively sedentary, tracked males travelled a mean distance of 2131 ± 917 m per day and the mean distance between consecutive fixes was 667 ± 143 m. We also recorded exploratory behaviour (in the form of long excursions) in two of the birds, of up to 49 km from the centre of their home range. The relatively small home ranges reported in this study are suggestive of productive foraging habitats whereby Long-crested Eagles can meet their energy requirements without having to travel long distances to obtain resources. Consistent with predictions, non-breeding Long-crested Eagles in this study showed similar ranging behaviour which includes occasional exploratory behaviour.

Keywords: Long-crested Eagle, home range estimate, agricultural landscapes, GPS transmitter

2.1 Introduction

The ranging behaviour of raptors in transformed habitats such as agricultural landscapes is becoming an increasingly important topic to conservationists due to the unprecedented high rate of land use change in recent years. Benton *et al.* (2003) emphasised the importance of restoring habitat heterogeneity in agricultural landscapes to maintain biodiversity. Heterogeneous landscapes are particularly important because they provide non-substitutable resources such as foraging and breeding sites (Michel *et al.* 2017). The movement of a raptor species from a nest site or roost site to foraging patches is correlated with breeding success (Michel *et al.* 2017) and therefore habitats that have these resources (foraging and nesting resources) in close proximity are more likely to be successful at fledging chicks than those where resources are widely spaced apart (Dunning *et al.* 1992). Foraging habitats in transformed and natural habitats may differ in the quality and quantity of the food resources they offer resulting in different home range sizes in these habitats (Buij *et al.* 2014, Morrison *et al.* 2016).

The area where an animal obtains its food and breeds is known as its home range (Burt 1943). Factors affecting the size of this area (home range) are not fully understood for most species (Börger *et al.* 2006) but habitat productivity, vegetation structure and foraging habits of a species are expected to contribute significantly to home range size as they relate to foraging success (Buij *et al.* 2014). In general, diurnal raptors tend to have larger home ranges in habitats with lower food availability (Newton 1979, McPherson *et al.* 2019), and those species that feed on sparsely distributed prey (e.g. avian vs mammalian prey) increase their home ranges in order to meet their energy requirements (Marzluff *et al.* 1997a, Peery 2000); a pattern also observed with Tengmalm's Owls (*Aegolius funereus*). Home range sizes of Tengmalm’s Owls increased with decreased prey abundance (Kouba *et al.* 2017). Therefore, raptor home ranges may expand or shrink depending on habitat quality and local food availability, age and competence of the bird and its immediate food needs (Newton 1979, Santangeli *et al.* 2012, Campioni *et al.* 2013).

Patches of intensive use within home ranges (core areas) are believed to be bearing important resources to an animal (Powell 2000) and in birds this area is usually around its nest (Newton 1979). During the breeding season nesting pairs spend a greater proportion of their time at or near their nests (Haworth *et al.* 2006), but they may also range outside of this territory, for example to seek better feeding opportunities (Pérez-García *et al.* 2013). Males of Lesser Kestrels (*Falco naumanni*) have been reported to take many short foraging trips around their nests as opposed to few long foraging trips taken by females suggesting different foraging strategies between the sexes (Hernández-Pliego *et al.* 2017).

Long-crested Eagles (*Lophaetus occipitalis*) occur in a variety of tropical and subtropical habitats across Africa including in agricultural landscapes, open woodlands and marshy areas (Steyn 1983), and may even occur in highly disturbed areas (Seavy and Apodaca 2002). These eagles maintain their nesting territories throughout the year in some areas (Brown *et al.* 1982), although it has been suggested that females, but not males, vacate their territories during the non-breeding season (Hall 1992). As generalists they are expected to benefit from heterogeneous habitats that result from anthropogenic land use changes in human-modified landscapes (Ferguson-Lees and Christian 2001) and have indeed moved into formerly treeless grasslands of South Africa (Johnson 2005). As expected of raptors specialising on small mammals, Long-crested Eagles appear to breed throughout the year (Johnson 2005), depending on food availability, which further highlights plasticity in their behaviour. The main objective of this study was to describe the home range of Long-crested Eagles in a human-modified mainly agricultural landscape, using geographic positioning system (GPS) transmitters. We expected the home ranges of male and female eagles to be similar in extent except during the breeding season when female home ranges were expected to be significantly smaller because of their brooding responsibilities.

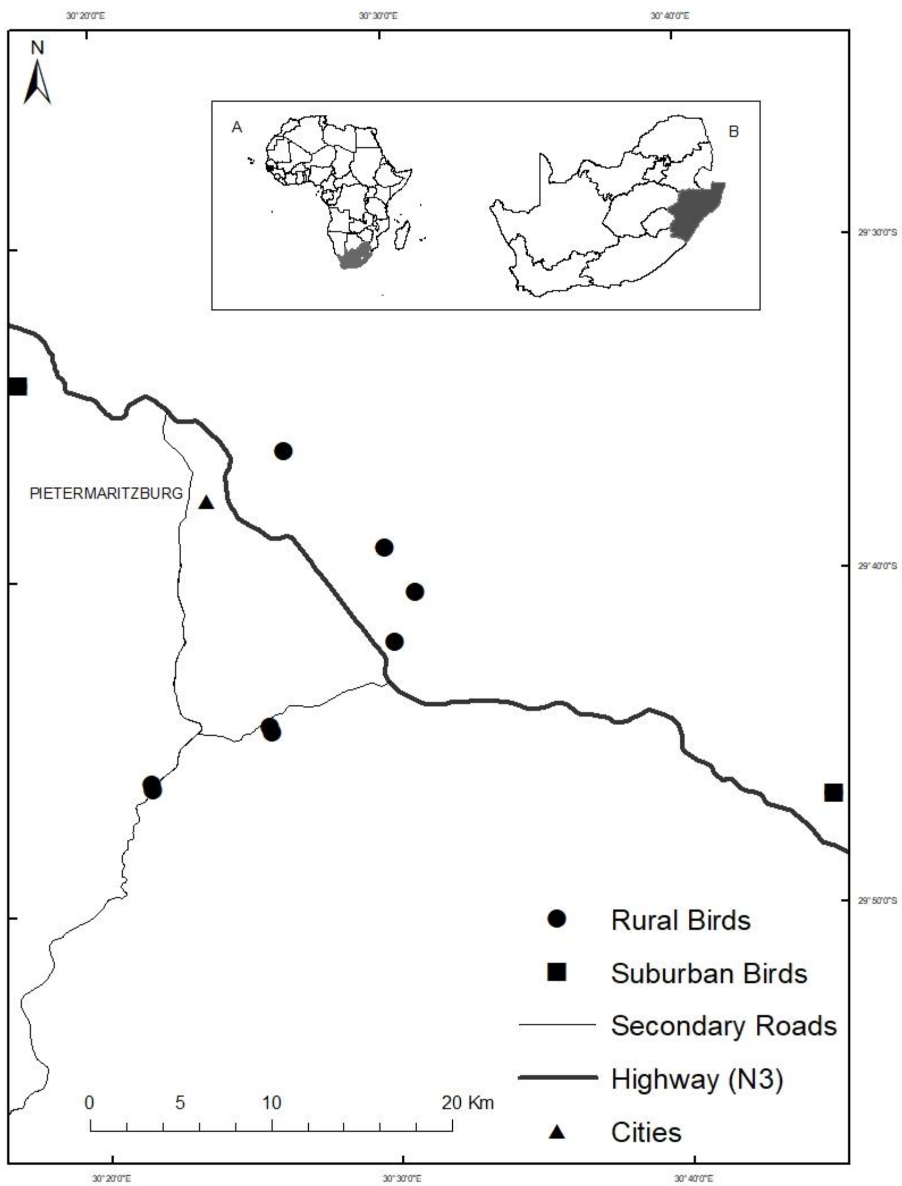

Figure 2.1: Location of all tagged Long-crested Eagles within the study area in KwaZulu-Natal Province, South Africa. Insert: location of South Africa in Africa (A) and location of the KwaZulu-Natal Province in South Africa (B).

2.2 Methods

2.2.1 Trapping and monitoring

From August 2016 to May 2017, 12 Long-crested Eagles were trapped using a bal-chaltri baited with laboratory mice in the Midlands of KwaZulu-Natal Province, South Africa (Fig. 2.1). Two of the eagles were located within suburban landscapes and the rest were located in agricultural landscapes. We placed the bal-chatri alongside roads within territories of resident birds. Standard morphometric measurements (mass, wing length, etc.) were taken from captured birds. A drop of blood for DNA and to verify sex was obtained from each using a 5ml syringe and venepuncture and later analysed by Molecular Diagnostic Services (Durban, South Africa). All birds caught were ringed and fitted with Geographic Positioning System (GPS) transmitters. Ten of the eagles were fitted with non-solar Ultra-High Frequency Geographic Positioning System (UHF-GPS) avian transmitters (www.wirelesswildlife.co.za) weighing ~40 g. They were programmed to take four GPS points per day (06h00, 10h00, 14h00 and 18h00) and to switch off at night to prolong battery life. Data were downloaded to a base station mounted on a vehicle which in turn transmitted data to a remote server via global system for mobile communication (GSM) network. We also used solar charged GPS-GSM-LoRa devices (http://iot-gps.co.za), weighing 30 g, programmed to take a GPS point every 2 hours between 06h00 and 18h00, on two of the eagles. The transmitters were attached to the birds as back packs made of 6 mm teflon ribbon (Bally Ribbon Mills, Bally, USA) and never exceeded 5% of the body mass of the bird as recommended by Kenward (2000). The data from each transmitter included latitude, longitude, date and time.

We defined breeding season as the period from the beginning of incubation to the day the nestling fledged, and all other times outside the breeding season were considered as non-breeding season. Only three tagged females were able to breed during the tracking period. Of these we obtained complete movement data (that included both breeding and non-breeding seasons) from one female because the other two started breeding towards the end of the tracking period. All tracked males did not breed during the study and their movements were considered to be outside of the breeding season.

2.2.2 Data analyses

Datasets from each tracked eagle were screened to remove null locations and duplicates. They were then transformed to Universal Transverse Mercator (UTM) projection, WGS 1984, UTM zone 36 S in R (R Core Development Team 2014). We used the rhr package to test for site fidelity for each bird as recommended by Laver and Kelly (2008). Home range analysis, movement and site fidelity tests were performed in R version 3.1.3 (R Core Development Team 2014) using rhr and adehabitat packages (Calenge 2006, Signer and Balkenhol 2015). The Kernel Density Estimator (KDE) method was used to estimate core areas and home range sizes. In this method contours (isopleths) are created around a predetermined percentage of the GPS points which are reflective of the amount of time the animal spends within a particular contour (Hemson *et al.* 2005). Home range estimates derived using KDEs are influenced by the band width (h) selected (Gitzen *et al.* 2006, Kie 2013). For this analysis the reference band width (h_{ref}) was used as it presented a more realistic representation of the home ranges when the contours and GPS points were overlaid on ArcGIS 10.3 (ESRI, Redlands, CA, USA). The 50 % contour predicted areas of intensive use (referred to as core areas here after) based on 50 % of the fixes and nests of breeding raptors are usually found within this area (Walker *et al.* 2005, Moss *et al.* 2014, Watson *et al.* 2014). To minimise exploratory movements, we used 95 % of the fixes to estimate home range sizes for each eagle following Moss *et al.* (2014). Minimum convex polygons (MCP) were also estimated to facilitate comparison with older studies. The distance between any two consecutive fixes was calculated using the adehabitat package (Calenge 2006). Distance covered per day was calculated by adding the distance between the four consecutive fixes within a day. Movements of females were expected to have considerable variations because of incubating females. Hence, we only described movements of males to avoid reporting means that have too much variation. Means are presented with their standard deviations (± SD).

2.3 Results

Three of the 12 transmitters (1 UHF-GPS and 2 GPS-GSM-LoRa devices) failed and their data could not be used for analyses. The UHF-GPS device failed because of mechanical faults and the GPS-GSM-LoRa devices failed because their batteries were prevented from charging by feathers that eventually covered the surface of the solar panels. Long-crested Eagles were tracked for an average of 212 ± 78 days (range: 101 - 294 days, Table 2.1) excluding one individual whose transmitter failed a few days after attachment. Mean home range of males estimated using the KDE method was 610 ± 504 ha (n = 5) and 1131 ± 1709 ha (n = 4) for females. The corresponding mean core areas for males and females was 118 ± 81 ha and 231 ± 388 ha for males and females, respectively. The MCP method yielded home range estimates of 455 ± 206 ha and 248 ± 177 ha for males and females, respectively. Core areas were estimated to be 94 ± 35 ha and 53 ± 52 ha for males and females, respectively, using the MCP method.

The KDE home range estimates were significantly influenced by the movements of two eagles that were recorded over 20 km away from the centre of their home range. One male was located 27 km away and another female travelled as far as 49 km from the centre of its home range. These locations were less than 1 % of the total fixes per bird and when they were excluded, mean home range estimates for males and females were 420 ± 180 ha and 315 ± 161 ha, respectively. Corresponding core areas were 80 ± 38 ha and 39 ± 20 ha for males and females, respectively. Movements of the two eagles had minimal effects on MCP home range estimates, 404 ± 218 ha for males and 246 ± 176 ha for females. Core areas estimated by the MCP method were 89 ± 41 ha and 25 ± 29 ha for males and females, respectively. Although males appeared to have larger home ranges (Fig. 2.2), this difference was not significant for both KDE home range estimates ($w = 30$, $p = 0.2703$) and MCP home range estimates ($w = 29$, $p = 0.3913$). Tracked males travelled a mean distance of 2131 ± 917 m per day and the distance between consecutive fixes was 667 ± 143 m.

Table 2.1: Home range sizes (ha) of Long-crested Eagles in a human-modified landscape in KwaZulu-Natal Province, South Africa. (Maximum = maximum distance between two consecutive points, KDE = Kernel Density Estimator, MCP = Minimum Convex Polygon).

Bird ID	**Gender**	**No. of fixes**	**No. of days**	**KDE 95 %**	**KDE 50 %**	**MCP 95 %**	**MCP 50 %**	**Maximum**
K2	F	992	275	100.21	15.36	52.78	4.65	6673.15
K1	F	1143	294	108.33	10.05	147.80	16.52	1928.08
A3	M	448	112	164.12	32.67	134.76	39.85	1468.34
A8	M	804	227	332.76	75.62	270.59	101.43	2923.09
A1	F	360	101	422.87	44.76	323.41	8.81	4118.07
H6	M	483	122	458.97	118.59	367.76	113.75	3603.27
H5	F	999	272	461.08	52.24	451.99	67.63	4273.62
A4	M	895	264	509.95	57.74	590.51	29.64	5389.74

A7	M	962	245	637.98	113.95	657.91	109.84	3627.55
Mean		787.33	212.44	355.14	57.89	333.06	54.68	3778.32
SD		284.15	78.05	191.52	38.86	207.17	44.44	1615.61

The tracking period of one the females which began in August 2016 and ended in May 2017 included two incubation periods. The home range size of this female was smallest during the incubation periods September/October 2016 and April/May 2017 (Fig. 2.3). In December 2016 when the chick left the nest, the home range size of the adult female rapidly increased and began to shrink again in March when it prepared to for the next breeding season. After the chick had fledged the home range of the adult reached a maximum size of 216 ha which was smaller than the mean home range for all the tracked females.

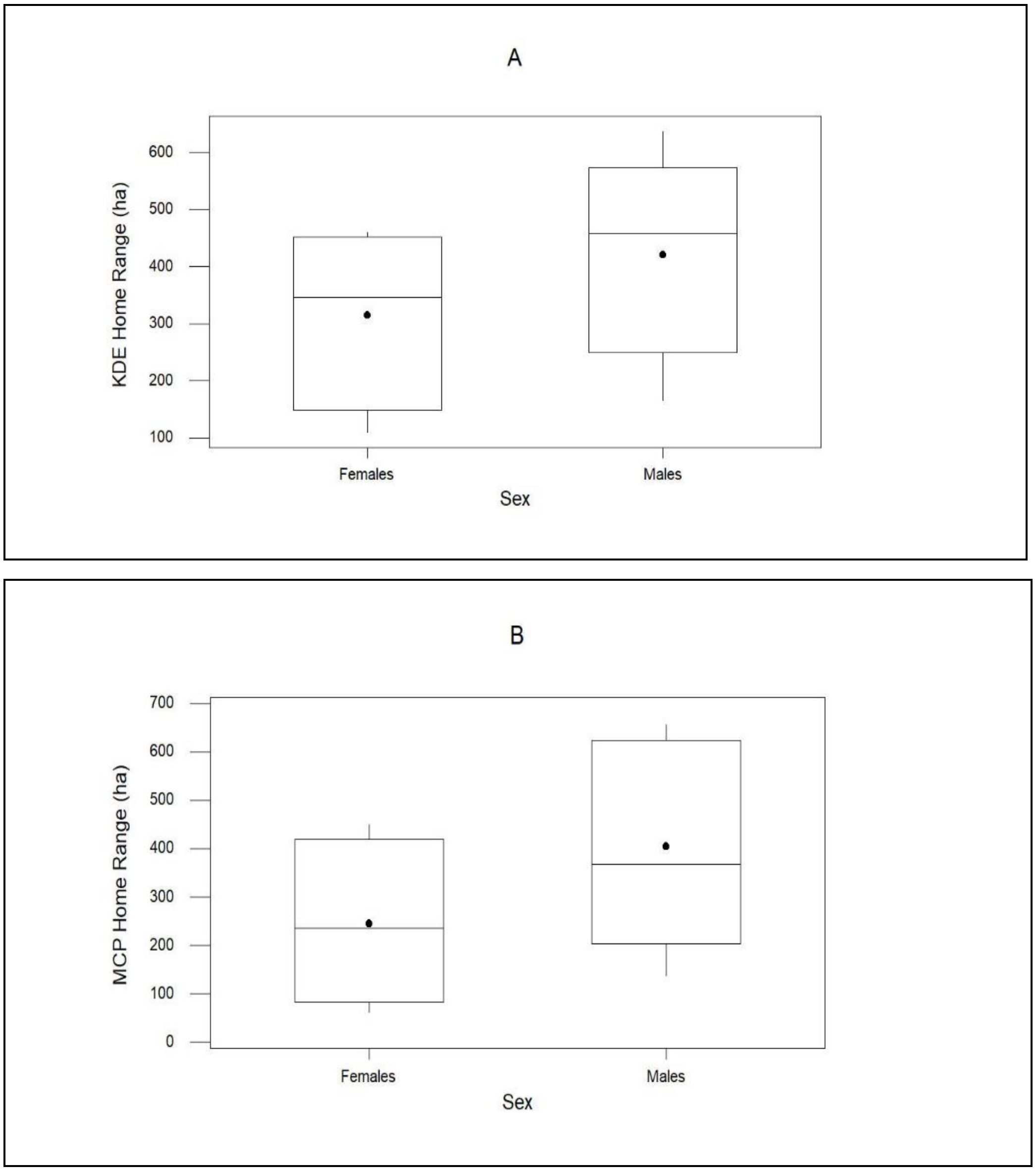

Figure 2.2. Boxplots of home range sizes of female and male Long-crested Eagles in a human-modified landscape in KwaZulu-Natal Province, South Africa where a.) is the Kernel Density Estimate and b.) Minimum Convex Polygon. (Black dots indicate means in each graph).

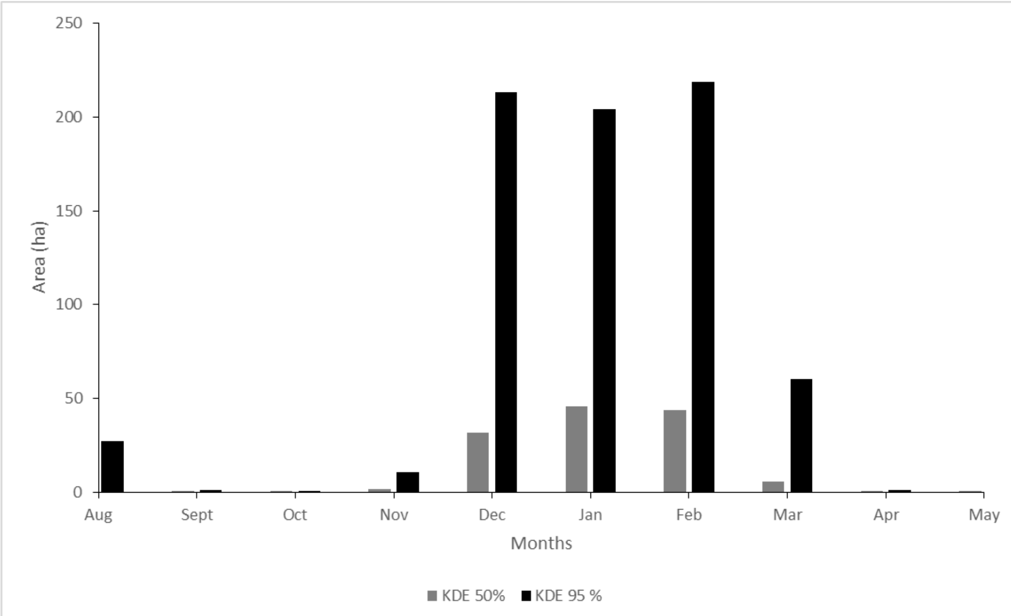

Figure 2.3. Changes in the home range size of a female breeding Long-crested Eagle in a human-modified landscape in KwaZulu-Natal Province, in South Africa. Incubation began in September and the nestling fledged in December 2016. The female then laid again in March/April 2017. KDE 50 % indicates areas of intensive use or core areas and KDE 95 % represents home range estimate using the Kernel Density Estimator method.

2.4 Discussion

Home ranges of male and female Long-crested Eagles were estimated to be 420 ± 180 ha and 315 ± 161 ha, respectively which are amongst the smallest known for Long-crested Eagles. These home ranges are similar to those reported by Steyn (1983) for Long-crested Eagles in Zimbabwe which were 400 – 650 ha, but smaller than estimates in Mpumalanga Province, South Africa, that were 2500 – 3500 ha (Steyn 1983, Johnson 2005). We suggest that this variation in home range size is most likely influenced by prey availability (rodents) which is thought to vary geographically and inter-annually as it may also be influenced by rainfall patterns and vegetation density as well (Bond *et al.* 1980, Monadjem 1997, Massawe *et al.* 2011). The combination of relatively good food and nesting site availability in the human-modified, mainly agricultural landscape studied here were probably the reason for the small home ranges obtained as suggested for Cooper's Hawks (*Accipiter cooperii*) (Mannan and Boal 2000). Small home ranges are generally indicative of high prey densities as eagles do not have to travel long distances to obtain food (Fernández *et al.* 2009). Home range sizes of males and females were not significantly different suggesting similar ranging behaviour between sexes.

The mean total distance travelled per day was at least 2 km and the distance between consecutive fixes was less than 700 m which highlighted the relatively sedentary behaviour of Long-crested Eagles. Raptors that rely on the sit and wait hunting strategy, like Long-crested Eagles, tend to spend most of their time perching and less time flying (Mendelsohn and Jaksic 1989, Plumpton and Andersen 1997, Baladrón *et al.* 2006). Long-crested Eagles often have a few favourite perches within their home range from which they hunt (Johnson 2005). They are also known to be opportunistic foragers, visiting new places where there is sudden abundance of prey (Steyn 1983), as is expected for a raptor specialising on rodents (Korpimäki and Marti 1995). The movements of the two eagles that were located 27 and 49 km outside of their home range (centre of home range) were possibly influenced by their search for new and better feeding opportunities elsewhere as suggested for Bonelli's Eagles (*Aquila fasciata*) (Pérez-García *et al.* 2013). Spanish Imperial Eagles (*Aquila adalberti*) were also recorded up to 35 km away from their nests during the breeding season and 62 km away during the non-breeding season (Fernández *et al.* 2009). However, in this case it is difficult to ascertain the motives for these long-distance movements as they could also represent exploratory behaviour such as searching for new territories. Hall (1992) suggested that during the non-breeding season females vacate their territories and may be seen outside of their home range. The present study demonstrated that such long-distance movements were not unique to females, as one of the birds in question was a male.

The nests of breeding Long-crested Eagles in this study were located within their core areas. In general, Long-crested Eagles appear to remain near their breeding areas throughout the year. Bosch *et al.* (2010) suggested that Bonelli's Eagles remain near their breeding sites to prevent nest usurpation by competitors. This likely applies to Long-crested Eagles, whose nest site potential competitors are Black Sparrowhawks (*Accipiter melanoleucus*) and Egyptian Geese (*Alopochen aegyptiaca*) (M. Maphalala pers. obs.). During the study at least one Long-crested Eagle nest was taken over by a Black Sparrowhawk and the following year the Long-crested Eagle built a new nest, about 400 m from its previous nest. Egyptian Geese appear to compete with Black Sparrowhawks for nests (Curtis *et al.* 2007, Wreford *et al.* 2017) and it would be reasonable to expect that they would also compete with Long-crested Eagles as well because these two raptors have similar nesting habitat preferences. Resident Egyptian Geese were observed in the nesting territories of two of the three breeding females studied here but no aggressive interaction was witnessed. Other raptorial species that are potential competitors for nesting trees with Long-crested Eagles include Black Kite (*Milvus migrans*), Wahlberg's Eagle (*Aquila wahlbergi*), Jackal Buzzard (*Buteo rufofuscus*) and the African Harrier-hawk (*Polyboroides typus*) (Malan and Robinson 2001).

The data from the eagle that was tracked for both the breeding and non-breeding seasons suggests that Long-crested Eagles used smaller home ranges during the breeding season and then expanded their home ranges during the non-breeding season. This can be explained by the fact that breeding raptors (females in particular) forage around their nests during the nestling period but progressively travel further as the chick grows older (Newton 1979). Home ranges of Golden Eagles (*Aquila chrysaetos*) in southwestern Idaho were found not to vary between years or sex but varied according to seasons, being larger in the non-breeding than the breeding season (Marzluff *et al.* 1997b). However, breeding birds have also been reported to have larger home ranges in places of low prey density resulting in the birds travelling to distant undefended territories where food is more abundant (Fernández *et al.* 2009). Since the sample size of breeding females in this study was relatively low, we cannot make robust conclusions, but it would be interesting to compare inter-annual variation in home range of breeding birds, for example see Pérez-García *et al.* (2013).

Whilst anthropogenic land use changes have resulted in habitat loss for many species, some species are showing signs of adapting to human-modified landscapes. The clearing of forests, presence of utility poles along roads and fences around farms all facilitates access to prey for some raptors like Long-crested Eagles (Johnson 2005). Studies have shown that the presence of perches in agricultural landscapes and roadsides encourages the use of these habitats by raptors as it allows less energy hunting behaviour (Widén 1994, Meunier *et al.* 2000). The relatively small home ranges reported in this study are suggestive of productive foraging habitats whereby Long-crested Eagles can meet their energy requirements without having to travel long distances to obtain resources. Since raptors require multiple environmental resources, species management plans should prioritise maintenance of nesting habitats and preservation of foraging habitats around nests.

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CHAPTER 3

Importance of native habitat patches for the persistence of Long-crested Eagles in human-modified landscapes

Machawe I. Maphalala[1], Ara Monadjem[2], Keith L. Bildstein[3], Shane McPherson[1], Ben Hoffman[4] and Colleen Downs[1*]

1. *Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, Pietermaritzburg, South Africa*
2. *Department of Biological Sciences, University of Eswatini, Kwaluseni, Eswatini*
3. *Acopian Centre for Conservation Learning, Hawk Mountain Sanctuary, USA*
4. *Raptor Rescue, Pietermaritzburg, South Africa*

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* Corresponding Author: Colleen T. Downs

Email: downs@ukzn.ac.za

Tel: +27 (0)33 260 5127

ORCID: http://orcid.org/0000-0001-8334-1510

Other emails: machawe158@gmail.com; aramonadjem@gmail.com; keith.bildstein@gmail.com; shane.mcpherson@gmail.com; rescue@africanraptor.co.za

Running header: Importance of native habitat patches for the persistence of Long-crested Eagles

Abstract

With the ongoing anthropogenic transformation across the world, conservation strategies are much needed to preserve biodiversity within transformed landscapes. Understanding the habitat use of species occurring in these human-modified landscapes is key to deriving such conservation strategies. The Long-crested Eagle (*Lophaetus occipitalis*) is an example of a raptor that occurs in human-modified landscapes but information on its habitat use remains limited. To study the habitat use of Long-crested Eagles in rural and suburban environments, we used geographic positioning system (GPS) transmitters fitted to nine individuals in a human-modified, predominantly agricultural landscape in KwaZulu-Natal Province, South Africa. Home ranges of eagles in rural environments predominantly comprised of cropland (33%) and savanna (22%), whereas in suburban environments they comprised of settlements (34%) and exotic tree plantations (23%). The latter were generally avoided by the eagles in both rural and suburban landscapes. In rural landscapes, the eagles avoided cropland but positively selected for natural patches such as wetlands, natural forest, natural forest edge and savanna. In suburban landscapes, only natural forest and forest edge were positively selected whilst cropland, settlements, grassland and roads were used in proportion to their availability. These results highlight the importance of maintaining natural patches within both suburban and rural landscapes. We therefore suggest that the conservation of natural habitat patches in suburban and rural human-modified landscape mosaic will benefit Long-crested Eagles, ensuring the long-term persistence of this top predator (with the ecosystem services that it provides) in such human-altered landscapes.

Keywords: habitat preference, land use type, *Lophaetus occipitalis*, GPS transmitter, core area

3.1 Introduction

Anthropogenic land use change, especially agricultural expansion, is expected to continue through the 21st century (Norris 2008; Laurance *et al.* 2014). Consequently, the contribution of conservation programs within agricultural landscapes, one of the largest terrestrial biomes on Earth (Foley *et al.* 2005), will increasingly be important in the conservation of biodiversity globally. Agricultural landscapes are mosaics of different land uses such as cropland, exotic tree plantations, grazing pastures, roads, wetlands, streams and patches or strips of natural or semi-natural vegetation that may all be interspersed with human settlements (Bennett *et al.* 2006). Heterogeneous landscapes are often associated with high species richness partly because of the complementary resources that come with diverse habitats. For example, birds that forage in grasslands may need native vegetation for nesting (Haslem and Bennett 2008) and may be important for the occurrence of habitat generalist raptors in transformed landscapes such as suburban environments (Rullman and Marzluff 2014). Some generalists are also able to survive in fragmented landscapes because they are not dependent on a single habitat type, but instead use resources from surrounding habitats as well (Andren 1994).

The conversion of natural land into other land use types usually results in the loss of native species, in particular those that are unable to adapt to modified habitats (McKinney 2002). There appears to be a gradient of species loss mirroring habitat loss from the least transformed natural landscapes to the most transformed urban landscapes (Chace and Walsh 2006; McKinney 2006; Carrete *et al.* 2009). Transformation in the form of agricultural intensification is recognised as a significant contributor to biodiversity loss (Benton *et al.* 2003; Green *et al.* 2005). For example, in Europe, farmland bird population declines, and range contractions were more pronounced in countries with more intensive agriculture (Donald *et al.* 2001; Šálek *et al.* 2018). As top predators, raptors provide valuable ecosystem services such as biological control of agricultural pests and increasing the aesthetic value of landscapes (Sergio *et al.* 2008; Donázar *et al.* 2016) but are currently one of the most threatened group of birds (Garbett *et al.* 2018; McClure *et al.* 2018). Hence, raptors stand to benefit from conservation strategies outside of formally protected areas, for example in farmlands and urban areas (Cox and Underwood 2011).

Anthropogenically transformed landscapes are inhabited by several raptor species across the world, including some specialists. The Verreaux's Eagle (*Aquila verreauxii*), a hyrax (*Procavia* and *Heterohyrax* spp.) specialist, was found to perform better in agricultural sites than in natural sites in terms of breeding rate and nesting success (Murgatroyd *et al.* 2016). One of the largest forest eagles in Africa, the Crowned Eagle (*Stephanoaetus coronatus*), persists in urbanised landscapes in South Africa where it hunts and breeds in available forest patches (McPherson *et al.* 2016, McPherson *et al.* 2019). The installation of nest boxes improved breeding success of Peregrine Falcons (*Falco peregrinus*) occurring in the city of Cape Town (Altwegg *et al.* 2014) contributing to the growing number of raptor populations colonizing urban landscapes. Growing populations of Cooper's Hawks have also been reported in urban environments in North America (Mannan *et al.* 2008, Stout and Rosenfield 2010).

Long-crested Eagles (*Lophaetus occipitalis*) are widespread avian predators in human-modified landscape mosaics across much of Africa, inhabiting forest edges, moist woodland, marshes, mixed farmland, edges of sugarcane plantations, pastures and orchards (Johnson 2005). They feed predominantly on rodents, and in particular *Otomys* spp. (Johnson 2005). In parts of its range, exotic trees such *Eucalyptus* spp. are used extensively for nesting, but other tree species may be used as well (Steyn 1983; Hall 1992). Nesting trees are usually tall and are generally located at the edge of a forest (Steyn 1983). The population of this species believed to be increasing (Ferguson-Lees and Christian 2001).

From 2005 to 2011 a 7.6 % loss in natural habitat was recorded in the KwaZulu-Natal Province, South Africa, because of anthropogenic land use transformations such as agriculture, exotic tree plantations, urbanisation, construction of dams and mining activities (Jewitt *et al.* 2015). In this study we investigated the habitat use of Long-crested Eagles in a human-modified, particularly agricultural, landscape in KwaZulu-Natal Province. We quantified habitat use and preference of the species by tracking eagles fitted with geographic positioning system (GPS) transmitters. Unlike the breeding biology of the species which is relatively well studied (Jarvis and Crichton 1978; Steyn 1978; Hall 1979a; 1992), very little is known about their habitat use and preference. Our specific objective was to determine habitat preferences of this eagle across a human-modified landscape, especially a rural-suburban gradient. We predicted that in both rural and suburban landscapes Long-crested Eagles would prefer open habitats with suitable perches to allow sit and wait foraging. These eagles hunt by perching on suitable lookouts such as trees or utility poles and surveying the ground below for rodents (Jarvis and Crichton 1978; Steyn 1983). As such marshy areas with short vegetation and savannas are suitable foraging habitats given their hunting strategy.

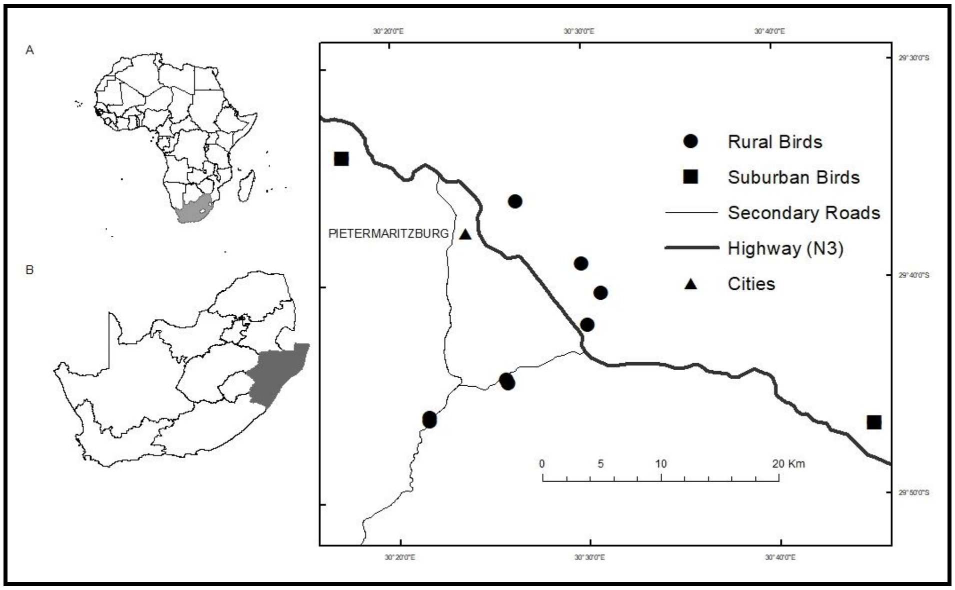

Figure 3.1. (A) Location of South Africa in Africa and (B) Location of KwaZulu-Natal Province in South Africa. Insert: Locations of all tagged Long-crested Eagles in the study area in KwaZulu-Natal, South Africa.

3.2 Methods

3.2.1 Study area

The study was conducted in the Midlands of KwaZulu-Natal Province, South Africa (Fig. 3.1). Natural habitats in this province consist of moist grasslands, savannas, forests and wetlands which are rich in biodiversity (Jewitt *et al.* 2015). The climate in the Midlands of KwaZulu-Natal is characterised by high humidity, high temperatures, and high summer rainfall falling in September-March (Fairbanks 2004). South Africa was undergoing a severe drought when the study was begun, i.e. 2015/16 summer rainfall season (Archer *et al*. 2017).

3.2.2 Trapping, tagging and tracking

We captured twelve Long-crested Eagles using a bal-chatri trap baited with laboratory mice in agricultural (n = 10) and suburban landscapes (n = 2). The eagles were tagged with non-solar geographic positioning system ultra-high frequency (GPS-UHF) transmitters (www.wirelesswildlife.co.za) (n = 10) and geographic positioning system, global system for mobile network, long range operation (GPS-GSM-LoRa) (http://iot-gps.co.za) devices (n = 2). The GPS-UHF transmitters were programmed to take four GPS points daily at 4 h intervals and to switch off at night and data were downloaded once per week to a GSM–UHF base station mounted on a vehicle (Chapter 2). The GPS-GSM-LoRa devices however, were programed to take a GPS position every two hours from 06h00 to 18h00 (Chapter 2).

3.2.3 Data analyses

Data from one of the transmitters were corrupted and could not be used for any analyses. Downloaded data were filtered to remove duplicates and null fixes. We used a 2014 land cover dataset (Ezemvelo KZN Wildlife 2014) to quantify habitat use in ArcGIS 10.3 (ESRI, Redlands, CA, USA). We used the rhr package and Kernel Density Estimator (KDE) with the reference bandwidth in R (R Core Development Team 2014) to estimate the 99 % contour marking the outer boundary of the home range of each tagged bird. Spatial analyst tools in GIS were used to reclassify and measure the areas of nine land cover types (land use type here after) within the home range: wetlands (all water bodies), exotic tree plantations, croplands, bare land, settlements (included area around houses), grassland, savanna (open bushland < 70 cc), natural forests (dense bushland (70 – 100 cc) and roads.

We overlaid the reclassified land use map with GPS fixes from all tracked birds and the proportion of points falling on to each land use type was considered as a proxy for habitat use.

Within each land use type, we tested if there was a significant difference between observed and expected number of fixes using the chi square test, following a method by Byers *et al.* (1984). Expected number of fixes in each land use type was obtained by multiplying the relative area of each land use type by the total number of fixes within the home range. Subsequently, Bonferroni usage intervals were calculated to determine if a land use type was preferred (positively selected), avoided or used in proportion to its availability (random use). If the calculated usage interval is above the expected proportion of usage, then the land use type is considered to be preferred whereas if it is below the expected proportion of usage then that land use type is considered to have been avoided (Byers *et al.* 1984). By contrast, if the expected proportion of usage falls within the usage interval, then that particular land use type is neither preferred nor avoided but used in proportion to its availability (i.e. random use).

Table 3.1: Long-crested Eagles tagged with transmitters in a human-modified landscape in KwaZulu-Natal, South Africa. (* Values obtained after removing points within 50 m of nest. U = Urban, R = Rural).

Bird ID	**Urban/Rural**	**99 % Home range (km^2)**	**No. of pts**	**Breeding**
K1	U	1.78	481* (1167 - 686)	Y
A3	R	1.92	435	N
K2	R	4.86	583* (1030 - 447)	Y
H6	R	4.99	484	N
A1	R	6.23	176* (378 - 202)	Y
A8	R	6.68	805	N
H5	R	7.82	427	N
A7	U	9.84	963	N
A4	R	18.94	914	N

During the nestling period, GPS fixes of breeding Long-crested Eagles females were clumped around their nests due to nest attendance (M. I. pers. obs.). We assumed that such clumped fixes did not reflect time spent foraging but attending a nest. Hence, we excluded all fixes within a 50 m radius from a nest location. Excluding points within 50 m of nests removed 59 %, 43 %, and 53 % for birds K1, K2 and A1 respectively (Table 3.1). Although excluding the points around nests resulted in data loss, the loss did not affect overall habitat preference because when the breeding birds were excluded altogether from the analysis, the habitat preference pattern did not change. In order to assess the importance of natural forest edges on habitat selection we created 20 m buffer zones around natural forests to represent edge habitats between natural forests and any other adjacent land use type.

3.3 Results

Data from three of the transmitters could not be used because the transmitters failed shortly after attachment (Chapter 2).

3.3.1 Habitat composition

Home ranges of Long-crested Eagles in rural landscapes (n = 7) were dominated by cropland (33 %), savanna (22 %) and natural forest edge (11 %) whereas in suburban landscapes the home ranges (n = 2) predominantly comprised suburban settlements (34 %), exotic tree plantations (23 %) and natural forest edge (15 %) (Fig. 3.2a, b). Core areas of breeding birds (n = 3) consisted of 41 % savanna and 32 % natural forest with other land use types that appeared in lower proportions (Fig. 3.2c). The core areas of non-breeding birds however, comprised predominantly of savanna (33%), natural forest (20%) and settlements (20%) (Fig. 3.2d).

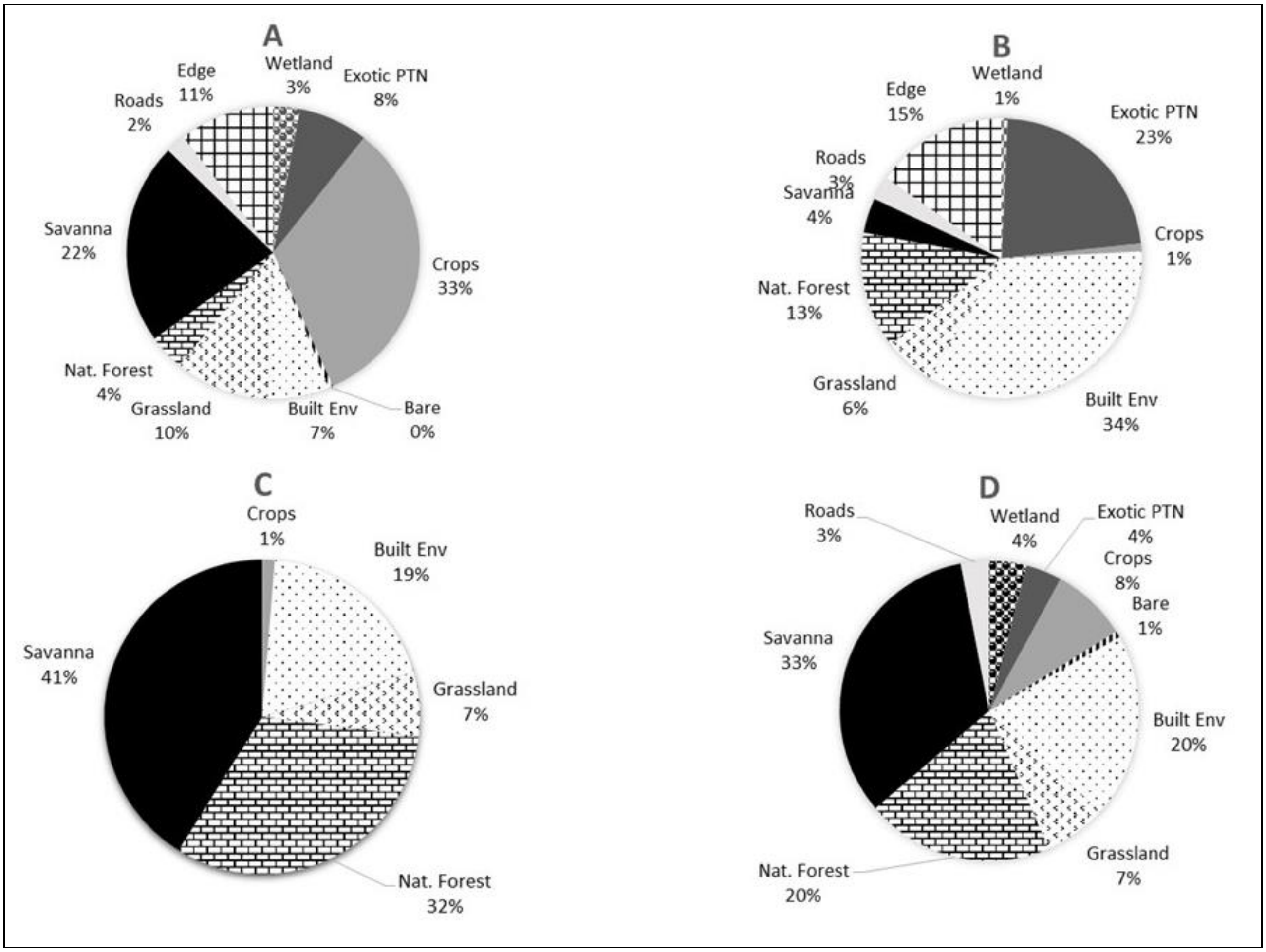

Figure 3.2: Long-crested Eagle habitat composition in a human-modified landscape in KwaZulu-Natal, South Africa: a) Rural home ranges (n = 7), b) suburban home rages (n = 2), c) breeding birds core area (n = 3), d) non-breeding birds core area (n = 6).

3.3.2 Rural vs suburban habitat use

Long-crested Eagles in rural landscapes positively selected wetlands, natural forest, savanna and natural forest edge. However, they avoided exotic tree plantations, cropland, rural settlements and grasslands. Roads were randomly used or used in proportion to their availability (Table 3.2a). In suburban landscapes, Long-crested Eagles preferred natural forest and natural forest edge but avoided exotic tree plantations and savanna, whereas cropland, suburban settlements, grasslands and roads were used in proportion to their availability (Table 3.2b).

3.3.3 Individual land use type selections

Wetlands were positively selected by two Long-crested Eagle individuals and avoided by four individuals (Fig. 3.3, Table 3.3). Two birds used wetlands in proportion to their availability. Exotic tree plantations were positively selected by three birds, avoided by four and randomly used by one bird. Croplands were not positively selected by any bird but was randomly used by three birds and avoided by six birds. All the eagles (except one) that avoided croplands appeared to prefer savanna as foraging habitat over croplands (Table 3.3). Only one bird had bare ground (quarry site) within its home range and this land use type was avoided. Settlements were positively selected by only one individual, randomly used by three and avoided by the rest. The selection pattern for grassland was similar to that of settlements. The savanna land use type was positively selected by five individuals, randomly used by one, and avoided by two individuals. Roads were positively selected by two birds, randomly used by three, and avoided by four individuals. Natural forest and natural forest edge had similar selection patterns, in that both were positively selected by five individuals, randomly used by three, and avoided by one individual.

Table 3.2. Bonferroni usage intervals for Long-crested Eagles in rural (a, n = 7) and suburban (b, n = 2) landscapes in the Midlands of KwaZulu-Natal, South Africa. When the usage interval is above the expected proportion of usage, then the land use type is considered to be preferred and when below the expected proportion of usage then that land use type is considered to have been avoided. Random use indicates that the expected proportion of usage falls within the usage

interval. Preferred land uses are marked with a (+), avoided land uses marked with a (-) and random use is marked with a (0).

Rural landscape (a)	Expected	Bonferroni Min	Bonferroni Max	Selection
Wetlands	0.029437889	0.08739752	0.105503337	+
Exotic tree plantations	0.076630742	0.020628623	0.03028937	-
Crops	0.327574423	0.095616804	0.114419915	-
Bare ground	0.004688541	-0.000188783	0.001167976	-
Settlements	0.067159717	0.04211326	0.05531636	-
Grassland	0.10479615	0.080837747	0.098354419	-
Natural forest	0.039404239	0.080603746	0.098098824	+
Savanna	0.223529813	0.322832746	0.351830657	+
Roads	0.021896938	0.01929771	0.028682707	0
Natural forest edges	0.104881548	0.171725912	0.19547115	+

Suburban landscape (b)	Expected	Bonferroni Min	Bonferroni Max	Selection
Exotic tree plantations	0.227645545	0.043743939	0.067521707	-
Cropland	0.009105821	0.004130969	0.013949699	0
Settlements	0.346322512	0.314800813	0.363919632	0
Grassland	0.059723477	0.041869879	0.065223306	0
Natural forests	0.13528172	0.265093095	0.312097448	+
Savanna	0.040574471	0.007290171	0.01913542	-
Roads	0.027685715	0.01576317	0.03152473	0
Natural forest edges	0.153660739	0.195588749	0.238347273	+

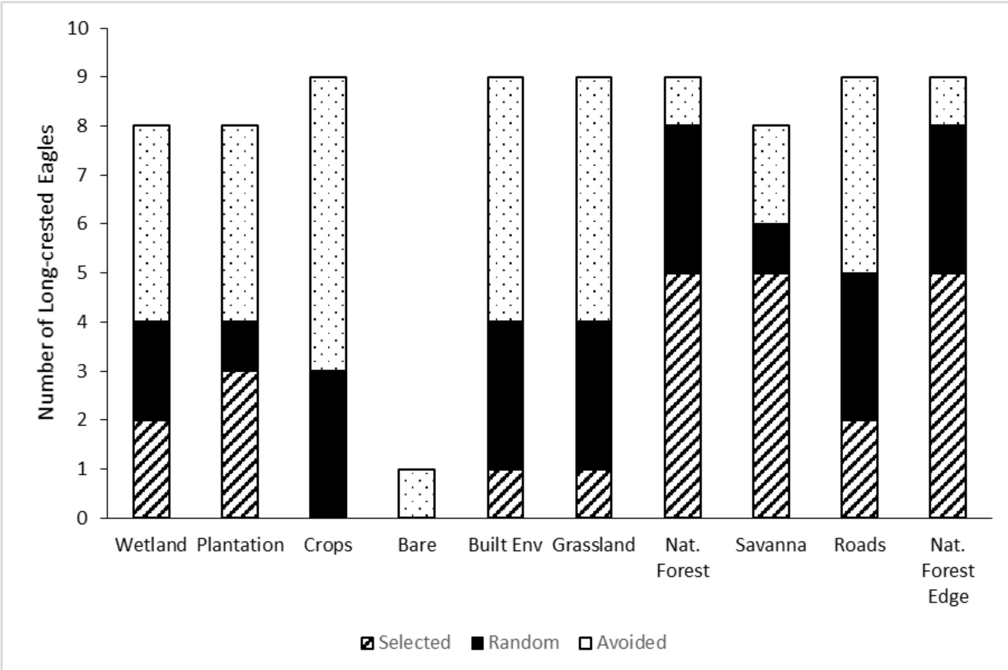

Figure 3.3: The number of Long-crested Eagle individuals selecting each land use type in South Africa.

Table 3.3. Individual land use type selection by individual Long-crested Eagles fitted with GPS transmitters in a human-modified landscape in KwaZulu-Natal, South Africa. Bold font indicates suburban eagles. + = preferred, - = avoided, 0 = random use, Nil = land use type not available.

Land use	**K1**	K2	A3	A4	H5	H6	**A7**	A8	A1
Wetland	**Nil**	-	+	+	0	0	**-**	-	-
Exotic tree plantations	**-**	-	0	-	+	+	**-**	Nil	+
Crops	**0**	-	-	-	-	-	**0**	0	-
Bare	**Nil**	Nil	Nil	Nil	Nil	Nil	**Nil**	-	Nil
Settlements	**-**	-	-	0	-	-	**+**	0	0
Grassland	**0**	-	-	0	-	0	**-**	+	-
Natural forest	**+**	0	+	-	+	+	**+**	0	0
Savanna	**-**	+	+	+	+	+	**-**	0	-
Roads	**0**	-	-	-	0	0	**-**	+	+
Natural forest Edge	**0**	0	+	-	+	+	**+**	0	+

3.4 Discussion

Natural habitats such as wetlands, natural forest, natural forest edges and savanna were important for Long-crested Eagles in the study area as they were all positively selected. The tracked eagles roosted and nested in the natural forest patches which were present in their respective home ranges either in a rural or suburban human-modified landscape mosaic. Savanna, wetlands and forest edges were most likely used for foraging as it is characteristic of this species (Steyn 1983; Johnson 2005). Availability of foraging habitats near nesting habitats may be the key to conserving birds in transformed landscapes (Pärt and Söderström 1999; Benton *et al.* 2003). This was demonstrated with the Western Marsh Harrier (*Circus aeruginosus*) that can benefit from agricultural intensification through its ability to breed in anthropogenic structures such as ponds and forage in the nearby cropland (Cardador *et al.* 2011). The proximity of foraging patches to nesting sites minimises foraging trips and may be associated with fitness and higher foraging success for breeders as suggested for the Black Kite *Milvus migrans* (Sergio *et al.* 2003a; Sergio *et al.* 2003b).

Long-crested Eagles in rural landscapes appeared to avoid foraging within croplands but preferred to use savanna instead, which included the natural vegetation on the edges of cultivated fields. This could possibly be due to limited access to prey as a result of thick vegetation cover as observed in western north America where Swainson's Hawks (*Buteo swainsoni*) appeared to avoid hunting over cultivated fields until after vegetation cover had been reduced, i.e. after harvesting (Bechard 1982). And indeed, the amount of vegetation cover may be more important than prey densities in hunting habitats as it determines prey accessibility (Bechard 1982; Widén 1994). Alternatively, the eagles may have avoided using croplands due to lack of hunting perches in the interior of cultivated fields. If the latter hypothesis is true, then they would have used fence posts on the edges of the fields where they could hunt on the natural vegetation adjacent to the fields. Since nearly all the birds that avoided croplands positively selected savanna, this might further support the hypothesis that the Long-crested Eagles in the study area most likely hunted on savanna habitats, including edges of cultivated fields. Wetlands or riverine habitats were positively selected in rural landscapes as well. Previous studies have highlighted the importance of marshy areas to Long-crested Eagles (Jarvis and Crichton 1978; Hall 1979b) perhaps due to the association of their preferred prey, *Otomys* spp., with moist habitats (Fuller and Perrin 2001).

The tracked birds in rural landscapes also avoided exotic tree plantations, grasslands, bare ground and settlements. Grasslands were possibly avoided presumably because of the lack of suitable perches, since Long-crested Eagles are known to occupy grasslands that have one or a few interspersed trees (Johnson 2005). Natural forests were important for Long-crested Eagles in both rural and suburban landscapes as they were positively selected. The telemetry data suggest that they were most likely used as roosting and breeding habitats. The importance of natural forest patches to the breeding of Long-crested Eagles was supported by the greater proportion of natural forest in the core areas of breeding birds (32 %) compared to core areas of non-breeding birds (20 %). During the breeding season the foraging distribution of a raptor may be influenced by the location of its nest (Thirgood *et al.* 2003). In general, birds of prey forage closer to their nests during the breeding season and then expand their home range after the breeding season (Newton 1979; Thirgood *et al.* 2003).

In suburban landscapes only natural forests and the edges around them were positively selected by Long-crested Eagles. Croplands, settlements, grassland and roads were randomly used in suburban landscapes whereas exotic tree plantations and savanna were avoided. Exotic tree plantations were clearly an unpreferred land use type as they were avoided by eagles in both rural and suburban landscapes. Surprisingly, savanna habitats were also avoided in suburban landscapes. Since Long-crested Eagles are known to forage in such habitats, this result is probably an artifact of identifying and marking of edge habitats. It is likely that most of the savanna habitat was part of the edge habitat which was positively selected.

Only a few studies have assessed the importance of habitat edges on raptor nesting site selection (Sánchez-Zapata and Calvo 1999, Carrete *et al.* 2000, Sergio *et al.* 2005, Zub *et al.* 2010) and foraging habitat selection (Balbontín 2005, Comfort *et al.* 2016) possibly due to the challenges of demarcating edge habitats using GIS where land use types are of unequal sizes, yet such analyses are important for species that are more likely to use the edge than the interior of a habitat patch. An animal using edge habitats gains maximum access to resources that occur in adjacent habitats (Ries *et al.* 2004). In this study Long-crested Eagles positively selected ecotones or edge habitats, which were patches between natural forests and any other land use type within their home range.

The eagles in the present study did not show a strong preference for roads but the the importance of roads to raptor foraging has been shown elsewhere (Meunier *et al.* 2000; Dean and Milton 2003). The random use of roads in this study could posibly be explained by the fact that a majority of the tracked birds were from farmlands or rural landscapes and did not necessarily rely on poles along roads but used trees that were further from the road. We suspect that roads would have been positively selected if more birds from suburban landscapes were tracked. Given the expanding anthropogenic changing land use, especially agriculture and urbanisation (Green *et al.* 2005; Chace and Walsh 2006; Laurance *et al.* 2014; Melliger *et al.* 2018), restoring habitat heterogeneity with emphasis on preserving and restoring natural patches is important for sustainable biodiversity conservation (Marzluff and Ewing 2001; McKinney 2002; Benton *et al.*

2003; Chace and Walsh 2006; Hass *et al.* 2018). Natural patches are important because the loss of natural vegetation greatly affects native species that depend on it (McKinney 2002; Wilson *et al.* 2017). There is a growing consesus about the value of preserving natural habitats within agricultural mosaic landscapes for the benefit of biodiversity, especially larger and connected patches (Whittingham 2007; Billeter *et al.* 2008; Hipólito *et al.* 2018). Results of the present study showed the importance of natural habitats for a raptor that is generally considered to be adaptable. Long-crested Eagles were found to have a strong preference for savanna habitats, wetlands, natural forests and edge habitats. We suggest that the conservation of natural habitat patches in suburban and rural landscape mosaics will benefit Long-crested Eagles, ensuring the long-term persistence of this top predator (with the ecosystem services that it provides) in such human-modified landscapes.

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CHAPTER 4

Influence of anthropogenic land use changes on the occupancy of Long-crested Eagles in an agricultural-urban landscape mosaic

Machawe I. Maphalala[1], Keith Bildstein[2], Ara Monadjem[3,4], Colleen T. Downs[1*]

1. *Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, Pietermaritzburg, South Africa*
2. *Acopian Centre of Conservation Learning, Hawk Mountain Sanctuary, Orwigsburg, USA*
3. *Department of Biological Sciences, University of Eswatini, Kwaluseni, Eswatini*
4. *Mammal Research Institute, Department of Zoology and Entomology, University of Pretoria, Pretoria, South Africa*

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* Corresponding Author: Colleen T. Downs

Email: downs@ukzn.ac.za

Tel: +27 (0)33 260 5127

ORCID: http://orcid.org/0000-0001-8334-1510

Other emails: machawe158@gmail.com; aramonadjem@gmail.com; keith.bildstein@gmail.com; rescue@africanraptor.co.za

Running header: Influence of anthropogenic land use changes on the occupancy of Long-crested Eagles

Abstract

In KwaZulu-Natal Province, South Africa, anthropogenic activities have resulted in a major loss of natural habitat in recent years. Agricultural intensification and urbanisation are some of the major contributors to this loss, with potential impacts on raptor communities. To assess the influence of land use type on the occupancy of Long-crested Eagles (*Lophaetus occipitalis*) in an agricultural-urban landscape mosaic, we conducted road surveys in KwaZulu-Natal Province, South Africa, from August 2017 to April 2018. The program PRESENCE was used to estimate detection probability and occupancy (proportion of sites occupied). Mean detection probability and occupancy of Long-crested Eagles in the top three competing models were 0.19 ± 0.06 and 0.76 ± 0.10, respectively. In the competing models, detection was either a function of savanna alone or an interaction between savanna and either natural forest or exotic tree plantations. Occupancy, however, was a function of cropland alone and had positive effect ($\beta = 4.71 \pm 2.28$). The covariates ‘savanna’ and ‘cropland’ had the greatest support in terms of summed model weights (w_i = 0.91 and 0.89) for site detection and occupancy, respectively. Southern African bird atlas project data suggests that Long-crested Eagles are increasing in most parts of their range within South Africa. These eagles appear to be benefiting from wildlife friendly management of cattle farms (savanna) as well as croplands. This study demonstrated that agricultural landscapes can support native species when their heterogeneous nature is maintained.

Keywords: Long-crested Eagle, road transect, occupancy estimation, KwaZulu-Natal

4.1 Introduction

Land transformation in the form of agricultural intensification and urbanisation are recognised as significant contributors to habitat loss for many species globally (Lindenmayer et al. 2019). For some species, however, human-modified landscapes bring new opportunities in form of novel habitats that they can exploit, i.e. the so-called winner species (McKinney and Lockwood 1999; Newbold et al. 2018). Understanding the ecology of species that thrive in human-modified landscapes can help conservationists formulate biodiversity management plans, especially in areas where transformation cannot be avoided such as places where people live and work (Miller and Hobb 2002). For example, studies have advocated for the retention of natural habitats in agricultural landscapes (Benton et al. 2003; Tscharntke et al. 2012) or urban greenspaces for the benefit of wildlife (Threlfall et al. 2017; McPherson et al. 2019).

Increasing the number of different habitat types within a landscape generally expands its capacity to support more species and thus increasing the overall biodiversity (Devictor and Jiguet 2007; Fahrig et al. 2011; McKinney 2002; Vickery and Arlettaz 2012). Natural habitat patches within anthropogenically transformed landscapes provide resources such as nesting and foraging habitats for birds that inhabit such human-modified landscapes (Söderström et al. 2003). The presence of urban green spaces has facilitated the colonisation of urban environments by some raptor species such as Red-tailed Hawks (*Buteo jamaicensis*) in North America and Crowned Eagles (*Stephanoaetus coronatus*) in South Africa (Morrison et al. 2016; McPherson et al. 2016). Raptors that respond positively to agricultural activities utilise nesting and roosting opportunities in these landscapes, as well as the abundant food associated with cultivated fields (Grande et al. 2018; Cardador et al. 2012; Cardador et al. 2014)

Long-crested Eagles (*Lophaetus occipitalis*) are resident, medium-sized raptors that occur mainly in moist open woodland with short grass and frequently perch at the edges of exotic tree plantations or cultivated areas, and marshy areas where prey is abundant (Brown et al. 1982; Ferguson-Lees and Christie 2001; Steyn 1983). They are opportunistic feeders and their prey consists of mainly rodents (Johnson 2005). As an open habitat species, Long-crested Eagles are thought to benefit from deforestation and are reported to frequently use disturbed habitats in Uganda (Seavy and Apodaca 2002). Consequently, the conversion of treeless grasslands into woodland may also be benefitting them (Johnson 2005). This species is considered highly adaptable (Ferguson-Lees and Christie 2001), a trait that has probably contributed to its success. The aim of the present study was to assess the role of anthropogenic land use change on the persistence of Long-crested Eagles in human-modified landscapes of South Africa (Ferguson-Lees and Christie 2001). Firstly, we used data from the Southern African Bird Atlas Project (SABAP) to map the changes in reporting rates between the first atlas project (SABAP1) and the second atlas project (SABAP2) to show trends in the abundance of Long-crested Eagles across South Africa. Secondly, we used road survey data to investigate the influence of land use type on the site occupancy of Long-crested Eagles within KwaZulu-Natal Province. Thirdly, we sought to determine the minimum survey effort needed to infer absence of Long-crested Eagles from a site.

Anthropogenic land use change in the KwaZulu-Natal Province is most likely to be having a significant impact on local raptor communities. For example, over 7 % of the remaining natural habitat was lost to agriculture, exotic tree/timber plantations, urbanisation, dams and mines in 6 years from 2005 to 2011 (Jewitt et al. 2015). In addition to afforestation, the KwaZulu-Natal grasslands are also transformed by overgrazing (O'Connor et al. 2003). Long-crested Eagles were expected to benefit from some of the anthropogenic land use changes in the study area such as cultivated areas which are generally rodent rich (Buij et al. 2012) and interspersed with natural patches. Heterogeneous and structurally diverse landscapes (such as agricultural areas) offer opportunities for generalists to hunt for alternative prey when the preferred prey is not as abundant (Terraube et al. 2011). Built up environments were expected to be negatively associated with Long-crested Eagles because of potential threats like human disturbance or persecution in these areas (Grande et al. 2018).

4.2 Methods

4.2.1 Changes between SABAP1 and SABAP2

The Southern African Bird Atlas Project is a long term national citizen science project where volunteers record bird species seen in a specific area for a given period of time (Amar and Cloete 2017). The first phase of the project (SABAP1) was carried out from 1987 to 1992 at a spatial resolution of 15-minute grid of longitude and latitude (Underhill 2016). SABAP2 on the other hand began in 2007 and is on-going. The projects were conducted at different spatial resolutions. Spatial resolution for SABAP1 was 15-minutes of longitude and latitude. The grid for SABAP2 however, was five-minutes of longitude and latitude which means that there were nine SABAP2 pentads within a SABAP1 quarter degree grid cell (Underhill 2016). Reporting rates (number of checklists with the species/total number of checklists) can be used to study population trends and changes in distributions (Underhill 2016; Loftie-Eaton 2015; Hofmeyr et al. 2014). Data on Long-crested Eagle reporting rates across South Africa were downloaded from the SABAP2 website (http://sabap2.adu.org.za/), from the start of the project (SABAP2) to the 25th January

2019. We used a method described by Underhill and Brooks (2016) to display the relative change in abundance of Long-crested Eagles in South Africa:

$C = \log(1-R_2)/\log(1-R_1)$

Whereby C is the ralative change in abundance and R is the reporting rate in each atlas project, i.e. reporting rate during SABAP1 was R_1 and it changed in SABAP2 to R_2. If $C = 1$, then there was no change in relative abundance between the two survey periods, if $C < 1$, the was decrease and if $C > 1$, then there was an increase (Underhill and Brooks 2016).

4.2.2 Site occupancy

Study area

The study was conducted in the Midlands of KwaZulu-Natal Province, South Africa, (29.5°S, 30.2°E) and covered 6 758 km^2 (Fig. 4.1). The altitude ranges between 419 – 1550 m a.s.l. The main land uses include exotic tree plantations, sugarcane plantations and other crops, cattle farms, protected areas and built up environment (urban and rural).

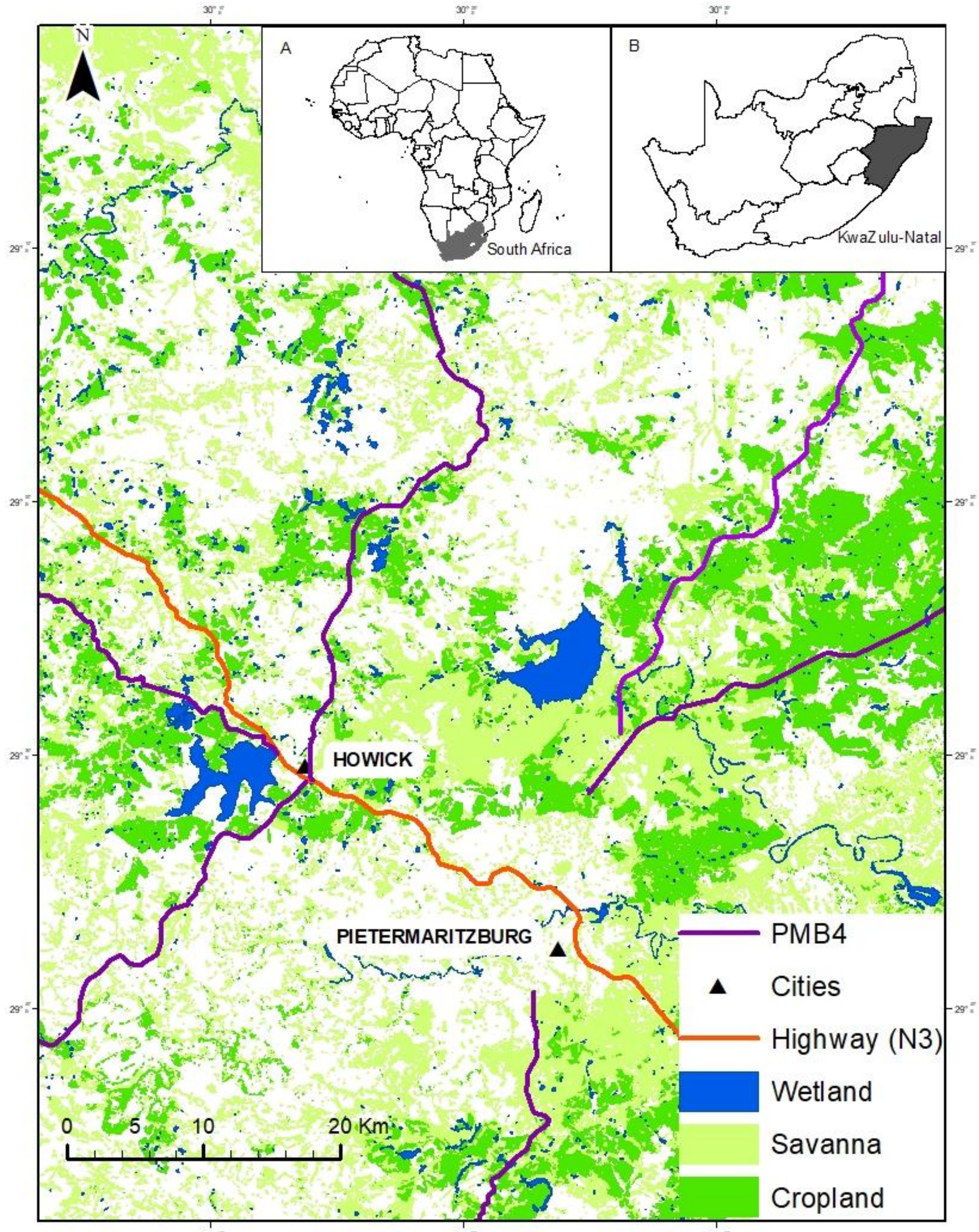

Fig. 4.1. Location of the study site and all Long-crested Eagle road transects in KwaZulu-Natal, South Africa. Insert: A. Location of South Africa and B. Location of KwaZulu-Natal Province, South Africa.

Data collection

We selected six secondary roads of varying length (min = 30 km, max = 52 km, mean = 46 km) in the study area traversing various land uses (Fig. 4.1). The six roads were further sectioned into 5 km road transects separated by 2 km unsurveyed stretches to achieve site independence which yielded 38 survey sites in total. Road surveys were conducted in a random order once a month between 06h30 and 12h30 by two observers (a driver and a passenger) monthly from August 2017 to April 2018. The vehicle was driven at a mean ($\pm$ SD) speed of 70.1 ± 53.7 km/h and upon seeing a possible Long-crested Eagle the vehicle was stopped to confirm the identity of the bird, age (i.e. juvenile or adult) and its location was recorded using a hand-held geographic positioning system (GPS) device (Garmin Etrek, Garmin International, Kansas, USA). A transect was surveyed in both directions to make up one survey occasion. This was done to improve detection probability at each site. There was a total of nine surveys per site. Surveys were not carried out on rainy days since such conditions may affect the behaviour of the birds and also limit detection by an observer (Andersen 2007).

Data analyses

A 500 m buffer was placed on both sides of each road transect. We used spatial analyst tools in ArcGIS 10.3 (ESRI, Redlands, CA, USA) to measure the area of seven relevant habitats considered to influence Long-crested Eagle occupancy: exotic tree plantations; savanna (open woodland); natural forest (dense bush land); grassland; cropland; wetland; and built environments (towns, villages and farm houses). For the land use types, we used a 2014 land cover data set (Ezemvelo KZN Ezemvelo KZN Wildlife 2014).

Data were inputted to program PRESENCE (Hines 2006) in vector form and standardised (z-scores) land cover-based site covariates which were the areas of the land cover types from each survey site. The program PRESENCE uses a likelihood-based method to estimate the proportion of sites occupied (ψ) when detection probability (p) is less than one (MacKenzie et al. 2002). Care was given to record only birds were clearly identified. Most of the sightings of Long-crested Eagles were of perched birds (M. I. pers. obs.) as is typical of their perch-hunting behaviour (Hall 1979; Jarvis and Crichton 1978) and therefore birds seen at each site were less likely to be double counts which further improved site independence.

The simplest model considered assumed constant occupancy across sites and constant detection through all surveys, ψ(.), p(.). Both parameters were then allowed to vary with each covariate, ψ(covariate) p(.) or ψ (.) p(covariate). Two or more covariates were also allowed to interact with each other for both parameters. We also produced a global model which contained all the variables and assessed model fit. Model fit was assessed by estimating the dispersion parameter ($\hat{c}$), whereby a model that is a best descriptor of the data has a value of 1 and values above 1 indicate lack of fit. Models were ranked by AICc (Akaike's information criterion adjusted for small sample size) and model weight where a model with the smallest AICc was considered as the best model (Burnham and Anderson 1998). The relative influence of each covariate on occupancy and detection was found by adding model weights of all models containing a specific covariate. Means are reported with standard error (± SE) throughout.

The minimum number of visits necessary to infer the absence of a species from a site (N_{min}) were calculated using the following formula:

Probability (N unsuccessful visits) = $\alpha = (1 - p)^N$ (Kery 2002; Pellet and Schmidt 2005)

Where p is the detection probability per visit. To determine the value of N_{min} at 95 % confidence interval, $\alpha = 0.05$, the following formula was used:

$N_{min} = \log (0.05)/\log (1-p)$.

4.3 Results

4.3.1 Changes between SABAP1 and SABAP2

Approximately 13% of the total cells within South Africa showed increase in reporting rates between the two survey periods and 8.5% of this figure corresponds to new grid cells in which Long-crested Eagles were not reported during SABAP1 (Fig. 4.2). Decrease in reporting rates was recorded in only 4.6 % of the total grid cells suggesting an increase in relative abundance of Long-crested Eagles across South Africa.

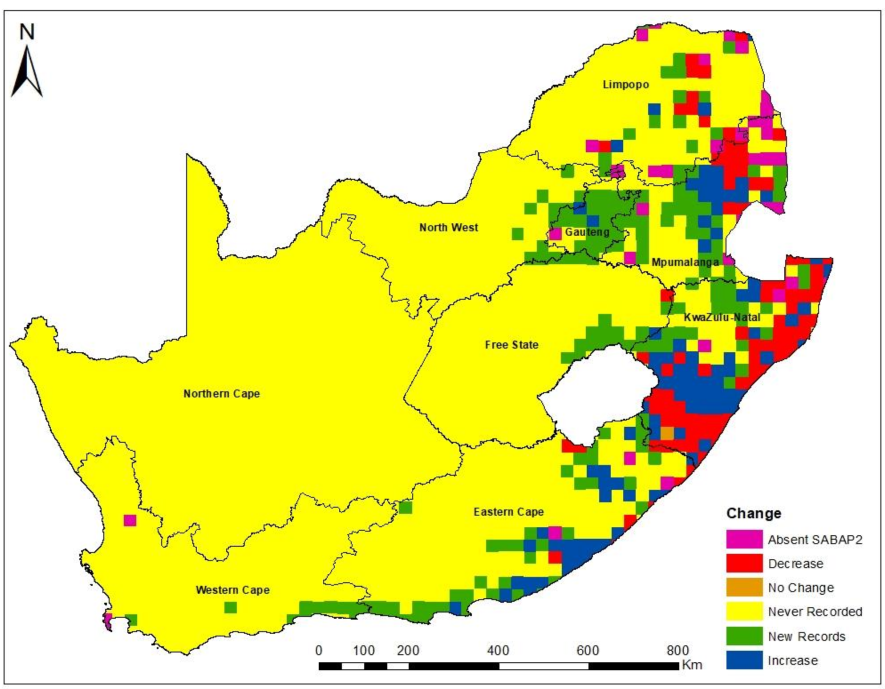

Figure 4.2: Changes in Long-crested Eagle reporting rates between Southern African Bird Atlas project (SABBAP) 1 and 2. Absent SABAP2: no sighting reported during SABAP2 survey at the

time data were downloaded, Decrease: SABAP2 reporting rate lower than SABAP1, No Change: reporting rates have not changed, Never Recorded: Species never reported during either survey, New Record: Species recorded during SABAP2 but not SABAP1, Increase: SABAP2 Reporting rate higher than SABAP1.

4.3.2 Site Occupancy

Long-crested Eagles were recorded at least once in 21 out of 38 sites (naïve occupancy = 0.55) based on nine survey occasions per site. The naïve occupancy remained constant after six survey occasions (Fig. 4.3). After accounting for imperfect detection in the top ranked model, the proportion of sites occupied was found to be 0.77 ± 0.10 or 29 out of 38 sites. Increasing the number of survey occasions slightly improved detection probability highlighting the benefit of multiple repeat surveys in this study. The estimate of occupancy declined with increase in number of survey occasions (Fig. 4.3).

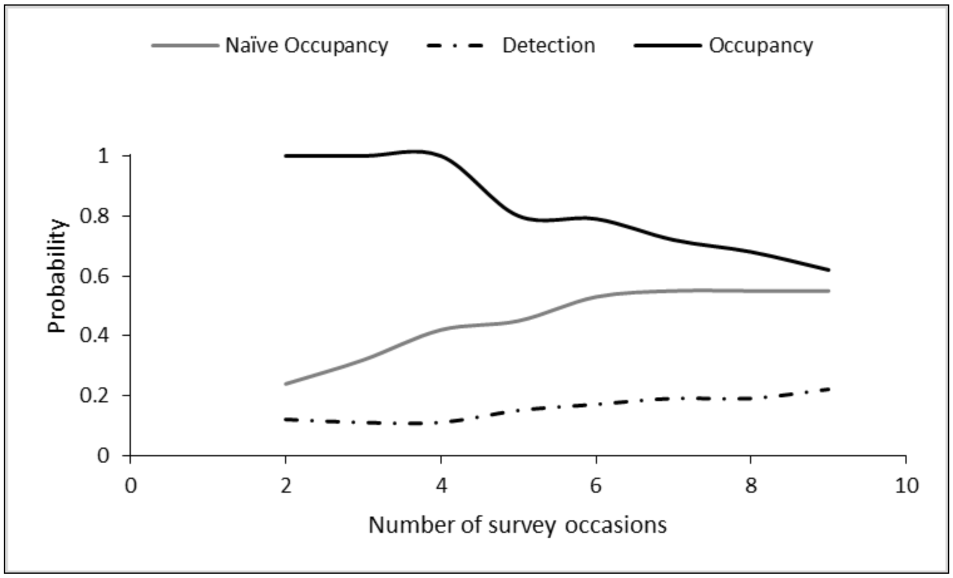

Figure 4.3: Cumulative effect of the number of surveys on naïve occupancy, occupancy and detection probability of Long-crested Eagles in a human-modified landscape in KwaZulu-Natal, South Africa.

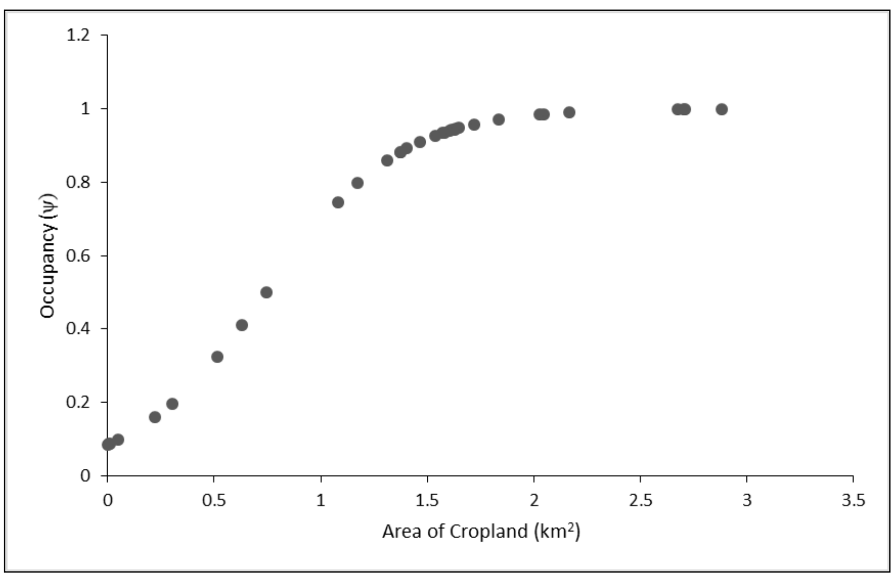

Figure 4.4: Effect of area of croplands on the occupancy of Long-crested Eagles in a human-modified landscape in KwaZulu-Natal, South Africa.

The global model and the top ranked models were good descriptors of the data ($\hat{c}$ = 0.84, 0.88 respectively). The top three competing models (ΔAICc < 2), are shown in Table 4.1 and these were ψ(Cropland),p(Savanna); ψ(Cropland),p(Savanna + Natural Forest) and ψ(Cropland),p(Savanna + Exotic Tree Plantation). Mean estimates of occupancy and detection probability were 0.76 ± 0.10 and 0.19 ± 0.06 respectively. In the competing models, croplands were the only covariate associated with Long-crested Eagle occupancy whereas detection was either a function of savanna alone or an interaction between savanna and either natural forest or exotic tree plantations. Croplands had a positive effect (nonlinear) on Long-crested Eagle occupancy (β = 4.78 ± 2.55, Fig. 4.4) and all covariates associated with detection probability also had a positive effect (Fig. 4.5, Table 4.2). None of the competing models, however, can be assumed to be best since their support was almost similar (ΔAICc < 2).

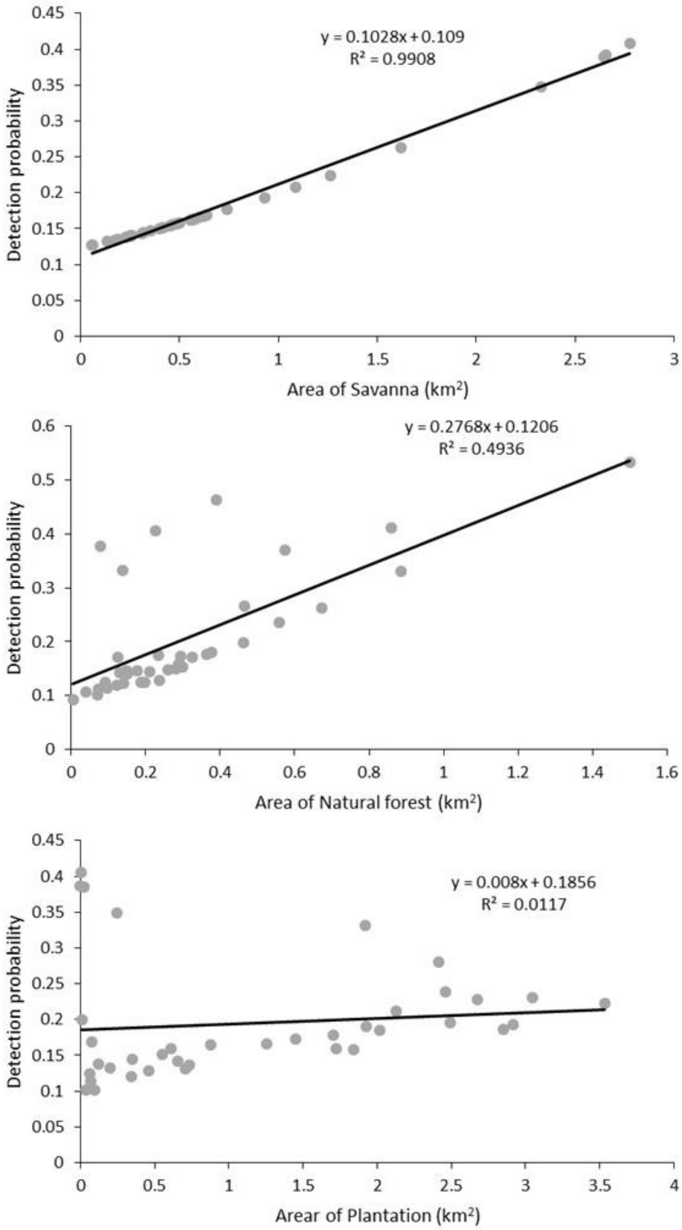

Figure 4.5: The effect of site covariates, a) area of savanna, b) natural forest and c) exotic tree plantations on detection probability of Long-crested Eagles in a human-modified landscape in KwaZulu-Natal, South Africa.

The summed AIC weights of covariates associated with occurrence of Long-crested Eagles were croplands: w_i = 0.89, wetlands: w_i = 0.13, built environment: w_i = 0.09 and grasslands: w_i = 0.09. For detection probability the summed weights across all models were savanna: w_i = 0.91, natural forests: w_i = 0.40 and exotic tree plantations: w_i = 0.01. Since the occupancy (Fig. 4.2) had not levelled off at the last survey occasion, we used the detection probability value of the simplest model (psi(.),p(.)), p = 0.22 to determine the minimum number of visits per site required to infer absence. The minimum number of visits required was found to be 12.06.

Table 4.1. Summary of Long-crested Eagle model selection parameters in a human-modified landscape in the Midlands of KwaZulu-Natal, South Africa. Models were ranked according to AICc values, best performing models with smaller AICc at the top. (Abbreviations: CPS = cropland, SAV = savanna, NFT = natural forest, PTN = exotic plantation, BLT = built up environment, WET = wetland and GRS = grassland. AICc = Akaike's information criterion adjusted for small sample size, AIC wgt = AIC weight, LL = LogLike, ψ (psi) = occupancy estimate, p = detection probability, SE = standard error).

Model	**AICc**	**ΔAICc**	**AIC wgt**	**ψ ± SE**	**p ± SE**
psi(CPS),p(SAV)	255.71	0.00	0.0844	0.77 ± 0.10	0.18 ± 0.06
psi(CPS),p(SAV+NFT)	255.81	0.10	0.0803	0.76 ± 0.09	0.21 ± 0.06
psi(CPS),p(SAV+PTN)	257.19	1.48	0.0403	0.75 ± 0.10	0.19 ± 0.05
psi(CPS),p(SAV+BLT)	258.11	2.40	0.0254	0.77 ± 0.11	0.18 ± 0.05
psi(CPS+WET),p(SAV)	258.11	2.40	0.0254	0.76 ± 0.12	0.18 ± 0.04
psi(CPS),p(SAV+NFT+PTN)	258.12	2.41	0.0253	0.76 ± 0.09	0.21 ± 0.06
psi(CPS+BLT),p(SAV)	258.15	2.44	0.0249	0.78 ± 0.12	0.18 ± 0.04
psi(CPS),p(SAV+WET)	258.23	2.52	0.0239	0.77 ± 0.11	0.18 ± 0.04
psi(CPS+GRS),p(SAV)	258.24	2.53	0.0238	0.77 ± 0.12	0.18 ± 0.04
psi(CPS+NFT),p(SAV)	258.26	2.55	0.0236	0.77 ± 0.11	0.18 ± 0.03

Model	AICc	ΔAICc	AIC wgt	ψ ± SE	p ± SE
psi(CPS),p(SAV+CPS)	258.28	2.57	0.0234	0.78 ± 0.10	0.18 ± 0.04
psi(CPS),p(SAV+GRS)	258.36	2.65	0.0224	0.77 ± 0.10	0.18 ± 0.04
psi(CPS+NFT),p(SAV+NFT)	258.36	2.65	0.0224	0.77 ± 0.10	0.21 ± 0.05
psi(CPS+SAV),p(SAV)	258.37	2.66	0.0223	0.78 ± 0.14	0.18 ± 0.04
psi(CPS+PTN),p(SAV)	258.38	2.67	0.0222	0.77 ± 0.16	0.18 ± 0.04
psi(CPS),p(SAV+NFT+GRS)	258.43	2.72	0.0217	0.77 ± 0.09	0.21 ± 0.06
psi(CPS+BLT),p(SAV+NFT)	258.49	2.78	0.0210	0.77 ± 0.10	0.21 ± 0.05
psi(CPS+GRS),p(SAV+NFT)	258.56	2.85	0.0203	0.76 ± 0.10	0.21 ± 0.05
psi(CPS+WET),p(SAV+NFT)	258.57	2.86	0.0202	0.76 ± 0.11	0.21 ± 0.05
psi(CPS+PTN),p(SAV+NFT)	258.58	2.87	0.0201	0.78 ± 0.12	0.20 ± 0.05
psi(CPS),p(SAV+NFT+CPS)	258.61	2.90	0.0198	0.76 ± 0.09	0.21 ± 0.06
psi(CPS),p(SAV+NFT+BLT)	258.61	2.90	0.0198	0.77 ± 0.09	0.20 ± 0.06
psi(CPS+SAV),p(SAV+NFT)	258.63	2.92	0.0196	0.77 ± 0.11	0.21 ± 0.05
psi(CPS),p(SAV+NFT+WET)	258.64	2.93	0.0195	0.76 ± 0.09	0.20 ± 0.05
psi(CPS+PTN),p(SAV+PTN)	259.16	3.45	0.0150	0.74 ± 0.10	0.20 ± 0.05
psi(CPS+WET),p(SAV+PTN)	259.32	3.61	0.0139	0.74 ± 0.12	0.20 ± 0.05
psi(CPS+GRS),p(SAV+PTN)	259.44	3.73	0.0131	0.75 ± 0.11	0.20 ± 0.05
psi(.),p(.)	262.2	6.49	0.0033	0.62 ± 0.10	0.22 ± 0.29

Table 4.2. Untransformed estimates of coefficients for covariates (Beta's) from the best occupancy and detection probability models for Long-crested Eagles in the human-modified landscape in the Midlands of KwaZulu-Natal, South Africa.

	Site occupancy			Site detection probability		
	Covariates	β estimate	Standard Error	Covariates	β estimate	Standard Error
Model 1	Intercept	3.37	2.21	Intercept	-1.55	0.19
	Cropland	4.78	2.55	Savanna	4.95	2.24
Model 2	Intercept	3.39	1.83	Intercept	-1.46	0.19
	Cropland	4.95	2.24	Savanna	0.45	0.15
				Natural Forest	0.4	0.24
Model 3	Intercept	2.87	1.61	Intercept	-1.48	0.2
	Cropland	4.39	2.05	Savanna	0.49	0.16
				Plantation	0.26	0.24

4.4 Discussion

Cropland was the only land cover variable associated with the occupancy of Long-crested Eagles in the study area in the present study. This result was consistent with our prediction that these eagles would benefit from croplands. A similar result was also obtained for Barn Owls (*Tyto alba*) in southern Idaho, USA, where their occupancy was positively associated with the amount of cropland (Regan et al. 2018). The eagles in this study probably took advantage of the availability of rodent prey in or near cultivated areas (Buij et al. 2012; Preston 1990). The Black-shouldered Kite (*Elanus caeruleus*) is another resident raptor known to extensively use croplands and its apparent range expansions in Europe may be linked to its use of agricultural landscapes (Howard et al. 2016; Mendelsohn and Jacksic 1989; Balbontín et al. 2008). Similarly, the apparent increase in relative abundance of Long-crested Eagles in South Africa, as suggested by increasing SABAP reporting rates across the country, can probably be attributed in part to the increase in agricultural land or cropland. The use of cropland by these eagles, however, is likely to be dependent on the amount of plant canopy cover. Swainson's Hawks in North America were reported to forage over cultivated fields only after harvesting when prey was less concealed (Bechard 1982).

Surprisingly, covariates such as savanna, wetlands and grassland which all represent open natural habitats did not significantly influence the occupancy of Long-crested Eagles in human-modified landscapes of KwaZulu-Natal. Based on the data collected we cannot give conclusive explanations, but we speculate that in agricultural landscapes the eagles strategically choose territories that comprises natural habitat patches as well to be able to access prey throughout the year, especially during seasons when plant canopy prevents them from accessing prey within croplands. This hypothesis is supported by results of telemetry data in the previous chapter (Chapter 3) which show that at the home range scale Long-crested Eagles disproportionately use savanna, wetland and grassland habitats. The value of natural habitats within a human-modified landscape is that they add to the heterogeneity of the landscape, making food and breeding resources available to the birds when needed (Vickery and Arlettaz 2012).

Repeat surveys are more suitable for raptors since raptors often occur at low densities and are likely to be missed during a single survey. The method used in this study accounts for imperfect detection (MacKenzie et al. 2002; Bailey et al. 2004). Detection probability was low ($p = 0.2$) as expected, however, increasing the number of repeat surveys gradually improved the detection probability. Important variables in the competing models for detection were savanna, natural forests and exotic tree plantations, with savanna having the greatest support of the three. The strong positive effect of savanna on detection can be attributed to the openness of the savanna habitat which improves detection probability and is most likely to be used by Long-crested Eagles as an open habitat species (Ferguson-Lees and Christie 2001). The two other variables received less support in terms of AIC weights. This confirmed the point highlighted by

Murn and Holloway (2016) that site covariates may contribute relatively little to detection probability as detection probability can also be influenced by survey specific covariates such as time and speed of observer during the survey. In this study we could not assess the effect of time on detection probability because road transects were surveyed in both directions to make up one survey occasion. The speed of the survey vehicle was kept at a mean speed of 70.1 ± 53.7 km/h for safety reasons, and this speed may be another variable that is important for detection probability as found by Murn and Holloway (2016). The minimum number of visits needed to conclude that a site is not occupied was found to be 12, given the detection probability of Long-crested Eagles in the study area. Whilst the number may seem high, it is necessary for quality wildlife monitoring programs. The minimum number of surveys is also expected to decrease when the detection probability is higher which may happen in other study areas or with other species, as reported for Egyptian Vultures (*Neophron percnopterus*) with a mean detection probability of 0.453 yielding a minimum of five visits (Olea and Mateo-Tomás 2011).

The results of the present study suggest that the behavioural flexibility and adaptations of Long-crested Eagles to foraging around croplands is one of the key factors for their apparent persistence and possible increase in their abundance in KwaZulu-Natal (Ferguson-Lees and Christie 2001). The suitability of croplands is probably reliant on the availability of natural habitat patches in close proximity, ensuring steady supply of prey throughout the year. Devictor and Jiguet (2007) demonstrated the importance of surrounding habitats, showing that the diversity of surrounding habitats influenced species richness in the main habitat. Therefore, heterogeneous surrounding habitats have a stabilising effect on birds occurring in croplands (Devictor and Jiguet 2007). Future studies should assess if habitat associations differ between juveniles and adults as it reported for the Pallid Harrier (*Circus macrourus*) and other Palaearctic raptors (Buij et al. 2012).

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CHAPTER 5

Causes of admission to a raptor rehabilitation centre and factors that can be used to predict likelihood of release

Machawe I. Maphalala[1], Ara Monadjem[2], Keith L. Bildstein[3], Ben Hoffman[4] and Colleen Downs[1*]

1. *Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, Pietermaritzburg, South Africa*
2. *Department of Biological Sciences, University of Eswatini, Kwaluseni, Eswatini*
3. *Acopian Centre for Conservation Learning, Hawk Mountain Sanctuary, USA*
4. *Raptor Rescue, Pietermaritzburg, South Africa*

Formatted for Animal Welfare

* Corresponding Author: Colleen T. Downs

Email: downs@ukzn.ac.za

Tel: +27 (0)33 260 5127

ORCID: http://orcid.org/0000-0001-8334-1510

Other emails: machawe158@gmail.com; aramonadjem@gmail.com; keith.bildstein@gmail.com; rescue@africanraptor.co.za

Running header: Causes of admission to a raptor rehabilitation centre and likelihood of release

Abstract

People around the world rescue injured animals, or animals perceived to be helpless or in human related danger, by handing them over to rehabilitation centres. Admission records of rescued birds are an important source of information for tracking the prevalence of human related threats to wildlife. In this study we used admission records from 2015 to 2016 to review the causes for raptor admissions to a raptor rehabilitation centre in Pietermaritzburg, South Africa and determined factors that can be used to predict the outcome of rehabilitation. During the study period, 242 raptors were admitted to the centre. The major causes of admission to the rehabilitation centre were collision related injuries (52.1%), grounded birds (11.6%) and orphaned chicks (9.5%). The most common casualties were Spotted Eagle-Owl *Bubo africanus* (22.7%), Yellow-billed Kite *Milvus migrans parasitus* (12%), Jackal Buzzard *Buteo rufofuscus* (10.3%) and Western Barn Owl *Tyto alba* (9.5%). The rehabilitation centre had a relatively high release rate of 48%. 'Reason for admission' was a significant predictor of the outcome of rehabilitation and other variables were not. Raptors with no severe injuries such as orphaned chicks and grounded birds were more likely to have successful rehabilitation treatment than raptors suffering from collision injuries. Results of the present study can be used by wildlife rehabilitators to develop triage guidelines for raptors admitted to rehabilitation centres. To ensure the welfare of admitted animals, we recommend the sharing of treatment protocols between rehabilitation centres and the opening of more specialised rehabilitation centres.

Keywords: Raptor Rescue, rehabilitation outcome, binary logistic regression, KwaZulu-Natal

5.1 Introduction

Human related mortality risks add to those that raptors are exposed to in the wild such as inclement weather, diseases, predation and accidents that occur when adults collide with obstacles or when fledglings are learning to fly (Dwyer *et al.* 2018). Globally, human landscapes are characterised by anthropogenic structures such as buildings, energy and road infrastructure that increase collision risk for birds of prey living in or near such environments (Donázar *et al.* 2016). For example, collisions with vehicles, windows, fences and powerlines are some of the leading causes of raptor mortality in human landscapes (Hager 2009, Dwyer *et al*. 2018, Smith *et al.* 2018). One way to track the prevalence of human related threats to raptors is through admission records at wildlife rehabilitation centres (Wendell *et al.* 2002, Mazaris *et al.* 2008, Mariachera *et al.* 2016, Arent *et al.* 2018). Animals that are injured or perceived to be in human related danger are rescued, rehabilitated and released back to the wild (Pyke & Szabo 2018). Rehabilitation records in some cases can under represent some threats because sick or injured birds are more likely to be brought in than dead birds (Rodríguez *et al.* 2010) and some birds may not be found by humans. However, the information on animals that do get admitted to rehabilitation centres is important because they provide unique research opportunities that may contribute to species conservation by improving understanding of anthropogenic impacts (Pyke & Szabo 2018).

Although the ultimate goal of rehabilitation is to release animals back to the wild after successful treatment (Sarà 2014), animals that have little chance of recovery due to severe injuries should be euthanised quickly, to prevent further suffering, through a triage decision process (Molony *et al.* 2007, Kelly *et al.* 2011, Mullineaux 2014). Ideally, the triage process involves a veterinary examination but trained non-veterinary staff can also make triage decisions based on clear guidelines (Mullineaux 2014). Studies investigating factors that influence the outcome of rehabilitation are important to inform the triage process so that resources can be directed to individuals that have a high probability of recovering (Molony *et al*. 2007). Molony *et al*. (2007) reported that the chances of survival in care until release were predicted by the severity of the symptoms of the injury. The outcome of rehabilitation was influenced by the season of admission for adult African Penguins in South Africa (*Spheniscus demersus*) (Parsons *et al.* 2018). Age and weight on admission were also found to be significant predictors of likelihood of release elsewhere (Kelly *et al*. 2011).

In this study we reviewed the causes for raptor admissions to a specialist raptor rehabilitation centre in KwaZulu-Natal, South Africa, using admission records. We then determined if the outcome of rehabilitation can be predicted from information obtained from the admission records in order to inform triage decisions. A previous long-term study conducted in the same rehabilitation centre by Thompson *et al.* (2013) used admission records (from 2004-2011) to identify most common threats to raptors and species most affected. The study reported that the main causes of admission were collisions with vehicles and buildings. Thirty-nine raptor species were admitted to the centre during the study period including species such as Spotted Eagle-Owls (*Bubo africanus*), Western Barn Owls (*Tyto alba*) and Yellow-billed Kites (*Milvus migrans parasitus*) (Thompson *et al*. 2013).

In addition to identifying causes for morbidity and mortality for raptors, the present study adds to the findings of the long-term study by assessing the factors influencing the outcome of rehabilitation. We examined if factors such as reason for admission, season of admission and raptor activity time (diurnal or nocturnal) can be used to predict the outcome of rehabilitation. Reason for admission can be an important predictor for rehabilitation outcome because some animals may have been rescued with no severe injuries and therefore can be expected to fully recover (Molony *et al*. 2007, Wimberger & Downs 2010, Kelly *et al*. 2011). In some cases the outcome of rehabilitation is influenced by the health condition of the animal before the injury or rescue as some adults rescued in spring or summer for example, may be in poorer health condition immediately after breeding (Parsons *et al.* 2018). Nocturnal raptors are often dazzled by headlights as they hunt along roads making them vulnerable to collisions with vehicles and fences (Anderson 2000, Molina-López *et al*. 2011, Hernandez *et al*. 2018).

5.2 Methods

5.2.1 Study area and data collection

The data used in this study were obtained from admission records of birds of prey admitted to the Raptor Rescue Rehabilitation Centre in Pietermaritzburg (29°40’32”S 30°30’52”E), South Africa, from 2015 to 2016, a facility that rehabilitates both diurnal and nocturnal birds of prey. In addition to injured birds brought in by the public or picked up by staff members, the rehabilitation centre also receives transferred raptors from other rehabilitation centres in the region such as FreeMe KZN Wildlife Rehabilitation Centre (Thompson *et al*. 2013). Information obtained from admission records included date of admission, reason for admission, species name, area where bird was found and outcome of rehabilitation. Reasons for admission were grouped into the following categories, orphaned chicks (nestlings up to age of fledglings), Collisions (with motor vehicles, windows and other human infrastructure), diseased, electrocuted, found inside a house (trapped inside a building), grounded birds (because of inclement weather and non-visible injuries or unknown cause), poisoned (suspected poisoning), shot, poached (confiscated from locals), stuck (entangled) and unknown (reason not recorded)

(Table 5.1). Admission dates were presented as seasons: spring (September – November), summer (December – February), autumn (March – May) and winter (June – August). For this study the outcome of rehabilitation was limited to two: 1) released back to the wild; or 2) died in care (including euthanised birds).

5.2.2 Statistical analyses

The binary logistic regression function on IBM SPSS Statistics 20.0 (IBM, Armonk, USA) was used to determine if the predictor variables, reason for admission, whether a bird was a diurnal raptor or not, and season of admission were significant predictors of the outcome of rehabilitation. The outcome of rehabilitation (released or died) was considered as a dependent variable. Multicollinearity between variables was tested using the linear regression command in IBM SPSS Statistics, with rehabilitation outcome as the dependent variable and 'reason', 'diurnal' and 'season' as independent variables. There was relatively little multicollinearity as all tolerance values were above 0.95. Only data with no missing information were used in the regression model. Furthermore, variables with fewer than 10 admission cases were not included in the model. This eliminated from the regression data reasons like 'poached', 'poisoned', 'diseased', 'electrocuted', 'shot', 'found inside house' and 'stuck' which accounted for fewer than 10 cases each (Table 5.1, 5.2). Odds ratios (the ratio of P [released] to P [died]) were used to present effect sizes and values greater than one indicated that a bird was more likely to be released than die in care (Molony *et al. 2007*). Whereas values less than one indicated that an admitted bird was less likely to have successful treatment. In order to calculate odds ratios within a categorical variable, the first category within the variable was assigned as a reference for the other remaining categories (Molony *et al*. 2007). Model fit was assessed using the Hosmer-

Lemeshow, Cox and Snell and Nagelkerke R square statistics. There was no significant difference between the fitted model and the data, suggesting good model fit.

Table 5.1: Reasons for admission of raptors to Raptor Rescue, KwaZulu-Natal in 2015 and 2016. Percentages indicate the proportion of raptors admitted due to the corresponding reason.

Reason	**Description**	**Number of birds**			**%**
		Diurnal	**Nocturnal**	**Total**	
Chick	Orphaned, Fell from nest, grounded fledgling	2	21	23	9.5
Collision	Collision with vehicles, wall, windows, fence	76	50	126	52.1
Diseased	Infections	3	3	6	2.5
Electrocuted	Electrocuted on powerlines	4	0	4	1.7
Found inside a house	Trapped inside building or structure	6	4	10	4.1
Grounded	Not able to fly, no obvious injuries	19	9	28	11.6
Other Injuries	Visible injuries from e.g. from dog attack, hailstorms	8	6	14	5.8
Poached	Confiscated from locals	4	1	5	2.1
Poisoned	Suspected food poisoning	12	0	12	5.0
Shot	Shot	5	0	5	2.1
Stuck	Entangled, stuck in dam	6	0	6	2.5
Unknown (not recorded)	Admission reason not recorded	2	1	3	1.2
Total		147	95	242	100.0

5.3 Results

5.3.1 Species of raptors admitted and causes of admissions

In the two years, 2015 and 2016, 242 raptors were admitted to Raptor Rescue, representing 33 raptor species (Table 5.3). Most raptors (52.1%) were admitted because of collisions related injuries, i.e. collisions with vehicles, walls, windows and fences. Other reasons for admission were grounded birds (11.6%) and orphaned chicks were 9.5% (Table 5.1). The most common admissions with over 20 admissions per species were Spotted Eagle-Owl *Bubo africanus* (22.7%), Yellow-billed Kite *Milvus migrans parasitus* (12%), Jackal Buzzard *Buteo rufofuscus* (10.3%) and Western Barn Owl *Tyto alba* (9.5%) (Table 5.3). Thirty nine percent (95 birds) of the admitted birds were nocturnal and 61% (147 birds) were diurnal raptor species. Notably, nocturnal raptors consisted of a higher proportion of orphaned chicks (22.1%) than diurnal raptors (1.4%).

5.3.2 Outcome of rehabilitation

Of the 242 raptors admitted, 116 (47.9%) were released back into the wild, 51 (21.1%) were euthanised and 40 (16.5%) died from their injuries. The outcomes of the remaining birds were either unknown/unrecorded (9.5%) or kept as long-term captives (5%). Long term captives were kept at the African Bird of Prey Sanctuary or Predatory Bird Centre for public education purposes. Out of the 95 nocturnal raptors, 56 (58.9%) were released, 32 (33.7%) died in care (died from injuries or euthanised), 3 (3.2%) kept as long-term captives and the outcome of 4 (4.2%) was unknown or not recorded. Out of 147 diurnal raptors, 60 (40.8%) were released, 59 (40.1%) died in care, 9 (6.1%) kept as long-term captives and 19 (12.9%) of unknown outcome.

Table 5.2: Descriptions of all variables selected to be used in the binary logistic regression for raptors admitted to Raptor Rescue.

Variable	Description	
Outcome (categorical)		Dependent variable: Released = 1, Died = 0
Diurnal (categorical)		Diurnal raptor = 1 and Nocturnal raptor = 0
Season (categorical)		
	Spring	September - November
	Summer	December - February
	Autumn	March - May
	Winter	June - August
Reason (categorical)		
	Collision	Collision with vehicles, wall, windows, fence
	Chick	Orphaned, Fell from nest, grounded fledgling
	Grounded	No obvious injuries
	Other Injuries	Visible injuries from e.g. from dog attack, hailstorms

5.3.3 Logistic regression

Only 173 records were used in the final model after filtering out variables with fewer than 10 cases or removing records with missing information (i.e. rehabilitation outcome and reason for admission). The model was significant (χ^2 = 20.56, df = 7, p = 0.004) when all the independent variables were included. The model correctly predicted 52.6% of the number of birds that died in care and 71.1% of the birds that were released back into the wild. The overall accuracy of the model was 63%. Only the variable ‘reason’ was a significant predictor of the outcome of rehabilitation. Orphaned chicks were 7.4 times more likely to be released than birds that were admitted due to collision related injuries. Additionally, birds admitted because they were grounded were 3.6 times more likely to be released than birds admitted due to collision injuries (Table 5.4). Other reasons such as ‘other injuries’ were not significant predictors of rehabilitation outcome.

Table 5.3: All raptor species admitted to Raptor Rescue Rehabilitation Centre, South Africa, from 2015 to 2016.

Common name	**Latin name**	**2015**	**2016**	**Total**	**%**
African Fish Eagle	*Haliaeetus vocifer*	2	2	4	1.7
African Goshawk	*Accipiter tachiro*	2	4	6	2.5
African Grass-Owl	*Tyto capensis*	1	0	1	0.4
African Harrier-Hawk	*Polyboroides typus*	4	1	5	2.1
African Marsh Harrier	*Circus ranivorus*	0	1	1	0.4
African Wood Owl	*Strix woodfordii*	5	4	9	3.7
Amur Falcon	*Falco amurensis*	3	3	6	2.5
Black Sparrowhawk	*Accipiter melanoleucus*	6	9	15	6.2
Brown Snake Eagle	*Circaetus cinereus*	1	0	1	0.4
Cape Eagle-Owl	*Bubo capensis*	1	3	4	1.7
Cape Vulture	*Gyps coprotheres*	3	8	11	4.5
Common Buzzard (steppe)	*Buteo buteo vulpinus/menetriesi*	2	3	5	2.1
Crowned Eagle	*Stephanoaetus coronatus*	2	3	5	2.1
Eurasian Hobby	*Falco subbuteo*	0	1	1	0.4
European Honey Buzzard	*Pernis apivorus*	0	1	1	0.4
Jackal Buzzard	*Buteo rufofuscus*	3	22	25	10.3
Lanner Falcon	*Falco biarmicus*	3	3	6	2.5
Lappet-faced Vulture	*Torgos tracheliotus*	0	1	1	0.4
Little Sparrowhawk	*Accipiter minullus*	1	5	6	2.5
Long-crested Eagle	*Lophaetus occipitalis*	0	1	1	0.4
Marsh Owl	*Asio capensis*	1	1	2	0.8
Martial Eagle	*Polemaetus bellicosus*	0	1	1	0.4
Palm-nut Vulture	*Gypohierax angolensis*	0	1	1	0.4
Peregrine Falcon	*Falco peregrinus*	0	3	3	1.2
Secretary Bird	*Sagittarius serpentarius*	2	2	4	1.7
Southern Banded Snake Eagle	*Circaetus fasciolatus*	0	1	1	0.4
Southern White-faced Owl	*Ptilopsis granti*	1	1	2	0.8
Spotted Eagle-Owl	*Bubo africanus*	33	22	55	22.7
Verreaux's Eagle	*Aquila verreauxii*	1	1	2	0.8
Wahlberg's Eagle	*Hieraaetus wahlbergi*	0	2	2	0.8
Western Barn Owl	*Tyto alba*	5	18	23	9.5
White-backed Vulture	*Gyps africanus*	0	3	3	1.2
Yellow-billed Kite	*Milvus migrans parasitus/aegyptius*	15	14	29	12.0
Total		97	145	242	100.0

Table 5.4: Summary of significant binary logistic regression models for raptors admitted to Raptor Rescue Rehabilitation Centre.

Variable	B	S.E.	Wald	df	P-Value	Odds ratio (95% C.I.)
Reason (Collision)			15.155	3	0.002	
Reason (Chick)	2.002	0.649	9.512	1	0.002	7.407 (2.075-26.443)
Reason (Grounded)	1.282	0.473	7.352	1	0.007	3.605 (1.427-9.11)
Constant	0.924	0.299	9.529	1	0.002	2.518

5.4 Discussion

Our study demonstrated that collisions with human infrastructure are a leading cause for raptor morbidity in KwaZulu-Natal, accounting for more than half of all admissions. Furthermore, birds that suffered from collision injuries were significantly less likely to be released than orphaned and grounded birds. The results of the present study corroborated previous findings by Thompson *et al*. (2013) in the same rehabilitation centre, which also indicated that collisions were the most prevalent causes of raptor admissions. They are also consistent with findings from other rehabilitation centres. For example, collision with windows and vehicles accounted for over 70% of Eurasian Sparrowhawk (*Accipiter nisus*) admissions in England (Kelly & Bland 2006). In Tenerife, collisions were also the most frequent cause of admission (Rodríguez *et al*. 2010). It was suggested that collision incidences increased during the study period, possibly due to increasing infrastructural development in the Canary Islands (Rodríguez *et al*. 2010). The current study shows that collision related injuries pose a more serious mortality risk than any other cause of morbidity as raptors that suffered from collision injuries were less likely to be successfully rehabilitated. Fractures resulting from collisions are often severe and rehabilitators opt to euthanise birds suffering from such injuries where full recovery is less likely (Kelly & Bland 2006).

The feeding habits of some raptors increases their susceptibility to specific morbidity risks (Wendell *et al*. 2002) such as collisions. Raptors that hunt for garden birds, for example, are more likely to collide with buildings or windows as they pursue their prey (Hager 2009, Dwyer *et al*. 2018). Motor vehicle collisions were expected to affect raptors that hunt on the side of the road or feed on roadkill. Such casualties in the present study included Jackal Buzzards (*Buteo rufofuscus*) and Yellow-billed Kites (*Milvus migrans parasitus*) which may scavenge carcasses (Dean & Milton 2003). Bullock *et al.* (2011) recorded Spotted Eagle-Owls (*Bubo africanus*) as one of the most common mortalities along roads in the arid Kalahari (South Africa) which they attributed to the blinding effect of car headlights on this nocturnal species. Scavenging raptors are also vulnerable to poisoning, although the percentage of such casualties in this study was small. It has been suggested that signs of weakness in vultures may be due to ingestion of low doses of a toxin (Naidoo *et al.* 2011). However, since poisoning can be difficult to detect in some cases where birds have been lightly poisoned (Naidoo *et al*. 2011), the number of poisoned birds was likely to have been an underestimate. Also, people were less likely to submit birds to the centre that were already dead.

Overall the centre's release rate of 48% was comparable to other studies Komnenou *et al.* (2005), Knight *et al.* (2009), Molina-López *et al.* (2013), and Montesdeoca *et al.* (2017) where 57%, 57%, 47% and 58% of the admitted raptors were released back to the wild, respectively. The release rate reported in this study was higher than that of the previous study by Thompson *et al*. (2013) which was 38%. Kelly and Bland (2006) reported a much lower release rate of 24% for Eurasian Sparrowhawks in England. During the study period the rehabilitation centre had a higher release rate for nocturnal raptors (59%) than diurnal raptors (41%). This difference can possibly be explained by the high proportion of orphaned chicks in the nocturnal raptors group which had the highest likelihood of being released.

Diligent keeping of admission records is crucial for developing an evidence-based triage protocol (Grogan & Kelly 2013). This study has demonstrated that the reason for admission to a rehabilitation centre can be a significant predictor of the outcome rehabilitation. Contrary to this study, Kelly and Bland (2006) found that clinical diagnosis was a significant predictor of rehabilitation outcome, not reason for admission. Ideally, it would be best to test both predictors ('reason for admission' and 'clinical diagnosis'), however, it was not possible to use both predictors in this study because they were either not clearly differentiated from each other in the medical records or information on clinical diagnosis was missing. The effect of 'age' and weight on admission' could not be assessed in this study because they were not recorded for most of the birds, but such variables have been suggested to be significant predictors of likelihood of release in Woodpigeons (*Columba palumbus*) (Kelly *et al*. 2011). Knowing the factors that can be used to predict rehabilitation outcomes can help the triage decision process and thus ensuring the release of birds that have similar chances of survival to their wild conspecifics as recommended by the Royal Society of Prevention of Cruelty to Animals (Grogan & Kelly 2013). The present study has highlighted reasons for admission as a significant predictor of the likelihood of release from a rehabilitation centre.

5.5 Recommendations for future studies

Since successful rehabilitation requires that the rehabilitated individual must be successfully integrated into the wild (Kelly & Bland 2006, Grogan & Kelly 2013), post release monitoring is critical to truly evaluate the contribution of rehabilitation centres to the welfare and conservation of animals. Rehabilitated Cape Vultures (*Gyps coprotheres*) for example, were found to have significantly lower survival rates than conspecifics of similar age (Monadjem *et al.* 2014). Where funds are available radio-tracking and ring recovery data can yield detailed short to long term information on the survival rates of rehabilitated raptors (Kelly & Bland 2006, Grogan & Kelly 2013).

5.6 Animal welfare implications

Although studies based on rehabilitation centre records tend to overestimate human related threats such as collisions (Wendell *et al*. 2002), a rise in number of admissions may be indicative of problem areas for some species or severity of particular threats and thus inspiring conservation actions that benefit wildlife (Pyke & Szabo 2018). People that rescue injured wild animals believe that by handing them over to wildlife rehabilitators they have helped save a suffering animal. This then places a huge responsibility on rehabilitation centres to do their best to save animals committed to their care. In order to prevent or limit substandard wildlife rehabilitation services, we suggest that communication between rehabilitation centres should be improved so that less experienced centres can benefit from more experienced rehabilitators through sharing of treatment protocols. The authors of this study support the recommendation by Wimberger *et al.* (2010) that the government, through knowledgeable hired wildlife officers, could enforce minimum standards for rehabilitation and then in return, the government could sponsor or subsidise post release monitoring for centres that meet those standards.

Wildlife rehabilitators also have a responsibility to release animals that will be able to survive on their own in the wild. For rescued animals it is imperative to determine their prognosis and suitability for rehabilitation and release as soon as possible to prevent unnecessary suffering and stress during treatment and after release (Vogelnest & Woods 2008). The present study and other studies have shown that the nature of injuries can be useful in determining the prognosis of rescued animals (Molony *et al.* 2007, Kelly *et al.* 2011). The relatively high release rate at Raptor Rescue maybe indicative of improved treatment protocols as result of the centre being a specialist for birds of prey. We therefore recommend the opening of more specialised rehabilitation centres for efficient rehabilitation of injured animals.

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CHAPTER 6

Conclusions

6.1 Overview

As in many parts of the world, habitat transformation in KwaZulu-Natal is happening at an enhanced rate and some of the key drivers are agriculture, timber plantations, built environment, dams and mines (Jewitt et al. 2015). Habitat transformation is often accompanied by biodiversity loss as some of these transformations take place in biodiversity hotspots (Boon et al. 2016; Kietzka et al. 2018). Landscapes that were once heterogeneous are replaced by simplified landscapes that contain less habitat types under habitat transformation, resulting in loss of biodiversity, ecological function and ecosystem services (Landis 2017). Retention of natural habitat patches (including natural forests, shrub patches and riparian corridors) has been found to be beneficial to biodiversity in agricultural landscapes (Benton et al. 2003; Wilson et al. 2017) and similarly, urban green spaces in urban landscapes (Beninde et al. 2015). More empirical studies are needed to quantify the use of these human-modified landscapes by different taxonomic groups to make recommendations that are supported by evidence. Using modern technology, geographic positioning system telemetry, more accurate information about the movement of animals in these habitats can be obtained and can be used to identify critical habitats for wildlife. The present study quantified habitat use of Long-crested Eagles (*Lophaetus occipitalis*) within home ranges in human-modified landscapes, predominantly agricultural landscapes. Moreover, factors influencing the occupancy of Long-crested Eagles were investigated at landscape scale.

6.2 Summary of findings

Although habitat transformation is negatively affecting many threatened raptor species (McClure et al. 2018), Long-crested Eagles (*Lophaetus occipitalis*) appear to respond positively to croplands in KwaZulu-Natal Province. This result supports the observation that habitat transformation does not affect all raptors in the same way as others do benefit from some of the land use changes if they provide foraging and nesting resources (Cardador et al. 2011; Cardador et al. 2014). The present study has demonstrated that at landscape level, Long-crested Eagle site occupancy was positively associated with area of cropland and therefore, the apparent increase in abundance as shown by Southern African Bird Atlas Project data can partly be attributed to increase in agricultural land (Chapter 4).

At a smaller scale ‘or home range’ scale however, the study has shown that Long-crested Eagles preferred natural habitats such as wetlands, savanna, natural forest and natural forest edge (Chapter 3) which is consistent with their known habitat preference (Ferguson-Lees and Christie 2001; Oberprieler 2012). As open habitats, wetlands, natural forest edge and savanna were probably used as foraging habitats and natural forests as roosting and nesting habitats. Overall, Long-crested Eagles appear to be using edges of cultivated fields that have natural vegetation and hunting perches, compensating for the lack of perches within fields. The results further highlight the importance of the proximity of foraging habitats to nesting habitats, i.e. complimentary habitats. In such a setup, the eagles do not have to make long trips between foraging habitats and nesting sites (Michel et al. 2017; Tucker et al. 2019). This was demonstrated by the relatively small home range sizes reported in this study, 420 ± 180 ha for males and 315 ± 161 ha for females (Chapter 2). Small home ranges may be an indication of high quality habitat with high abundance of prey (Cardador et al. 2014; Kouba et al. 2017). The availability of both natural habitats and cropland within home ranges allowed the eagles to switch foraging habitats when prey was less accessible in one habitat due to thickness of vegetation or other factors such as seasonal fluctuations in prey populations (Valkama et al. 1995; Vickery and Arlettaz 2012).

Human-modified landscapes are not without challenges to species living in them. One of the key human related threats is the high risk of collision with vehicles and buildings. Raptors that suffered collision injuries were found to be less likely to have successful rehabilitation than orphaned or grounded birds (Chapter 5). Long-crested Eagles are vulnerable to collisions, in particular vehicle collisions because they frequently use utility poles along roads as hunting perches (pers. obs.). Other threats include electrocution on powerlines, persecution or disturbance at nesting sites and poisoned prey. The presence of Long-crested Eagles in human-modified landscapes benefits humans by supressing rodent pests and raising the aesthetic value of the landscapes. In the face of accelerated loss of natural habitats, people can work together to make human landscapes more habitable to wildlife.

6.3 Conservation recommendations

In recent times, Long-crested Eagles are increasingly associated with farmlands (Ferguson-Lees and Christie 2001; Johnson 2005; Oberprieler 2012). Nesting sites and foraging habitats are the key resources needed to promote the persistence of this species (Vickery and Arlettaz 2012). That said, crop farms should avoid clearing all-natural forests with potential nesting trees, i.e. tall large trees. Nesting trees may also include exotic species. Nesting sites should not be disturbed, especially during the breeding season. Often property owners cut down large old trees and, in the process, destroy nests and their contents. To avoid disturbing nesting eagles, potential nesting trees within private properties should be checked for nests first before being cut. Intensified land use that involves complete removal of natural vegetation should be avoided to maintain the heterogeneity of the landscape and thus providing foraging habitats for Long-crested Eagles. Michel et al. (2017) reported that the availability of food resources close to nesting sites increased the productivity of Little Owls (*Athene noctua*). Retaining natural habitats and growing different kinds of crops in agricultural mosaics will most likely enhance food availability/accessibility for these eagles and other species dependant on such landscapes. Long-crested Eagles are likely to benefit from management practices that keep natural grasslands short, such as hay farms.

Given the prevalent threats in human-modified landscapes, the role of rehabilitation centres in the conservation of raptors cannot be overlooked. As suggested by Wimberger and Downs (2010), good management practice for rehabilitation centres would be teaching the public to leave uninjured juveniles in the wild. The present study showed that young and grounded raptors have a greater likelihood of successful rehabilitation. Therefore, in cases where triage is necessary, rehabilitation centres can make such decisions based on the nature of the injuries.

6.4 Future research

Future work could investigate Long-crested Eagle nest site selection across a rural-urban gradient and assess how nest site occupancy changes over time. In addition, a study of the diet of Long-crested eagles in these human-modified landscapes through collection of casting under nests, for example Swatridge et al. (2014), and the use of camera traps would be valuable. A follow up study could investigate how far Long-crested Eagle juveniles disperse from their natal sites. The dispersal of juveniles would require non-solar GPS transmitters as solar powered transmitters could potentially be covered by the back feathers and thus preventing the panels from charging.

6.5 Concluding remarks

Although Long-crested Eagles are ranked as a Least Concern species (BirdLife International 2016), this does not mean that conservation efforts should be delayed until the population starts declining, i.e. conservation should aim for a proactive approach rather than relying on reactive conservation measures. There is a need to systematically monitor the breeding of common raptors in order to detect signs of decline early. Such data could become long-term data sets that could be used to study various aspects such as the impacts of an increasing raptor population on another raptor population occurring in the same landscape or region.

6.6 References

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