

Urban Ecology of the Crowned Eagle

Stephanoaetus coronatus

in KwaZulu-Natal, South Africa

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ABSTRACT

Urban environments comprise a complex and dynamic landscape, and urban sprawl is irreversibly transforming large areas of land globally. Increasingly, the need for incorporating ecosystem services into urban landscapes provides opportunities for green-space to benefit biodiversity and indigenous wildlife. Enhancing urban green-space maximises indigenous biodiversity and provides conservation value, and can also benefit people by enriching their experience and awareness of nature. Large charismatic species can stimulate awe and interest as emblematic representatives of the wilderness. As the global population becomes ever more urban, this enriches the human experience. The crowned eagle (*Stephanoaetus coronatus*) is a large predatory raptor and a threatened species that is increasingly known to inhabit the Durban Metropolitan Open Space System (D'MOSS), within eThekweni municipality, KwaZulu-Natal (KZN), South Africa. This research investigated the ecology of the crowned eagle in the urban environment and suggests opportunities for enhancing the urban landscape for conservation benefits.

Globally, dramatic land use change typical of urbanisation negatively affects biodiversity, especially for top predators. The D'MOSS design faces the challenge of conserving biodiversity in a regional hotspot in the face of rapid urban growth in one of Africa's major commercial hubs. Understanding habitat use of keystone and apex species provides urban planners with an opportunity to integrate biodiversity in a growing city.

Consequently, we investigated habitat use and nest site selection of crowned eagles on various spatial scales within this urban mosaic. Unexpectedly the inter-nest distances were small in this human-dominated landscape. However, breeding sites were not evenly distributed through the landscape and were closely associated with natural forest, while nest trees were most frequently in patches of exotic large riverine Sydney blue gum (*Eucalyptus saligna*, Smith 1797) within the D'MOSS planning zones. Crowned eagles showed a strong tendency to avoid informal settlement areas, however they were tolerant of proximity to established formal settlements and occupied dwellings. Further, home range and habitat selection were investigated with GPS telemetry, albeit with a limited sample size ($n=5$) due to the limitations of abundance and dispersion of this apex predator. The 350 km² urban core study area comprised a matrix of mainly formal settlements (44%), and DMOSS green space areas (29%). The study area was occupied by up to 22 active breeding pairs of crowned eagles. We documented a mean ($n = 4$) annual home range of 13 km² (hull_{100%}) containing 6.3 km² of territory per pair (LKDE H_{LSCV 95%}). These relatively small home ranges for a large eagle included shared territorial boundaries. Rapid replacement of vacancies at breeding sites suggests a saturated population. Habitat selection within the home range, thresholds of critical habitat, exotic trees, and correlation with DMOSS show the importance of pockets of indigenous forest in this urban mosaic landscape. These forests are fragmented and fragmentation increases the available edge habitats and landscape heterogeneity, potentially enhancing resource availability for crowned eagles in a highly modified landscape. The

presence of remnant patches of mature *Eucalyptus* was more preferred than monotypic timber plantation stands. Consequently, continued protection of the D'MOSS system, and a considered approach to management of *Eucalyptus* are required for the persistence of the crowned eagle in this landscape

The study of diet is pivotal in understanding a species, particularly for quantifying a predatory raptors' economic niche and potential for human-wildlife conflict. In close association with urban development, the local population of crowned eagles has the potential to be a concern to the safety of domestic stock and pets. Time-lapse cameras were positioned at urban nest sites (n = 11) to identify the prey composition during breeding, particularly in regards to taxa with human associations. This was the first use of this technique for this species. The numerical proportion of avian prey, particularly hadeda ibis (*Bostrychia hagedash*) pulli, was several times greater than any previous diet description. The methodology used and the abundance of hadeda ibis in these urban environments are potential contributing factors. Rock hyrax (*Procavia capensis*) was the primary prey and where hyrax were unavailable, the diet composition was broader and included more vervet monkeys (*Chlorocebus pygerythrus*). Domestic stock comprised only 6% of the identifiable prey. Contrary to popular belief, no dogs (*Canis familiaris*) and few cats (*Felis catus*) were delivered to the nest by breeding eagles in this study. In situ pet attacks are most frequently attributed to juvenile and immature crowned eagles in winter and spring.

Attacks on pets by crowned eagles, especially on small dog breeds, although relatively rare have a substantial influence on human-wildlife conflict and public perceptions. Pet attacks are generally attributed to juvenile and immature crowned eagles during periods of limited resources, particularly winter and during dispersal in the juveniles' first spring. Negative social perceptions have resulted in persecution (n = 5), one of the main causes of recorded injury and mortality to crowned eagles in the region. Gunshot persecution, electrocution and collisions with anthropogenic structures have the greatest impact on juvenile and immature survival in the region. We provide management recommendations regarding various categories of crowned eagle human-wildlife interactions. Collaboration of wildlife authorities with NGO's and public stakeholder input creates an environment for successful crowned eagle conservation and management of human-wildlife conflicts. Public awareness is an important aspect to the sustainability of the urban crowned eagle population.

This study demonstrates that urban mosaic landscapes can provide conservation benefits for the crowned eagle. The land planning strategies enacted in Durban can guide urban expansion in tropical forest biomes to enhance indigenous biodiversity in urban mosaic landscapes in Africa, and globally.

PREFACE

The data used in this thesis were collected in the Republic of South Africa from April 2012 to November 2015. All field observations were carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Professor Colleen T. Downs and co-supervisor Dr. Mark Brown.

This thesis, submitted for the degree of Doctor of Philosophy in the College of Agriculture, Science and Engineering, University of KwaZulu-Natal, 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.



.....
Shane C. McPherson

November 2015

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

November 2015

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DECLARATION 1 - PLAGIARISM

I, Shane C. McPherson, 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.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
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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

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

SCM conceived paper with MB and CTD. SCM collected and analysed data, and wrote the paper. DL, MB and CTD contributed comments to the manuscript.

Publication 2

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

SCM conceived paper with MB and CTD. SCM collected and analysed data, and wrote the paper. MB and CTD contributed comments to the manuscript.

Publication 3

McPherson, S. C., Brown, M. and Downs, C. T. In prep. Navigating an urban jungle: home range of breeding crowned eagles in the Durban Metropolitan Open Space System, South Africa.

SCM conceived paper with MB and CTD. SCM collected and analysed data, and wrote the paper. MB, and CTD contributed comments to the manuscript.

Publication 4

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SCM conceived paper with BH, BP, and CTD. SCM collected and analysed data, and wrote the paper. BH, BP, and CTD contributed comments to the manuscript.

Publication 5

McPherson, S. C., Brown, M. and Downs, C. T. In prep. Morphometric variation in Crowned Eagles in KwaZulu-Natal, South Africa: Size matters in raptors

SCM conceived paper with MB and CTD. SCM collected and analysed data, and wrote the paper. MB, and CTD contributed comments to the manuscript.



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Juvenile (left) and mature (right) African Crowned Eagles photographed in Durban, South Africa. Photos: Shane C McPherson 2012.

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1 INTRODUCTION

“One can argue that if one seeks to conserve the places where nature is most intact, one should focus on areas as far from cities as possible... But if one is arguing that conservation should seek to restore the human relationship to nature, then the cities are the most important places for conservation exactly because the majority of people live there.” (Sanderson & Huron, 2011, p. 421)

1.1 Urban ecology

1.1.1 Background

Globally, one of the biggest factors affecting wildlife and human-wildlife interactions is the growth of urban environments (United Nations Population Fund, 2007). The human population is now an urban-dwelling majority, which is projected to reach five billion by 2030 (United Nations, 2006). Urban growth and the demands for land are expected to triple, transforming 1.2 million km² in the next 30 years (Seto *et al.*, 2012). This land transformation is irreversible, and is one of the leading causes of habitat loss and species extinctions (McKinney, 2006, Seto *et al.*, 2012).

Urban ecology is an increasingly relevant and important discipline which endeavours to integrate high density human populations and wildlife into mutually supportive ecosystems (McKinney, 2002, Sukopp, 2002, Alberti *et al.*, 2003, Marzluff *et al.*, 2008, Magle *et al.*, 2012). Fundamental changes associated with urbanization include the occurrence of novel anthropogenic habitats; these are typified by buildings, impervious surfaces, transport and utility networks, artificial lighting, and high human densities (Adams *et al.*, 2006). Abiotic effects of these alterations include the urban heat island, pollution of air, water and soil with exotic anthropogenic chemicals (e.g. plastics, pesticides, heavy metals), as well as noise and light pollution (Alberti *et al.*, 2003, McCarthy *et al.*, 2010, Dominoni *et al.*, 2013). These effects typically result in impoverished biological richness and diversity compared with surrounding rural and natural landscapes (Chace & Walsh, 2006, Beardsley *et al.*, 2009, Reis *et al.*, 2012). In addition to being detrimental to wildlife, these ecological conditions have a negative impact on the physical and psychological well-being of citizens (Ulrich, 1979, Wilson, 1984, Miller, 2005, Fuller *et al.*, 2007, Dye, 2008). Generally urban areas exhibit a gradient of effects, highest at the most modified urban core (McDonnell & Hahs, 2008), although modern industrial cities expand in complex and dynamic ways characterised by sprawl developing in fractal patterns (Ramalho & Hobbs, 2012).

A variety of land use types exist within a city, each with distinct configurations (Ramalho & Hobbs, 2012). Major land use types include; industrial, commercial, mixed use, multi-family residence, single family residence, and green space (Alberti *et al.*, 2003). Green

spaces are important for wildlife and the provision of ecosystem services, and are usually artificially created from city planning strategies (Alberti *et al.*, 2003). Green space may be rehabilitated grey space, naturalizing brown-space, restored highly modified land, or relicts of unmodified natural habitats, with the desire for use as aesthetic parklands, recreational areas, buffer zones, or environments for native species and ecosystem processes – therefore green spaces undergo many and varied temporal trajectories (Kattwinkel *et al.*, 2011, Ramalho & Hobbs, 2012). In addition to the formal management of public space, many habitats useful for wildlife are created in privately owned properties. In low density residential zones the biotic desires of citizens result in a landscape featuring high structural complexity and variety. Lawns, gardens, shade trees, and the provision of food plants, ponds, nest cavities, and supplementary food (e.g. bird feeders) are used to attract wildlife to these areas (Fuller *et al.*, 2008, Davies *et al.*, 2009). The flux from one land use to another and the speed of this conversion greatly affects the structure of wildlife communities. Value to wildlife is enhanced by connectivity between highly fragmented green-space habitats, and is usually associated with roads and water courses (Fernandez-Jurcic & Jokimäki, 2001, Kociolek *et al.*, 2011).

Worldwide, urban areas share several central ecological characteristics. As a transformed habitat the species richness is poor, this is reflected in simplified food webs and a greater influence of bottom-up processes (Faeth *et al.*, 2005). While this is true across taxa the review here will focus on vertebrates and particularly birds. Niche flexibility and the capacity of further adaptations over time vary between vertebrate species (Vandermeer, 1972). Generally, species with large home ranges are more sensitive to fragmentation and species which occupy edge and mosaic habitats in natural settings are pre-adapted to urban fragmentation effects while other species show a behavioural capacity to adapt (Evans *et al.*, 2009).

Most indigenous wildlife is negatively impacted by land transformation and fragmentation of natural habitats. The diversity of indigenous species decreases with proximity to the urban core (Kark *et al.*, 2007, Reis *et al.*, 2012). Urban adapters may tolerate some change while still requiring areas of natural habitats to persist, while urban exploiters can effectively use anthropogenic resources to thrive in urban environments. Urban exploiters, or synurban wildlife, are those species that have “greatly benefited from the availability of anthropogenic resources.” (Parker & Nilon, 2012, p. 316). Species such as house sparrow (*Passer domesticus*) and rock dove (*Columba livia*) typify life history traits that permit the exploitation of anthropogenic resources; cavity nesting, sociality, tolerance of human proximity, inclination for dispersal, omnivorous, a capacity for feeding innovations, and high fecundity and adult survival (Chace & Walsh, 2006, Ditchkoff *et al.*, 2006, Møller, 2009). Synurban species make such effective use of anthropogenic resources and opportunities that, despite reduced species richness, the overall biomass in an urban

environment can be higher than surrounding natural habitats (McKinney, 2006, Kark *et al.*, 2007).

Despite the general trend of deprived biological diversity some native species may benefit from cities, and conservation can be effectively applied in some areas (McKinney, 2002), but are more often unintentional sanctuaries. The availability of reliable resources include; roosting and nesting sites which are constantly dry, more thermally stable, and inaccessible to predators (Gering & Blair, 1999, Gehrt & Chelsvig, 2003), food in the form of refuse and bird feeders (Chace & Walsh, 2006, Jones, 2011), and permanent water availability in birdbaths and impervious surfaces (Waite *et al.*, 2007). Due to firearms restrictions, deer, game fowl and raptors are relatively less affected by persecution than in rural areas (Chace & Walsh, 2006, Dandy *et al.*, 2011). In addition, proximity refugia exist where prey species have a greater tolerance of human proximity than their predators (Møller, 2008). In South Africa, some residential estates are managed with the specific goal of conservation, catering for particular requirements of endangered species enclosed within the estate (Grey-Ross *et al.*, 2009).

1.1.2 Urban human-wildlife conflict

Wildlife conflicts are an exchange between humans and wildlife where one, or often both parties, receive perceived or actual detrimental effects (Treves *et al.*, 2006). In the urban environment – where humans attribute a particularly anthropocentric value to resources, the wildlife conflicts can be many, varied, and extreme. These perceptions are typically regarded as the human dimensions of urban wildlife (Adams *et al.*, 2006). Despite an overarching positive influence of biodiversity on human well-being some species are the subjects of human animosity. Typically these are intuitive assessments, and while some may accurately reflect detrimental effects, others are biased mythologies. Further, different stakeholders can perceive the same species in opposing regard. Fortunately perceptions are malleable and can be shaped by media hyperbole, directed public education, and by providing community empowerment of management actions (Kleiven *et al.*, 2004, Adams *et al.*, 2006).

Impacts are usually one or a combination of three major components; ecological, economic, and health and safety (Curtis & Hadidian, 2010). Ecological impacts include; competitive exclusion such as super-abundant synurban species commandeering nest cavities, hyper-predation of wildlife such as that which occurs with nutritionally subsidised cats (*Felis catus*) that remain recreational hunters, and nuisance wildlife such as noise disturbance and concentrations of faecal soiling (Braband, 1995, Loss *et al.*, 2013). Economic impacts can be measured in real monetary terms including damage to property and loss of horticultural produce and domestic livestock. The dietary preferences and economic impact a species concurs against human production can be defined as an economic food niche (Litvaitis, 2000). Health and safety impacts can be the most intense form of conflict. Animal disease (zoonoses) risk is highest in those species which are closely associated with humans,

taxonomically or via cohabitation (Garrett, 1994, Bradley & Altizer, 2007). New emergences of zoonoses in human populations are of particular concern, in particular a number of simian viruses (Garrett, 1994, Fuentes, 2006, Plowright *et al.*, 2011, Verhagen *et al.*, 2012). Trophic effects of vertebrate systems can alter the dynamics of disease transmission (Levi *et al.*, 2012). Zoonoses often spread to humans via free-roaming pets as vectors, and include toxoplasmosis in cat faeces and rabies from dog bites. As people typically develop emotional attachment to household pets, the safety of pets from wildlife predators is another locus of conflict. Threats to personal injury from direct wildlife attacks, especially to children, are of greatest concern and readily result in animal removal campaigns (Kleiven *et al.*, 2004, Hudenko *et al.*, 2010, Bateman & Fleming, 2012). These circumstances are where mammalian and avian predators are of greatest concern in an urban environment.

1.1.3 Urban predators

The presence of high biomass of synurban wildlife entices predators to urban areas. Most research on urban predators involves the mammalian class Carnivora, and research is concentrated in North America and Europe, thus there is a need for more research on urban predators in Africa, Asia and South America (Magle *et al.*, 2012).

Two mammalian predators in particular have had an exceptional historical association with urbanization, such that they are now completely integrated with human lifestyles. In most urban settings, the domestic cat, and domestic dog (*Canis familiaris*) are the pervasive carnivores of urban areas, often occupying ecological space at a density orders of magnitude greater than native carnivores. The ecological impacts of cats and dogs vary depending on their ability to roam; from housebound pets in one extreme, to feral colonies in the other (Baker *et al.*, 2010). Nutritional subsidies are responsible for high abundance of cats and enhance their impact as a super-abundant recreational hunter (Baker *et al.*, 2010, van Heezik *et al.*, 2010, Balogh *et al.*, 2011, Loss *et al.*, 2013). While free-roaming dogs are successful omnivorous scavengers and are effective at harassing terrestrial wildlife, they also pose a disease risk particularly in the spread of rabies (Markhandya *et al.* 2008, Hughes & Macdonald, 2013).

Worldwide there is a growing understanding of urban-adapting native carnivores which are typically: small to medium size, r-selected, solitary foragers, diet generalists with a discreet lifestyle, have a capacity to scavenge, and are tolerant to human proximity (Iossa *et al.*, 2010). A small diversity of carnivores over 10 kg in mass are able to obtain their entire needs from urban resources, while species over 20 kg may only incorporate urban areas in a larger home range and are typically transient visitors to scavenge human refuse (Beckmann & Lackey, 2008, Gehrt & Riley, 2010, Abay *et al.*, 2011). With large carnivores, human-wildlife conflicts arise from perceived threats to the safety of humans and domestic animals, which generate the need for management and removal strategies (Bjerke *et al.*, 2003, Kleiven *et al.*, 2004, Gavashelishvili & Lukarevskiy, 2008).

Despite threats to human safety, super-predators often have positive ecological influences through top-down regulation of trophic systems (Faeth *et al.*, 2005). Mesopredator release occurs when an apex predator is removed from a system, the subsequent eruption of mesopredators can lead to trophic cascades and the local extinction of shared prey (Courchamp *et al.*, 1999). Primates in urban areas are considered here as a mesopredator. Gregarious, troops move together as an efficient foraging team, naturally foraging on diverse vegetable foods and supplementing their diet with insects, small vertebrates and birds' eggs and chicks (Skinner & Chimimba, 2005, Apps, 2012). As a particularly successful urban exploiter in South African cities, vervet monkeys (*Chlorocebus pygerythrus*) are able to calculate human behaviours and respond accordingly (Ramkissoon, 2005, Fuentes *et al.*, 2007), enabling them access to urban areas that their natural predators, leopard (*Panthera pardus*), African rock python (*Python natalensis*), and crowned eagle (*Stephanoaetus coronatus*), cannot always access (Hart, 2007).

More so than mammalian carnivores, globally a wide diversity of avian carnivores (raptors) have adapted to urban environments. Abundant synurban wildlife, particularly rodents and pigeons, have attracted a variety of owl, falcon, and accipiter species. Small accipiter, buzzard, and kite species are well represented; favouring species which can breed in small fragments of parkland, hunt avian prey in woodland and garden habitats, or exploit refuse areas (Bloom & McCray, 1996, Salvador *et al.*, 2008, Cava *et al.*, 2012, Boggie & Mannan, 2014).

Large raptors (>3 kg) are typically excluded from urban areas but may include urban areas as a part of a larger home range. Large raptors are most frequently using urban areas for refuse scavenging (Elliott *et al.*, 2006, Mandel & Bildstein, 2007, Gbogbo & Awotwe-Pratt, 2008), and in so doing provide ecological benefits. Historically, meat processing and community livestock necropolises in India were quickly cleaned by large numbers of vultures (Galushin, 1971). However due to catastrophic population crashes from veterinary diclofenac poisoning (Ogada *et al.*, 2012), the dominant scavengers at these necropolises are now feral dogs, with a corresponding rise of rabies outbreaks (Markandya *et al.*, 2008).

Worldwide, the most widespread and thoroughly urbanised raptor is the peregrine falcon (*Falco peregrinus*), and colonisation of modern urban areas has been extensive and well documented. The colonisation by peregrine falcons of a modern city was pioneered by the conservation actions of The Peregrine Fund in the USA (Cade *et al.*, 1994). Artificial eyries on high buildings and towers are fair analogies to natural cliff nesting sites, while pigeons, preferred prey of falcons, are one of the most successful synurban birds and provide an abundant reliable food supply (Bell *et al.*, 1996, DeCandido & Allen, 2006). In a further adaptation towards urban exploitation, peregrine falcons use artificial lighting to hunt migrating passerines at night (DeCandido & Allen, 2006). Presently peregrine falcons breed or winter in cities across America, Europe, India, Asia, Australia and Africa (Dixon *et al.*,

2013, Audobon & Cornell Lab of Ornithology, 2014), including a contemporary colonisation of the metropolitan district of Cape Town (Jenkins, 2010b, 2010a, Pollack, 2010).

1.1.4 South Africa's urban raptors

The majority of studies of urban raptors are of North American and European regions (Magle *et al.*, 2012). Despite a high diversity of southern African diurnal raptors (68 species) (Ferguson-Lees & Christie, 2005), little has been published regarding the urban raptor phenomenon in this region. Consequently a brief review is provided hence from preliminary data obtained (1 June 2013) from the ongoing bird atlas project SABAP2 (Animal Demography Unit, 2011). A data set of raptor detection frequencies was compiled for nine South African provincial urban cities. The relevant urban areas were designated using discrete SABAP2 'pentads (5 minutes of latitude, 5 minutes of longitude)', from aerial photos where the 80% majority of each pentad was highly urban. City expanse ranged in size from 1 to 25 pentads (Fig. 1.1). The total number of cards ranged from 14 to 211 cards per pentad, with two cities (Rustenburg and Kimberley) producing less than 50 cards per pentad at the time of data acquisition. Reporting rates of each species may be biased due to underreporting of cryptic species and unequal distribution of observers and observer locations within the urban areas, however despite these considerations some insights can be gained from this data.

Fifty species of raptors were recorded in urban centres at least once, with 29 species having a reporting frequency greater than 10% in at least one of the cities. The species composition of urban raptors varied greatly among regions (Table 1), reflecting different climates and biomes across the country. Six species were widespread urban adapters, reported in frequencies greater than 10% in four or more of the nine cities; black-winged kite (*Elanus caeruleus*), African fish-eagle (*Haliaeetus vocifer*), common buzzard (*Buteo buteo vulpinus* subsp.), African goshawk (*Accipiter tachiro*), yellow-billed kite (*Milvus aegyptius*), and black sparrowhawk (*Accipiter melanoleucus*).

Three large predatory raptors occur as residents in South African cities; the African fish eagle, crowned eagle, and Verreaux's eagle (*Aquila verreauxii*). The Verreaux's eagle is reported in Cape Town (23%) and Johannesburg (8%). In Johannesburg increasing urbanization and reduction in habitat of their favoured prey, rock hyrax (*Procapra capensis*), has correlated with an increasingly diverse diet, and necessitated supplementary food provisioning to ensure breeding success (Symes & Kruger, 2012). The crowned eagle (Gill & Donsker, 2014) occurs in three eastern main cities; Nelspruit (2%), Port Elizabeth (10%), and Durban. With a reporting rate of 36% in Durban the crowned eagle is the third most frequently reported raptor in this urban area after the yellow-billed kite and African goshawk.

Table 1.1 The seven most frequently reported raptors in the main urban centre of each of nine provinces in South Africa. (From SABAP2 data obtained 1 June 2013).

RUSTENBURG	FREQUENCY	JOHANNESBERG	FREQUENCY	POLOKWANE	FREQUENCY
Verreaux's eagle	0.23	Black-winged kite	0.34	Black-winged kite	0.48
Black-winged kite	0.24	Ovambo sparrowhawk	0.17	Yellow-billed kite	0.44
Amur falcon	0.17	Common buzzard	0.13	African fish eagle	0.16
Jackal buzzard	0.17	Little sparrowhawk	0.09	Long-crested eagle	0.14
Common buzzard	0.12	Black sparrowhawk	0.08	African harrier-hawk	0.1
Black-chested snake eagle	0.12	Verreaux's eagle	0.08	Cape vulture	0.08
Rock kestrel	0.11	African fish eagle	0.07	Common buzzard	0.07
KIMBERLY		BLOEMFONTEIN		NELSPRUIT	
Black-winged kite	0.56	Black-winged kite	0.49	African goshawk	0.76
Gabar goshawk	0.31	Lesser kestrel	0.26	Black-winged kite	0.34
Pale chanting goshawk	0.31	Amur falcon	0.13	African harrier-hawk	0.3
White-backed Vulture	0.29	Common buzzard	0.09	African fish eagle	0.2
African fish eagle	0.24	Lanner falcon	0.05	Long-crested eagle	0.18
Lesser kestrel	0.16	Gabar goshawk	0.04	Little sparrowhawk	0.17
Secretary bird	0.11	Peregrine falcon	0.03	Black sparrowhawk	0.12
CAPE TOWN		PORT ELIZABETH		DURBAN	
Black sparrowhawk	0.28	Black sparrowhawk	0.28	Yellow-billed kite	0.6
Black-winged kite	0.26	African goshawk	0.24	African goshawk	0.39
African goshawk	0.22	Rock kestrel	0.14	Crowned eagle	0.36
Peregrine falcon	0.21	Peregrine falcon	0.13	African fish eagle	0.25
Jackal buzzard	0.21	Yellow-billed kite	0.12	Black sparrowhawk	0.22
Rock kestrel	0.19	Crowned eagle	0.1	African harrier-hawk	0.18
African marsh harrier	0.19	Common buzzard	0.09	Common buzzard	0.13

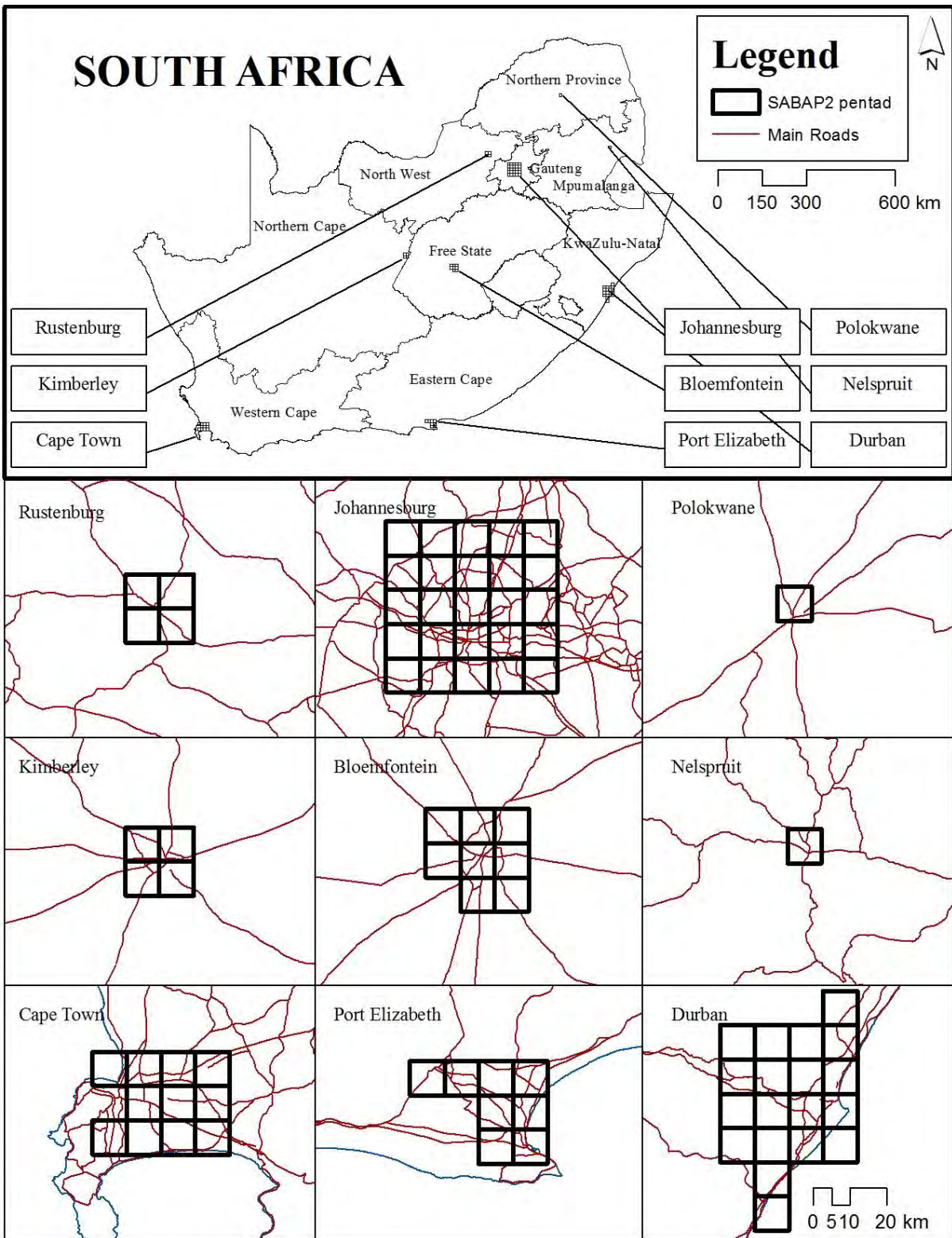


Figure 1.1 The main urban centres of each South African province, and the corresponding SABAP2 pentads interrogated for the presence of urban raptors.

1.2 Study species

1.2.1 Species description

The crowned eagle (alternative names include African crowned eagle, see Hockey *et al.* 2005, and African hawk-eagle, see Clements 2007) (*Stephanoaetus coronatus*, Linnaeus 1776) is the apex avian predator of forested habitats in sub-Saharan Africa. Their range extends from Guinea and Angola in the west, across the tropical belt to Kenya and south along the eastern seaboard to the Western Cape Province, South Africa (IUCN, 2014). Isolated populations persist in Senegal and Ethiopia. Sub-specific variations across the species range have not been defined, nor are regional populations clearly distinct (Ferguson-Lees & Christie, 2005).

A dark brown coloured eagle with rich rufous, white, and brown mottling on the breast and an expressive double crest adorn the eagle with an aesthetic beauty (Ferguson-Lees & Christie, 2005). Despite their size (3-4.5 kg), the crowned eagle's cryptic colouration and secretive habits of an ambush predator enable them to easily go unnoticed by the unobservant or inattentive, though boisterous aerial displays during courtship and territorial rituals provide a conspicuous contradiction to a typically secretive lifestyle (Brown & Amadon, 1968). Relatively short wings and a long tail is a conformation typical of accipiters, providing explosive acceleration and low-speed manoeuvrability in closed environments such as the lower strata of forests (Fox, 1977). The exceptionally large flexor tendons, relatively short toes and large inner talons are powerful weaponry that allows crowned eagles the ability to subdue prey much larger than their body mass (Fowler *et al.*, 2009). In forest reserves with abundant prey, crowned eagles maintain breeding territories an order of magnitude smaller than the slightly larger, savannah inhabiting, martial eagle (*Polemaetus bellicosus*) (Brown, 1976, Herholdt & Kemp, 1997, Shultz, 2002).

1.2.2 Breeding biology

As an extreme K-strategist, the life history of the crowned eagle is typified by a long lifespan, low reproductive rate and long maturation period. One or two eggs are laid, but as a consequence of obligate fratricide only one young can be fledged per breeding attempt. Dependant juveniles are often reliant on parental prey provisioning for 7 to 13 months, and therefore it is typical for the crowned eagle to breed on a biennial cycle. Sub-adults reach maturity and begin to breed at 4-6 years of age. (Tarboton & Allen, 1984, Brown & Amadon, 1989, Pickford & Tarboton, 1989, Skorupa, 1989, Shultz, 2002, Hall, 2007, Shultz & Thomsett, 2007).

The length of the breeding cycle of the crowned eagle varies regionally. Some studies in South Africa conclude that the crowned eagle exhibits successful annual breeding (Vernon, 1984, Malan, 2005, Oatley, 2008). This strategy occurs frequently enough to validate further investigation as there are conflicting perceptions as to whether this is a consequence of stress in marginal habitats, high juvenile mortality, or a result of successful exploitation of

disturbed and fragmented habitats. It has been postulated that regions where eagles prey on larger species breed biennially, whereas annual breeding nests tend to obtain smaller prey items (Vernon, 1984, Skorupa, 1989). In addition, southern Africa has an annual pulse in photoperiod and rainfall, which is contrasted by the biannual sequence in tropical regions – this may affect the breeding biology and timing of crowned eagles in the southern extent of their range (Schoech & Hahn, 2007).

1.2.3 Diet

Ubiquitously, the crowned eagle is a predator of medium-sized diurnal mammals, of 1-5 kg (Swatridge *et al.*, 2014). Where intact rainforest persists the diet is dominated by antelopes and monkeys, with monkeys more prevalent in equatorial latitudes and antelopes more prevalent in higher latitudes (Struhsaker & Leakey, 1990, Msuya, 1993, Mitani *et al.*, 2001, Shultz, 2002, Swatridge *et al.*, 2014). In dryer hilly habitats hyrax constitutes a primary proportion of the diet (Jarvis *et al.*, 1980, Tarboton & Allen, 1984, Boshoff *et al.*, 1994). The predatory flexibility of this eagle is seen in the variety of small and large mammals, as well as occasionally birds and reptiles (Boshoff *et al.*, 1994, Symes & Antonites, 2014). Further, the capacity to prey on antelope species up to 20 kg in mass, occasionally qualify the crowned eagle in a super-predator niche (Brown & Amadon, 1989, Thomsett, 2011). Forest raptors such as the ancestor of the crowned eagle is likely to have shaped predator avoidance behaviour in primates, including Pliocene hominids (Berger & McGraw, 2007, McGraw & Berger, 2013)

Where there is encroachment of rural and subsistence communities into forest edge habitats, the loss of traditional crowned eagle prey can result in prey switching to livestock such as goats, sheep, pigs, chickens and other fowl (Jarvis *et al.*, 1980, Boshoff *et al.*, 1994). In urban areas, small companion animals are sometimes preyed upon (Boshoff, 1990, Whittington-Jones, 2014). Indeed in a few locations feral cats may provide a majority of the diet (A Middleton 2011 unpubl. data). As a predator of primates, it cannot go unmentioned to the perceived risk to human children. Cases of predatory attacks on children (Steyn, 1983) are exceedingly rare and may comprise largely of desperately hungry individuals or unusual circumstances (S Thomsett 2006 pers. comm.). Defensive attacks on human intruders at nest sites are well reported (Brown 1976, S Thomsett 2006 pers. comm., B Hoffman 2012 pers. comm., B Padbury 2012 pers. comm.).

1.2.4 Threats and conservation

The 2012 revision of the IUCN Red List of Threatened Species has reclassified the crowned eagle from Least Concern to Near Threatened (IUCN, 2014). Threats are widespread throughout their range and the reduction in habitat and food availability due to deforestation (timber, charcoal, agricultural expansion, mineral mining), and the competition with the bushmeat industry is poorly understood in much of its central African range (Greenpeace International, 2007, Whytock & Morgan, 2010, John *et al.*, 2014, Buij *et al.* 2015).

Critically, as human populations expand, direct persecution is a major threat for the crowned eagle (Whytock, 2012), occurring intensively in 90% of its range primarily due to perceived loss of domestic stock, and a high value in muthi (traditional medicine/witchcraft) items (Thomsett, 2011). A classification of the IUCN status now coincides with the long held South Africa status of Near Threatened (Barnes, 2000), which has just been uplisted to Vulnerable (Taylor 2015). This contradicts a recent removal from the Threatened or Protected Species (ToPS) list revision which has been motivated by locally sound populations and the desire for reduced bureaucratic procedures in the mitigation and management of 'problem' and rehabilitated individuals (Department of Environmental Affairs and Tourism, 2007).

1.2.5 Previous research on the species

Foundational research was conducted in Kenya by Leslie H Brown (Brown, 1966, 1971, 1972), and for a time the crowned eagle was one of the most well studied raptors. The biology and ecology of the crowned eagle in tropical regions has also been described in more recent times, though these are becoming dated (Skorupa, 1989, Struhsaker & Leakey, 1990, Mitani *et al.*, 2001, Shultz, 2002, Shultz & Noe, 2002, Shultz & Thomsett, 2007). Past and current research activity on crowned eagles is most productive in South Africa, and as such perhaps biases the knowledge of the species from a peripheral area of their range. In South Africa, publications contribute valuable knowledge on; nesting success and periodicity (Vernon, 1984, Malan & Shultz, 2002, Hall, 2007), diet (see references in section on diet above), and on the urban eagle phenomenon (Boshoff & Vernon, 1988, Boshoff, 1990, Malan, 2005, Hoffman & Hoffman, 2009, Mckibbin, 2009).

There are many individuals and organisations with a deep interest and wealth of personal experience in observations of crowned eagle biology. For instance, S. Thomsett has observed the changing conditions for raptors in Kenya over the past 40 years and much of this remains unpublished. Likewise valuable data including several years of observations of peri-urban crowned eagles in Harare, Zimbabwe remain unpublished (A Middleton pers. comm. 2011), and longitudinal population studies in Savé Conservancy, Zimbabwe (Hartley, *et al.* date unknown). The crowned eagle Working Group, an affiliate of the Endangered Wildlife Trust, has monitored the crowned eagle population in Mpumalanga Province, South Africa, since 2006 and longitudinal data on breeding success remain unpublished (G Batchelor pers. comm. 2012). This accumulated unpublished knowledge provides valuable insight via personal communication. In addition there is a wealth of grey literature in the form of local newspaper articles, website pages, and personally observed accounts on the crowned eagles in the urban areas of KwaZulu-Natal, South Africa which should not be overlooked. Records are often haphazard and irregular, however, some records can be qualified in the form of dated journal entries, and photographs with accurate EXIF data.

1.3 Study site

The scope of the research covers a 20,000 km² area of southern KwaZulu-Natal province from the coordinate S29° E30° in the north-western point, to the coastline (Fig. 1.2). Four biomes occur within this area. Within *ca.* 20 km of the humid coastline area is the Indian Ocean Coastal Belt. Between 20 and 60 km from the coast, Sub-escarpment Savannah occurs, with a cline towards Sub-escarpment Grassland inland from 60 km. Patches of zonal forest are dispersed throughout these regions and are floristically diverse. Within these biomes, KwaZulu-Natal Coastal Belt, KwaZulu-Natal Sandstone Sourveld, and Midlands Mistbelt Grasslands are endangered ecosystems with high biodiversity value (SANBI & DEAT, 2009, eThekweni Municipality, 2011).

Urban areas are concentrated along a T-shaped intersection of the national highways N2 and N3, which is the focus of research effort within the wider area. This area includes the cities Durban and Pietermaritzburg (within the municipalities of eThekweni and uMgungundlovu, respectively) as well as a series of coastal towns to the north and south of Durban. Pietermaritzburg is the provincial capital, with a population of 475,000 inhabitants (Statistics South Africa, 2011). Port Natal is among the 10 largest trade harbours in the world (Burger, 2011), supporting Durban, one of Africa's fastest growing cities, with currently 3.4 million citizens (Statistics South Africa, 2011).

Sixty-five percent of the land area of eThekweni Municipality is rural in character, but 80% of people live in densely populated urban areas. The greatest threat to urban safety and stability is the inequality in poverty, healthcare, unemployment, and education (Dye, 2008). Despite progress in the post-apartheid era, there still remain large inequalities in the distribution of wealth, education, and health in the region (Freund, 2001, Patel, 2003, O'Leary, 2007).

Residential areas of Durban and other South African cities have features not commonly recognised in American and European cities. For instance low density community conservancies and estates provide security to residents and wildlife with security services and perimeter fences impervious to wildlife and human traffic (Grey-Ross *et al.*, 2009). Tall barbed, razor and/or electrified fencing are ubiquitous throughout affluent residential areas of Durban as a deterrent to theft and other crimes. Very often these properties are additionally protected by large-breed dogs free to roam within the property boundaries day and night (pers. obs.), which must also deter a number of wildlife species. On the other extreme, informal settlements in these cities are areas of high density simple dwellings with people of disadvantaged socio-economic opportunities. Health impacts are higher in these settlements due to fewer municipal services including an absence of refuse collection, water and electricity availability, and effective sewerage systems (Patel, 2003). Settlements are typically closer to industrial and landfill areas and their pollutants, more reliant on wood and charcoal fuel for cooking, and households experience overcrowding; these features having repercussions for human health (Donaldson-Selby *et al.*, 2007, Leonard, 2012). Population

growth is most rapid in informal settlements, and managing the expansion of these areas is difficult to enforce. Peri-urban informal settlements have ready access to surrounding rural areas and green spaces and therefore utilization of natural resources is relatively high (eThekweni Municipality, 2007). The use of snares and hunting dogs to target mammals is frequent in the Durban peri-urban areas (pers. obs.). The effects on flora and fauna are difficult to quantify.

Durban’s natural assets were identified by the Wildlife Society in 1979, and subsequently authorities developed a planning strategy incorporating the Durban Metropolitan Open Space System, D’MOSS (eThekweni Municipality, 2007). The D’MOSS strategy focuses on connected, functional ecosystems on a catchment scale (Roberts, 1994, eThekweni Municipality, 2007). The D’MOSS system can be characterised by large fragments of indigenous forest on predominantly sloping terrain, which have a legacy of rough terrain limiting development. Residential zones abutting D’MOSS reserves have defined limitations on minimum property area and number of dwellings within, establishing buffer zones (Environmental Branch, 1998).

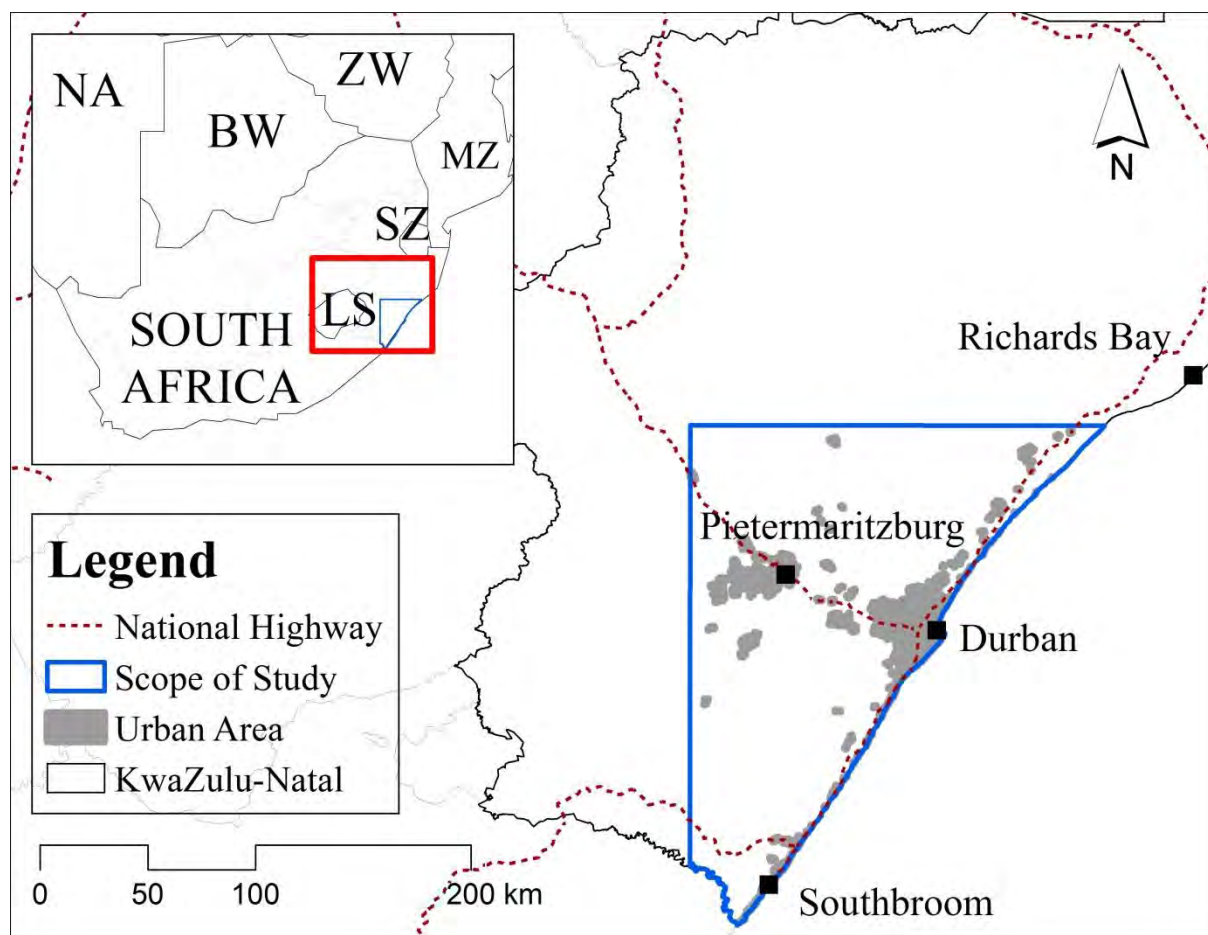


Figure 1.2 The scope of the study in KwaZulu-Natal, South Africa.

1.4 Motivation and objectives of study

Crowned eagles are large active predators fulfilling an apex predator niche. In many regions of their range they are susceptible to persecution, habitat loss, and competition with people for the same prey species (IUCN, 2014). Prey can include domestic stock and pets in near-urban areas (Boshoff, 1990, Boshoff *et al.*, 1994). Unexpectedly, contrary to this general trend, the occurrence of crowned eagles in the urban centres of eastern South Africa appears to be high. Relatively little information on large avian predators is available for urban areas, particularly in Africa (Magle *et al.*, 2012). Municipal authorities may use urban planning as a conservation tool for threatened species, and therefore provide conservation benefits as well as greater awareness of biodiversity to enhance public appreciation and health (McKinney, 2002). Human dimensions are many and varied, and can change over time depending on possible changes in the economic niche of a species, and with new educational information and media publicity (Adams *et al.*, 2006).

The presence of a population of crowned eagles within the large industrial cities in KwaZulu-Natal provides an opportunity to investigate urban ecology, eagle population biology, and human-wildlife conflicts. The urban eagle phenomenon can be described by investigating 1) dispersion and selection of breeding sites in relation to the landscape features, 2) the breeding diet, and 3) home range and habitat use of crowned eagles in the southern KwaZulu-Natal urban mosaic landscape. It was expected that the crowned eagle would 1) nest as far from human disturbance as possible within the limits of the green-space available, and further 2) informal settlements would be more detrimental to the occupation of crowned eagles due to greater persecution and direct competition with prey species. In urban areas it was expected that crowned eagle diet would 3) rely to a great extent on synurban wildlife species as pet focused individuals would be quickly removed from the population. We expected 4) home range of breeding pairs to be unevenly distributed in the urban green space mosaic with 5) habitat selection favouring the largest most intact indigenous forest patches.

1.5 Thesis structure

The thesis is prepared with the chapters mainly as manuscripts. Consequently the remainder of this thesis consists of data chapters, five of which are experimental chapters formatted for publication in peer-reviewed journals. As these chapters have been written for publication independent of one-another there is inevitably some repetition of material. The experimental chapters are:

Chapter 2 describes the breeding distribution of crowned eagles in the urban areas of KwaZulu-Natal. A particular focus on landscape effects within the D'MOSS system is relevant to urban planning for conservation elsewhere in Africa.

Chapter 3: The diet of the crowned eagle is investigated by the implementation of time-lapse photography at active nest sites. Prey volumes are described in particular to address human-wildlife conflict perceptions regarding domestic stock and pets, and therefore the most urban of nest sites were selected for study.

Chapter 4: Home range and habitat selection of crowned eagles is described using GPS telemetry. The fragmented structure and volume of artificial and indigenous habitats provide thresholds to apply in future urban transformation.

Chapter 5: Threats to crowned eagle survival in the urban landscape, and human livelihoods via human wildlife conflicts are summarised. A number of management options and mitigation recommendations are proposed.

Chapter 6 provides morphometric data obtained from gender-verified samples of live crowned eagles. Both adults and nestlings size variations are described and this clarifies the ambiguity in previously available literature.

The thesis ends with a concluding chapter (Chapter 7), that summarises the various findings of this study.

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2 Crowned eagle nest sites in an urban landscape: Requirements of a larger eagle in the Durban Metropolitan Open Space System

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Highlights

- Eagle nest site preferences were examined on a landscape scale.
- Nearest neighbour distances were less than in natural landscapes within the Region.
- Most nests were in green-space zones near an interface with formal residential areas.
- An exotic invasive Eucalyptus tree was the most frequently used nest tree species.

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Abstract

Globally, dramatic land use change typical of urbanisation negatively affects biodiversity, especially for top predators. The Durban Metropolitan Open Space System (D'MOSS), South Africa, faces the challenge of conserving biodiversity in a regional hotspot in the face of rapid urban growth in one of Africa's major commercial hubs. Consequently, we investigated nest site selection of crowned eagles (*Stephanoaetus coronatus*) on various spatial scales within this urban mosaic. Unexpectedly the inter-nest distances were small in this human-dominated landscape. However, breeding sites were not evenly distributed through the landscape and were closely associated with natural forest, while nest trees were most frequently in patches of exotic large riverine Sydney blue gum (*Eucalyptus saligna*, Smith 1797) within the D'MOSS planning zones. Crowned eagles showed a strong tendency to avoid informal settlement areas; however they were tolerant of proximity to established formal settlements and occupied dwellings. Consequently, continued protection of the D'MOSS system, and a considered approach to management of *E. saligna* are necessary for the persistence of the crowned eagle in this landscape. Future research should focus on food requirements, post-fledging survival, and recruitment to determine which nest sites are most productive and whether this population is acting as a source or a sink.

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2.1 Introduction

With the extensive and rapid land transformations of urban growth there is an increasing urgency to protect indigenous biodiversity, either by urban densification or optimal integration of wildlife habitats into urban sprawl (Dallimer, 2011; Ramalho & Hobbs, 2012). Raptors are widely considered as an indicator clade for ecosystem health (Sergio, Newton, Marchesi, & Pedrini, 2006; Sergio et al., 2008). Raptor populations are important for regulating food webs and are a visible indicator of trophic dynamics in ecosystems (Faeth, Warren, Shochat, & Marussich, 2005; Sekercioglu, 2006). Many raptors have more sensitive requirements for nesting resources and lower tolerance of human disturbance than their prey species (Tapia, Kennedy, & Mannan, 2007; Møller, 2008). Similarly, smaller sized raptor species are more able to adapt to the fragmented urban landscape than larger species (Chace & Walsh, 2006). By considering the preferences of sensitive raptors, particularly those of threatened species, landscape planning strategies can be optimised to enable the richest biodiversity and conservation benefits (Cade, Martell, Redig, Septon, & Tordoff, 1996; Simmons, Rodrigues, Woodcock, Steyn, & Jenkins, 2007; Sanderson & Huron, 2011; Isaac, White, Ierodiaconcu, & Cooke, 2013).

The crowned eagle (Gill & Donsker, 2014) (*Stephanoaetus coronatus*, Linnaeus 1766) is the third largest predatory raptor in Africa (*ca.* 3.6 kg, Hockey, Dean, & Ryan, 2005). Its status has recently been revised to Near Threatened globally (IUCN, 2013), which aligns with a long standing regional status of Near Threatened (Barnes, 2000).

Regionally, the crowned eagle is expected to soon be uplisted to Vulnerable (Martin Taylor, pers. comm.). The crowned eagle has a long reproductive cycle, producing one young per breeding attempt either biennially (Brown, 1976; Tarboton & Allen, 1984; Swatridge, 2009), or annually in cases of abundant prey and/or juvenile mortality (Fannin & Webb, 1975; Vernon, 1984; Malan, 2005; Oatley, 2008). Their nests are vast structures at established sites (over 2 m in diameter and 3 m deep), with new material added every breeding season (Tarboton, 2001). In many cases, they show high site fidelity using particular locations for decades and perhaps even generations (Brown & Amadon, 1989). In indigenous forests, their nests are positioned in a canopy-isolated emergent tree; however, in South Africa a variety of other nest locations are known including forested cliffs and exotic trees such as *Eucalyptus* spp. and conifers (*Pinus* spp.) (Tarboton & Allen, 1984; Malan & Shultz, 2002). To date, the major natural threat to their breeding success is antagonism by primates, especially baboons (*Papio* spp.) which disturb brooding females and kill undefended nestlings (Brown, 1971; Hockey et al., 2005). The most important microhabitat variable driving their nest site position is flight accessibility, particularly the need for an easy approach for nest building, prey delivery, and nest defence (Tarboton & Allen, 1984; Skorupa, 1989; Malan & Shultz, 2002). Meanwhile, their nest site selection on a landscape scale has been scarcely documented.

The crowned eagle is primarily adapted to primary Afro-tropical forest, but can occupy marginal woodland mosaic habitats where suitable nesting trees are available such as riverine and gallery forest patches (Tarboton & Allen, 1984). In southern Africa, a contiguous population of crowned eagles along the eastern escarpment region occupies *Eucalyptus* timber plantation, nesting in mature ‘escapee’ *Eucalyptus* and indigenous trees in riparian patches surrounded by forestry plantations (Swatridge, Monadjem, Steyn, Batcelhor, & Hardy, 2014). Minimum nearest neighbour distances between nests are variously reported as: “1 mi” (1.6 km Kenya, rounding not specified), 2 km (Eastern Cape), 2.5 km (Mpumalanga), 6 km (Western Cape), and 4 km in Zimbabwe (Tarboton & Allen, 1984; Hockey et al., 2005). The most thorough local-scale population study calculating minimum home range requirements, estimated breeding pair density at 6.5 km² in pristine Afro-tropical forest in Cotê de Ivore, with mean nearest neighbours 1.81 km apart (Shultz, 2002).

A population of crowned eagles has been documented breeding in close proximity to urban settlements in southern KwaZulu-Natal (KZN) province of South Africa, the location of the large cities of Durban and Pietermaritzburg, and a series of coastal towns and resorts (Malan & Shultz, 2002; Hoffman & Hoffman, 2009; McKibbin, 2009). This is the largest population known to the authors in high association with urban landscapes. The city of Durban faces the challenge of conserving biodiversity in a regional hotspot in the face of rapid urban growth in one of Africa’s major commercial hubs. The Durban Metropolitan Open Space System (henceforth D’MOSS) has been demarcated by the municipal authority as a network of green spaces of high importance for ecosystem services and biodiversity. The objective of this study was to define the limiting factors of crowned eagle nest sites on a landscape scale, and inform the future planning strategies of the metropolitan area to enable persistence of the crowned eagle population. Based on the requirements of crowned eagles for suitable nest trees (Malan & Shultz, 2002), and the effects of tolerance thresholds in a landscape of anthropogenic disturbance (Møller, 2008), we predict that in the urban environment, nest sites would be close to streams inside large patches of natural forest, while being further from roads, occupied dwellings, and human land cover classes than random locations.

2.2 Methods

2.2.1 Study site

The wider area of interest included 20,000 km² of KZN, South Africa, south and east of the coordinate S29° E30° (Fig. 1.1, inset). The western majority of this area is comprised of inland Sub-Escarpment Savannah, and the eastern section Indian Ocean Coastal Belt biome. Urban areas were of particular interest, including the major cities of Pietermaritzburg (population 475,000), and Durban (South Africa’s third most populated, 3.4 million), and a number of coastal towns and resorts (Statistics South Africa, 2011).

A 500 km² area in the eThekweni Metropolitan Municipality, centred at the city of Pinetown, KZN (Fig. 2.1), defined an area of high confidence in the occurrence and nest locations of crowned eagles. Thereafter, we conducted a detailed landscape analysis of crowned eagle nest site selection in this focal area. The region has a humid subtropical climate with an annual rainfall of 1000 mm, primarily in summer. Elevation ranged from 80 m a.s.l in the East to 650 m a.s.l in the West. The topography is mostly rough terrain. Durban city has a small coastal plain and the first foothills are situated on the eastern boundary of the study area. The higher altitude landscape to the West is strongly dissected by rivers with several steep sided gorges, adjacent to plateaus which have been thoroughly transformed into a residential mosaic. The river gorges have been historically undeveloped, and a program identifying the metropolitan natural assets has been developing since 1979 by successive Durban municipal authorities (eThekweni Municipality, 2007). Incremental steps towards a management plan and increasing desire for protection of ecosystem services and function has led to the current established D'MOSS, with a focus on catchment scale conservation, functional ecosystems and connectivity (Roberts, 1994; eThekweni Municipality, 2007).

Steep-sided ravines are forested with relic Afromontane and Scarp Forest patches. Krantzkloof Nature Reserve contains the largest tract and only statutorily protected Scarp Forest, a tall, ancient and species rich floristic type, in eThekweni Municipality, (eThekweni Municipality, 2007). Prior to rapid urban growth the rolling plateau areas were historically fire-managed pastoral grasslands, the KwaZulu-Natal Sandstone Sourveld ecosystem (KZNSS). KZNSS is an endangered ecosystem and has rapidly reduced in area by urban development and afforestation processes (SANBI & DEAT, 2009). Since the 1950s, large areas of former KZNSS have been both inadvertently and intentionally afforested due to fire suppression and residential landscaping activities, respectively (eThekweni Municipality, 2007). In addition to afforestation efforts, *Eucalyptus saligna* invades slopes and riparian areas rapidly (Forsyth, Richardson, Brown, & Van Wilgen, 2004).

Previously an independent metropolitan area, the city of Pinetown has recently been incorporated into the eThekweni Municipality. The low income residents are disproportionately distributed in very high-density settlements in the periphery of the metropolitan area, a vestige of the apartheid era (Freund, 2001; O'Leary, 2007). Many of these high density housing areas are defined as informal settlements, with few municipal amenities including lack of water and waste services, and high rates of unemployment (Statistics South Africa 2011). A small portion of houses continue to rely on wood for light and cooking, and these communities harvest medicinal plants and wildlife from the local KZNSS and forest environments (Nesvag, 2002; eThekweni Municipality, 2007; Statistics South Africa, 2011). Of particular relevance are three informal settlements which are on the North, East, West, and southern boundaries of the study area. Generally, residential land value is greatest bordering D'MOSS reserves. These reserve-adjacent properties have

municipal restrictions on the density of housing, providing somewhat of a buffer for urban-avoiding wildlife (Environmental Branch, 1998).

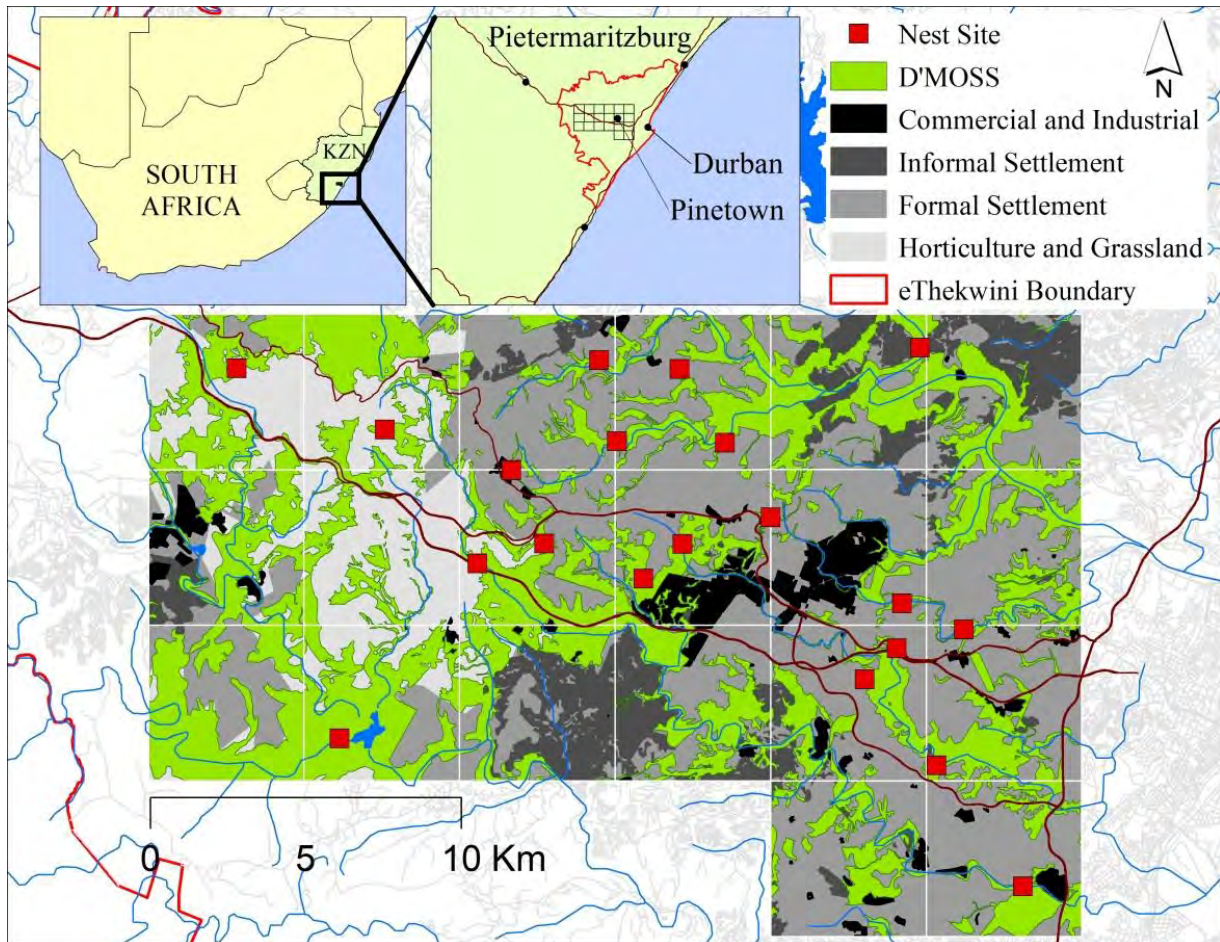


Figure 2.1 The 500 km² study area within the eThekweni Municipality (inset). Crowned Eagle nest sites presented in relation to a set of twenty 25 km² grids and aggregated land cover classes.

2.2.2 Locating crowned eagle nests

Surveys were conducted in southern KZN throughout the period from April 2012 to January 2014, with most sampling effort between June and October each year when courtship and nest building behaviours were most intense. Public outreach was used to collate all nests known to the researchers, bird-watchers, and local communities. Stationary observations of 1 h or more were conducted over 33 forest areas, with ad hoc visits *ca.* 3 times per week between June and October in all years. Occasionally ground searches were conducted in areas unsuitable for lookout observations.

All crowned eagle nest sites reported in southern KZN were visited; GPS positions of all but two nests were obtained using a Garmin Oregon™ 450, with a fix accuracy of < 5 m. The two inaccessible sites were georeferenced using triangulation estimates to project coordinates. Where more than one nest occurred within a breeding territory, only the most recent breeding nest was included in the analysis. Seven sites were thus excluded from our

analyses, including the only crowned eagle nest known on an artificial structure, last used in 2008. Thus, 46 crowned eagle nests comprised the dataset. Tree species, tree size and form, forest patch size and shape, surrounding land cover, and measurements to physiographic features were recorded on site for each nest site (Table 1.1). Of these 46 nests, 20 nests were located within the 500 km² metropolitan area included in the urban landscape analysis.

2.2.3 Landscape analysis

All landscape data were measured using ArcGIS 10 (ESRI, 2011). Two scales of land area buffer were applied to crowned eagle nest sites. A proximity area of 3.1 ha was designated using a 100 m radius. A maximum exclusive territory area was also employed using data on nearest neighbours from this study, which defined the maximum exclusive radius around each nest to be 700 m (154 ha), 25% of the minimum home range reported by Shultz (2002). An equivalent 154 ha area was applied to analysis on the D'MOSS parameters.

The 20 crowned eagle nest sites located in the 500 km² urban landscape were subdivided into a grid of twenty 25 km² cells (Fig. 2.1). Two sets of 20 randomized locations 'non-nests' were used as control groups. One control group was positioned in the centre of each cell ("uniform non-nest", UNN). A random number generator provided coordinates for the second control group and aerial photos were used to reposition this random coordinate to the nearest large tree (>DBH 50, informed random, INR), with the added factor that it was more than 1400 m from any other INR site.

A variety of physiographic and anthropogenic factors which may impact raptor nest site selection (Table 1.1) were measured using site visits, aerial imagery, and shape files from eThekweni Municipality's corporate GIS website (eThekweni Municipality, 2011). Land cover 2008 and 2005 data (GeoTerraImage, 2008) were obtained from the University of KwaZulu-Natal's geography department. The original forty-seven cover types were reclassified to 14 main themes, with integration of particular features from the 2005 polygon layer. The data were >90% accurate, and amendments were made to habitat shapes within the 154 ha site buffers using 2010 aerial images and site visits to confirm recent land cover changes (particularly regarding new housing developments and *Eucalyptus* removal). The D'MOSS layer described 14 categories of land cover types within the study area. Land cover and D'MOSS categories were further aggregated on similar classes to six primary categories for optimal graphic representation; three levels of habitat (forest, mixed, open), and three levels of human impact (high, moderate, low; Table 2.1).

2.2.4 Statistical analysis

All statistical tests were performed in R 3.0, with $\alpha = 0.05$ (R Development Core Team 2011). Nearest neighbour distances and the cluster distribution of nests were calculated in ArcGIS 10 (ESRI, 2013). Parametric data was normalised by natural log transformation, and verified using a Shapiro-Wilks test. Two tailed *t*-tests were used to compare parametric data between nests and UNN, and nests and INR control sites. Ordinal data (slope position and

D'MOSS edge class) were tested using Mann-Whitney U . Rayleigh's Z score for slope aspect data were obtained with the R package CircStats (Lund & Agostinelli, 2012). Land cover and D'MOSS spatial data were classified and measured in ArcGIS 10, using the LO31 projection. Regressions for selection of land cover were not robust due to relatively small sample size, high zero bias in many classes, high standard error, and fixed sum area correlations. However, strong visual trends are presented with summary statistics as an indication of tolerance thresholds to key land cover classes.

2.3 Results

2.3.1 Nest sites

Crowned eagle nests are often used for many years, and the knowledge of interest groups and community outreach attributed to acquiring 87% ($N = 40$) of the total nests recorded in this study. At areas of recent historical occupation, stationary and ground searching for new nests allowed location of the remaining 13% ($N = 6$) of nests where locations were not first indicated from other sources.

2.3.2 Nearest neighbours

The 20 crowned eagle nests in the study site were evenly dispersed across the 500 km² landscape (NN index = 1.246, $Z = 2.105$, $P = 0.04$). The nest neighbours were built with a median distance of 2.6 km, (mean: 3.1 km, range: 1.4 – 7.2 km). Five nest sites with neighbours less than 2.1 km away did not fledge chicks in the same year as their neighbour. This includes two nests and their neighbours in the DMOSS formal residential interface, 1.7 km apart in 2012, and 1.4 km apart in 2013, where in each case one nest failed shortly after hatching. Such proximity between breeding pairs is supported by a cluster of three nests 140 km South of Durban. These three nests were separated by 1.4 km and 1.9 km along a linear axis, and each nest site successfully fledged a chick in the 2013 season. In addition, pair of nests within the settled matrix of Pietermaritzburg, 55 km northwest of Durban, was 1.2 km apart. One nest has excellent historical records since 1980 with a biennial breeding period until recent years with greater irregularity, while the newer nest has produced two chicks since it established in 2008. We could not clarify simultaneous sightings that would indicate two separate adult females.

2.3.3 Tree species and sizes

Of the 46 crowned eagle nest trees known in the greater area of investigation, 30 were within an urban - open space matrix. The origin (indigenous, exotic) of trees in which nests were recorded did not vary between urban and non-urban nests ($\chi^2 = 0.314$, $P = 0.58$). The shape of a tree clump was a reliable predictor of nest tree by provenance, with indigenous nest trees more frequently immersed (non-emergent) in a large forest while exotic trees were more frequently in small elongate or round shaped patches, emergent trees were equally represented between indigenous and exotic trees ($\chi^2 = 9.0186$, $P = 0.03$). Nests within the

D'MOSS study area were evenly divided between exotic and indigenous trees, with a greater richness of indigenous tree species, the single most used tree was the exotic *E. saligna* (Table 2.2).

2.3.4 *Physiographic features*

Crowned eagle nest sites were significantly closer to streams than either UNN or INR control groups. The prediction that nest sites would be further from streets and dwellings was rejected for all but one test (Table 2.3). There was a significant selection of nesting trees in the lower third ($N = 16$) and floodplain ($N = 13$) of a slope ($U = 319$, $P = 0.001$), and more frequently southwest facing slopes ($Z = 0.517$, $P = 0.004$). No significant result was obtained from comparing the slope gradient between nest sites and random sites.

2.3.5 *Land cover types*

In the 3.1 ha proximity area, nest trees were located in or on the edge of a forest patch (Fig. 2.2a, Table 2.4a). The smallest proportion of forest in the immediate area of a nest site was 27% (0.8 ha), with the remainder of that site comprised of an established formal residential area in the Palmiet suburb. The median (chosen here to represent the average of a non-normal distribution) forest area was 2.2 ha (71%). Compared to random sites, a negative relation to high impact anthropogenic disturbance was found (Table 2.4a). Of the five sites with high impact classes, two sites were informal settlement (25% and 18%), two were in close proximity to the national highway forest overpasses (21%, 17%), and one to a provincial road (6%).

There were large areas of forest (Table 2.4b), particularly natural forest (100cc), occurring at all 20 nests while only occurring at 12 of 20 sites in each control group. A mean of 22 ha (14%) of natural forest at each nest site is greater than the total availability of 6% in the 500 km² study site. The mean area of exotic forest and dense bush did not differ markedly between all groups, but patches of exotic forest occurred twice as frequently in the nest group (70% of sites) as in each control group, (35% and 40%). Moderate human impact land cover, primarily established formal residential land, was a widespread land cover within 154 ha of crowned eagle nests (Fig. 2.2b). Of the High Impact land cover classes, road area did not vary markedly between all groups. However industrial and informal residential cover was rarer at nest sites than available across the landscape.

Table 2.1 All parameters measured for the analysis of nest site selection of crowned eagle in this study.

CODE	DESCRIPTION	MAJOR CLASS
Categorical landscape features		
BIOME	Biome class from Arcgis layer SANBI 2006	
URBCLASS	Landscape matrix urban, rural surrounding forest patch	
TRCLUMP	Shape of patch isolate, long, round, immersed	
MOSS50	Site within, beyond 50m in or out of a moss edge	
MOSS100	Site within, beyond 100m in or out of a moss edge	
Tree features		
TRSP	Tree species (Boon 2010)	
TRPROV	Tree provenance	
TRHT	Tree height (m)	
NTH	Nest height (m)	
Physiographic features		
STREAM	Distance to nearest stream (m)	
MRIVER	Distance to nearest major river (m)	
PROVRD	Distance to nearest provincial road (m)	
STREET	Distance to nearest gazetted street (m)	
DWELLING	Distance to nearest occupied dwelling (m)	
ASPECTDEM	Aspect at site in degrees	
GRADDEM	Slope gradient in degrees in 20m cell at nest	
SLOPEPOS	Position of nest tree in local topography	
ASPCARDO	Slope in cardinal directions including flat	
Land cover classification		
OPENWATER	Dams and lakes	Open
RIPARIAN	Riverine habitats	Mixed
GRASSLAND	Developed, indigenous pastures	Open
HORTICULTURE	Sugar cane and field crops	Low impact
URBPARK	Parks, golf courses, school grounds	Moderate impact
BUSHWOOD	Bush <70 closed canopy (cc) savannah	Mixed
DENSEBUSH	Dense bush 70-100 cc	Forest
NATFOREST	Restored and unmanaged forest	Forest
EXOFOREST	Forest dominated by exotic species	Forest
INDCOMM	Industrial and commercial zones	High impact
INFRES	Informal residential zones	High impact
FORRES	Formal residential areas	Moderate impact
ROAD	Primary traffic routes	High impact
RAIL	Railway lines	Moderate impact
MOSS classification		
WATERBODY	Dams and lakes	Open
WETLAND	Riverine habitats	Mixed
GRASSLAND	Natural grasslands	Open
WOODLAND	Woodland and savannah	Mixed
THICKET	Bush <70 cc	Mixed
FOREST	Forest and dense bush	Forest
EXTRACTIVE	Sand and rock mining	Industrial
UTILITY	Municipal electric and water utilities	Industrial
TREECROP	Orchards	Industrial
FIELDROP	Associated with informal settlements	Settlement
SETTLEMENT	Informal settlements	Settlement
RECREATION	Golf courses and managed parks	Recreation

Table 2.2 The number of tree species used for nesting by crowned eagle in southern KwaZulu-Natal, South Africa. The third column 'D'MOSS Group' identifies the 20 nest sites used in analysis of the 500 km² study area.

TREE SPECIES	NEST TREE PROVENANCE		MOSS GROUP
	EXOTIC	INDIGENOUS	
<i>Eucalyptus saligna</i>	19		6
<i>Eucalyptus camaldulensis</i>	3		2
<i>Pinus elliotii</i>	2		
<i>Pinus patula</i>	1		1
<i>Cinnamomum camphora</i>	1		1
<i>Grevillea robusta</i>	1		
<i>Trichilia dregeana</i>		3	1
<i>Macaranga capensis</i>		2	2
<i>Ficus burkei</i>		2	2
<i>Ficus natalensis</i>		1	1
<i>Ficus polita</i>		1	1
<i>Protorhus longifolia</i>		1	1
<i>Podocarpus falcatus</i>		2	
<i>Celtis africana</i>		1	
<i>Chrysophyllum viridifolium</i>		1	
<i>Cussonia sphaerocephala</i>		1	
<i>Ekebergia capensis</i>		1	
<i>Mimusops caffra</i>		1	
<i>Rauvolfia caffra</i>		1	
Unknown, decayed		1	1

Table 2.3 Results of t-tests on log transformed parametric data comparing crowned eagle nest sites with uniform non-nests (UNN) and informed random (INR) control groups.

NEST SITE SCORE	Mean ± S.E.	Min - Max	Groups	t
Distance to major river (m)	363 ± 83	2 – 1093	INR	-2.2034 *
Distance to provincial road (m)	706 ± 122	83 – 2277	INR	-0.26
Distance to stream (m)	40 ± 14	2 – 265	UNN	-4.3182 **
			INR	-4.4336 **
Distance to street (m)	133 ± 26	12 – 467	UNN	2.4579 *
			INR	1.7081
Distance to dwelling (m)	162 ± 50	31 – 1070	UNN	1.6517
			INR	1.5777

*P < 0.05.

**P < 0.001.

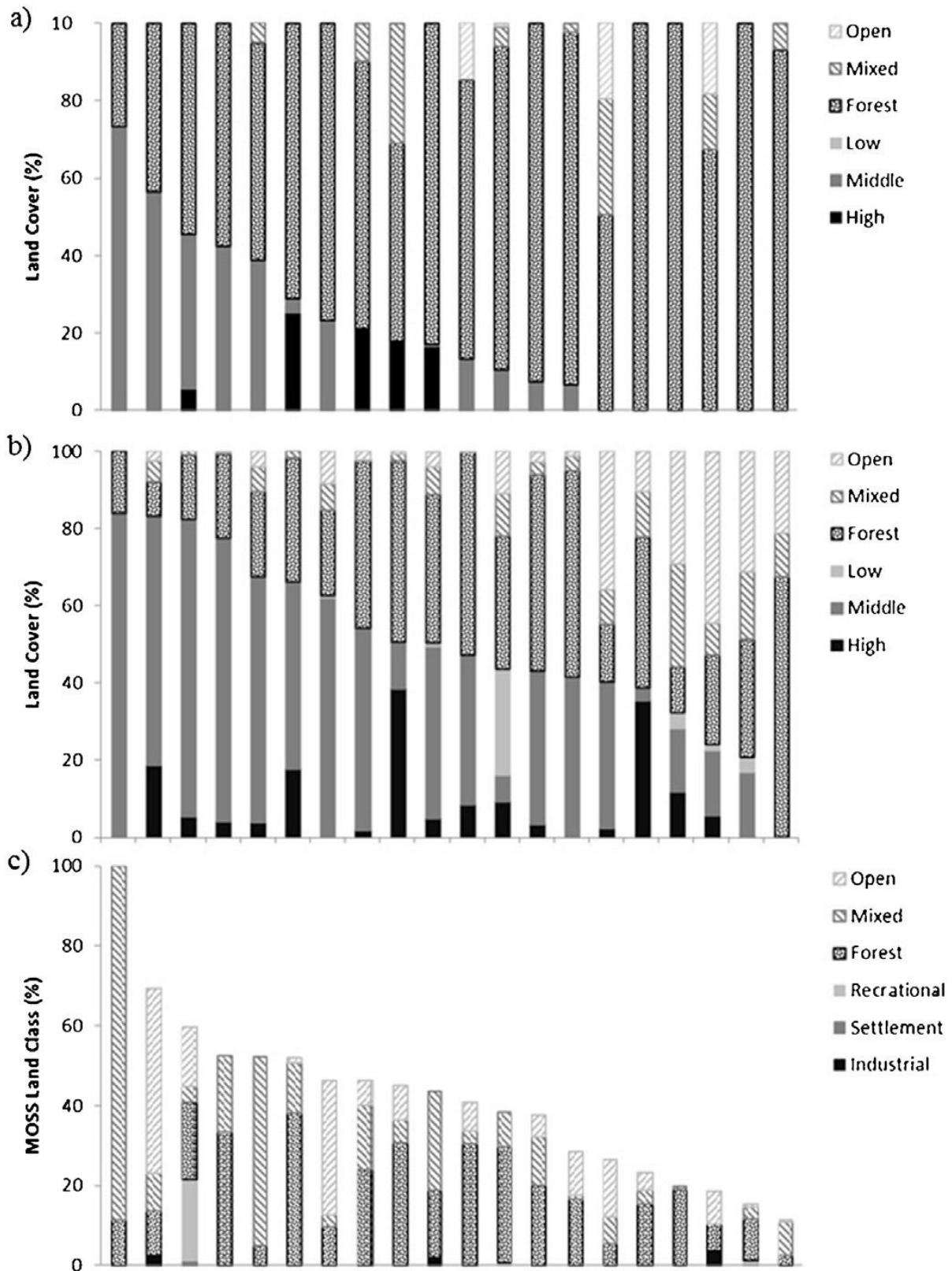


Figure 2.2 Area of land cover within (a) 3.1 ha, (b) 154 ha, and (c) percentage land cover of D'MOSS categories, of 20 crowned eagle nest sites situated within the eThekweni Municipality, South Africa.

Table 2.4 Summary statistics for land cover types within (a) 3.1 ha, and (b) 154ha, as well as (c) D'MOSS categories within 154 ha, of crowned eagle nest sites, uniform non-nests (UNN), and informed random (INR) control sites.

AREA AND LAND COVER TYPE		NEST SITES		UNN		INR	
		Mean \pm 1 SD	Range	Mean \pm 1 SD	Range	Mean \pm 1 SD	Range
(a) 3.1 ha land cover	High Impact	0.1 \pm 0.3	0.0 - 0.8	0.9 \pm 1.2	0.0 - 3.1	0.6 \pm 1.3	0.0 - 3.1
	Medium Impact	0.5 \pm 0.7	0.0 - 2.3	0.7 \pm 1.1	0.0 - 3.1	1.0 \pm 1.3	0.0 - 3.1
	Low Impact	0 \pm 0	0.0 - 0.0	0.2 \pm 0.7	0.0 - 2.8	0.0 \pm 0.1	0.0 - 0.5
	Forest	2.3 \pm 0.7	0.8 - 3.1	0.8 \pm 0.9	0.0 - 2.8	1.0 \pm 1.1	0.0 - 3.1
	Mixed	0.2 \pm 0.3	0.0 - 1.0	0.3 \pm 0.5	0.0 - 1.8	0.4 \pm 0.7	0.0 - 2.9
	Open	0.1 \pm 0.2	0.0 - 0.6	0.4 \pm 0.7	0.0 - 2.6	0.1 \pm 0.3	0.0 - 0.9
(b) 154 ha land cover	High impact	13 \pm 17	0 - 59	36 \pm 41	0 - 138	29 \pm 40	0 - 143
	Medium impact	61 \pm 40	0 - 129	43 \pm 40	0 - 125	56 \pm 47	0 - 131
	Low impact	3 \pm 9	0 - 42	6 \pm 18	0 - 73	4 \pm 11	0 - 45
	Forest	50 \pm 25	14 - 104	34 \pm 26	7 - 101	37 \pm 28	7 - 105
	Mixed	10 \pm 10	0 - 41	18 \pm 21	0 - 98	18 \pm 21	0 - 67
	Open	16 \pm 21	0 - 68	16 \pm 17	0 - 50	10 \pm 11	0 - 42
(c) 154 ha D'MOSS categories	Industrial	0 \pm 1	0 - 6	0 \pm 1	0 - 4	0 \pm 0	0 - 1
	Settlement	2 \pm 1	0 - 4	0 \pm 1	0 - 2	0 \pm 2	0 - 8
	Recreational	2 \pm 7	0 - 31	1 \pm 6	0 - 27	2 \pm 9	0 - 39
	Forest	27 \pm 16	4 - 59	12 \pm 13	0 - 40	15 \pm 19	0 - 75
	Mixed	12 \pm 13	0 - 49	21 \pm 22	0 - 65	17 \pm 17	0 - 52
	Open	13 \pm 19	0 - 72	7 \pm 11	0 - 34	6 \pm 12	0 - 49
	Total D'MOSS	64 \pm 32	17 - 154	49 \pm 43	0 - 149	49 \pm 41	0 - 146

2.3.6 Durban Metropolitan Open Space System

There was a strong preference of nests being located inside a D'MOSS area (Nests UNN $U = 70$, $P < 0.001$ and INR $U = 286.5$, $P = 0.012$). Nineteen of 20 nests (95%) were within a D'MOSS area, yet the system comprised only 34% of the 500km² study area. Only one nest site's 154 ha zone was entirely contained by D'MOSS, while the minimum area for a site's D'MOSS composition was 17 ha. The mean forest cover per nest site was 27 ha, double that of control groups (Table 2.4c). There appeared to be no clear trend in avoidance of the anthropogenic activities within D'MOSS reserves, which comprised very small proportions of the total area and only occurred in a small frequency of sites (Fig. 2.2c).

2.4 Discussion

Crowned eagles were able to establish breeding sites within close proximity to formal residential areas, provided natural or exotic forest patches were available for nesting. All sites require natural forest in close proximity, which is correlated with established D'MOSS areas. As predicted, streams and lower valleys were preferred in the local topology. However nests were not, as predicted, further from dwellings and roads as control sites.

Searching for crowned eagle nests was initially established using the knowledge of social and public networks. This was exceptionally useful however the authors noticed in a

few cases (four known cases) that some resident's attempted to obfuscate the search for nest sites. The misdirection of the author's efforts appeared to be due to an ignorance of the value, or general mistrust, in the scientific investigations performed by the authors. Large areas of scarp forest in the study area were inaccessible on foot due to impenetrable vegetation and sheer terrain. Furthermore, safety constraints limited the coverage of forests adjacent to informal settlements, and organising security personal to accompany on surveys was very limited for this study. In addition to the 20 known nests in the 500 km² study area, three territories were present where an active nest could not be located. Beyond the 500 km² study site, large areas of land were not thoroughly surveyed for absence of crowned eagle occupation. Aerial drone technology is perceived by the authors as the next great leap in nest surveying of large forest raptors.

Of all 46 crowned eagle nests monitored in the wider area of interest, the minimum nearest neighbour distance was 1.2 km apart, at nests in an urban interface in Pietermaritzburg. We could not clarify sighting times that would suggest two different adult females breeding at each nest, and suggest the use of two sites in alternating years by one female. In two other cases where pairs of nests were 1.4 and 1.6 km apart, in 2012 and 2013, respectively, nests were simultaneous occupied by females, in both cases only one of the two nests successfully fledged a chick. In Southbroom, 150 km south of Durban, a trio of nests (inter-nest distances of 1.4 - 1.9 km on a linear axis) all fledged a chick in the 2013 year. This is to our knowledge the closest reported distances of active nests for crowned eagle, except for a population in a pristine tropical forest of Tai National Park, Ivory Coast (Shultz, 2002). This indicates that there is a saturated breeding population of crowned eagles within the D'MOSS – formal residential matrix within the eThekweni municipality.

In the 500 km² study area, D'MOSS comprised only 34% of the land area and yet contained 95% of crowned eagle nests. Furthermore 54% of the area of D'MOSS was within 100 m from an edge, in turn containing 75% of crowned eagle nest sites. It is likely that nest site discovery was biased towards the urban interface of a D'MOSS area and dedicated forest-interior surveys may locate more forest-interior nests. Despite this, we describe a high number of nests at the edge of D'MOSS-residential interface.

The predictions that crowned eagles would avoid anthropogenic factors were rejected which suggest a high tolerance of this population to human activity. Indeed in cases within the study area and wider area of interest, it was astonishing how certain pairs could coexist with human activity. Nine sites were less than 60 m from permanently occupied residences, with one site a distance of 30 m from the nearest house, this nest was originally further from housing, but extending developments in the village subsequently built underneath the nest tree, it continues to be a productive breeding site (Hoffman & Hoffman, 2009). Other successful nest sites include one in a mature *Eucalyptus* abutting a 0.5 ha community garden, and another in a *Eucalyptus*, 30 m distance and at eye-level from the nest to a restaurant balcony. However, there does appear to be a strong aversion to informal settlements and

industrial/commercial areas within the immediate area of nest placement. Differences in community interaction with the surrounding wildlife in these informal settlement areas, reduced prey availability for crowned eagles, or direct persecution, are likely factors for this difference. Whether this highly tolerant urban population demonstrates a more widespread phenotypic plasticity of the species or is driven by a unique character founder effect is an area of interest (Lowry, Lill, & Wong, 2013). Juvenile crowned eagles across a variety of regions are confiding and inquisitive of human visitors, which precedes conditions for habituation or alternatively, easy persecution. Our results indicate crowned eagles have the capacity to occupy urban indigenous green-space in many African cities in forest biomes provided they are protected from direct human persecution.

Riparian habitats are critical areas of importance for water and biodiversity conservation in modified environments (Bennett, Nimmo, & Radford, 2014). The significant nest site selection towards stream proximity by crowned eagles may reflect a correlation between three factors; eagle preference to lower slopes enhances accessibility while carrying nesting material and prey, steep gorges and flood valleys have naturally deterred development prior to implementation of formal green-space management plans, and suitably large nesting trees grow fastest near streams with year round water availability (pers. obs.). An excellent example of this is the growth rate of riparian *Eucalyptus* which was the single most frequently used nest tree species.

Invasive *Eucalyptus* species are one of a host of invasive plants targeted by a government funded nationwide management scheme; ‘Working for Water’, which aims primarily to provide poverty-relief by employing task forces to control invasive vegetation and restore indigenous hydrological systems (Forsyth et al., 2004; Turpie, Marais, & Blignaut, 2008; WfW, 2009). Within the study area *Eucalyptus* trees have been killed by ring-barking, including trees with active crowned eagle nests and black sparrowhawk (*Accipiter melanoleucus*) nests in them. These dead trees stand defoliated and decaying for many years, resulting in a nest site less sheltered from wind, rain, and direct sunlight. While Working for Waters’ goals to provide poverty amelioration is worthy, in such cases as this where there are conflicting conservation goals, *Eucalyptus* removal perhaps represents an overenthusiastic over-shoot (Dickie et al., 2014). This overshoot is also illustrated in areas of the Western Cape Province, South Africa, where gum trees provide the only suitable nesting sites for African fish-eagles (*Haliaeetus vocifer*) (Welz & Jenkins, 2005).

2.4.1 Recommendations

Ground searching within forest was a very inefficient method of locating nests, and searching for the remote nests on foot was demoted in preference of thorough survival monitoring of known nest sites. Recognizing these limitations, the study area has been selected to reduce bias in the under-sampling of informal areas by excluding all but the internal edges of such settlement areas. Inferring from mean inter-nest distances described in this study, and

assuming forests near informal settlements are habitable for crowned eagles, the study area ought to support an additional nine territories. Future research should concentrate on providing reliable presence/absence data from forests near informal settlements, using drones to search interior regions of forests, and quantifying prey availability in the different areas. Additional nest sites will allow multivariate modelling that was not statistically powerful with the current sample size (Nur Jones, & Geupel, 1999; Burnham & Anderson, 2002).

While suitable prey can be obtained from a variety of forest types, crowned eagles preferentially nest in mature indigenous forest and patches of exotic forest. Very small patches of <20 *Eucalyptus* trees surrounded by thickets and light bush or abutting low density formal residential zones are frequently used for nesting. Large *Eucalyptus* trees appear to be particularly difficult for vervet monkeys to climb and are easily defended from threats to nestlings. In the absence of indigenous forest with emergent tree species, it is recommended that small stands (< 20 trees) of *Eucalyptus* over 25 m in height are available within D'MOSS mixed mosaic areas for nesting approximately every 1.5 km along stream lines. In addition if complete *Eucalyptus* eradication is a priority, restoration should involve a successional approach of thinning and under-planting *Eucalyptus* stands with sapling indigenous trees, particularly *Trichilia dregeana*, *Celtis africana*, and *Ficus* spp. that would replace exotic trees in 100 years hence.

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Supplementary I: SCIENTIFIC POSTER

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CROWNED EAGLES IN URBAN GREENSPACE NEST SITE SELECTION AT ITS LIMITS

Sept 2015

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INTRODUCTION

The Durban Metropolitan Open Space System (D'MOSS) faces the challenge of conserving biodiversity in a regional hotspot in the face of rapid urban growth^[1]. Raptors are considered as an indicator clade for ecosystem health^[2], therefore the preferences of sensitive raptors in urban landscapes can direct optimal landscape planning, enabling biodiversity and conservation benefits for threatened species^[3]. Surprisingly, a productive population of Africa's third largest eagle: the crowned eagle (*Stephanoaetus coronatus*) is breeding within the D'MOSS landscape. We investigate micro-habitat and landscape scale features at crowned eagle nests to determine the limiting requirements for successful nesting.

METHODS

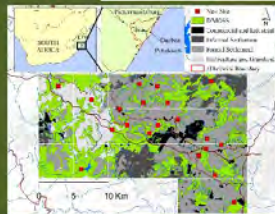
MEASURED VARIABLES

GPS location
Tree species
Tree and nest height
Position in the topology
Distance to stream
Distance to road
Distance to houses

Nest position with regard to the D'MOSS boundary and landuse types (high, med, low human impact) within 1.5 km² of each nest

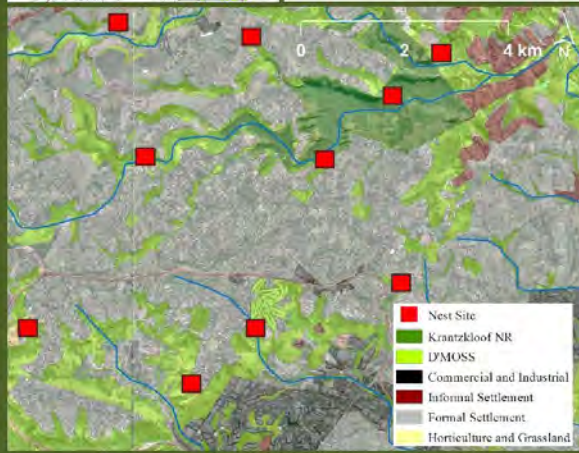


Photo by Jacques Schipper



This crowned eagle nest in Hilton, KZN is the highest recorded in the study area. It is 42m up a 65 m Blue Gum (*Eucalyptus saligna*).

LEFT: A 500 km² area of the outer west suburbs of Durban was the focal area of this land-use study



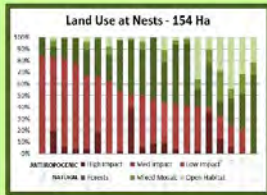
ABOVE: Inter-nest distances were (mean) 2.3 km apart and showed high affinity to streams and the Durban Metropolitan Open Space System boundary

RESULTS

46 nests in study area of KwaZulu-Natal. 20 of these within eThekweni Municipality

Over half of the nests were in exotic tree species, 41% of all nests were in Blue gum

Nests could be in copses of only 5 mature gums, provided forest and bush is available in a wider area



TREE SPECIES	# NESTS
Sydney Blue Gum (<i>Eucalyptus saligna</i>)	13
Red River Gum (<i>Acacia saligna</i>)	3
Forest Natal Mahogany (<i>Tournefortia argentea</i>)	3
Slack Elm (<i>Ulmus laevis</i>)	2
River Macaranga (<i>Macaranga ramosa</i>)	2
Common WMS Fig (<i>Ficus latifolia</i>)	2
Small-leaved Yellowwood (<i>Podocarpus falcatus</i>)	2
Clutter Elm (<i>Ulmus laevis</i>)	1
Campbell Tree (<i>Macaranga ramosa</i>)	1
Gibby Oak (<i>Quercus laevis</i>)	1
Coastal Stringer Fig (<i>Ficus latifolia</i>)	1
Tree-leaf Fig (<i>Ficus latifolia</i>)	1
Red Beech (<i>Prunella laetevirens</i>)	1
White Birchwood (<i>Ulmus laevis</i>)	1
Planted Willow (<i>Salix caprea</i>)	1
Round-head Cabbage Tree (<i>Styphelia saligna</i>)	1
Cape Ash (<i>Acacia saligna</i>)	1
Coastal Red Willow (<i>Salix caprea</i>)	1
Quinine Tree (<i>Acacia saligna</i>)	1
Indigenous tree	1



Exotic trees grow to greater heights, and faster, than indigenous trees.

CONCLUSIONS

D'MOSS covers vital crowned eagle habitat, including 95% of the nest sites. The landscape within 1.5 km² of the nest requires a minimum 14 ha (mean = 50 ha) indigenous forest. Eagles avoid nesting near high human-impact areas (e.g. informal settlement, industry, and main roads).

Several African raptors now readily nest in Blue Gums^[4,5]. The rapid growth, radial structure, height, and smooth bark may all provide benefits, particularly protection from harassment by vervet monkeys^[6].

Municipal and national schemes to remove exotic flora are worthy pursuits^[7]. But the task of removing riparian gums to protect water flow may put nest trees at risk. Protecting raptor nests in exotic trees presents a challenging management issue.

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Malecore

3 Diet of the crowned eagle (*Stephanoaetus coronatus*) in an urban landscape: potential for human-wildlife conflict?

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Abstract

The study of diet is pivotal in understanding a species, particularly for quantifying a predatory raptors' economic niche and potential for human-wildlife conflict. The crowned eagle (*Stephanoaetus coronatus*) is one of Africa's apex predators and a population is present within the urban green space mosaic of Durban and Pietermaritzburg, KwaZulu-Natal, South Africa. In close association with urban development, the local population of crowned eagles has the potential to be a concern to the safety of domestic stock and pets. Time-lapse cameras were positioned at urban nest sites (n = 11) to identify the prey composition during breeding, particularly in regards to taxa with human associations. The numerical proportion of avian prey, particularly hadeda ibis (*Bostrychia hagedash*) pulli, was several times greater than any previous diet description. The methodology used and the abundance of hadeda ibis in these urban environments are potential contributing factors. Rock hyrax (*Procavia capensis*) was the primary prey and where hyrax were unavailable, the diet composition was broader and included more vervet monkeys (*Chlorocebus pygerythrus*). It was found that domestic stock comprised 6 % of the identifiable prey. Contrary to popular belief, no dogs (*Canis familiaris*) and few cats (*Felis domesticus*) were delivered to the nest by breeding eagles in this study. The negative consequences of small proportions of pet losses should be considered against the majority of wildlife prey consumed, which also have various wildlife conflict interactions. Juvenile and sub-adult eagles are most frequently identified at in situ attacks of pets, particularly toy dog breeds. Further research on juvenile dispersal and winter diet will provide insights on the ecological impacts of eagle management strategies in the region.

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Keywords Crowned eagle; *Stephanoaetus coronatus*; Diet; Camera trap; Human-wildlife conflict; Raptor; Urban

3.1 Introduction

Effective foraging is pivotal to the life of an individual and the evolution of species adaptations (Holt 1983; Pyke 1984). Some raptors have adapted to urban areas, making use of abundant synurban avian and mammalian prey (Cade et al. 1994; Chace and Walsh 2006; Charter et al. 2007). Knowledge of the factors influencing dietary selection has implications for a species' economic food niche, and wildlife conflicts within human dominated landscapes (Litvaitis 2000). Raptors are widely considered as an indicator clade for ecosystem health and are a visible indicator of trophic dynamics in ecosystems (Sekercioglu 2006; Sergio et al. 2006, 2008).

Feeding behaviours are an important and widely studied aspect of biology of many of the worlds' raptors (Marti et al. 2007). Most often, raptor diet studies analyse a collection of accumulated prey remains and regurgitated pellets containing hair, feather, and/or bone material at nest or roost sites (Marti et al. 2007). Pellets tend to; over-represent mammalian and underrepresent avian composition (Redpath et al. 2001), feature high species detection but under-represent small sized animals (Bakaloudis et al. 2012), and pose quantification problems where prey items are large and consumed over several meals (Marti et al. 2007). Analyses of prey remains are biased towards the larger persistent types of remains (Redpath et al. 2001) and analysis of feather and hair can accurately assess taxa with time consuming analysis, but will not clearly present numerical data (Keogh 1983, 1985; Buys and Keogh 1984). Pooling these two indirect techniques can counterbalance respective biases (Simmons et al. 1991; Lewis et al. 2004; Bakaloudis et al. 2012), although not in all cases (Collopy 1983; Redpath et al. 2001).

Direct observation techniques, with adequate skill, situation, and persistence can obtain complete and accurate samples. Effort is most rewarded with smaller raptors that deliver multiple prey items each day to a nest site (Redpath et al. 2001). Additional advantages include obtaining information on biomass quantification and behavioural data such as delivery rates and feeding schedules (Marti et al. 2007). However, direct observational data can be limited by knowledge, skill, and observer fatigue as well as an absence of a verification process (Lewis et al. 2004; Rogers et al. 2005). Direct observations of raptors in their hunting habitat are also valuable data but such methods are difficult to obtain adequate sample sizes (Marti et al. 2007).

The use of videography and photographic techniques is considered to be effective and reliable (Kristan et al. 1996; Lewis et al. 2004; Margalida et al. 2006). In recent years, miniaturization and power efficiency have made automated 'camera traps' useful in ecological studies, although functionality was primarily driven by the demands of game hunters (Oconnell et al. 2011; Meek and Pittet 2012). Feeding biology of large eagles makes

the use of camera traps the most effective option now available (Rogers et al. 2005; López-López and Urios 2010). Large prey items are delivered infrequently and eagles selectively feed on easily digestible portions, thereby producing fewer pellets (Boshoff et al. 1994).

The crowned eagle *Stephanoaetus coronatus* (Linnaeus 1766), is the third largest predatory raptor of Africa and is a powerful eagle capable of taking prey several times its body mass (Brown and Amadon 1968; Ferguson-Lees and Christie 2005; Hockey et al. 2005). Restricted to forested and dense woodlands, they regularly include monkeys and antelope species of a mass between 1 and 5 kg, and rarely, up to 20 kg (Brown 1972; Swatridge et al. 2014). Exceptionally rare circumstances include two instances of human remains at nests (Steyn 1983; Thomsett 2011). Taphonomic evidence on *Australopithecus africanus* remains indicate that forest eagles have had a potentially significant effect on the evolution of predator avoidance behaviour of early hominins (Berger and McGraw 2007, p. 498, McGraw and Berger 2013).

Twelve diet studies on crowned eagles were found in the literature, building on founding studies in Kenya by Brown (1966, 1971, 1976); Brown and Amadon 1968. Available studies are not representative across the eagle's distribution. In particular there is limited data from the humid tropical forests of central and west Africa (Skorupa 1989; Mitani et al. 2001; Shultz 2002), and better data from dryer eastern and especially southern regions (Jarvis et al. 1980; Steyn 1983; Tarboton and Allen 1984; Msuya 1993; Boshoff et al. 1994; Swatridge et al. 2014; Symes and Antonites 2014). The overwhelming majority of diet descriptions have used prey remains, and to a lesser extent pellets, with small samples of direct observations amended to a few studies. These studies assert that the crowned eagle is mostly constrained to mammalian prey. In studies with high volume of remains, including those obtained from visits to the active nest site (as opposed to collections from the base of the nest tree), bird and reptile remains are a small component (Boshoff et al. 1994; Shultz 2002; Symes and Antonites 2014). Furthermore there are no published studies of diet in urban areas.

In prey remain collections at crowned eagle nests, domestic stock including sheep, goats, cats, and chickens are found in proportions rarely above 1 %, with one published record of a dog (Jarvis et al. 1980; Boshoff et al. 1994). One nest in peri-urban Harare, Zimbabwe consisted of a majority of prey as feral cats (A Middleton, unpubl. data). In eastern regions of South Africa, particularly urban KwaZulu-Natal, pet attacks by raptors are reported in local newspapers annually, and is an ongoing conflict issue for the public, local wildlife management, and raptor rehabilitation organisations (Whittington-Jones 2014; B Hoffman pers. comm.). The local population of crowned eagles is dispersed amongst the suburban green-space mosaic, and therefore the potential for interaction with small stock and pets and resulting human-wildlife conflict is high. The crowned eagle breeding cycle in KwaZulu-Natal is seasonal, with peak egg laying between August and October (Hockey et al.

2005). All young of the season have fledged by March and remain dependent on their parents, taking prey deliveries on the nest for at least 3 months post-fledging.

The primary objective of this study was to describe the breeding diet of the crowned eagle in the urban environment, and in particular the implications for human-wildlife conflicts with regards to domestic stock and family pets. It was predicted that the diet would comprise primarily of synurban wildlife, and in particular rock hyrax (*Procavia capensis*) and vervet monkeys (*Chlorocebus pygerythrus*), and due to long established conflicts and learned behaviours, stock and pets would not be frequently selected prey.

3.2 Methods

3.2.1 Study area

During 2012 and 2013 there were 46 crowned eagle nests (e.g., Fig. 3.1) located in the southern KwaZulu-Natal province. From these, ten nests were selected on a priori criteria (high degree of urban interface in home range, historical reports of pet depredations) to maximise the potential for obtaining diet data of importance to human-wildlife conflict issues. Eight nests were selected within the urban green-space mosaic (Fig. 3.2, nests 3–11, 4 & 5 are the same nest site replicated in 2012 and 2013) of the Durban Metropolitan Open Space System (D'MOSS), one nest on a residential interface in Pietermaritzburg (Fig. 3.2, nest 2), and one nest in Zimbali Coastal Resort, on Durban's North Coast (Fig. 3.2, nest 1). Of the eight land cover types defined, the important anthropogenic land cover within a 1 km radius of nests were residential, golf estates, and smallholdings, with mean cover of 44, 14, and 3 % respectively, (Table 3.1).

3.2.2 Data collection

Cameras (Ltl Acorn 5210MG and 6210MG, with rechargeable AA batteries and 32 GB SDHC memory card) were installed 2–3.5 m from the front edge of each crowned eagle nest, between 20 and 80° pitch. Nests were between 10 and 25 m above ground, and accessed using a fixed-rope jumar technique. In the 2012 season, cameras were installed when the eagle chick was 14–26 days old (mean 20.4 days) and in 2013 between –9 (prior to hatching) and 37 days old (mean 13.9 days), on warm, shaded days. Cameras were each housed in a custom steel box and strapped to available tree architecture. Total duration of climbing installation visits varied between 30 min and 1.5 h, and servicing visits were typically 20–30 min, except when ringing (banding) the chick (1.5 h). Motion-activated functions were disabled and cameras were set to operate only in diurnal periods (on >30 min before sunrise and off >30 min after sunset). Time lapse schedule of 1 image /1 min was employed until the chick was ringed between 68 and 85 days of age, and then all cameras were set on 1 image /2 min schedule for the remaining duration of their use. Batteries were replaced and data collected every 16–18 days for the /1 min schedule, and every 20–28 days for the /2 min schedule. With the exception of the ringing-to-fledge period where each

camera was left until natural fledging was observed (93–120 days, mean 106 in literature). Therefore in 2012 very few nest cameras were powered between chick age 90 to ca.110 days. In addition firmware instability resulted in a varying amount of data loss in every camera at stochastic intervals, and cases of program switching to video recordings (e.g., Fig. 3.1). All field activities were performed with Ezemvelo KZN Wildlife permit and the University of KwaZulu-Natal Animal Ethics approval.



Figure 3.1 An adult male crowned eagle (*Stephanoaetus coronatus*) arriving at the nest with a juvenile rock hyrax (*Procavia capensis*). The juvenile eagle has fledged and is 193 days old, but returns to the nest to wait expectantly upon hearing the adult calling as it approaches with food

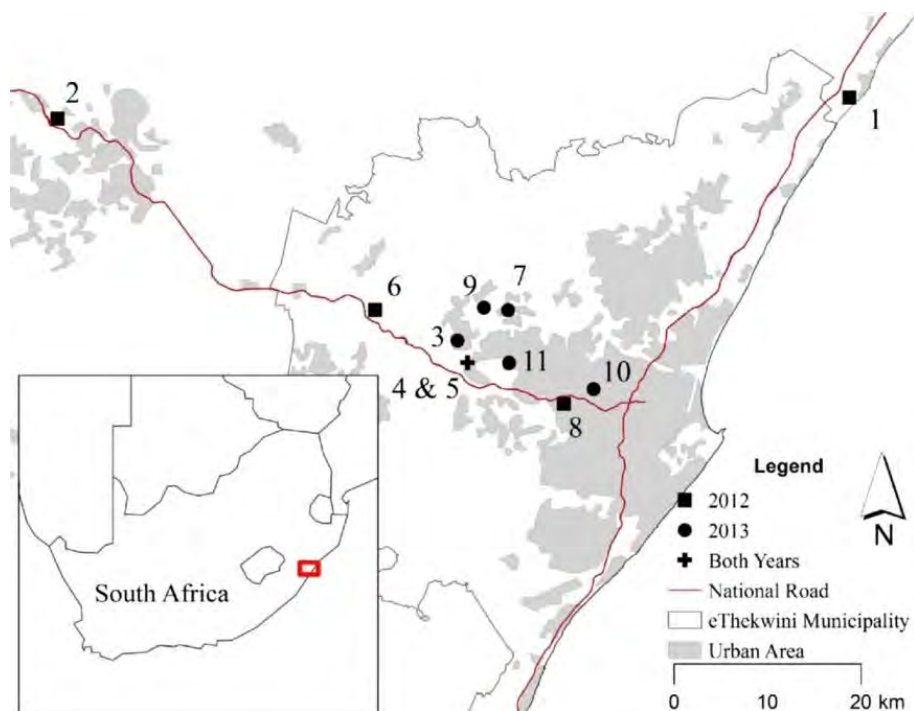


Figure 3.2 The locations and year(s) of 10 crowned eagle nest sites sampled with time-lapse cameras.

3.2.3 Data analyses

Crowned eagle camera data were reviewed in continuous sequences (~15 days, 14,000 images per session) and prey items were tracked from arrival to consumption and/or discard. Images were catalogued to a prey items table, which summarised prey on an individual prey animal level (larger species are delivered in multiple parts over 1–3 days) and a per day scale.

Table 3.1 Percent land cover within 1 km radius of crowned eagle nests monitored by nest cameras in the 2012 and 2013 seasons

LAND COVER (%)	1	2	3	4 & 5	6	7	8	9	10	11	Mean
Residential	25	10	0	60	4	84	47	74	46	77	44
Forest and bush	40	20	15	21	23	10	39	23	21	4	22
Golf estate	28	61	48	0	0	0	0	0	16	0	14
Grassland	0	0	33	12	39	0	2	0	17	8	11
Sugar Cane	0	3	0	0	0	0	0	0	0	0	0
Roads and commercial	7	0	4	7	0	6	12	3	0	11	5
Smallholding	0	0	0	0	34	0	0	0	0	0	3
Ocean	0	6	0	0	0	0	0	0	0	0	1

Alongside, metadata including date, camera operation schedules, chick age and verification notes were appended. Prey delivery frequency and accuracy of identification were documented. Prey identification accuracy was not different between the /1 min and /2 min schedules. A group of experts (n = 6) in relevant regional vertebrate taxa assisted with identification of difficult items (n = 91). Where identification was doubtful the next appropriate clade (order, class, phylum, none) of accuracy was recorded. Species identification was treated conservatively to eliminate Type I errors, as were attempts to estimate some age classes for prey. Resolution did not permit separation of sub-adult and adult bovids where skeletal remains provide a clear age distinction (based on e.g., horn size, length). Rock hyrax and blue duiker (*Philantomba monticola*) were regarded as morphospecies due to the difficulty in visual distinction and apparent absence of tree hyrax (*Dendrohyrax aboreus*) and red duiker (*Cephalophus natalensis*), respectively (L Richards pers. comm.).

To be comparable with published literature on crowned eagle diet, prey was counted by frequency of individuals. To estimate whether the samples adequately reached a species richness (Chao1) asymptote, individual-based rarefaction curves were calculated in EstimateS (Gotelli and Colwell 2011; Colwell 2013). Ecological differences in prey composition between nests were measured with Richness, Shannon Index (Shannon and Weaver 1949; Spellerberg and Fedor 2003), Simpson's Index of Diversity (Simpson 1949), and Evenness, E_{var} (Smith and Wilson 1996; Beisel et al. 2003). The sum of Pianka's (1973) niche overlap index was used to assess variation between sites of eight taxa (Hamer et al. 2001). The

demographic structure of the three most abundant prey taxa was given as a monthly frequency per site to assess seasonal changes.

3.3 Results

Cameras recorded 812,327 images from 11 crowned eagle nests between 10 August 2012 – 8 April 2013 (n = 5), and 25 September 2013 – 9 March 2014 (n = 6). From a combined operation period of 1598 days, 1252 days (78.3 %) of uninterrupted continuous daily data were captured (Fig. 3.3), plus an additional 202 days of partial data (91.0 % of days with > 10 % daily coverage). Incomplete data sequences occurred when programmed schedules were disrupted by firmware faults. The last cameras were removed on 8 April for the 2012 season, and on 9 March in 2013, therefore for ease of division a month is defined by the starting and ending on the 10th. All 11 young from nests with cameras survived beyond the monitoring period. Prey delivery rates were at their maximum during the first 40 days post-hatch (mean = 0.8 prey/day). From 120 to 200 days old (80 days post-fledge) prey deliveries still occurred at the nest (mean = 0.35 prey/day). Prey was still occasionally delivered to the nest beyond 250 days (pers. obs.).

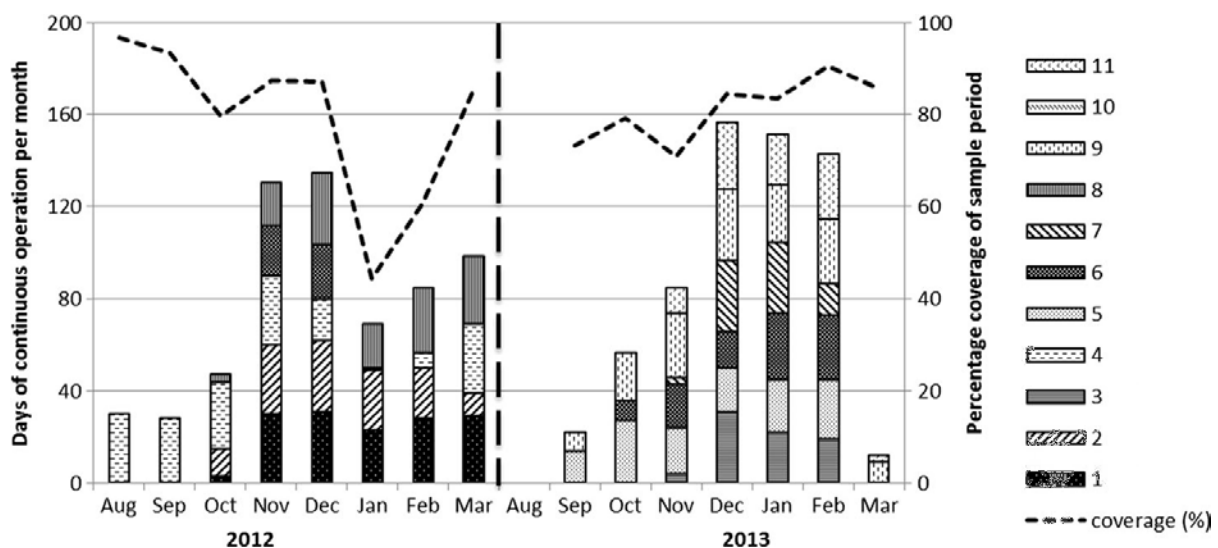


Figure 3.3 The volume and continuity of complete daily records of time-lapse data captured at crowned eagle nest sites in 2012 and 2013 breeding seasons (4 & 5 are the same nest monitored in two different years)

3.3.1 Prey composition

The summed Pianka's values of the nests within eThekwini had the greatest degree of similarity with a 0.77 point difference between all 9 sites. Nest 2 in urban Pietermaritzburg varies from the eThekwini group by 1.5 points, and Nest 1 was an extreme outlier (Table 3.2). Nest 1 had the highest in all values of richness, diversity and evenness (Table 3.2). We identified 836 prey animals, and were able to classify 84.7 % to species, and 92.9 % to class (Table 3.3). The species richness for the entire data set was 22 plus two unidentified species,

a wild dove and a rat. Rock hyrax was the single most abundant prey (42 %), with hadeda ibis second (19 %). The majority of hadeda ibis prey was pulli (89 %), with only very rare cases of other young bird species represented.

Of the 716 prey items identified to species, 93 % were wildlife. Domestic stock (chickens *Gallus domesticus*, racing pigeons *Columba livia*, guineafowl *Numida meleagris*, and one goat *Capra hircus*) comprised 6 %, and were mostly chickens (4 %). Pets comprised 1 % (primarily cats and one rabbit, Fig. 3.4). It is of considerable note that no dogs were identified as breeding season prey during this study.

Hadedea ibis pulli first appeared in the prey observations in October and with decreasing numbers continued to be delivered to the nest as late as March when the cameras were discontinued (Fig. 3.5). Frequency of adult rock hyrax appeared to be greatest in August and September but the trend was not strong, while juvenile hyrax had a November peak (Fig. 3.5). No significant trends could be deduced from data on duiker (specifically blue duiker, and combined bovids) due to high standard error in the samples.

Table 3.2 Richness, Diversity, Evenness and Pianka's Niche Overlap values of breeding diet from 11 nesting periods of crowned eagles, sampled by nest cameras.

NEST	RICHNESS	SHANNON DIVERSITY (h')	SIMPSON INDEX OF DIVERSITY	E SHANNON EVENNESS	SUM OF PIANKA
1	13	1.97	0.83	0.4	0.89**
2	7	1.31	0.65	0.31	1.77*
3	7	1.35	0.69	0.38	3.16
4	10	1.47	0.68	0.34	3.22
5	11	1.52	0.67	0.37	3.24
6	6	1.31	0.64	0.51	3.36
7	5	1.03	0.58	0.32	3.6
8	6	0.94	0.47	0.27	3.75
9	6	0.96	0.47	0.32	3.76
10	4	0.81	0.51	0.23	3.8
11	6	0.88	0.4	0.39	3.93

3.3.2 Predicted asymptotic richness

Based on the rarefaction curve, two sites were far from reaching a species accumulation asymptote; Nest 1 and Nest 3, which predicted minimum richness of 33.7 and 12.85 species respectively (Chao1, c.f. Table 3.2). Nest 2 had a predicted minimum richness of 9.96, while the remaining 8 sites were within 2 points of an asymptotic limit. These results were not correlated with sample size ($R = 0.015$, $p = 0.714$).

Table 3.3 The diet of crowned eagle in urban areas of KwaZulu-Natal, South Africa. Diet was assessed using time-lapse cameras at 11 nests sites over two seasons (Aug-April 2012 and Sep-March 2013). (Taxonomy follows (Hockey et al. 2005, Skinner and Chimimba 2005))

ORDER AND SPECIES	COMMON NAME	n	total	% neonate ¹
Not identified to any Taxon		59	7.1	
CLASS MAMMALIA				
Unidentified mammal		41	4.9	
Hyracoidea				
<i>Procavia capensis</i>	Rock Hyrax	353	42.2	26.6
Primates				
<i>Chlorocebus pygerythrus</i>	Vervet monkey	40	4.8	37.5
<i>Otolemur crassicaudatus</i>	Greater galago	4	0.5	50.0
Ruminantia				
<i>Philantomba monticola</i>	Blue duiker	60	7.2	18.3
<i>Sylvicapra grimmia</i>	Grey duiker	10	1.2	
<i>Tragelaphus scriptus</i>	Bushbuck	5	0.6	80.0
<i>Capra hircus</i>	Goat	1	0.1	
Unidentified ungulate		5	0.6	
Lagomorpha				
<i>Oryctolagus cuniculus</i>	Rabbit (domestic)	1	0.1	
Carnivora				
<i>Felis domesticus</i>	Cat (domestic / feral)	7	0.8	
<i>Mongos mongo</i>	Banded Mongoose	6	0.7	66.7
<i>Genetta tigris</i>	Large Spotted Genet	5	0.6	
<i>Atilax paludinosus</i>	Marsh Mongoose	2	0.2	
<i>Herpestes ichneumon</i>	Large Grey Mongoose	1	0.1	
Unidentified mongoose		1	0.1	
Afrosoricida				
<i>Amblysomus hottentotus</i>	Hottentot Golden Mole	1	0.1	
Rodentia				
<i>Thryonomys swinderianus</i>	Greater Cane Rat	6	0.7	
Unidentified rat species		2	0.2	
CLASS AVES				
Unidentified Aves		20	2.4	
Ciconiiformes				
<i>Bostrychia hagedash</i>	Hadeda Ibis	162	19.4	88.9
Galliformes				
<i>Gallus gallus</i>	Chicken (domestic)	28	3.3	25.0
<i>Numida meleagris</i>	Helmeted Guineafowl	5	0.6	
<i>Scleroptila shelleyi</i>	Shellys Francolin	1	0.1	
<i>Guttera edouardi</i>	Crested Guineafowl	1	0.1	
Columbiformes				
<i>Comba livia</i>	Racing pigeon (domestic)	6	0.7	
Unidentified wild dove		2	0.2	100.0
Strigiformes				
<i>Bubo africanus</i>	Spotted Eagle-owl	1	0.1	
CLASS Reptilia				
(none)			0.0	
TOTAL		836	100.0	

¹ where possible for species listed. Includes teenage monkeys, juvenile hyrax and bovids, bird pullus. Nearly-full grown subadults are not included in neonate group

3.4 Discussion

Our predictions that synurban wildlife would provide a majority of the diet were confirmed, except for an unexpected paucity of urban vervet monkeys in most cases. The frequency of stock and pets were very low as expected, and the public perception of high pet predation rates must reflect a reporting bias. This study presents the single largest quantity of direct observations (1252 complete days from a total of 11 breeding attempts) of breeding season prey at crowned eagle nests since perhaps those by Brown (1966) in Kenya. The use of camera traps on a minute-scale time-lapse setting was an effective and efficient methodology that is highly recommended for studies on eagle diet. While the crowned eagles were found to habituate to the fortnightly access visits, a remote servicing and download method would improve on these methods, especially for sensitive species and/or breeding periods such as incubation and fledging. Crowned eagles can comfortably carry items approximately 2 kg in body mass thus many prey species heavier than this – such as adult hyrax, bovids, and monkeys, are usually dismembered at the kill site and delivered to the nest in parts. For particularly large prey such as adult blue duiker and immature bushbuck (*Tragelaphus scriptus*), typically 2–4 parts delivered to the nest rarely comprise the complete sum of the animal. Legs are more frequently delivered than the head for bovids (pers. obs.). Small prey such as juvenile hyrax and especially bird prey are often delivered headless – likely consumed by the adult at the kill site. At the nest, hadeda ibis pulli are typically entirely consumed including the soft legs and feet. During the first 50 days after hatch when the adult female is still restricted to the nest area, we observed her remove skeletal remains and prey items >4 days old. Field observations suggest these are often carried to a favourite observation tree ca. 30 m from the nest tree and dropped. Pellets were also found less often on the nest than expected, and are presumably discarded at observation perches away from the nest. These behavioural patterns will bias dietary descriptions using prey remains collected underneath a crowned eagle nest. To eliminate Type I errors, ‘unidentified prey’ would be overcounted rather than undercounted due to amorphous items belonging to an otherwise identified prey individual. Typically multipart prey is delivered over 6 h, and including the next morning for evening kills. Given a clear view of the nest, the time-lapse resolution allows for accurate tracking of each prey item, differences in prey body size and the nature of the dismemberment of parts reduce inaccuracies further when multiple animals occur on the nest simultaneously. Species accumulation curves were predicted (Chao1) as near-asymptotic for all but three crowned eagle nests. However, greater diversity and evenness in the diet during declines in abundance of preferred prey might be expected (Litvaitis 2000; Palma et al. 2006). Direct observations of crowned eagles in their hunting locations would be of great benefit to quantify differences between prey eaten on site and prey delivered to the nest, as well as prey selected during the non-breeding season.

However, to unobtrusively observe such an ambush predator and its' prey in forest and dense bush would be a considerable challenge. The minimum post-fledging parental care period in crowned eagles is 280 days, and may extend to 350 days (Brown 1966; Skorupa 1989). Food is rarely delivered to the nest beyond 9 months post-fledging, and prey delivery rates fell to below 1 item per 5 days after the juvenile age reached 250 days (current study). We suggest that 200 days is the upper limit of efficient diet sampling at crowned eagle nests.

Figure 3.4 The proportion of prey identified to species (n = 716), by level of human-association, recorded at crowned eagle nests during the 2012 and 2013 breeding season as assessed by 11 time-lapse cameras

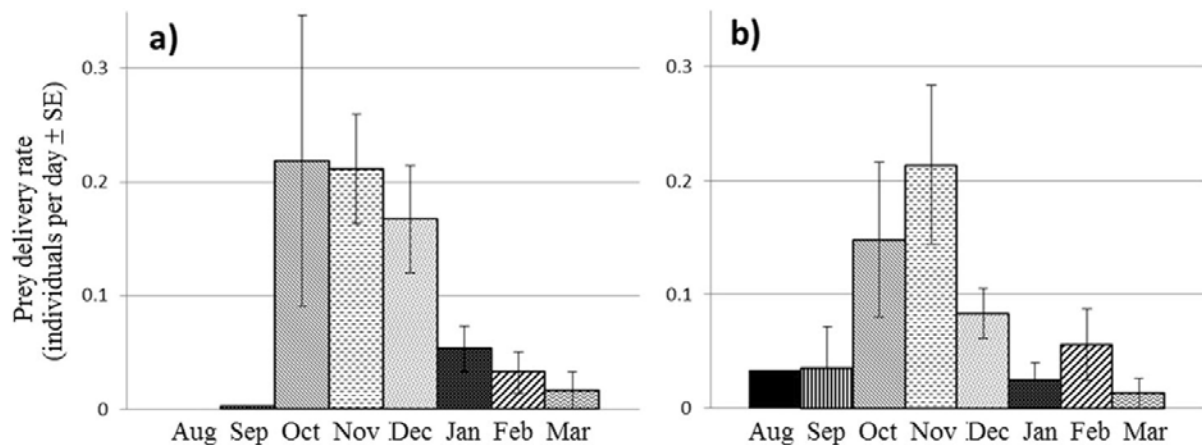
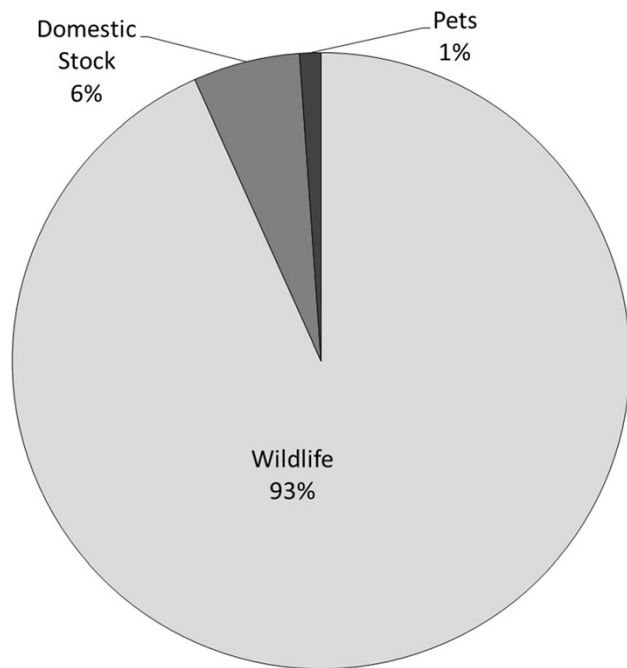


Figure 3.5 Seasonal changes in the delivery rates of hadeda ibis pulli (a) and rock hyrax juveniles (b) to crowned eagle nests.

3.4.1 Wildlife prey

The prevalence of birds, particularly pulli, in this study is unique amongst the dietary data available on crowned eagles. The next highest documented proportion is of trumpeter hornbills (*Bycanistes bucinator*), which comprised 8 % of prey in Taï, Côte d'Ivoire (Shultz 2002). In recent decades hadeda ibis have exploited suburban areas of South Africa and

continue to increase in abundance across South Africa. Landscape characteristics such as year-round moist soils, suburban gardens, parks, golf courses, and horticultural fields allow for greatly increased breeding success rates (CJ Vernon unpubl. data in Hockey et al. 2005). A dispersed, solitary nesting strategy in forest trees may make searching for and removing hadeda ibis nestlings a profitable tactic by crowned eagles in this study area. Observations of adult crowned eagles visiting hadeda ibis nest sites in residential gardens have been locally reported (pers. comm.), and a foraging crowned eagle will leave a nest of hadeda eggs, returning after the chicks have hatched, and returning again when the hadeda ibis' second clutch has hatched.

The dietary abundance of hadeda ibis is a contradiction to published knowledge of crowned eagle diet (primarily describing bone collections at nests). Whether this difference on prey composition is due solely to the methodology or the variation in prey availability in the urban environment is still to be determined, but is likely a combination of both. Additionally, observations from nests in local sugarcane landscapes report snakes and water monitor (*Varanus niloticus*) as prey delivered to the nest (McKibbin 2009; J du Preez pers. comm., T Hardman pers. comm.). This invites further investigation. Reptilian remains, like bird remains, are prone to complete consumption or rapid decay, therefore studies of raptor diet in areas where reptilian prey may be important, should consider camera monitoring techniques.

In accordance with the literature for southern Africa, rock hyrax is an important prey in this study area. The rock hyrax's capacity for exploiting urban resources is currently under investigation (C. Schoeman pers. comm.). The rock hyrax population appears to have expanded in Durban by using anthropogenic refugia; storm drains, culvert rock fillings, under houses; and modifying foraging behaviour (nocturnal foraging under street lights). A significant crash in the rock hyrax population between 1984 and 1994 across KwaZulu-Natal is mostly known from local knowledge and grey literature, a viral disease was suspected but no conclusive results are available (Alcock 2009). Some historical crowned eagle sites appeared to have been abandoned at this time (B Hoffman, J Johnson pers. com.). Future assessment of the urban rock hyrax population and corresponding crowned eagle productivity is pivotal to the understanding of the sustainability of the local crowned eagle population. Nest 1, at Zimbali Coastal Resort, did not have a hyrax population available within their home range. The Zimbali pair had the highest richness, diversity, and evenness indexes of those in this study, and a predicted minimum richness asymptote of 34 species. This is surely enhanced by an effective 'mainland island' management program of indigenous coastal flora and fauna.

Vervet monkeys, like rock hyrax, have adapted to exploit urban resources and locally increased in range and abundance. Vervet monkeys also polarize the public on human-wildlife conflict issues (Ramkissoo 2005; Pillay and Shezi 2012). Although the crowned eagle is a monkey-eating eagle, especially in Afro-tropical forests, the proportions

of monkeys in urban eagle diet is relatively low. Nests 1 and 2 have distinctly higher proportions of vervet monkeys in the diet than the others. There was a polynomial inverse correlation ($R^2 = 0.83$) between prey frequencies of hyrax and monkey. Declines in rock hyrax and hadeda ibis may induce prey switching and subsequently impact other prey species including monkeys and domestic animals (Phelan and Robertson 1978; Steenhof and Kochert 1988; Palma et al. 2006). Prey switching, and population declines have been documented in Verreaux eagle (*Aquila verreauxii*), an African eagle highly dependent on rock hyrax populations (Hockey et al. 2005; Alcock 2009; Symes and Kruger 2012).

3.4.2 Domestic prey

Domestic prey in the local crowned eagle diet was very low during the breeding period. Of those domestic species recorded the relatively high proportion of domestic chickens is effected by actions of the public. In some instances residents nearby a crowned eagle nest purchase a number of poults in spring and intentionally have them free-range on the property in the expectation of losses (pers. obs.). While some cats were identified as prey, the assertive approach was to class all cats as pets irrespective of whether any were feral. The same assumption was made for guinea fowl which are kept as garden pets in the suburban areas where feral flocks are rare.

The inflated public perception of pet mortality rates can be attributed to the close relationship that pets have with families, and the enduring memories that result from a traumatic case of eagle predation of a pet. These losses accumulate in the public psyche over many years, devoid of context relative to the volume of wildlife prey that is consumed unnoticed. In addition, lost pets in the neighbourhood of a known crowned eagle nest are also generally suspected of becoming eagle prey without further evidence, despite a wide range of potential causes of mortality. Generally, the losses of pets are attributed to juveniles during and following dispersal from 250 to 300 days (Boshoff 1990; Whittington-Jones 2014). The impact on pets and related factors including habituation, supplementary feeding by the public, and prey imprinting require further investigation.

The authors acknowledge that relative abundance of prey in the landscape was not measured and therefore prey selection could not be known. Quantifying a representative availability index for such a diverse array of taxa (conspicuous and cryptic mammalian and avian wildlife, stock numbers, and pets) in the urban environment is problematic. Despite an absence of abundance data for the various prey species, our results highlight that the adult crowned eagles do not appear to be ‘targeting’ pets, especially not during the breeding season. The abundance of rock hyrax and hadeda ibis in the urban environment is providing a valuable resource, and therefore maintaining healthy wildlife populations may be reducing the impact on pets and livestock. A strong emphasis on informing the residents near active breeding sites of the prey preferences of these eagles may ameliorate the concern of Durban’s citizens, and help to protect the eagles from unnecessary persecution.

3.5 Acknowledgments:

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Supplementary II : SCIENTIFIC POSTER

Presented at the World Forestry Conference. 8 Sept 2015, International Convention Centre, Durban, South Africa




INTRODUCTION

Urban ecology is an increasingly relevant and important discipline. Planned greenspace can provide indigenous habitats and ecosystem services within an urban mosaic^[1,2]. A crowned eagle (*Stephanoaetus coronatus*) population is successfully breeding throughout the Durban Metropolitan Open Space System^[3], South Africa. This powerful apex predator typically hunts medium sized mammals 1-15kg in mass^[4,5]. Livestock and pets are within this size range^[6,7]. Requiring a high food budget to raise an eaglet, the nest site is the ideal location to observe prey composition^[8,9]. Latest camera-trap technology was used to describe prey provisioning choice, and to assess depredation on livestock and pets.

METHODS

CAMERA TRAPPING

Model: Ltl Acorn 6210 MG
 Period: 2012 + 2013 : Sept to March
 Duty Cycle: Daily, ON:Dawn, OFF:Dusk
 Settings: Timelapse 1 image per 2 mins
 Camera: Installed 3m from nest
 Study Site: See map (TOP RIGHT)
 Sample Size: 11 nests
 Installed At: Eaglet age (mean) = 14 days old

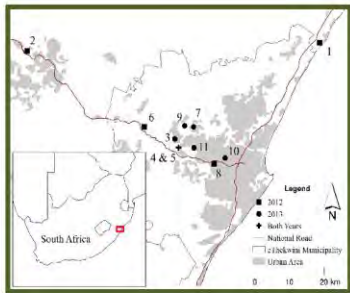


TREE CLIMBING

Fixed-rope jumar technique with limits on chick age (hatch/fledge)

DATA ANALYSIS

Very efficient method for observing crowned eagles while breeding. We captured 1,598 days of data which was analysed in 400 hours

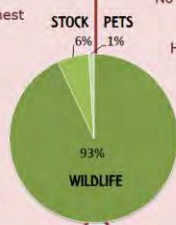


RESULTS

1 598 days observed (1 252 complete days)
 836 prey items recorded delivered to the nest
 716 (86%) were identified to species

16 mammal and 8 bird species
 Species Richness from 4-13 spp. per nest

IMPORTANT PREY
 Rock hyrax (an abundant urban coloniser)
 Hadedea ibis (especially nestlings)
 Small bovids (e.g blue duiker)
 Small carnivora (e.g. mongooses, genet)
 Vervet monkey (abundant urban coloniser)



Diet includes some livestock and few pets such as Chickens 3.3% and cats 0.7%. No dogs were recorded on nest cameras

The abundance of urban-exploiting Hadedea ibis is reflected in prey (22%) as well as the success of rock hyrax and other urban adapting species

Where hyrax are not abundant in an eagles territory, they rely on a greater variety of alternative prey including monkeys and mongoose

PREY PREFERENCE OF CROWNED EAGLES IN AN URBAN LANDSCAPE

Sept 2015

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CONCLUSIONS


Remote power and data download would be of benefit to future studies using these cameras. Regular service visits were mildly disruptive, however the eagles habituated readily and all 11 eaglets fledged successfully.

The high abundance of Rock hyrax and Hadedea ibis in the urban environment is providing a valuable resource. Prey switching may occur if these species populations declined suddenly, increasing risk to pets and stock^[10]. The Durban Metropolitan Open Space System encompasses forest and waterways, providing sufficient habitat and an abundance of wildlife prey for the crowned eagle.


Pets and livestock were found to be minor components of the diet. The social impact of pet depredations may be inflated by a reporting bias. Juvenile and sub-adult eagles during dispersal are those most identified as offenders in rare, *in situ* pet attacks^[11]. More research in this topic is needed. Greater public awareness of these findings will aid in advocacy of urban eagles.

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8 November 2014. Mother offers a small morsel of Hadedea ibis chick to her eaglet at the Victoria Country Club Estate.



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4 Navigating an urban jungle: home range of breeding crowned eagles in the Durban Metropolitan Open Space System, South Africa

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Abstract

Globally, urbanization has resulted in extreme landscape transformation. With human population increases and more land transformation expected, the challenge is to ensure optimal integration of ecosystem services, functional biodiversity, and conservation goals into urban landscapes. Generally, apex predators have high resource requirements and are sensitive to human disturbance and persecution. A population of crowned eagles (*Stephanoaetus coronatus*) within eThekweni municipality, KwaZulu-Natal, South Africa, exemplifies the conservation and biodiversity value of the green space network or Durban Metropolitan Open Space System (DMOSS). Understanding habitat use of keystone and apex species provides urban planners with an opportunity to integrate biodiversity in a growing city. Consequently we investigated crowned eagle home range and habitat use using GPS-UHF telemetry on five breeding adults for one year. The 350 km² study area comprised a matrix of mainly formal settlements (44%), and DMOSS green space areas (29%). The study area was occupied by up to 22 active breeding pairs of crowned eagles. We documented a mean (n = 4) annual home range of 13 km² (hull_{100%}) containing 6.3 km² of territory per pair (LKDE H_{LSCV 95%}). These relatively small home ranges for a large eagle included shared territorial boundaries. Rapid replacement of vacancies at breeding sites suggests a saturated population. Habitat selection within the home range, thresholds of critical habitat, exotic trees, and correlation with DMOSS show the importance of pockets of indigenous forest in this urban mosaic landscape

KEYWORDS: African Crowned Eagle, *Stephanoaetus coronatus*, home range, habitat selection, urban wildlife

4.1 Introduction

Globally, urbanization has resulted in extreme landscape transformation and fragmentation, and this is expected to continue at rapid rates (Seto *et al.*, 2012a, Seto *et al.*, 2012b). Urban transformation generally results in reduced biodiversity and poor ecological function (Kark *et al.*, 2007, Reis *et al.*, 2012). Urban planners are required to shape the growing configuration of an urban landscape, facing the challenge of integrating high density human populations and wildlife into mutually supportive ecosystems (Marzluff *et al.*, 2001, McKinney, 2002, Sukopp, 2002, Alberti *et al.*, 2003). Urban growth strategies lie on a continuum from residential densification to optimal integration of wildlife habitats into low density sprawl (Eigenbrod *et al.*, 2011). Getting the balance right can enable wildlife to successfully persist in functional urban mosaic landscapes (Stott *et al.*, 2015).

Home range and habitat use is species-specific and scale-dependent. Johnson (1980) posited four orders of spatial selection (first to fourth): global distribution and geographic range, population home range matrix, habitat use within home range, and use of specific micro-habitats within selected habitats. The resulting utilization distributions arise from internal decisions on foraging, resting, reproduction, and combinations of these, but are also influenced by external drivers such as competition and predation risk (Burt, 1943, Krauseman, 1999). Understanding the habitat choice and movement patterns on various scales is essential for effective conservation measures (Sanderson & Huron, 2011).

The latest advances in telemetry technology have dramatically improved the ability to investigate how animals use space (Tomkiewicz *et al.*, 2010, Bridge *et al.*, 2011, Hussey *et al.*, 2015, Kays *et al.*, 2015). As highly mobile apex predators, raptors are an indicator clade for ecosystem function (Sergio *et al.*, 2006). These species exhibit a wide range of habitat sensitivity and mobility including urban exploiting species (Cade *et al.*, 1994), and transcontinental migrations (Ferguson-Lees & Christie, 2005). Recent advances in miniaturization, power efficiency, and GPS accuracy (Fielder, 2009) make multi-year, and highly detailed tracking possible (422south.com, 2013). Development in the hardware, software and statistical techniques allow landscape planners to better access and apply spatial information to functional urban ecosystems. There is little research on the home range and movements of urban raptors. Further, landscape management and hazard mitigation can provide conservation benefits at individual and population levels (Walker *et al.*, 2005, Dixon *et al.*, 2011).

The crowned eagle (*Stephanoaetus coronatus*) is Near Threatened (IUCN, 2014), and regionally vulnerable in South Africa (Taylor *et al.*, 2015). Pair fidelity and nest site fidelity are generally high (Brown, 1972), producing one offspring biennially, sometimes annually (Brown & Amadon, 1989, Pickford & Tarboton, 1989, Malan, 2005). Dispersion of occupied nesting territories is the best available predictor of home range size and population density for the species. Nearest neighbour distances vary; those in southern African coastal and savannah biomes as; 1.6 km, 2.5 km (Mpumalanga), 6 km (Western Cape), and 4 km in Zimbabwe

(Tarboton & Allen, 1984, Brown & Amadon, 1989, Hockey *et al.*, 2005, Swatridge *et al.*, 2014). Further north in the distribution we find breeding pair densities of 6.5km² in Cotê de Ivore (n = 10, 65km²) (Shultz, 2002), and ‘1 mile’ (1.6km) in Kenya (Hockey *et al.*, 2005). Crowned eagle nest sites in near-urban settings have been known since those in Karen, Nairobi (Brown, 1966), and Durban (Malan *et al.*, 2001, Christine Smart pers. comm. 2012 (nest established in 1979)). Recent surveys of the Durban metropolitan area have revealed a mean nearest neighbour distance of 2.3 km (n = 20, 500 km²) in KwaZulu-Natal (KZN) Province, South Africa (McPherson *et al.*, 2016a). The Durban metropolitan area combines residential sprawl with a network of green spaces including indigenous forests, woodlands, wetlands, and grasslands, as well as restored and developed recreational spaces comprising the Durban Metropolitan Open Space System

As an ambush predator, the crowned eagles’ foraging tactics include perch-hunting and stalking in the sub-canopy of forest, and occasionally cooperatively ambushing forest bovines and monkeys (pers. comm.; S Thomsett 2007, A Stevenson 2011, H Chittenden 2013). Prey studies have shown there to be sufficient urban-exploiting indigenous wildlife to sustain the urban breeding population of crowned eagles in Durban (McPherson *et al.*, 2016b). Very little is known of crowned eagle home range and spatial choices in general and this study is to our knowledge the first describing *in situ* telemetry study of adult crowned eagles. We predicted that this large eagle can utilize small home ranges within a larger multi-use landscape. However, we expect the availability of indigenous forests patches to determine the dispersion of the crowned eagle population.

Our objectives were to describe second- and third order habitat selection using GPS telemetry on resident adult crowned eagles. Second order habitat selection was used to determine the home range size and saturation of territories across the landscape. Habitat selection, thresholds of critical habitat, and correlation with the DMOSS are discussed.

4.2 Methods

4.2.1 Study site

Durban city is the fourth largest in South Africa, with 3.4 million people (Statistics South Africa, 2011). The commercial hub is centred at S29.9 E30.1, on a small coastal plain adjacent to the major sea-port enclosing Durban Harbour. The greater metropolitan area comprises 2,290 km² of eThekweni municipal land (GIS layer download 2013) in the Indian Ocean Coastal Belt and Sub-Escarpment Savannah biomes (Munica & Rutherford, Reprint 2011). The region experiences humid Indian Ocean summer rainfall. The topology rises towards the west to 650 m a.s.l, where sandstone plateaus are dissected by rivers frequently within gorges and steep valleys.

Grassland plateaus were the areas of greatest transformation during Durban’s 20th century industrial growth. Urban development and afforestation processes have greatly reduced the endangered KwaZulu-Natal Sandstone Sourveld ecosystem (SANBI & DEAT,

2009). River gorges, due to their topography, have been afforded some protection from development. A program identifying the metropolitan natural assets began in 1979 and was developed by successive Durban municipal authorities (eThekweni Municipality 2007). The DMOSS areas were developed incrementally using principals of connectivity, catchment scale conservation, and functional ecosystems (Roberts, 1994, eThekweni Municipality, 2007).

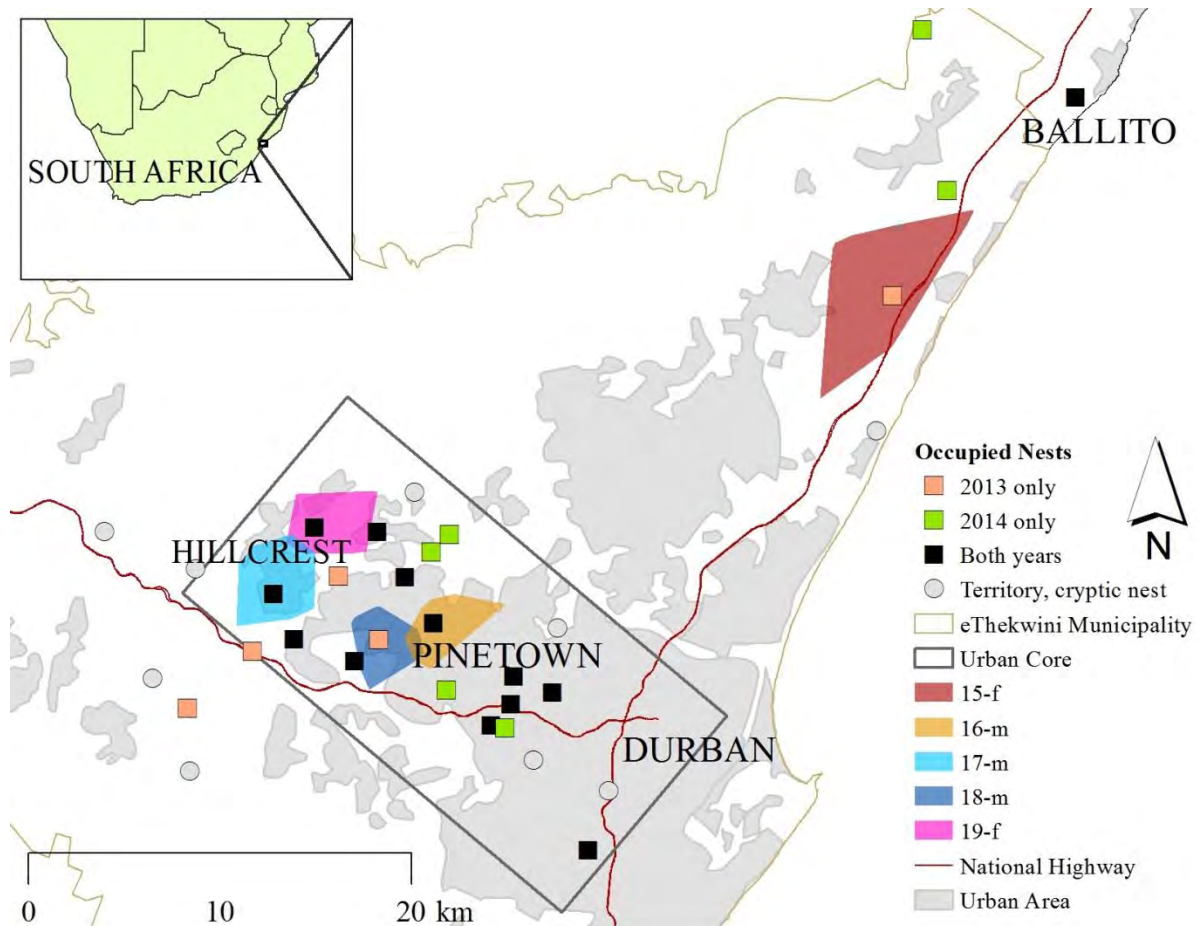


Figure 4.1 The distribution of known crowned eagle nest sites in eThekweni municipality, South Africa. Four telemetered eagles were within the urban core; a 350 km² area containing up to 22 breeding pairs amongst formal residential and green space matrix.

Suburban sprawl has hastened afforestation; with landscaping activities and fire suppression on the formerly pastoral, fire-managed grasslands of the endangered KwaZulu-Natal Sandstone Sourveld. In addition to suburban afforestation, blue gum (*Eucalyptus saligna*) invades disturbed slopes and riparian areas rapidly (Forsyth *et al.*, 2004). Formal settlements define the western urban sprawl. Environmentally these suburbs are characterised by shade and landscape trees, gardens, lawns, and greenbelts. Properties adjacent to DMOSS reserves have municipal restrictions on housing density, providing somewhat of a buffer for wildlife (Environmental Branch, 1998). A gradient occurs from the formal residential areas and commercial centres, through informal settlements and rural settlements to the boundary of eThekweni Municipality. Informal settlements are typically low-income, low employment,

high-density areas (Freund, 2001, O'Leary, 2007), and rely to a greater extent on obtaining wood fuel, and medicinal plants and animals from nearby KwaZulu-Natal Sandstone Sourveld and forest environments (Nesvag, 2002, eThekweni Municipality, 2007, Statistics South Africa, 2011).

The urban study area was 350 km², characterised by the greatest concentration of Formal Residential zoning (44%) with a DMOSS mosaic comprising 29%. Centred at the commercial hub of Pinetown, the area incorporated western suburbs from the Durban coastal plain to Hillcrest (Fig. 4.1). This focal area was occupied by 18 breeding crowned eagle pairs and four territories (of unknown breeding status) as of March 2015.

4.2.2 *Trapping and monitoring*

A trial telemetry device (15-f) was deployed in December 2012. Following the successful field test of the trial unit, four telemetry units were remodelled then fitted to adult crowned eagles from October-December 2013. We targeted individuals in the suburban-DMOSS mosaic in outer west Durban (Figure 1).

Bal-chatri traps and noosed meat portions were used to trap adult crowned eagles (Bloom *et al.*, 2007) near their nest sites when their eaglet was > 40 days of age. WW1500AS-AVIAN GPS/UHF tracking devices (www.wireless-wildlife.org) were deployed. We relied only on lithium-ion batteries due to the potential light limitations of solar charged units for this forest dwelling eagle. Transmitters were 95 - 115g, and weighed < 4 % of the mass of individuals. The 15-f GPS device was fitted with elasticised Teflon pelvic mount, while the urban four were mounted with 6 mm Teflon backpack harnesses (Bierregaard, 2014). A duty cycle of 1 location (accuracy 5-30m) per 2 h, from 0400 to 1800 daily was employed. This duty cycle predicted a lifespan of 3,200 locations (400 days). The 2 hourly duty cycle was chosen to exclude serial auto-correlation, allowing the use of Location Kernel Density Methods (LKDE, as opposed to Movement KDE or Brownian Bridge methods which are path-based (Cumming & Cornelis, 2012, Kranstauber *et al.*, 2012)). Data were downloaded from the devices by a car mounted UHF base station moved to vantage points within core areas until successful download. Audial signals verified a successful download on the base station, and were validated on the website server 6-24 h later. Data downloads from telemetry units occurred every 4 weeks and more frequently towards the end of the unit's battery life. These data were stored on an online server. The complete dataset of telemetry locations were verified by the technical supplier and then obtained from the server in September 2015.

4.2.3 *Statistical analysis*

We followed the most recent recommendations for standardizing animal home range analysis (Laver & Kelly, 2005, Cumming & Cornélis, 2012). Downloaded data were provided with location (WGS 1984), date, time, and velocity. Our data were first assembled onto a time

series and NULL locations were counted. Few points were truncated at nest sites for females 15-f and 19-f so these datasets were altered by an additional decimal point randomisation.

Statistical analyses were performed in the open-source software R (R development core team, 2013). We used the package rhr (Signer & Balkenhol, 2015) to obtain site fidelity, statistical independence, core delineation, and asymptotic functions using the Location Kernel Density Estimator (LKDE) bandwidth H_{REF} , and 100 and 95 Convex Hulls. All in-text values refer to mean \pm SD, all significance tests were to $\alpha = 0.05$. Spatial manipulation and analyses were performed in ArcGIS 10.2 (ESRI, 2011), and LKDE estimations for H_{LSCV} , $H_{PLUG-IN}$, and $H_{USER-DEFINED}$ were calculated in GME for ArcGIS 10.2 (Beyer, 2012). All area calculations were obtained in ArcGIS with the Transverse Mercator Lo31 projection.

Table 4.1 Fourteen habitat classes with their corresponding mapping colour palate, alongside each of the 8 primary categories on which the habitat classes were grouped.

Habitat Classes	Primary Category Name
Road	High Impact
Industrial	High Impact
Commercial	High Impact
Residential Informal	High Impact
Residential Rural	High Impact
Residential Formal	Formal Residential
Rail	Rail
Urban Park	Urban Parks
Open Water	Other Natural
Riparian	Other Natural
Woodland and Scrub	Other Natural
Horticultural	Other Natural
Grassland	Other Natural
Exotic Forest	Exotic Forest
Dense Bush	Dense Bush
Indigenous Forest	Indigenous Forest

While reporting of Minimum Convex Polygon (MCP, convex hull) fits the original HR definition, these are now considered obsolete due to its bias towards range extremities (Laver & Kelly, 2005). Nonetheless we report the 100% and 95% convex hull to allow for a broad spectrum of comparable metrics. Three of the frequently recommended LKDE bandwidth selections were used; H_{LSCV} , $H_{PLUG-IN}$, as well as a high resolution $H_{USER-DEFINED}$ (1 000). The parameters of Kernel function, smoothing method, contouring method, and least squared cross-validation search function were all defaults within the GME programme. Raster grid resolution was set at 5 m². The user defined H values were tested from 100-5 000 and $H_{1\ 000}$

was visually selected as the appropriate high-resolution parameter for the scale of the urban mosaic (smoothing buffer distance = 30 m). This showed a high resolution distribution that better represents the eagle’s capacity to move rapidly between preferential habitat patches (Fig. 4.4), and this fragmented bandwidth is appropriate with mobile species in urban landscapes (Walter *et al.*, 2012). We reported H_{REF} Core Delineation (Seaman & Powell, 1996), and continued to use the traditional 50% and 95% isopleth values to standardise with other data (Table 4.3).

Table 4.2 Metadata of the GPS telemetry units and the crowned eagles that were carrying the devices.

UNIT ID	15	16	17	18	19
LANDSCAPE TYPE	Peri-urban Sugarcane	Suburban mosaic	Suburban mosaic	Suburban mosaic	Suburban mosaic
AGE SEX	Adult Female	Adult Male	Adult Male	Adult Male	Adult Female
CAPTURE DATE	18-Dec-12	15-Oct-13	06-Nov-13	18-Dec-13	06-Dec-13
Tx MOUNT	pelvic	backpack	backpack	backpack	backpack
Tx PERIOD	377	122	343	421	386
NULL LOCATIONS	9	13	13	35	16
TOTAL VALID	2951	963	2730	3330	3057
TRUNCATED	56	1	1	1	15
1ST SPRING	failed - chick	non-breeding	fledged	fledged	fledged
2ND SPRING	fledged	*dead	fledged	non-breeding	fledged

4.2.4 Sampling seasons

In addition to the complete data sets, each unit was divided into three biologically relevant 4-month periods: nesting season (NS = Sep-Dec), recently fledged (RF = Jan-April), and winter transition (WT = May-Aug). NS is divided by gender: the behaviour of females is characterised by range contraction to the immediate nest area while incubating and raising a nestling; while the males are foraging for himself, the female and later, the chick (pers. obs.). Consequently, the male’s home range represents the ‘breeding unit’s’ home range requirements. RF period is characterised with a fledged nestling sedentary within 200m of the nest area. Both adults hunt for food and their food-dependant offspring (alternatively, sedentary following a failed breeding attempt). WT is when the ageing fledging is less food dependant and begins pre-dispersal forays. Late in the WT the pair shows increasing interest in nesting building and courtship. In addition to seasonal variation we pooled all velocity data from all units to gain basic insights into the energetic strategies of the crowned eagles in our study.

4.2.5 Habitat selection and the use of DMOSS areas

KwaZulu-Natal Land cover 2008 and 2005 data (GeoTerraImage, 2008) were merged to user-defined habitat classes. The original forty-seven cover types were reclassified to 14

main features. Integration of the 2005 layer improved the detail of urban residential classes to; formal, informal, and rural. Data were accurate to >95% in the core area, however 2010 aerial imagery and site visits were used to update for land transformations up to 2013. Aerial imagery and the DMOSS boundary data were obtained from eThekweni Municipalities corporate GIS website (eThekweni Municipality, 2011). After initial data exploration the 14 habitat classes were further pooled into eight categories (Table 4.1). Habitat selection coefficient with Bonferroni's confidence intervals ($\alpha = 0.05$, $k = 8$) were conducted on telemetry point data (Byers *et al.*, 1984). We used LKDE H_{1000} to identify and measure patch size of selected habitats within the home range. In addition a Pearson χ^2 was conducted to describe selection of DMOSS designated areas.

4.3 Results

4.3.1 Telemetry deployment and data acquisition

We obtained one full year from four adult crowned eagles (2 ♂ and 2 ♀, Table 4.2). Thirteen complete seasonal datasets were obtained; each included a range of 850-967 GPS points. Four transmitters ran the course of the year and batteries expired while still deployed on live birds. One individual (16-m) died after 122 days of data collection (15/02/2014), therefore only the RF season was used in analysis for this individual. This crowned eagle (16-m) died due to anthropogenic effects. Its death occurred at approximately 0400 (nautical dawn) as it flew into the wall of a house. The impact was heard from inside the house, and its body was collected from the garage roof underneath an impact smudge on the wall of the house. A post-mortem examination of the individual found it in ideal body condition including no skin abrasion marks from the harness and transmitter placement. The cause of death was acute head and neck trauma.

All crowned eagles monitored held a territory continuously for the duration of the study. Three (17-m, 18-m and 19-f) had dependant offspring during the RF and WN periods. The two females (15-f and 19-f) showed extreme range contraction as the NS commenced towards the end of the data collection year, both successfully fledging young at the end of the NS season. One (19-f) therefore successfully bred in 2012 and 2013 (unpubl. data).

All velocity metrics were within a crowned eagles' physiological capacity, with a maximum speed recorded at 118 km/h (Fig 2). 91.3 % of all locations ($n = 13\ 105$) were stationary 0 km/h, and a further 5.3% at 1 km/h. A velocity bin indicated a mean flight speed of 30 - 40km/h. This basic insight into crowned eagle movement profile supports the idea that crowned eagles' energy budget strategy is conservative, with punctuated movements between selected microhabitats such as hunting perches and resting areas.

Table 4.3 Summary of home range technique used for crowned eagle in the Durban urban mosaic. Variation in bandwidth selection, and differences between seasons and genders.

ISOPLETH	95	95	95	95	100
TOTAL (km ²)	H _{1,000}	H _{PLUG-IN}	H _{LSCV}	Hull	Hull
15-f	2.34	3.91	11.40	19.68	38.34
19-f	1.57	1.90	5.30	5.91	13.23
16-m					
17-m	4.05	6.40	9.20		15.92
18-m	2.03	2.72	4.50	5.26	10.40
Urban Four (x ± SD)	2.55 ± 1.08	3.67 ± 1.96	6.33 ± 2.05		13.18 ± 2.25
NESTING SEASON					
15-f	0.09	0.04	0.08	0.11	0.64
19-f	0.05	0.10	0.05	0.02	0.13
16-m					
17-m	1.99	4.97	7.94	6.44	12.24
18-m	1.38	2.30	3.78	3.84	7.13
Female Mean	0.07	0.07	0.07	0.07	0.10
Male Mean	1.68	3.63	5.86	5.14	9.69
RECENTLY FLEDGED					
15-f	1.60	4.96	12.59	12.63	25.83
19-f	1.53	3.20	5.86	6.53	11.49
16-m	1.64	3.02	5.71	8.62	10.89
17-m	3.05	6.85	9.32	7.07	9.82
18-m	1.65	2.89	4.52	4.86	5.91
Urban Four (x ± SD)	1.96 ± 0.63	3.99 ± 1.66	6.35 ± 1.79	6.77 ± 1.34	9.53 ± 2.17
WINTER TRANSITION					
15-f	2.56	10.99	20.97	23.26	35.17
19-f	1.37	2.95	5.89	4.64	6.70
16-m					
17-m	2.78	7.45	10.62	9.20	11.98
18-m	1.75	3.34	5.69	5.45	9.51
Urban Four (x ± SD)	1.67 ± 0.59	4.58 ± 2.04	7.40 ± 2.28	6.43 ± 1.99	9.40 ± 2.16

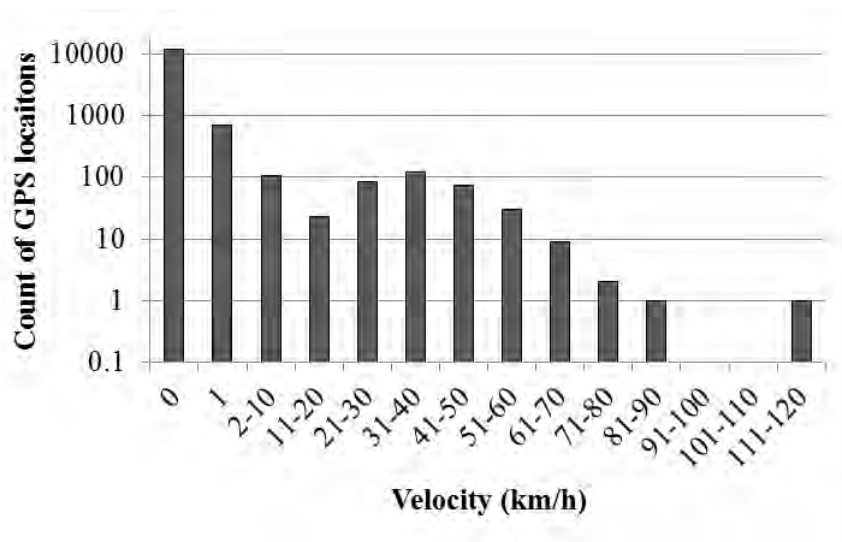


Figure 4.2 Pooled activity profile based on velocity of five crowned eagles. All locations were obtained throughout the year, every even hour, daily from 0400 to 1800 (N = 13 105). No filter was required as all points were within biological limits. The highest speed recorded was 118km/h.

Table 4.4 Summary statistics from tests performed in rhr (Laver & Kelly, 2005), ‘Sequential AS’ refers to the range of sequential points in which an asymptote of home range size is reached, with the string and bootstrap 24.10.5 used for this test. These are shown with the corresponding home range metrics of five crowned eagles in Durban’s urban mosaic.

rhr	N	SITE FIDELITY	STATISTICAL INDEPENDENCE	SEQUENTIAL AS 24.10.5	CORE LEVEL	CORE AREA	H _{REF} 95	H _{REF} 50
15-f	3 007	TRUE	TRUE	> 3 000	97.25	16.79	13.92	0.91
16-m								
17-m	2 731	TRUE	TRUE	1 000 - 1 100	93.26	8.46	10.23	2.36
18-m	3 331	TRUE	TRUE	1 100 - 1 400	96.04	4.97	5.51	0.82
19-f	3 072	TRUE	FALSE	> 3000	96.28	6.5	5.87	0.89
Nesting Season								
15-f	969	TRUE	FALSE	800 - 950	99.8	0.07	0.12	0.04
16-m								
17-m	797	TRUE	TRUE	750 - 900	93.8	7.43	7.93	1.65
18-m	964	TRUE	TRUE	> 850	96.2	4.74	4.34	0.84
19-f	935	TRUE	TRUE	failed	99.7	0.46	0.66	0.02
Recently Fledged								
15-f	968	TRUE	TRUE	> 800	95.24	15.34	15.05	2.1
16-m	963	TRUE	TRUE	>850	96.42	6.75	5.97	0.72
17-m	960	FALSE	TRUE	600 - 900	92.31	8.07	9.28	2.21
18-m	947	TRUE	TRUE	failed	95.58	5.11	4.94	1.13
19-f	957	TRUE	TRUE	800 - 950	89.7	5.2	6.86	1.31
Winter Transition								
15-f	966	TRUE	TRUE	750 - 950	94.11	21.68	23.19	3.54
16-m								
17-m	974	TRUE	TRUE	200 - 300	91.49	9.2	10.65	3.07
18-m	974	TRUE	TRUE	600 - 750	94.95	5.83	5.84	1.35
19-f	980	TRUE	TRUE	750 - 850	88.3	4.59	6.14	1.47

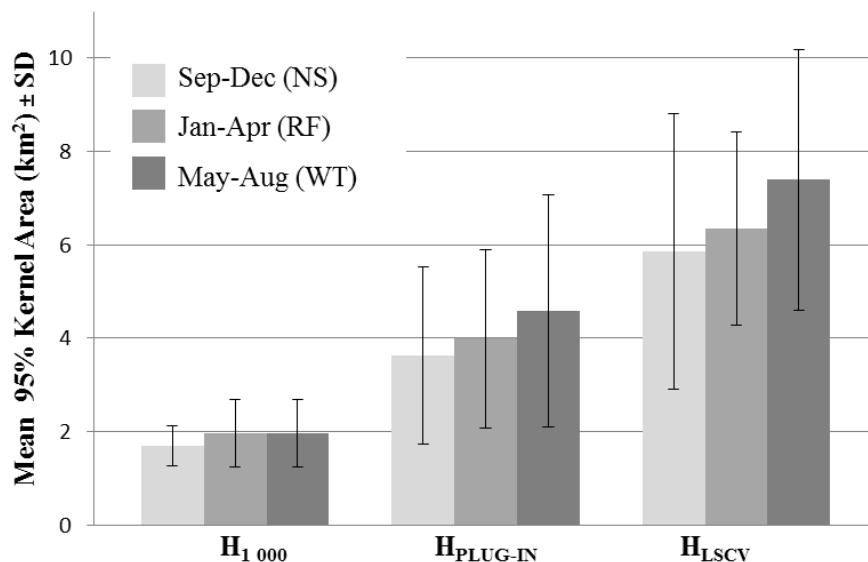


Figure 4.3 Seasonal variation in the utilisation distribution of urban crowned eagles (n = 4). Differences between bandwidth measurements were greater than between seasonal differences within a band with metric. Though slight, the Winter Transition (WT) period was the time of greatest home range requirements.

4.3.2 Home range characteristics

While the female's (15-f and 19-f) reached a convex hull asymptote prior to the NS period when their respective range collapsed to 0.07 km² around the nest site area. The telemetered males did not reach a hull asymptote after one year (10.4 - 15.92 km²) (Table 4.3). The LKDE H_{REF} metrics however, showed home range of crowned eagles in this study reached a randomised location asymptote at 1000-2200 points (mean = 1 550 (194 days), range 1 000 – 2 200). Sequential location asymptotes were similar for males; however female NS range contraction greatly disrupted the asymptotic function. Time to statistical independence was within parameters for all cases except 19-f (full year), and 15-f (NS only). We were unable to test time to biological independence with the rhr version. The selection of three biological seasons comprising *ca.* 976 GPS locations per four months was at the lower limit of statistical independence for most samples (Table 4.4).

Second order annual home range mean area was 6.3 km² ($N = 3$, LKDE H_{LSCV}) within the urban landscape, and an outlier ($n = 1$) of 11.4 km² from 15-f in the peri-urban landscape (Table 4.3). The peri-urban individual had an extreme convex hull of 38 km², ranging at least 6.5 km from the territory centre. The H_{1 000} bandwidth best demonstrated the patchy and localised spatial distribution of GPS locations at scales relevant to third order selection; comprising 1.57 - 4.05 km² of space within the home range ($n = 5$), this included a 50% utilization distribution mean of 0.38 km² (range 0.10-0.86, $N = 5$, LKDE H_{1 000}) (Table 4.3).

Gender differences in seasonal variation of home range were only distinct during NS when females were building, brooding, and defending the nest, while the male contributes to almost all of the food provisions (*pers. obs.*). The home range of males increased from NS season to RF season to WT season (Fig. 4.3). Consistently across different bandwidth measures, WT season showed the largest HR for both genders; however this difference was not significant ($SD \pm 1\sigma$).

Two adjoining urban territories suggested some resource sharing at overlapping boundaries. The two overlapping boundaries were; Greenmeadow in Hillcrest between 19-f and 17-m (full year), and Edgecliff in Pinetown between 16-m and 18-m (RF season only) (Fig. 4.1). Hull overlap was 0.66 km² and 0.36 km² for Greenmeadow and Edgecliff respectively (Fig. 4.4 and 4.5). At Greenmeadow these did not include LKDE 95% isopleth intersects. However, the Edgecliff boundary included 650 ha of shared space at the LKDE H_{1 000} 95% isopleth during the RF season (Fig. 4.5).

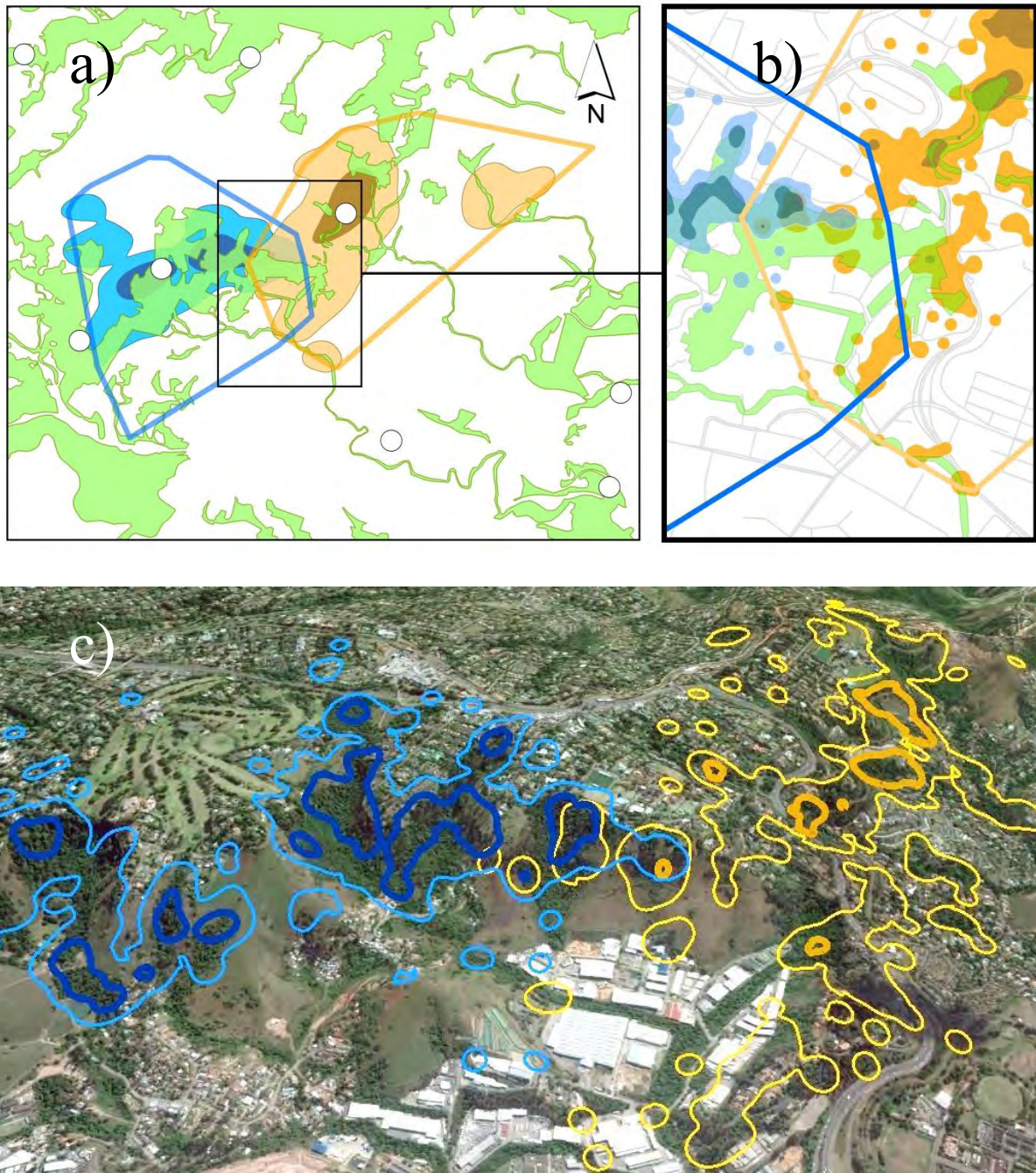


Figure 4.4 Home range and territory overlap of crowned eagles at the Edgecliff boundary between 18-m (blue) and 16-m (orange). The period covers from 1 December 2013 – 31 March 2014. Home range (50 and 95% isopleth) displayed using a) LKDE H_{LSCV} , b) H_{1000} , and c) H_{1000} GoogleEarth aerial and elevation imagery.

4.3.3 Habitat selection

Crowned eagles in this study consistently selected for indigenous forest, dense bush, and exotic forest (Fig. 4.6). Indigenous forest was a critical habitat and was significantly preferred, dense bush was less critical and tended to be selected in proportion to abundance. Exotic forest patches were positively selected, although never significantly so, and were

highly varied between individuals and patch features (Fig. 4.6). All other natural and anthropogenic classes were avoided to varying degrees and significance, with the exception of rail habitat which was slightly selected for by 16-m. The total area of selected habitats were 0.41 - 0.87 km² (mean = 0.64, $N = 5$) for each individual (Table 4.5). These resulted from an accumulation of 3-8 patches of indigenous forest (mean = 5) and 2-6 patches of exotic forest (mean = 4), dense bush and rail were difficult to distinguish between connected and indiscrete patches. These fragmented patches equate to between 4 and 19 % of the total home range per individual (H_{LSCV} 95 contour)

Indigenous forest fragments were more dispersed in the peri-urban sugarcane landscape and therefore 15-f moved longer distance between suitable forest patches, resulting in a larger home range compared to urban crowned eagles (Fig. 4.1). 16-m and 17-m used the smallest cumulated area of forest and bush within the respective home range, and both also included greater areas of formal residential areas (Table 4.6). Indeed with 16-m, rail habitat was also included and used in proportion to availability.

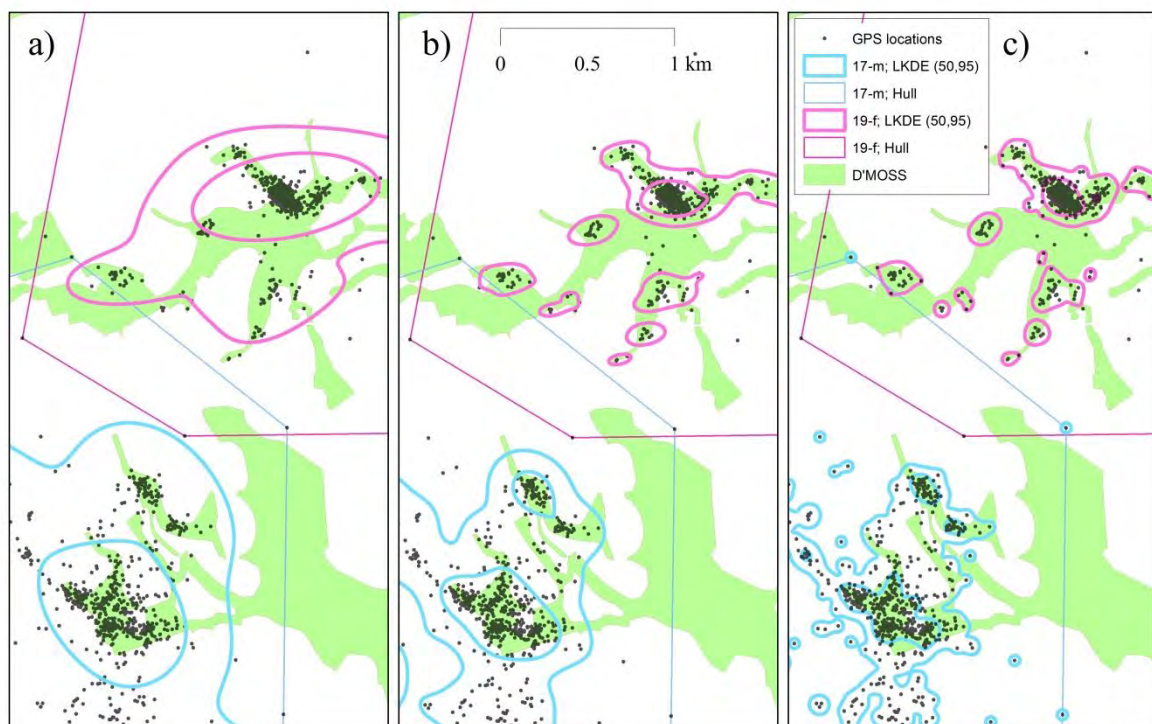


Figure 4.5 Three bandwidth treatments; a) H_{LSCV} , b) $H_{PLUG-IN}$, and c) H_{1000} , of crowned eagles 17-m, and 19-f at the Greenmeadow territory boundary. The bandwidth H_{1000} resolution (smoothing buffer at ca. 30m) is appropriately scaled to the fragmented urban landscape and Durban Metropolitan Open Space System.

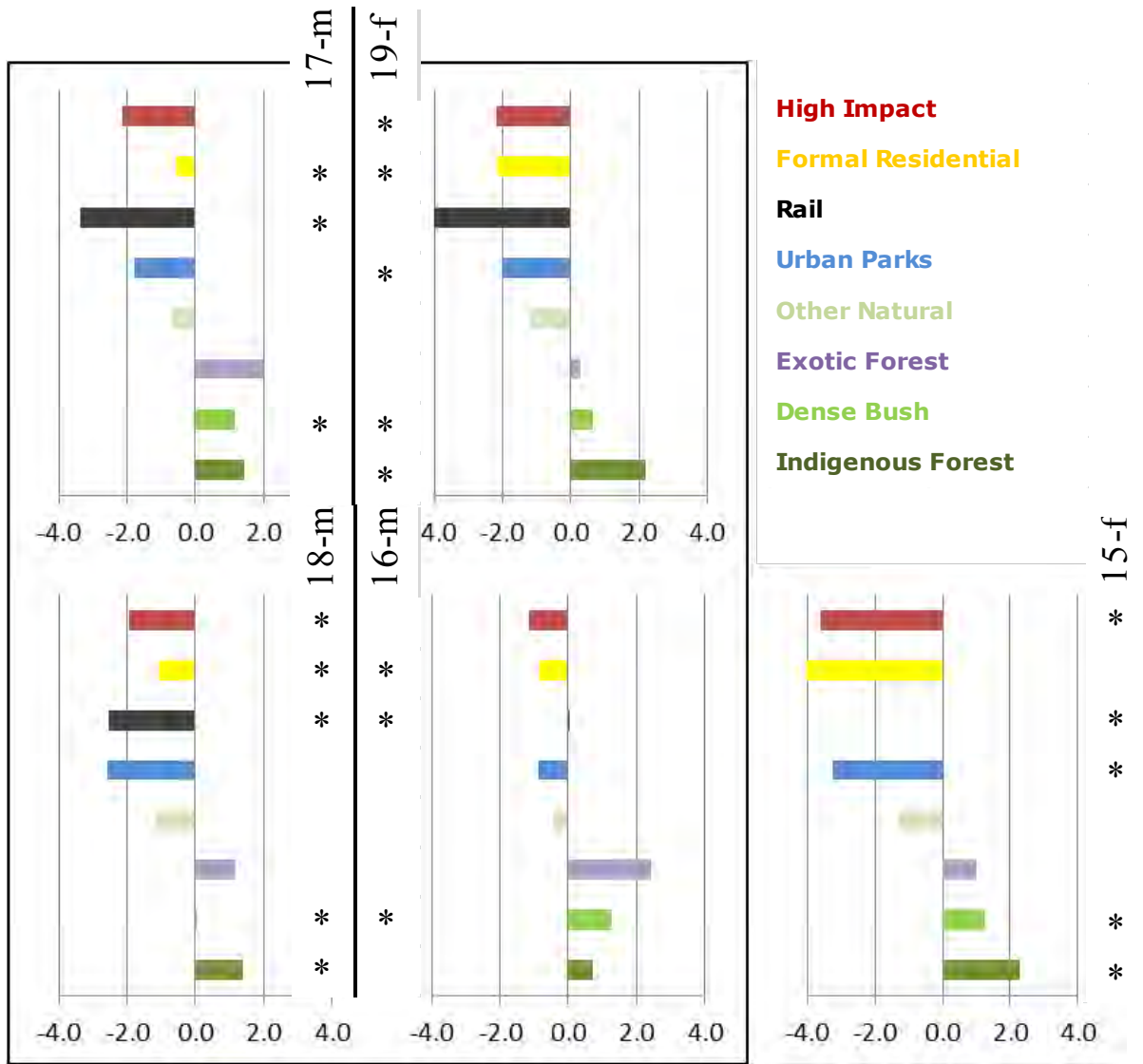


Figure 4.6 Third order selection coefficients for eight primary habitats available to crowned eagles in eThekweni Municipality, South Africa. (Significant selection or avoidance (*, $p = 0.05$) shown using Bonferroni's confidence intervals.)

Structural differences were apparent within habitat classes while using aerial imagery to ground truth habitat layers. These internal differences included differences in housing density, gardening choices, and canopy cover within residential areas. These differences varied in city-wide, neighbourhood, and property scales. *Eucalyptus* fragments also differed greatly in structure, from large monotypic timber plantations, expansive mixed age invasion of steep disturbed slopes, to fragmentary remnant stands of large emergent mature trees after wider invasive control operations, the latter being highly utilized by crowned eagles. The DMOSS incorporated much of the preferred forest and bush habitats required by crowned eagles. Correlation to DMOSS use is extremely significant (Pearson $\chi^2 = 2\ 631$, $p < 0.001$, Fig. 4.7).

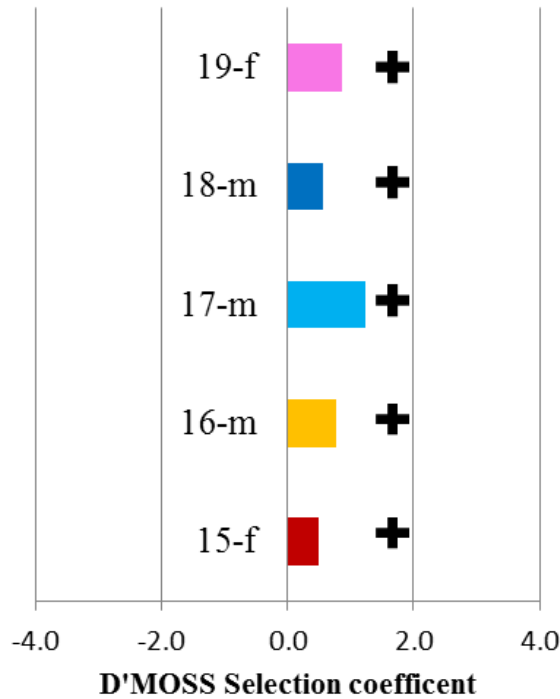


Figure 4.7 Third order DMOSS Selection coefficient, all sites were strongly selected with highly significant Bonferroni's intervals (+).

Table 4.5 The combined sum of the area (km²) of each critical habitat type, and combined total, used within the home range of adult crowned eagles in the Durban urban mosaic in southern KwaZulu-Natal, South Africa.

	INDIGENOUS FOREST	EXOTIC FOREST	DENSE BUSH	RAIL	COMBINED AREA (km ²)	% of LSCV HOME RANGE
15-f	0.32	0.07	0.39		0.77	7
19-f	0.3	0.13	0.3		0.72	14
16-m	0.1	0.09	0.16	0.06	0.41	7
17-m	0.13	0.1	0.18		0.41	4
18-m	0.53	0.18	0.16		0.87	19

4.3.4 Population size and saturation

We described the first telemetry study of crowned eagles known by the authors, as well as the first telemetry study of a large raptor in an African urban landscape. We identified 18 breeding pairs and four additional territories within the 350 km² urban matrix. Limited extra-territorial forays and evidence of overlapping hunting areas for this territorial species suggest a saturated crowned eagle population. This was further demonstrated by the case of rapid replacement of adult mortalities, which required a surplus of floating non-breeding adults. This suggests the local population is sustainable, provided current parameters of wildlife prey

and habitat availability remain stable. Investigation into breeding success and population demographics are needed to validate this prediction (McPherson, unpubl. data).

4.4 Discussion

4.4.1 Observations of crowned eagle telemetry in the field

Our pilot telemetry device was fitted by pelvic mount, the subsequent four transmitters were remodelled with reinforced UHF aerial and backpack mount design modelled from (Bierregaard, 2014). Both females were successfully fertilized by their mate while the pelvic and backpack mounts were attached; they laid eggs and subsequently successfully fledged offspring. The harnesses did not impact pair-bonding and parental behaviour.

The crowned eagle male (16-m) died on 15 February 2014, a territory identified to have the lowest forest patch area. The telemetry and the harness had no apparent impact on the incident. Two months later, the female was nest building with a new male, 140 m from the previous nest site. This was a rapid replacement and indicated the replacement male was readily available to fill the vacancy.

4.4.2 Home range and territory structure

The home range of each urban crowned eagle was temporally dynamic as seasonal UD's changed in size and shape. The three males did not reach an MCP (Hull) asymptote after one year. Bonelli's eagles (*Hieraaetus fasciatus*) appeared to reach a convex hull asymptote after three years (Perez-Garcia *et al.*, 2012) and multi-year telemetry of crowned eagles is predicted to reveal constantly dynamic territorial boundaries. These spatial and temporal fluctuations are influenced by the distribution of foraging resources, refuge from disturbance, shifting territorial priorities, and stochastic mortality or eviction. In addition, several behavioural states may occur depending on environmental and social forces.

A distinct behavioural state is apparent for females during breeding. In both cases the female's home range contracted to the immediate area of the nest during the NS. The female nest built, incubated, then brooded and defended the eaglet, taking four months before starting to increase her home range again. Despite doing the majority of foraging, all three crowned eagle males still used the smallest seasonal area during this NS period. As would be expected, the largest area was used during the winter transition season, when food resources were predicted at their lowest. In addition, the juvenile from the previous successful breeding attempt was also occupying the territorial pair's space prior to dispersal at 12-15 months (pers. obs.).

Because the hull metric emphasises the extremes of an animal's home range this provides insights into extra-territorial movements. Crowned eagles in the urban landscape made only limited exploratory movements, ranging up to 3.5 km from the core of the territory. This was contrasted by the female (15-f) in the peri-urban sugarcane landscape who

ranged up to 6.5 km². Landscape features such as fragmentation and size of critical habitats were reflected in local home range area and nearest neighbour distances.

Individuals in adjacent territories overlapped the 100% hull of home range. Considering the mean hull overlap (*ca.* 5 %) by the number of adjoining neighbours suggested an estimation of exclusive territory at 7.3-7.9 km². Further, males (16-m and 18-m) shared a 650 ha area of kernel utilization at Edgecliff. This area was not shared simultaneously, but sequentially over the course of weeks. Simultaneous GPS points did not reveal any proximity however the temporal resolution was very limited at one fix per 2 h, and up to 1 min variation from schedule fix times. Future studies using high temporal resolution telemetry methods would observe interactions between individuals.

4.4.3 Habitat selection

Indigenous forest patches were consistently highly preferred. A number of small connected fragments within a larger mosaic appear most suitable. The use and selection of micro-habitats within the same habitat type determine fourth order selection. As we cannot see and move through the environment as the study species does, our capacity to identify and discriminate differences in habitat quality within the same habitat class type is likely to be very limited (Krauseman, 1999).

Unexpectedly, formal residential areas were significantly avoided, despite nest site selection favouring edges of forest and formal residential areas (McPherson *et al.*, 2016a). Urban parks included the grounds of education and recreation facilities, sports grounds, school grounds and golf courses. Despite frequent use by some preferred prey species such as hadeda ibis (*Bostrychia hagedash*) and rock hyrax (*Procavia capensis*) (McPherson *et al.*, 2016b), and green parkland with large shade trees, these green spaces were avoided by crowned eagles. In particular, golf courses appear to have important differences in design and layout of relevance to crowned eagles and other raptors. The important structural difference between Kloof Country Club (in 18-m's territory), and Cotswold Downs Golf Estate (in 19-f's territory), is that the former is confined to a smaller area, with parallel fairways separated by only single trees rather than fragments of forest, bush, and wetlands. Because of human activity, recreational areas provide proximity refugia for more human-tolerant species (Møller, 2008), and these tightly arranged golf course areas are more saturated with human activity and proximity refugia. This also demonstrates that not all green spaces are equally valuable for indigenous flora and fauna (Ramalho & Hobbs, 2012, Chong *et al.*, 2014).

4.5 Recommendations

Technological advances in animal tracking are developing at a staggering rate (Bridge *et al.*, 2011). The most recent opportunities include GPS enhanced accelerometer based units. High resolution movement or path-based telemetry would enlighten details of crowned eagle energetics, micro-habitat selection, hunting tactics, and social interactions including cooperative pair hunting strategies, extra-pair copulation, and territorial competition.

Breeding success of raptors, particularly crowned eagles may be influenced by natural and anthropogenic effects, and human disturbance is especially likely in urban landscapes. Identifying critical spatial and temporal parameters can aid wildlife managers to make effective wildlife protection strategies. Here, the telemetered females each occupied 0.07 km² during the four month NS. Therefore, 7.1 ha area (150 m radius) centred at each active crowned eagle nest should be afforded full protection from human disturbance and landscape disruption from August to January, annually.

Anthropogenic landscapes can better enhance biodiversity by increasing local heterogeneity and edges between different habitats. These can be specifically tailored to support endangered species (Suárez *et al.*, 2000, Pawson *et al.*, 2010, Seaton *et al.*, 2010). Many raptors of both open and closed environments can utilize often small (<1 Ha) forest stands for nesting, including the exotic *Eucalyptus* in South Africa (Malan & Robinson, 2001, Welz & Jenkins, 2005, McPherson *et al.*, 2016a), Management of the urban landscape to enhance crowned eagle presence should carefully consider heterogeneity, including the persistence of small fragments of gum trees as a unique resource for raptor nesting.

In forthcoming expansion of urban landscapes in the Indian Ocean Coastal Belt biome, indigenous forest should comprise 10% of the landscape, and dense bush a further 10%. As indicated by crowned eagle second- and third-order habitat selection, these ratios can comprise high connectivity and edge to area ratio of 5-10 forest fragments per 10 km² area. The current DMOSS principles of catchment scale conservation, connectivity, and functional ecosystems, permit this green space system to effectively support a population (and requisite nesting and foraging resources) of crowned eagles, a flagship apex predator in the urban landscape of southern Africa.

4.6 Acknowledgements

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5 Surviving the urban jungle: Anthropogenic threats, wildlife-conflicts, and management recommendations for crowned eagles in southern KwaZulu-Natal, South Africa

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Abstract

Wildlife management is primarily a human response to reduce or eliminate causes of economic or social harm. However these must be balanced against conservation goals regarding threatened species. The public stakeholders in an urban landscape have strong influences on the management of dangerous large animals such as mammalian carnivores. Crowned eagles (*Stephanoaetus coronatus*) in the urban landscapes of southern KwaZulu-Natal, South Africa, live in close proximity to suburban areas. We identified negative incidents to human livelihoods, particularly predation on pets and livestock, and causes of harm or loss of crowned eagles due to injuries. Anthropogenic causes are more likely to be found and notified than remote natural deaths, which provide opportunities for mitigation. Most importantly, electrocution on utility poles and persecution via gunshot wounds are readily avoidable. Collision with structures, glass panes, vehicles and fence wires are more challenging and complex to mitigate, however have a serious impact on many other species as well. While camera studies at urban nest sites (McPherson *et al.*, 2016a) demonstrated a small overall percentage of predation on livestock and pets (6 and 1%, respectively), the winter diet may include different prey not delivered to nest sites while breeding. We document 24 verified attacks on dogs from 2012-2015, which has a detrimental impact on social perception and acceptance of urban crowned eagles. These attacks were primarily by juveniles and sub-adults, and 38% occurred during winter months. Activities such as rehabilitation and falconry can coordinate to achieve a high standard of public support and conservation outcomes for human wildlife conflict concerning crowned eagles. We provide management recommendations regarding various categories of crowned eagle human-wildlife interactions. Collaboration of wildlife authorities with NGO's and public stakeholder input creates an environment for successful crowned eagle conservation and management of human-wildlife conflicts. Public awareness is an important aspect to the sustainability of the

urban crowned eagle population. We provide support for the use of management intervention including rehabilitation, falconry, and re-wilding processes. Lethal control of specific individuals in the most extreme circumstances will drive artificial selection towards compatible behaviours.

Keywords: raptor, urban, human-wildlife conflict, wildlife management, nest sites

5.1 Introduction

Wildlife management is primarily a human response to reduce or eliminate causes of economic or social damage caused by wildlife (Treves *et al.*, 2006). As humans transform landscapes on a global scale, conflict between wildlife and human livelihood and economic systems increase, (Distefano, 2005). Conservation goals are becoming an important part of wildlife management, and conflicts with stakeholders often arise (Redpath *et al.*, 2013). Damage to food crops, livestock, and managed game are widespread causes of economic and social impact in ex-urban landscapes, involving farmers, game managers, and interest groups (Redpath *et al.*, 2004).

In urban landscapes the public stakeholders have a strong bearing on perceptions of wildlife species that pose a perceived or real threat to human safety, and children in particular (Treves *et al.*, 2006, Gehrt *et al.*, 2010). This perception is extended to furry family members; pets and companion animals (Gehrt *et al.*, 2010, Poessel *et al.*, 2012). While traditional responses were to hunt or otherwise target harmful species, in the case of large carnivores this is often illegal through conservation regulations, or socially unacceptable on grounds of animal welfare (Treves *et al.*, 2006). In some cases, lethal control or removal of specific individuals can help to alleviate public fear and drive artificial selection in the population (Treves & Nauton-Treves, 2005).

The urban landscape is dominated, even defined, by anthropogenic structures: Impervious surfaces for vehicles, electrical networks, artificial lights, fences, glass windows, and mirrors, are some of the novel elements that affect urban wildlife. These structures have collateral harmful impacts on many animals on individual and population scales (Chace & Walsh, 2006). More importantly, mitigation measures should make quantifiable offsets to enhance conservation of target species and habitats. The most direct mitigatable threat is persecution, which generally can be best influenced with awareness campaigns and stakeholder empowerment via engaging management plans (Distefano, 2005).

As humans are directly and indirectly responsible for large scale ecosystem disruption and animal mortality, we are increasingly aware of compensating for negative impacts. Within the birds of prey, injuries that incapacitate hunting aptitude often result in starvation, illness, infection, and death. Individuals with these types of injuries could heal and recover if able to feed and safely rest. Circumstances of rehabilitation and release procedures (e.g.

hard-release of long term admissions) of raptors may be met with poor post-release survival (Holtz *et al.* 2006, Monadjem *et al.* 2014). Falconry, a centuries old cultural heritage (UNESCO, 2012), is ‘taking quarry in its natural state by means of trained birds of prey’ (IAF, 2015). The use of falconry techniques in rehabilitation and release has been successfully demonstrated (Holz *et al.*, 2006, IAF, 2013), and rehabilitated raptors have a significant influence to the benefit of that individuals’ life, and endangered species populations. Further, many bird of prey conservation, education, and research programmes have often been initiated or led by falconers (Hartley, 1991, Cade & Temple, 1995, Kenward, 2009, Lombard, 2010, Dixon *et al.*, 2011, IAF, 2015).

An urban population of crowned eagles (*Stephanoaetus coronatus*) persists in southern KwaZulu-Natal (KZN), South Africa, within a residential green space mosaic landscape (Malan *et al.*, 2001, McPherson *et al.*, 2016b). There is likely to be increasing numbers of human-eagle interactions in the region, both regarding harm on livelihoods via pet and livestock attacks, and harm on eagles due to anthropogenic mortality. Crowned eagles have occasionally been documented as a conflict species preying on livestock and pets (Boshoff, 1990, Boshoff *et al.*, 1994, McPherson *et al.*, 2016a) and in very rare circumstances, predatory attacks on children (Steyn, 1983, Thomsett, 2011).

Our objective was to identify and classify causes of livelihood threat and harmful incidents regarding human-crowned eagle conflicts. These results formed the foundations of a series of discussions with local wildlife officials and stakeholders. Our discussions resulted in a management strategy with the aim to reduce future human-wildlife conflict and facilitate crowned eagle conservation in the region.

5.2 Methods

Our data were collated from 2012-2014 on crowned eagles in southern KZN, South Africa (Fig. 5.1). These records are largely qualitative and were categorised into; nesting disturbances, threatening hunting behaviour or attacks on pets and humans, and causes of injuries and eagle mortality (Table 5.1). Age classes were defined as; juvenile (fledge – 12 months), immature (1-2 years), sub-adult (2-5 years), and adult (5+ years). Regional awareness of the research and citizen science involvement was developed via outreach to existing formal and informal conservation networks, public seminars (n = 49; conservancy’s, bird clubs, eco-estates), a Facebook community page, articles in local newspapers (Dardagan, 2012, Ngqulunga, 2012, Denny-Dimitriou, 2013), and field activities in residential areas. Most incidents and concerns were recorded via feedback from concerned stakeholders; the public, rehabilitation organisations, Natal Falconry Club (NFC), Ezemvelo KZN Wildlife officers (EKZNW), eThekweni municipality, and the Durban Natural Science Museum. Incident reports were responded to personally (by SCM, BHH, BDLP) or with the aid of; Raptor Rescue Rehabilitation Centre (RR), Centre for the Rehabilitation of Wildlife (CROW), Free-Me, Monkey Helpline, NFC members, and EKZNW officers.

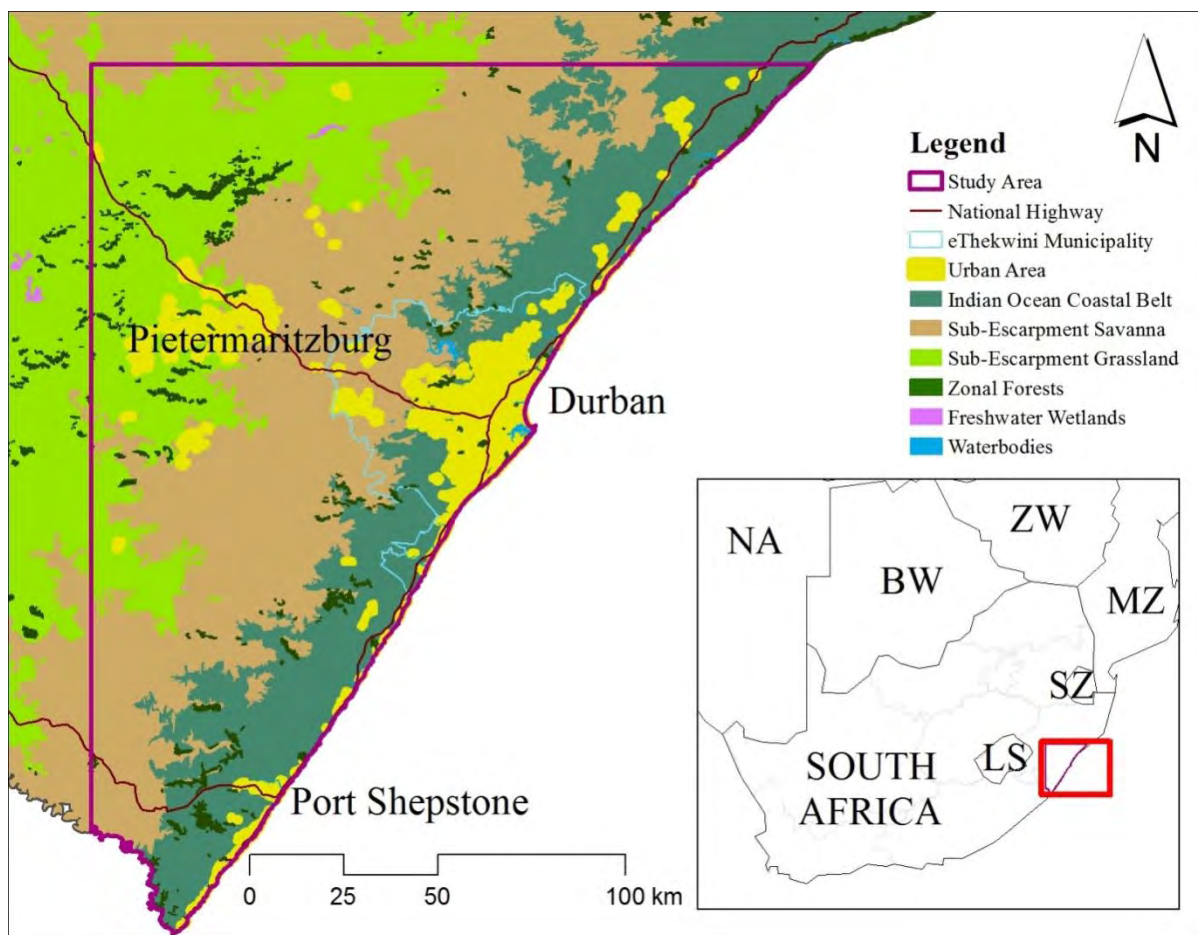


Figure 5.1 The study site area within southern KwaZulu-Natal, South Africa.

5.3 Results and Discussion

5.3.1 Nest site threats

5.3.1.1 Alien tree management

To date, 74 used (current and historical) nests of crowned eagles were known in the southern KZN study area (Fig. 5.1). Of these, 36 were in gum trees (*Eucalyptus saligna*, *E. camaldulensis*). Working for Water, municipal, and conservancy taskforces remove alien invasive plants in the region (Working for Water, 2012). Gum tree copses are included as a target species, yet these provide nesting sites for crowned eagles, black sparrowhawk (*Accipiter melanoleucus*), fish eagle (*Haliaeetus vocifer*), and woolly-necked stork (*Ciconia episcopus*) among others (pers. obs.). From 2011 to 2015, some nests trees were identified within a stand of *Eucalyptus*, and protected from removal. Three crowned eagle nest trees in the study area stand isolated and exposed after this type of management. Other operational strategies include ring-barking the standing tree, whereby it quickly defoliates then remains decaying for 5-15 years. Crowned eagles with high site fidelity continue to use these now defoliated nest trees (n = 4). Both strategies increase exposure to weather extremes, possibly reducing nesting survival (McPherson, unpubl. data).

Multi-year nest-site fidelity in crowned eagles requires that identified nest trees should remain protected for at least three years after a breeding event. Protection should extend to the immediate trees around the nest tree (4-10 trees with DBH >500 mm) to provide shelter and seclusion.

Table 5.1 Categories of threats and areas of management opportunity for crowned eagles in southern KZN, South Africa.

NEST SITE THREATS	
Exotic tree removal	felling patch or tree with active nest
Ring-barking exotic trees	defoliating nest tree, reduced cover
Proximity disturbance	recreation / construction near nest
Nest collapse	natural occurrence easily countered
INJURY / MORTALITY	
Electrocution	phase-phase / phase-ground
Persecution	shot, injured, muthi
Collision	walls, windows, wires, vehicles
Natural death	starvation, intraspecies conflict
Other	categorise e.g. muthi harvest
PETS AND LIVESTOCK	
Types in incidents	identify breeds, locations, frequency
Biological context	dispersal ecology, prey imprinting
Social context	perceptions / supplementary feeding

5.3.1.2 Nest disturbance

Crowned eagle nest site disturbance appears site specific based on local human activity, habitat, topology, and individual variation in sensitivity. Weather and disturbance are the two most likely causes for the observed *ca.* 30% annual breeding failure rate (McPherson, unpubl. data). While most individuals showed signs of disturbance at 100 - 150 m, some pairs were habituated to daily residential and recreational activity within 30 m of the nest tree (McPherson *et al.*, 2016a). Recently fledged crowned eagle offspring at these sites are inquisitive and habituate readily to benign human activities. Learned tolerance and the founder effect may increase the ability for future generations to persist locally, and expand into urban forests elsewhere.

One crowned eagle nest in Durban is positioned on a waste water pipeline bridge (Fig. 5.2). The setting is reasonably remote and rarely accessed by informed maintenance staff and contractors via a gated footbridge along the pipeline. The bridges' single pylon resembles a large tree trunk supporting the structure, and the nest is placed directly above this pillar on the maintenance footpath. This nest was first identified in 1989, with incomplete breeding records including a failed attempt in 2008 when human disturbance was suspected (pers. comm. N Leidenberg 2012). This site was not used for several subsequent years until the

authors recorded sporadic presence of sub-adults and adults between 2012-2015. In 2014 while being monitored by a trail camera this nest successfully fledged an eaglet, while in seasons prior and since, without camera monitoring we note frequent breeding failure. While many raptor species are known to nest on artificial structures (Cade *et al.*, 1994, Machange *et al.*, 2005), this appears to be the only crowned eagle nest known to occur naturally on an artificial structure (after widespread literature review and personal communications).



Figure 5.2 The first crowned eagle nest recorded on a human-made structure. SCM installs a monitoring camera, the eagle successfully fledged in Jan 2015. The nest is centred above the bridges' single support pylon, rising from the Umbilo rivers edge, Durban, South Africa. Photo credit Adam White, 2014.

5.3.1.3 Nest site collapse and mitigation

Naturally, crowned eagles have high site fidelity, and fresh nesting material is added annually to rebuilding size and shape as old strata decay. This process sometimes leads to imbalance and eventually collapse of the entire nest structure. This is particularly likely to occur during the violence of summer thunderstorms, affecting nestlings and recently fledged juveniles. In emergency situations a wooden pallet frame attached within 5 metres of the fallen nest (Fig. 5.3) can serve as platform with which to return a fallen eaglet (Hoffman & Hoffman, 2009). With foresight, a long term solution can be prepared for unstable nests in advance of the nesting season. Platforms constructed of treated timber beams and interwoven branches, placed in the immediate vicinity of a previously collapsed nest, can be used as solid nest foundations for some eagles. At one nest at Victoria Country Club Estate, Pietermaritzburg, such a platform was installed and the pair immediately started building a nest on top (Fig. 5.4).



Figure 5.3 An artificial platform a) was erected 3 m from a collapsed crowned eagle nest. The eaglet survived and was held overnight at Raptor Rescue Rehabilitation Centre for observation before being b) returned to the new platform. The parent crowned eagles would not land on the nest, but drop food from the branch above. The eaglet fledged successfully. Photo credit: Shannon Hoffman.



Figure 5.4 An adult female crowned eagle feeds an eaglet at the Victoria Country Club nest, 28 October 2012. An artificial platform was constructed to replace the nest site which collapsed in 2011 (location indicated with orange triangle). Photo credit: Burkhard Schlosser, 2012.

This platform was used to successfully fledge a chick in 2012. It remained unoccupied for the following season, where it was re-fitted with more concealed and natural looking structure. The platform supported a larger nest in 2014 which also saw an eaglet successfully fledge. At another site, a platform was installed 1 meter lower than the original position of a collapsed nest. This platform was ignored as the pair built a new nest from scratch in the original position on a natural fork, the third time in as many years.

5.3.2 *Injury and mortality*

Twenty five separate incidents of harm to crowned eagle were documented during this study. Nineteen of these occurred from 2012 to 2015, while six were reliable recent accounts before this (pers. comm.; Darryl Brighton, Mike Neethling, Eileen Rasmussen, and (Reporter, 1997)). Incidents mostly affected juvenile and immature crowned eagles (Table 5.2), with the peak number of occurrences in autumn ($n = 10$), double that of each other season.

There is growing international and national awareness of the impact of electricity networks on raptor electrocution and collision with wires (Lehman *et al.*, 2007, Jenkins *et al.*, 2010). The South African national electricity provider ESKOM have partnered with the Endangered Wildlife Trust and developed a reactive mitigation response for raptor electrocutions (Van Rooyen, 1999, Hoogstad & Chetty, 2015). Crowned eagle electrocutions were documented and reported, and follow up visits confirmed insulation strips were fitted within the three months of reporting. Electrocution can have significant population-level effects (Harness *et al.*, 2008, Fox & Wynn, 2010). The issue is a legacy of a nationwide systemic design in South Africa, and we urge the inception of statutory requirements for rapid proactive replacement of unsafe designs.

Collisions with vehicles, window panes, walls, and wire fences, as well as gunshot wounds, and electrocutions together accounted for 80% of all incidents (Table 5.3). It is unknown what fraction of mortality is successfully reported, and we suspect large proportions of electrocutions and gunshot deaths avoid detection. Post-fledging telemetry studies to gain quantitative knowledge of mortality is urgently needed.

Crowned eagle juveniles can become habituated quite easily in the first three months post-fledging if given positive close encounters with humans – especially regarding food. This makes them trusting and susceptible to harmful persecution in surrounding areas. For example, in a historical incident of supplementary feeding of a fledged juvenile (pers. comm. Darryl Brighton 2012), the individual was provided portions of red meat frequently over the course of several weeks. It habituated to a point where it could be fed from a gloved hand. At eight months of age it was also spending time in close proximity to other houses in the neighbourhood, and was shot in a resident's yard.

Table 5.2 Categories of incident types harming crowned eagles in southern KwaZulu-Natal.

INCIDENT TYPE	TOTAL COUNT	= DEATH	PRIOR TO 2012	THIS STUDY 2012-2015
Collisions	8	6	3	5
Gunshot	6	5	3	3
Electrocuted	4	4		4
Airstrike	1	1		1
Unknown / natural	1	1		1
Harassed by people/pets	3	0		3
Ingested Poison	1	0		1
Trapped	1	0		1
TOTAL	25	17	6	19



Figure 5.5 A juvenile crowned eagle (ID N2), from the 2012 breeding season at Zimbali Coastal Resort, Ballito, South Africa. N2 is demonstrating the high levels of human habituation possible with wild crowned eagles at urban nest sites, while a visitor takes a camera-phone photo (upper-right of image). The image is a screenshot of a video taken on 04 April 2014 by an anonymous contributor.

The 2012 juvenile from Zimbali Coastal Resort (ID: N2) also became extremely habituated, by being forced by natural events to feed on prey dropped to the forest floor below the nest. This location was 15 m from the footpath to a restaurant. This eagle eventually allowed

humans to approach within 1 m, calmly perched on a footpath handrail (Fig. 5.5). On two documented occasions this eagle injured people walking or jogging on the footpath by grasping at the head or shoulders during a daring flyby (Table 5.2). Although considered 'play' or practice rather than hunting attempts, the 60 mm long talons and great grip strength makes these potentially serious incidents. *In situ* human-aversion training was given to increase the eagles' perceived comfortable flight-distance. No other human-attacks (except towards researchers climbing to nests) have been recorded during the study period.

5.3.3 *Pet and livestock attacks*

Eighty-eight percent of verified attacks ($n = 24$) on pets were by juvenile and immature crowned eagles, and these tended to peak in winter (38%). Awareness of the research and reports of verified incidents appeared to be high in some areas of the study area.

The first significant 'problem eagle' during the research occurred in winter 2012. A juvenile eagle was identified in three dog attacks and implicated in more than 12 cat disappearances within one neighbourhood from May to November 2012. Postscript information came to light that recently vacated tenants in the neighbourhood had been offering (specifically, processed Vienna) sausages to the juvenile eagle on their property. This likely resulted in the individuals' food search pattern directed towards human habitations. Initial success on domestic species while learning to hunt could develop a search pattern to a particular prey. Various threats on the eagle's life were received and intervention (temporary admission or translocation) was intended, however capture attempts failed and shortly thereafter in October 2012 the last sightings were recorded.

Dog attacks appeared much more likely to be reported than cat attacks. Perhaps this is due to predatory tactics (rapid removal of a cat from the attack location), socio-demographic factors, differing perceptions of conflict issues, and basic knowledge and motivation of reporting avenues. Five individual eagles could potentially be attributed to the non-validated reported disappearance of 35 cats from 2012-2015, whereas 13 dogs were injured or killed. Dog breeds included in this sample include; Jack Russell, Chihuahua, Daschund, mini Doberman Pincher, Yorkshire Terrier and various unattended puppies e.g. German Shepherd. These breeds, especially brown-coated types, are superficially similar in size and shape to the preferred prey, rock hyrax.

Non-mortal attacks on pets were typically locally addressed by veterinary clinics. The range of injuries observed could be caused by crowned eagles, as well as dogs and vervet monkeys, therefore reliable identification of taphonomic signs are required for accurate documentation. Developing awareness in veterinary clinics with an easy reporting scheme would increase the reliability, quantity and distribution of pet-eagle interactions and would assist in improving awareness and management efficacy.

Negative experiences (e.g. frightened during a hunting attempt or kill, lack of food reward from hunting attempt) provide an opportunity for an individual eagle to adjust

behaviour and reduce interest and intent on domestic animals, which would otherwise generate negative public attitudes. Where an individual eagle becomes habitual in foraging for pets or stock, removal of the individual could prevent a wider public reaction towards the crowned eagle population as a whole. Exercising non-lethal measures by removal or translocation of specific individuals could serve to protect both the individual, and the species reputation (Treves & Nauton-Treves, 2005), and allows for low impact and sustainable use of these individuals.

5.4 Management recommendations

5.4.1 Reducing pet-wildlife interactions

The first step in reducing threat and harm to domestic pets is to encourage pet owners to have an outdoor enclosure for their pets. Catio (wordplay on patio) enclosures are becoming popular and commercially available (CatioSpaces, 2015). We highly recommend the development of the pet enclosure ethos in Durban and Pietermaritzburg. This type of enclosure benefits the health of the pet and of the indigenous fauna: It protects the cat or small dog from being attacked by large wild animals, including crowned eagle and wandering dogs. It also protects the garden wildlife from recreational hunting by domestic cats which has a vast impact on wildlife (Loss *et al.*, 2013). Finally, the enclosure isolates the cat or dog from wild animals and zoonosis such as rabies, toxoplasmosis, mange, and disease vectors such as fleas (Garrett, 1994, Bradley & Altizer, 2007, Lepczyk *et al.*, 2015). Without an enclosure, dogs over 10 kg as pack companions to small dogs reduce opportunities for crowned eagles to attack.

5.4.2 Procedural management

Actively managing crowned eagle wildlife conflict will benefit the community and the persistence of the breeding urban population. A decision flow chart (Fig. 5.6) provides procedural information for documentation, site evaluation, and management actions. This was developed over successive meetings and correspondence with EKZNW, eThekweni Municipality, RR, and NFC.

5.4.2.1 Proactive awareness

Through the course of the study, public awareness of crowned eagles has developed through social media, seminar series, posters, newsletter articles, and especially, site visits. These methods have empowered citizens to be involved in the research. An annual press release in local newspapers and interest club magazines would aid in the better reporting and data collection of incidents and attacks (information poster, Appendix II). Attacks on pets by crowned eagles most frequently occur in autumn and winter; therefore the information is best distributed in April.

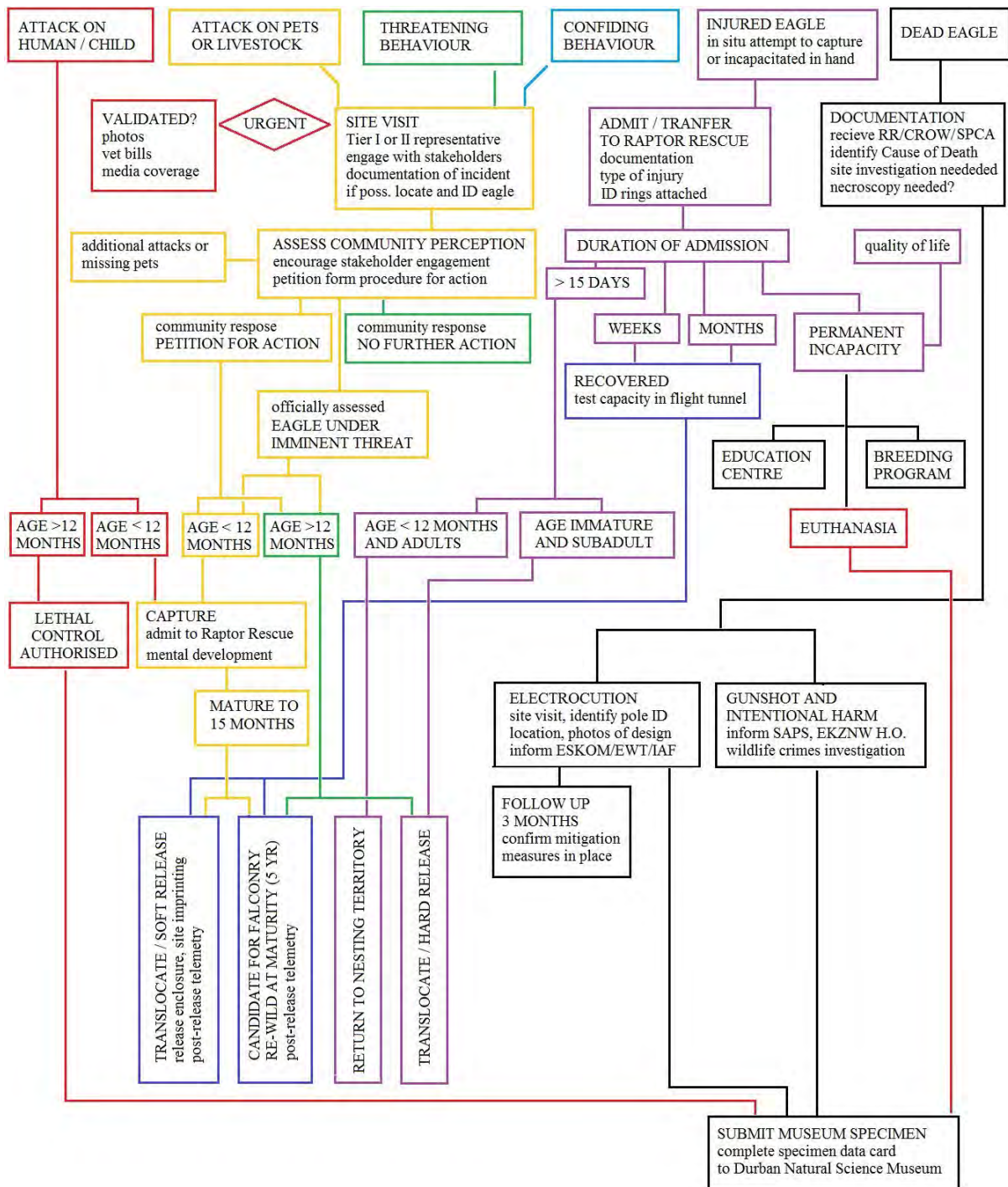


Figure 5.6 Decision flow chart of management actions regarding human-wildlife conflicts concerning crowned eagle in southern KwaZulu-Natal, South Africa.

5.4.2.2 Reactive responses

When a pet is killed or seriously injured, or an eagle is threatening and confiding to humans, management action will help mitigate the social and ecological impact of the identified culprit. A site visit from an individual from the collaborating organisations can inform of the management options available. Necessary ID, location and report information is documented on the EKZNW/UKZN research database. If further conflict occurs or there is strong

community support for management action (in the form of a community petition, Appendix III), actions may include a direct translocation (*ca.* 1-6 h in capture and transit), or admissions to rehabilitation, soft hack, and falconry re-wilding (1 month to 4 years).

5.5 Conclusions

Despite our qualitative summary of crowned eagle mortality there remains a gap in our knowledge about the quantitative, population level effects of this mortality. Ongoing research of breeding success and mark-resighting data will be used to model the population dynamics to inform recruitment, dispersal, gene flow, and population stability. Future research should focus on quantitative identification of sub-adult mortality. To better understand the post-release behaviour, and outcomes of management intervention the use of modern telemetry is affordable and scientifically valuable. A suggested voluntary requirement of the sustainable use of 'problem' crowned eagles for falconry and falconry-based re-wilding efforts is the sponsorship and fitting of post-release telemetry - preferably multi-year lifespan, mortality alert system, and PT or GPS with CTT, GSM, or Argos transmission in the southern KZN region.

Incidents of persecution should be investigated further. Wildlife-crimes investigations should be pursued to raise awareness and reservations of further illegal persecution. In particular, surveys into the local muthi markets were not included during our research. This would be a valuable addition to quantify population impacts on crowned eagles in peri-urban and rural areas. The impacts of electrocution and collisions should be a primary focus of this further research as these could be readily mitigatable (Jenkins & Benn, 1998, Dwyer & Mannan, 2007, Dwyer *et al.*, 2014).

Currently there is good engagement and collective effort for crowned eagle conservation in the study area. This is demonstrated with the involvement of various NGOs (RR, SAFA, NFC, CROW, Free-me, Birdlife SA) and Ezemvelo KZN Wildlife. These collaborations are valuable foundations for the success of a management strategy.

5.6 Acknowledgements

We greatly appreciate the stakeholder input throughout the study area. Discussions with many participants shaped the results and recommendations in this manuscript. In particular we thank; Brent Coverdale, Johann Vermeulen, Atholl Marchant, Bill Howells, Geoff Nichols, Graham Berry, Ross Kramm, Errol Douwes, Sean O'Donoghue, Nick Liedenberg, David Allan, Paolo Candotti, and George Victor.

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6 Morphometric variation in Crowned Eagles in KwaZulu-Natal, South Africa: Size matters in raptors

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Abstract

Sex determination of marked birds is beneficial for field studies. Although most raptor species are sexually dimorphic, many species are non-discrete in some metrics. Roberts VII, *Birds of Southern Africa* (Hockey et al 2005), suggests crowned eagles exhibit non-discrete sexual dimorphism. Consequently we investigated the gender-related morphometric data of crowned eagles (*Stephanoaetus coronatus*) with corresponding genetic avian sex tests. These birds were trapped, measured and released in KwaZulu-Natal, South Africa from 2012 to 2015. We suggest tarsus width, mass, and hind claw measurements are suitable for discriminating sexes of adult crowned eagles. We comment on the use of SAFRING and colour read-rings as a marking technique in crowned eagles, and suggest suitable parameters for marking nestlings.

Keywords: African Crowned Eagle, Crowned Hawk-eagle, *Stephanoaetus coronatus*, Raptor, Morphology, Ringing, Banding, Growth, Gender

6.1 Introduction

Identity marking of birds is essential for tracking each individual's life history and is beneficial to interpreting dispersal ecology and population demographics of a study population. Knowing the gender of the individuals at the time of marking adds further value to studies. Many bird species can be identified by sexual dimorphism such as body size, bill shape, or chromatic variation. Reverse sexual dimorphism in raptors is suggested as enhancing resource partitioning within a monogamous pair, and while nesting, the larger female can produce larger eggs and provide more effective nest defence (Andersson & Norberg, 1981, Krüger, 2005). While most raptor species are sexually dimorphic (especially falcons and accipiters), many species are non-discrete in the size of body parts (Ferguson-Lees & Christie, 2005). In such species with uniform plumages and overlapping body sizes, gender-determination requires other techniques. Dissection to reveal gonads is only possible post-mortem, while endoscopy is not practical for field situations. With affordable commercially available avian sexing tests now available, gender determination during temporary live capture has been enabled. Efficient marking of a study species can be enhanced by accurate ageing and execution of nestling ringing efforts during a breeding season (Hurley et al., 2013).

In southern Africa little information is available on the gender-related morphometric data of crowned eagles (*Stephanoaetus coronatus*). The *magnum opus* of bird identification for the Southern African region, Roberts VII (Hockey *et al.*, 2005), provides data on the variation of male and female morphometrics of crowned eagles (n = 16) (in text citations) highlighting the paucity of data and low sample size. Many of these morphometrics presented show overlapping ranges in size. Consequently we investigated the morphometrics of crowned eagles in KwaZulu-Natal (KZN) Province, South Africa, using genetic avian sex tests to identify the best morphometric indicators for gender-determination (Fig. 6.1). We provide insights into the robustness of various measurements for determining sex in adults and immature birds. Feather development and topological cues can be used to age nestlings, and we comment on suitable nestling age for ringing based on tarsus growth parameters.

6.2 Methods

All samples were collected from a population of crowned eagles occupying southern KZN, South Africa (Fig. 6.1). Trapping adult crowned eagles required extensive field efforts, and included a mean effort of eight attempts (one attempt per day) per successful capture. We gathered morphometric data from fully developed crowned eagles (adult and immature individuals >8 months) while being handled for fitting GPS telemetry (see Chapter 4, Methods, for trapping techniques), and ID ring marking. Samples of fully developed individuals were also obtained from admissions to raptor rehabilitation centres.

Nestlings (eaglets, hereforth pullus/pulli) were ID ringed by being extracted from the nest when the estimated age was 70-80 days of age. Fifteen pulli were of known hatching

time within 24 hours, and the remainder were estimated to ± 3 days. Time from nestling extraction to being returned to nest was 0.5-1.5 h. Feather development was obtained using the total and unfurled lengths of the P8 (8th primary) and R6 (left-centre tail) feather. Time-lapse cameras at nest sites provide a reference series (Appendix IV) for ageing chicks from developmental cues at a distance.

Several research assistants were recruited to collect data to reflect variation across the national group of ringers submitting measurement data to SAFRING. A selection of morphological measurements (Table 6.1) was conducted as described in Wink (2007). All measurements were also in accordance with the SAFRING user manual. (Chapter 6 pp. 44-66) (de Beer et al. 2001). Feather morphometrics were measured with a straight rule to nearest 1 mm, while ‘hard’ parts were measured with electronic callipers to the nearest 0.1 mm. Mass was measured with an electronic hanging scale to the nearest 5 g. Blood samples were taken either from the tarsus vein while drawing 3cc for blood chemistry analysis or via a blood spot from between the first and second distal scales of the first toe (Fig. 6.2). The blood spot from the toe is highly recommended as our experiences show this is easy to execute and has the most minimal trauma compared to alternate techniques, and especially in comparison to the widespread ‘brachial vein spot’ technique which has the added risk of creating a haematoma. The authors assert the brachial vein practice should be abandoned wherever possible. Blood samples including an avian sex kit were obtained. Samples of avian sexing tests were posted to Molecular Diagnostics Services in Durban, and results were retrieved from an online portal within five days.

SAFRING recommends the G-ring, 26 mm internal diameter, and these were fitted on the tarsus of each eagle. An INTERREXTM colour read-ring (28 mm or 30 mm) was fitted on the other tarsus. Two variations of the colour read-rings were used, a) during 2012 and 2013 seasons single rolled rings were glued at the overlap, and b) 2014 season and beyond, with a double rolled design with rivet fixing the outer two layers of the three layer overlap, with the inner layer protecting the tarsus from abrasion with the head of the rivet. All data were obtained with techniques approved and permits provided by Ezemvelo KZN Wildlife, SAFRING, and University of KwaZulu-Natal Animal Ethics Committee.

Statistical analyses were conducted in R (v 3.0) and ggplots2 package (R development core team, 2013). All significance tests used $\alpha = 0.05$. Difference of Means was tested with Welch's t-test for unequal sample sizes and unequal variance.

6.3 Results

Our sample consisted of five adults and 13 immature eagles in the full grown category and 41 pulli with valid AS tested gender-verification.

6.3.1 Full grown crowned eagles

All morphometric measures, except head length, showed significant differences between sexes of adult crowned eagles (Table 6.2). The lowest p-values were from mass, tarsus

width, first claw, and particularly the hind claw ($p < 0.001$). These metrics show the strongest bimodal separation of the largest male and smallest female metrics (2 standard deviations). Wing cord, tail length, tarsus length, cere to tip length and culmen length all showed significant mean differences between sexes. Culmen length was distinct between sexes while the other aforementioned metrics presented overlap comparing the largest males with the smallest females. Only the head length metric demonstrated no significant mean difference between the sexes (Table 6.2).

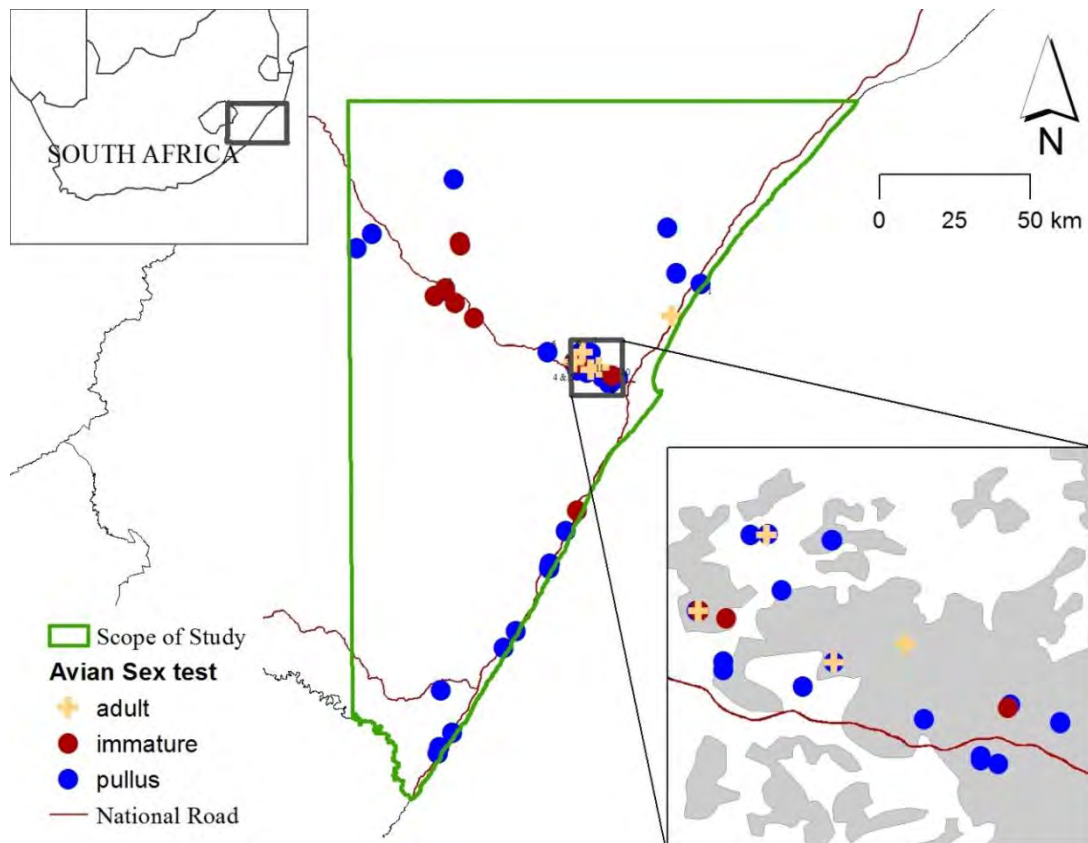


Figure 6.1 Locations of each crowned eagle ringed, and from which morphometric data were collected and genetically sexed in southern KwaZulu-Natal, South Africa.

6.3.2 Pulli crowned eagles

41 pulli contributed to the avian sexing tested population sample. Due to observer error in estimating the age of pulli from a distance, the ringing age ranged from 60-80 days of age (mean = 73) when measured. Tarsus width is an early maturing bone structure for crowned eagles and mean pulli size at 75 days is 100% and 96% the size of mean adult measurements for males and females, respectively. This enables reliable fitting of the tarsus ID rings.

We experienced 2 of 41 pulli jump from the nest upon climbing to the nest edge, one at 62 days of age and one at 90 days; the former falling into understory vines below the nest and the latter gliding across the valley into hanging lianas. Both pulli were rescued

immediately, inspected by an onsite vet nurse, found to be uninjured and given the all clear to be returned to the nest. Both subsequently survived > 8 months.

The ratio of total to unfurled length of developing feathers was highly correlated in both P8 ($y = 0.0019^2 + 0.2904x$, $R^2 = 0.9777$) and R6 ($y = 0.0021x^2 + 0.2517x$, $R^2 = 0.9801$). This correlation was not supported when adding the factor of age to the total sample, and so we eliminated pulli of ‘estimated age’. This smaller but more accurately aged sample did not decrease the variance (Fig. 6.3). Consequently feather development showed great variation and was not reliable for sex determination or accurate ageing of nestlings (Fig. 6.3).

Table 6.1 Sample size of each morphometric feature collected from gender-tested crowned eagles.

	Adults		Immature		Pulli	
	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE
Mass	2	2	2	6	21	20
Tarsus length	3	2	2	5	21	18
Tarsus width	3	2	2	5	20	20
Hind claw length	3	2	2	5	21	20
First claw length	3	2	2	4	19	19
Cere to tip	3	2	2	5	20	20
Culmen length	3	2	1	5	21	18
Head length	3	2	1	5	21	20
Wing cord	3	2	2	5	21	20
Tail length	3	2	2	5	21	20
P8 metrics					8	4
R6 metrics of known age					6	4

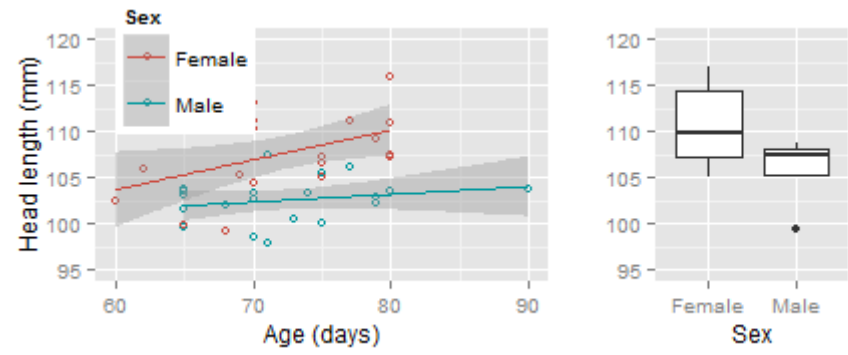
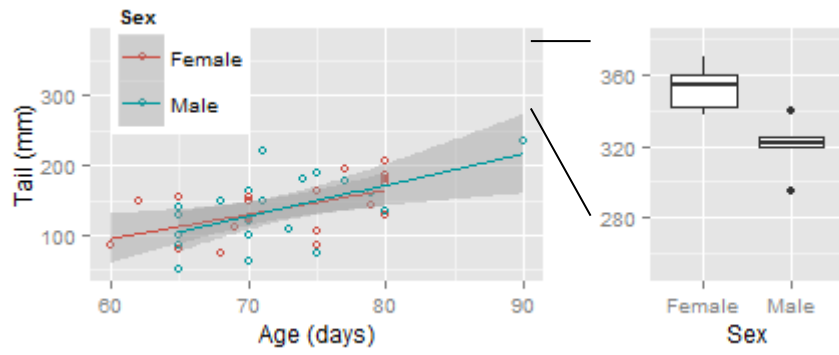
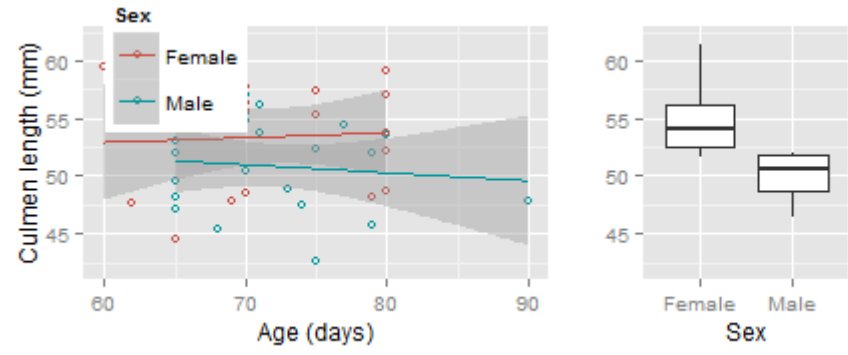
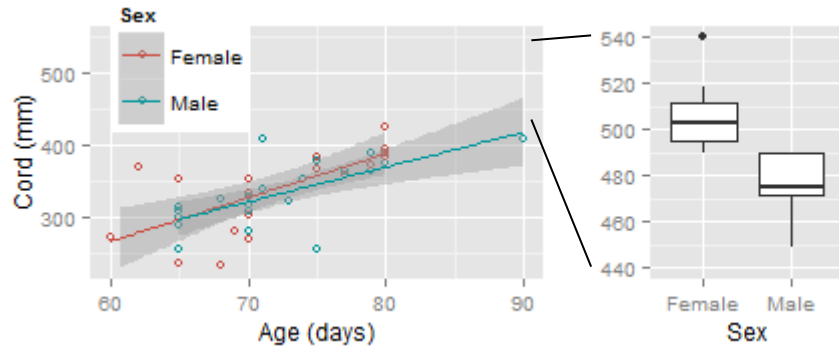
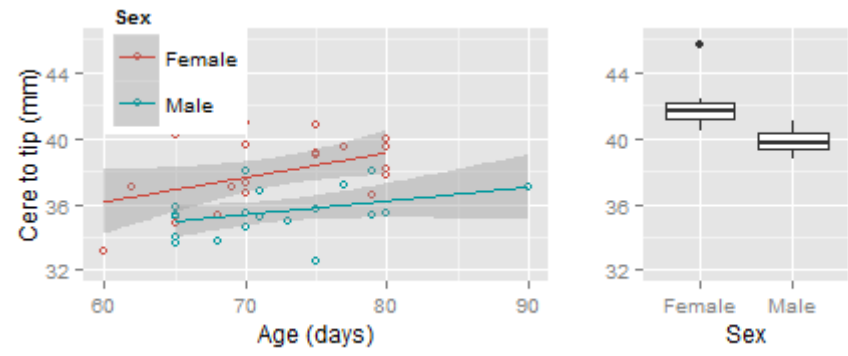
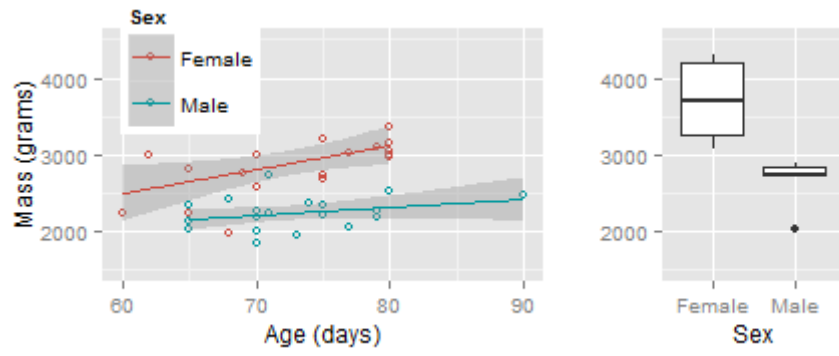
6.4 Discussion

Variation existed in crowned eagles both across individuals for a particular metric and within the preciseness of the measurement. We have observed that there were metrics more subject to interpretation or sampling variation. True variation occurs, for instance, with mass varying by several hundred grams daily depending on; food intake and excrement, hydration, body condition, and fat reserves (pers. obs.). While sampler induced errors occur in field situations in which for example ‘wing cord’ could be measured flattened, or more practically, along the camber. Tarsus length and head length have been observed to have sampler induced variation.

Contrary to Hockey et al. (2005), we found discrete ranges of sex-discriminated morphometrics. Body mass, tarsus width, and hind claw length were the best predictors of gender for both full grown individuals and pulli crowned eagles. Hind claw measurements are not always including in standard morphometric sets (pers. obs.), but ought to be investigated for sex determination in other African eagles. This was previously shown for golden eagles (*Aquila chrysaetos*, Bortolotti, 1984) and African fish eagle (*Haliaeetus*



Figure 6.2 Blood-spot sample from the first toe of crowned eagle pulli in this study. Photo credits; Esmarella Bourret 2013, Jacques Sellschop 2013.



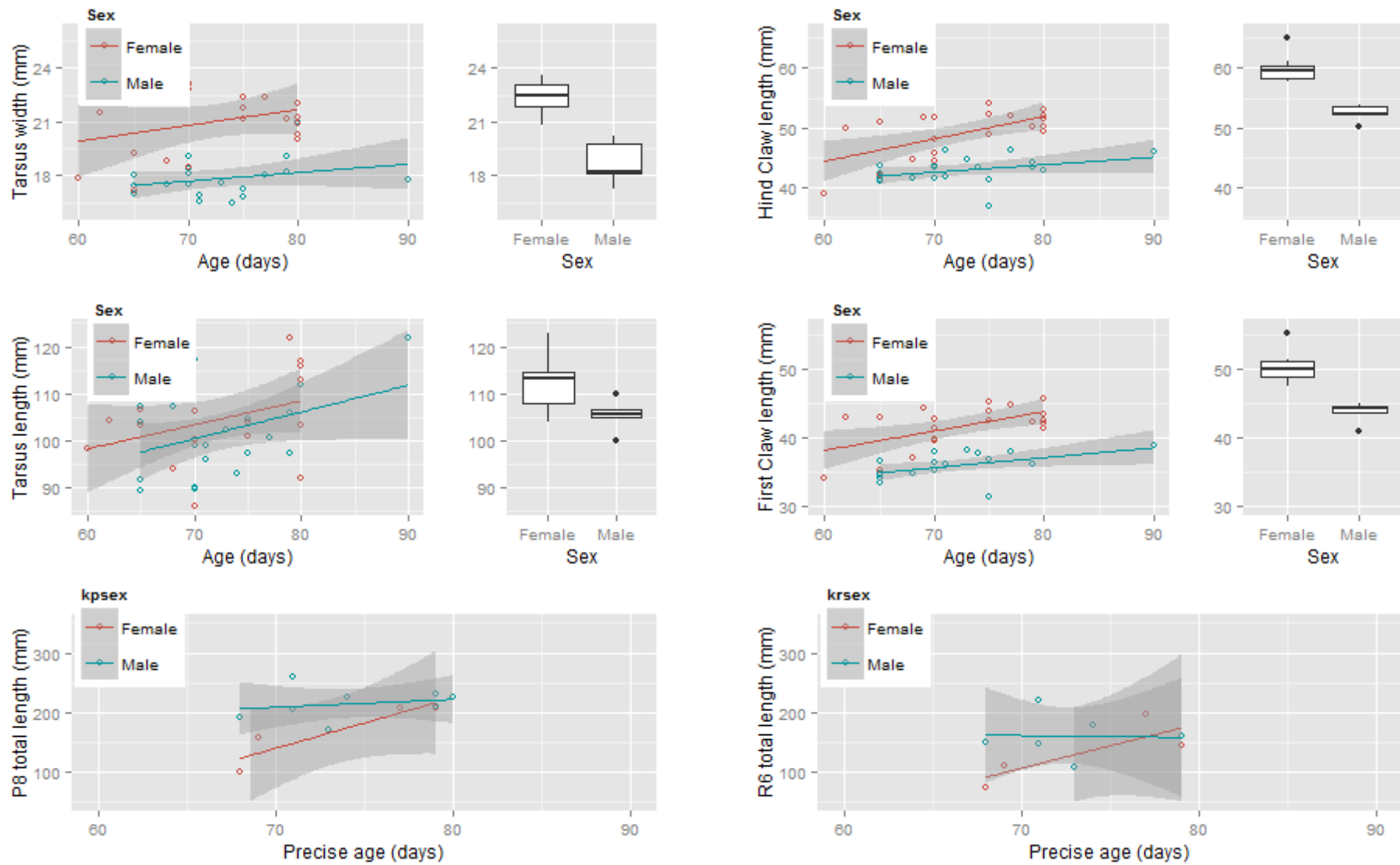


Figure 6.3 Gender differences of morphometric features of pulli (scatter) and full grown (boxplot) crowned eagles measured in this study.

Table 6.2 Summary statistics of crowned eagle morphometric samples, and comparison with Roberts VII data.

	This study (mature individuals > 8months old)								Roberts VII		
	n =	Range		Mean		Welches t test			n =	Range	
		Male	Female	Male	Female	t =	p =			Male	Female
Mass	11	2.0-2.9	3.1-4.2	2811	3710	-5.0159	0.001	***	4	3.4-4.1	3.2-3.85
Tarsus length	13	100-110	104-122.9	105.4	112.2	-2.328	0.043	**	16	86-116	90-116
Tarsus width	13	16.9-20.2	20.8-23.6	18.7	22.4	-5.4802	0.001	***			
Hind claw length	13	48.6-53.6	58.0-61.2	52.4	60.0	-6.5244	0.000	***			
First claw length	12	40.8-45.0	48.4-55.0	43.7	50.4	-5.061	0.001	***			
Cere to tip	12	38.7-41.1	40.4-45.7	39.8	42.0	-2.8662	0.018	**			
Culmen length	12	46.5-52.0	52.0-61.4	50.0	54.9	-2.7294	0.026	**	16	46.5-53.3	43-52.2
Head length	12	99.5-108.8	105.0-117.0	105.9	110.8	-1.7658	0.121				
Wing cord	13	449-490	490-540	475	507	-3.1695	0.012	**	16	456-503	460-552
Tail length	13	295-340	337-370	320	352	-3.7344	0.007	**	15	303-340	280-363

*p = 0.1, **p = 0.05, ***p < 0.001

vocifer, Hollamby *et al.* 2004), whereas foot mass by displacement and other foot measurements are less practical in field studies (Kochert & McKinley 2008).

The SAFRING G-series rings (26mm) are currently the recommended ring. The largest female in this sample had a tarsus width of 23.6mm. It is worth considering a larger size (i.e. 30mm diameter) to comfortably fit the largest females. C shaped rings of this diameter can be removed by adult eagles (pers. obs.) and a more secure design (e.g. bolted, overlapped, or riveted flange) should be implemented. Colour read-rings were obtained from INTERREX, in 2012 these were glued and eight of twelve were removed by the eagle within 6 months (pers. obs.). From 2013 to 2015, split pins and rivets were used to secure the rings. The latest design, double rolled, appears very robust and none have yet been known to be removed. We have, however, observed single-rolled plastic rings being broken and removed by bite force (pers. obs. of a crowned eagle confined while being rehabilitated). NB. This is not an endorsement of INTERREX as a supplier as we have experienced poor post-purchase support of manufacturing errors.

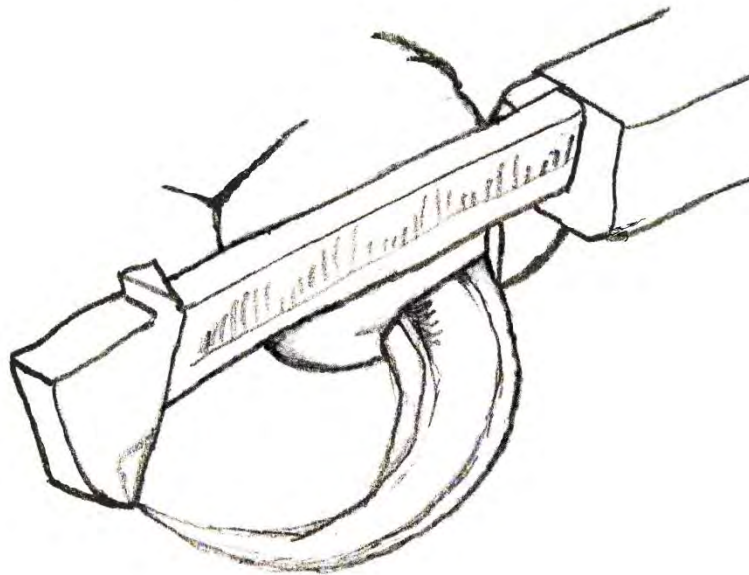


Figure 6.4 Hind claw length of a crowned eagle being measured with electronic callipers.

Marking crowned eagles while they were nestlings was a cost-effective method for ID ringing individuals. Due to feather and behavioural development, once the pullus reaches 85 days old the chances of force-fledging increases greatly. Late access should then be done with great hesitation. The youngest age for nestling ringing is suggested at 65 days of age, determined by a sufficiently developed tarsus and foot. We provide a photographic sequence showing topological developmental cues (relative size and feather development) of male and female pulli of known age to enhance pulli ageing at a distance (Appendix I). The optimal ringing age of crowned eagle pulli is suggested as 75 ± 5 days old. A supplementary

photographic series of pulli known age are provided to assist with using visual topological cues from a distance to prepare ringing schedules.

With the use of commercial and in-house genetic testing of samples from active field studies, genetic testing is becoming more widely used and reliable. We suggest the regional database for avian morphometrics (SAFRING), include a categorical field “gender determination method” with such factors as; genetic test, plumage, morphology, cloacal shape, brood patch, etcetera. These factors should be mandatory when gender is entered as definite male (1) or female (2). We suggest that measurements such as tarsus width and hind claw length should become part of the ‘standard set’ when collecting morphometric data on raptors.

6.5 Acknowledgements

We thank the following assistants for their help with their measurements: M. Witteveen, L. Thompson, K Beer, T. Caine, T. van der Meer, M. Jessen, P. Banville, T. Kunca, E. Bourret, A. White, L. Bambini, and A. Pickles. A bursary was provided by Ethekwini Municipality – University of KwaZulu-Natal Joint Research Partnership.

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7 CONCLUSIONS

7.1 Overview

Urban environments comprise a complex and dynamic landscape, and urban sprawl is irreversibly transforming large areas of land globally. Increasingly, the need for incorporating ecosystem services into urban landscapes provides opportunities for green-space to benefit biodiversity and indigenous wildlife. Generally, large apex predators are first affected and excluded from urban development (Bateman & Fleming, 2012). Enhancing urban green-space can also benefit people by enriching their experience and awareness of nature. Large charismatic species can stimulate awe and interest as emblematic representatives of the wilderness. As the global population becomes ever more urban this enriches the human experience.

Large predators have greater resource requirements, and are thus often used as ecological indicators (Sergio *et al.*, 2006). The crowned eagle *Stephanoaetus coronatus* is a large predatory raptor and a threatened species of forested areas of sub-Saharan Africa. I have shown that there is a large, seemingly saturated population of crowned eagles in an urban landscape in KwaZulu-Natal (KZN), South Africa (Chapters 2 and 4). The population of crowned eagles in urban areas of KZN was poorly understood prior to this research. Here I contribute new knowledge in three categories;

- a) Crowned eagle biology (Chapter 3, 6) and ecological requirements (Chapter 2, 4) in an urban landscape
- b) Successful execution of the latest field techniques such as camera traps (Chapter 3) and GPS telemetry (Chapter 4) revealed new insights into ecology and behaviour
- c) Human wildlife conflicts are addressed within this urban landscape of southern KwaZulu-Natal (Chapters 2, 3, 4 and 5). Human-wildlife conflicts include pet attacks and causes of eagle mortality, thus we propose management guidelines (Chapter 5).

From April 2012 – July 2015, 74 crowned eagle nest sites and *ca.* 180 breeding attempts have been documented. Over 55 nestlings have been marked with colour read-rings. These have been in preparation for long term monitoring. Citizen scientist involvement and additional researcher monitoring will better address questions regarding breeding success, demographics, and recruitment. Finally, I suggest new directions for future research in similar fields.

7.2 The contribution to biological and ecological knowledge

Novel aspects of the biological and ecological aspects of crowned eagles are described in this thesis, which are regionally and globally significant. First I performed a desktop analysis of preliminary SABAP2 atlas data to describe the occurrence of urban raptors in provincial centres throughout South Africa (Chapter 1). This provides a platform for identification of additional research interests on other urban-adapting raptor species. The crowned eagle is

identified as a special case of a large predatory raptor consistently observed in highly urbanised landscapes in forest biomes; which includes Durban metropolitan area, Pietermaritzburg, and KwaZulu-Natal coastal settlements.

Gender-related dimorphism has been previously poorly described (Hockey et al. 2005), and here (Chapter 6) we provide a dataset demonstrating which morphometric characteristics are best used for determining sex of crowned eagles in the hand. In addition a photographic reference of nestling development is provided to better estimate age of nestlings from a distance. These data enable efficient planning of invasive techniques such as camera monitoring and ID ringing.

This is the first study to use GPS telemetry on adult breeding crowned eagles to investigate home range characteristics and habitat selection (Chapter 4). The sample size of five was very low and care must be taken when drawing conclusions based on this data, however inferences can be suggested and this study paves the way for a more thorough study using these techniques. We describe a saturated population of territories dispersed amongst an urban residential-green space mosaic. With inter-nest distances average 2.3 km apart, denser than other populations in the region (Tarboton & Allen, 1984). The fragmented nature of the DMOSS and fragmented indigenous and exotic habitat types reveal an adaptive capacity of crowned eagles. Surprisingly, the crowned eagle is tolerant of human activity in the urban environment, with nest sites inclined to edge areas of formal residential and DMOSS boundaries. Socio-demographic factors appear to limit crowned eagle presence in forest patches close to informal and rural settlements. Therefore social equality will benefit both humans and wildlife (Luck *et al.*, 2013). Habitat use and nest site selection of crowned eagles (Chapter 2) reveal potential conservation conflicts regarding the dispersion of exotic trees, especially blue gum.

Several diet studies are available in the literature, however this study is the most comprehensive study on crowned eagle diet thus far (Chapter 3). The study sought to address public perceptions of human-wildlife conflict and prey choice, and we dispel myths about the frequency and nutritional composition of stock and pets.

7.3 Execution of advanced field techniques

The nest camera study provides the largest direct-observation data on crowned eagles (Chapter 3) and perhaps of a large eagle globally. Eighty-seven percent of 836 prey items were classified, which were obtained from 11 nests and 1 598 survey days. The quantity of archived data, which was analysed in *ca.* 400 hours which further demonstrates the high efficiency of this technique (Marti *et al.*, 2007). The archived time-lapse data is used to gain further insight into nutritional and nesting behaviours (Supplementary III).

Installation of nest cameras required climbing access to active nests. We identify parameters of disturbance to sensitivity and demonstrate the safe execution of these techniques for camera servicing and nestling ID ringing. A significant effort was invested in

capturing adult crowned eagles in order to fit telemetry devices (Chapter 4). These learning experiences have been shared in the field during collaborative communication with peers (especially Megan Murgatroyd, UCT Verreaux eagle research in Cederberg Wilderness Area, and Rowan van Eeden, UCT, Martial eagle research in Kruger National Park).

7.4 Management of ecological and social factors of human-wildlife conflicts

The primary purpose of the research was to provide suggestions for active management and mitigation of conservation conflicts and human-wildlife conflicts on multiple scales. On a landscape scale the vital importance of DMOSS and its natural habitats, especially indigenous forests, is clearly demonstrated in nest site selection, home range, and habitat use of crowned eagles in the urban landscape (Chapters 2 and 4). Expansion of the urban sprawl in southern KZN should allow for a connected mosaic of indigenous forest and bush comprising 20% of the landscape to enable the persistence of breeding pairs of crowned eagles and their corresponding habitat and food resources to persist.

Many species of raptors benefit from the use of exotic trees as secure nesting sites (Smith, 1974, Malan & Marais, 2002, Welz & Jenkins, 2005). Blue gum (*Eucalyptus saligna*) was a particularly important nesting tree for the crowned eagle in the urban environment, particularly small patches of mature trees. Positive and negative effects of exotic trees are many and varied including; soil ecology, water use, erosion control, forest succession, and honey production. Therefore the ecological impacts and management of exotic trees should be carefully considered (Dickie *et al.*, 2014).

I demonstrate that urban wildlife is the primary food source for urban crowned eagles in the study area, with primary prey choice being rock hyrax. Rock hyrax have recently adapted to urban environments in South Africa, using culverts, covered decking, and other anthropogenic structures as den sites. Hyrax are prone to temporal fluctuations and a historical crash throughout KwaZulu-Natal was suspected to impact local crowned eagle and Verreaux's eagle *Aquila verreauxii* populations (Alcock, 2009). Foraging adaptability of crowned eagles, and potential fluctuations in preferred urban adapting wildlife species, particularly rock hyrax and hadeda ibis nestlings, may result in prey switching and increased threats to livestock and pet depredations.

Pet attacks have a significant impact on the perceptions and likeability of crowned eagles in the urban landscape. I identify instances of pet attacks which most frequently occur in winter and by juvenile and immature crowned eagles. This provides understanding and opportunity for awareness, advocacy, and direct management of human wildlife conflicts of this nature. Regular correspondence with official wildlife authorities, management NGOs and public stakeholders has informed the development of a management strategy (Chapter 5).

During the course of the research from April 2012 to November 2015, ID tagged and untagged eagles were identified in incidents of harm and mortality to crowned eagles. Threats are primarily anthropogenic including collisions with fixed and moving structures,

persecution by gunshot, and phase to ground electrocutions on electrical distribution lines. Addressing these anthropogenic impacts can further increase the robustness and sustainability of an urban crowned eagle population.

7.5 Summary statement

This study of crowned eagle ecology is of importance as an indicator of robust ecosystem function in a large urban ecosystem. The urban mosaic landscape provides conservation benefits for this threatened species (IUCN, 2014), and in particular highlights the value of the D'MOSS plan and wildlife conflict issues. Other African cities may benefit by adopting D'MOSS urban design principles. Further, globally, cities in tropical forest biomes have the potential for providing landscapes suitable for local species of threatened forest raptors. The majority of the world's human population are urban citizens, generally removed from a daily connection with nature's diversity. Large predators are the emblematic symbols of wild animals; therefore large charismatic species such as the crowned eagle provide an avenue for bringing 'the wilderness to the people'.

7.6 Suggestions for future research

Longitudinal studies on the long-term dynamics of crowned eagle breeding productivity, land use change, and changes in prey availability would be of great benefit to understanding the temporal dynamics within this environment. In particular the dynamics of the main prey base, rock hyrax and hadeda ibis *Bostrychia hagedash*, and whether prey switching occurs as these populations diminish is needed. In addition the disease dynamics of rock hyrax populations is poorly known. Longitudinal studies are typically limited and difficult to obtain within the timeline of an academic student. Establishing a succession of researchers or a community based monitoring program would aid in the collection of longitudinal data. We provide the basis for a centralised crowned eagle database for long-term research.

Using the urban landscape requirements of the crowned eagle population, evaluations of habitat quality in other African forest cities may be used to estimate potential for crowned eagle occupation. In addition, comparing crowned eagle life history traits with other forest eagles (particularly endangered species such as Philippine eagle *Pithecophaga jefferyi*, and the dynamics of urban areas within the range, may be used to predict urban areas which could provide conservation benefits to those species.

7.7 Proposed future publications from data captured during this study

In addition to the data presented within this thesis, there are several additional components to prepare and publish.

1. Due to a protracted, often biennial breeding cycle, obtaining adequate samples for crowned eagle breeding success and demographic data requires long term monitoring. As of July 2015 there were 180 breeding attempts documented. The 2015 season will

raise this beyond 200 attempts over 4 seasons. Describing trends in breeding success is very limited during graduate degree timeframes.

2. During this research, nestlings have been marked with 'read rings' and SAFRING codes. Amongst crowned eagle populations, this study provides one of the highest potential chances for assessing recruitment and population demographics. This data will be a valuable contribution globally in the longer-term future. Currently 59 crowned eagles have been ringed locally, including 54 juveniles who will mature from 2017 and beyond. A future study from 2020-2023 would provide valuable insights into recruitment.
3. In addition to the diet data already described (Chapter 3) the nest cameras have captured observational data not commonly found in the literature. The bipartisan occupation of a crowned eagle nest by a newly-fledged juvenile eagle and a breeding pair of Egyptian geese (*Alopochen aegyptiacus*) is a significant finding of a commensal interaction. Interactions and succession of a complex nature occurred between crowned eagles, fish eagles, black sparrowhawk, and Egyptian geese. In addition the presence of other raptors, dormice, and breeding birds such as weavers and mannikins reveal the use of the large crowned eagle nests as a microhabitat for a variety of species.

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Appendix I.

List of common and scientific bird names in Table 1.1

Common name (English)*	Species (Scientific)*
Secretary bird	<i>Sagittarius serpentarius</i>
Western osprey	<i>Pandion haliaetus</i>
Black-winged kite	<i>Elanus caeruleus</i>
African harrier-hawk	<i>Polyboroides typus</i>
White-backed vulture	<i>Gyps africanus</i>
Cape vulture	<i>Gyps coprotheres</i>
Black-chested snake eagle	<i>Circaetus pectoralis</i>
Crowned eagle	<i>Stephanoaetus coronatus</i>
Long-crested eagle	<i>Lophaetus occipitalis</i>
Verreaux's eagle	<i>Aquila verreauxii</i>
Gabar goshawk	<i>Micronisus gabar</i>
Pale chanting goshawk	<i>Melierax poliopterus</i>
African goshawk	<i>Accipiter tachiro</i>
Little sparrowhawk	<i>Accipiter minullus</i>
Ovambo sparrowhawk	<i>Accipiter ovampensis</i>
Black sparrowhawk	<i>Accipiter melanoleucus</i>
African marsh harrier	<i>Circus ranivorus</i>
Yellow-billed kite	<i>Milvus aegyptius</i>
African fish eagle	<i>Heliaetus vocifer</i>
Common buzzard	<i>Buteo buteo</i>
Jackal buzzard	<i>Buteo rufofuscus</i>
Lesser kestrel	<i>Falco naumanni</i>
Rock kestrel	<i>Falco rupicolus</i>
Amur falcon	<i>Falco amurensis</i>
Lanner falcon	<i>Falco biarmicus</i>
Peregrine falcon	<i>Falco peregrinus</i>

* Taxonomy follows Gill & Donsker 2014

Appendix II

Information poster. PDF available for printing in A2 format.

AFRICAN CROWNED EAGLE IN YOUR BACKYARD

Kroonarene (A), uKhozi (X), isiHuhuwa (Z)
Stephanoetus coronatus

CONSERVATION STATUS: NT (IUCN 2012), VULNERABLE IN SA
Protected in all provinces by the Nature Conservation Ordinances/Acts



ABOVE: Juvenile (left) and adult (right) crowned eagle

IDENTIFICATION

This is a large eagle, the long heavily barred tail is diagnostic, grey cere (on bill), yellow gape and feet, black and white spotted feathers on legs

Juvenile: Dark grey above with white belly, as the juvenile ages, becomes tan, then mottled on breast

Adult: Dark brown above and below with mottled white and rufous breast feathers

Sexes: similar, female larger and darker below

In flight: broad round wings with 2-3 bars, long tail

Call: Adults in a flight display utter continuous series of kieu-kieu-kiew while in steep U shaped dives perched females also call a quiet koi-koi-koi-koi Juveniles begging have a distinctive high-pitched repetitively whistled ki-ki-ki-ki-ki...

GENERAL BIOLOGY

Locally, in forested areas of eastern South Africa, especially the Limpopo/Mpumalanga Escarpment, KwaZulu-Natal Coastal Belt, and the Eastern Cape

In Durban, as many as 25 pairs breed among Durban's green-space system. The well-known 40 year old nest at Krantzklouf Nature Reserve is worth a visit

A forest dwelling species that builds a large nest high in a main fork of a large tree. Breeding from June-February, one chick per 1 or 2 years. The juvenile needs post-fledging care and may remain in the nest area for a further 6-12 months

LEFT: Adult crowned eagle with sprig of pine for lining the nest



RIGHT: Immature eagle with ID ring 'yellow N2'



RESEARCH AND CONFLICT MANAGEMENT

Research includes using ID rings and tracking devices on eagles in KwaZulu-Natal Sighting information on eagles and especially colour ring ID, along with date and address or GPS location, will greatly assist the research.

Report sightings of ID ringed eagles to: kzncrowneagle@gmail.com
Join the eagle-watchers community at: [facebook.com/CrownedEagleResearch](https://www.facebook.com/CrownedEagleResearch)

Immature and sub-adult eagles are typically identified in the occasional attacks on pet and livestock. These individuals are young and less adept at hunting, usually dispersing or transient. There are strategic options for eagles threatening, or at threat, from harm. [Contact Raptor Rescue](#) for conflict management alerts. Your local Conservation Officer will also respond to alerts and concerns.

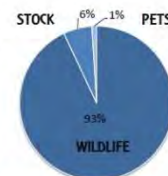
NATURAL DIET

Mammals 1-5kg in weight. Mainly; hyrax (dassies), small antelope, monkeys, mongooses, large rodents, some birds and reptiles

In KwaZulu-Natal, studies show preference for hadeda ibis nestlings in urban areas. Cane rats, snakes and water monitor are prey in sugarcane landscapes

Stock and pets such as chickens, ducks, young lambs, cats and small dog breeds sometimes are prey for crowned eagles

Crowned Eagle Research in urban areas of KZN show only small proportions of pets as prey



Juvenile and immature eagles on dispersal movements, and especially from May-Oct, are the most likely times for occasional pet and stock attacks



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McPherson et al. 2015
Nest site characteristics in urban landscape.
Landscape and Urban Planning, 148

Poster produced Nov 2015 by SC McPherson, CT Downes (UKZN); B Coverdale, A Marchant (EKZNW); B Padbury, G Berry (Natal Falconry Club), B Hoffman (Raptor Rescue)

Appendix IV

Growth sequences of known-age crowned eagle pulli, one male E4 and one female C3.

Male "E4" hatched 8 October 2012. Camera install on the 29 Oct 2012 when E4 was 21 days of age.

21 25 29



Female "C3" hatched 18 September 2013. Camera installed 25 September 2013 when C3 was 7 days of age.

07 23 26



Male E4

33



Ltl Acorn VCCE ◀ 077°F 025°C 09/11/2012 11:00:32

37



Ltl Acorn VCCE ○ 066°F 019°C 13/11/2012 09:09:55

41



Ltl Acorn VCCE ▶ 062°F 017°C 17/11/2012 16:42:57

Female C3

32



Ltl Acorn ◀ 062°F 017°C 10/20/2013 08:51:29

36



Ltl Acorn ◀ 069°F 021°C 10/24/2013 08:53:49

38



Ltl Acorn ○ 071°F 022°C 10/31/2013 08:46:04

Male E4
45



Ltl Acorn VCCE 069°F 021°C 21/11/2012 13:04:31

48



Ltl Acorn VCCE 091°F 033°C 24/11/2012 15:45:08

52



Ltl Acorn VCCE 066°F 019°C 28/11/2012 09:44:27

Female C3
44



Ltl Acorn 082°F 028°C 11/01/2013 13:32:21

47



Ltl Acorn 059°F 015°C 11/04/2013 05:39:41

51



Ltl Acorn 080°F 027°C 11/08/2013 11:48:05

Male E4
55

60

65



Ltl Acorn VCCE ☾ 073°F 023°C 01/12/2012 11:26:55

Ltl Acorn VCCE ☾ 082°F 028°C 06/12/2012 14:57:13

Ltl Acorn VCCE ○ 062°F 017°C 11/12/2012 11:12:38

Female C3
57

63

67



Ltl Acorn ☽ 082°F 028°C 11/13/2013 15:55:21

Ltl Acorn ☾ 075°F 024°C 11/20/2013 06:26:17

Ltl Acorn ☾ 068°F 020°C 11/24/2013 07:33:42

Male E4
67



Ltl Acom VCCE ○ 080°F 027°C 13/12/2012 14:48:49

77



Ltl Acom VCCE ▶ 078°F 026°C 21/12/2012 09:15:11

80



Ltl Acom VCCE ● 080°F 027°C 26/12/2012 13:28:36

Female C3
69



Ltl Acom ◀ 060°F 016°C 11/28/2013 10:55:10

75



Ltl Acom ▶ 071°F 022°C 12/04/2013 13:35:13

81



Ltl Acom ▶ 069°F 021°C 12/10/2013 11:52:14

Male E4
85

92

102 (branching)



Ltl Acom VCCE ◀ 082°F 028°C 30/12/2012 17:05:50



Ltl Acom VCCE ◀ 084°F 029°C 07/01/2013 12:38:54



Ltl Acom VCCE ▶ 087°F 031°C 17/01/2013 14:19:48

Female C3
84

92

103



Ltl Acom ● 078°F 026°C 12/13/2013 11:24:43



Ltl Acom ◀ 078°F 026°C 12/21/2013 16:42:32



Ltl Acom ○ 084°F 029°C 01/01/2014 11:45:17