The influence of the conservation of forests and public attitudes on the persistence of African crowned eagles in the mosaic of eThekwini Municipality, KwaZulu Natal, South Africa

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ABSTRACT

Globally, natural landscapes are under immense pressure brought by the ever-increasing human population. The transformations and modifications of global landscapes because of anthropogenic activities are mainly happening in indigenous and semi-natural environments, which makes them more detrimental to fauna, especially terrestrial species. Consequently, the effects of land-use change and increase in human population, especially in urban areas, have been documented to impact several bird species, including raptors, negatively. Generally, raptor species are sensitive to significant changes within their environments, occur at low densities and are at the top of the food chain; hence, they are used as indicators of ecosystem health. In addition, raptors ensure the long-term functioning of the ecosystem through ecosystem provision, but persecution and poisoning because of human-raptor conflict could be detrimental to their persistence. The present study investigated the persistence of African crowned eagles (*Stephanoaetus coronatus*, hereafter crowned eagle) and documented the potential threats (i.e., competition and climate change) across the urban-rural mosaic landscape of eThekwini Municipality, Durban, KwaZulu Natal, South Africa. Furthermore, the study investigated the attitudes and perceptions of eThekwini Municipality residents toward crowned eagles.

Firstly, crowned eagles point count surveys (i.e., presence/absence) were used to model the occupancy and detection probability in 42 forest/woodland areas of eThekwini Municipality, KwaZulu Natal. Forest ($\beta = 3.66 \pm 1.70$) was the only variable which positively influenced the occupancy of crowned eagles whereas disturbance ($\beta = -4.70 \pm 1.78$) and building density ($\beta = -2.65 \pm 1.34$) had a negative influence. Exotic tree plantations ($\beta = 0.62 \pm 0.38$) and disturbance ($\beta = 0.51 \pm 0.27$) were the variables which positively influenced detection probability whereas surrounding settlements (i.e., urban or rural) ($\beta = -0.42 \pm 0.40$) had a negative influence. Overall, the results indicated the importance of forests in ensuring the persistence of crowned eagles in the mosaic landscape of eThekwini Municipality. Secondly, the nest characteristics of crowned eagles and black sparrowhawk (*Accipiter melanoleucus*) nesting sites were compared to determine if there could be any competition for nesting sites between the two raptors in the mosaic landscape of eThekwini Municipality. There was no significant difference in nest characteristics such as nest cover, tree cover, nest height and distance to (i) road (ii) building and (iii) water. The only nest characteristic that significantly differed was tree height. Overall, our results showed that large exotic tree plantations are crucial for the persistence of raptors as they are the most commonly used nesting substrates in this urban mosaic landscape.

Thirdly, through online surveys/questionnaires and face-to-face interviews, the attitudes and perceptions of eThekwini residents towards crowned eagles were determined. Generalised linear mixed models (GLLMs) were used to determine which factors influenced attitudes and perceptions of eThekwini residents. Overall, the results showed that crowned eagles are 'loved' by the residents, but the level of education and threat they pose to livestock and pets have a negative influence on the attitudes and perceptions. Lastly, how climate change effects (i.e., an increase in the frequency of thunderstorms) will likely affect the population of crowned eagles in the mosaic urban landscape of eThekwini Municipality using demographic modelling was investigated. Population viability analysis showed that the increase in the number of thunderstorms will have detrimental effects on the population of crowned eagles. Overall, the implementation of climate change mitigation strategies and increased education/awareness campaigns can be crucial in conserving crowned eagles in eThekwini Municipality. The results of this study highlighted how the communities of Durban appreciate and see the necessity of conserving crowned eagles, especially during the time of rapid urbanisation and changing climate.

PREFACE

The data described in this thesis were collected in Pietermaritzburg, Republic of South Africa, from May 2019 to October 2021. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg campus, under the supervision of Prof Colleen T. Downs and Dr Manqoba M. Zungu.

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

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April 2022

We certify that the above statement is correct, and as the candidate's supervisors, we have approved this thesis for submission.

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DECLARATION 1 - PLAGIARISM

I, Mfundo Sibongakonke Terrance Maseko, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.
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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 DRAFT PUBLICATIONS that form part and/or include research presented in this thesis.

PUBLICATION 1

MST Maseko, MM Zungu, ST Gumede & CT Downs

Occupancy and detectability of African crowned eagles in an urban landscape mosaic: the importance of natural forest areas

Author contributions:

MSTM, MMZ and CTD conceptualised the study. MSTM collected and analysed the data with assistance from STG and MMZ. MSTM wrote the draft manuscript. STG,MMZ and CTD contributed valuable comments to the manuscript.

PUBLICATION 2

MST Maseko, MM Zungu & CT Downs

Nest characteristics of African crowned eagles and black sparrowhawks: Is there potential competition for nesting sites in an urban landscape mosaic?

Author contributions:

MSTM, MMZ and CTD conceptualised the study. MSTM collected and analysed the data. MSTM wrote the draft manuscript. MMZ and CTD contributed valuable comments to the manuscript.

PUBLICATION 3

MST Maseko, MM Zungu & CT Downs

Public perceptions of African crowned eagles in an urban-rural mosaic of eThekwini Municipality, KwaZulu Natal, South Africa

Author contributions:

MSTM, MMZ and CTD conceptualised the study. MSTM collected and analysed the data. MSTM wrote the draft manuscript. MMZ and CTD contributed valuable comments to the manuscript.

PUBLICATION 4

MST Maseko, MM Zungu & CT Downs

Population viability analysis of the Near-Threatened African crowned eagles (*Stephanoaetus coronatus*) simulated under increasing extreme weather events in a mosaic urban landscape, Durban, South Africa

Author contributions:

MSTM, MMZ and CTD conceptualised the study. MSTM collected and analysed the data. MSTM wrote the draft manuscript. MMZ and CTD contributed valuable comments to the manuscript.

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April 2022

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KUFEZIWE

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CHAPTER 1

INTRODUCTION

1.1 Urbanisation and challenges

Landscape transformations as a result of rapid urbanisation remain a major reason for the loss of natural environments and functioning ecosystems (Marzluff 2001; Chace and Walsh 2006; McKinney 2008; Cilliers et al. 2014; Carvajal-Castro et al. 2019), and this is because the effects and damages caused by the process of urbanisation are irreversible and severely detrimental to biodiversity (McKinney 2008; Møller 2008; Ortega-Alvareza and MacGregor-Fors 2009; Seto et al. 2011). Many studies worldwide have demonstrated how the process of urbanisation threatens the persistence of global fauna and flora (McKinney 2008; Concepción et al. 2015; Murray and St Clair 2015; Samia et al. 2017; Guneralp et al. 2018). Cities are relatively small when compared with rural/farm areas, but are presently occupied by more than 3,5 billion humans, and future global human population predictions suggest that more than 65% of humans will reside in urban areas in 2050 (Aronson et al. 2014; Guneralp et al. 2018; Reynolds et al. 2019). Therefore, because of projected increases in urbanisation, there is a more urgent and pressing need to understand the impacts of urbanisation to enact proactive conservation measures. Since projections indicate that human population and urbanisation, especially in towns and cities, will continue to increase rapidly (Seress and Liker 2015; Reynolds et al. 2019), it is important to determine how biodiversity persists in these areas.

Generally, especially in temperate developed regions, urbanisation significantly reduces the proportion of native habitats in landscapes and creates modified environments which typically result in habitat reduction, habitat loss and the introduction of non-native species which can adapt and exploit the anthropogenically modified environments (Marzluff et al. 2001; Clergeau et al.

2006; McKinney 2002, 2006; Møller 2009; Shochat et al. 2010; Rogers et al. 2021). Consequently, this generally results in the loss of native (and specialist) species and an increase in introduced species (and generalists) which, in the long run, results in biotic homogenisation (i.e., reduced ecological functions) (Blair 2004; Chace and Walsh 2006; Clergeau et al. 2006; McKinney 2006; Møller et al.2012; Concepcion et al. 2015). Furthermore, the other traits of these urbanised landscapes include high levels of light and noise pollution (Dominoni et al. 2013). The generally observed trend in bird communities between urban and rural/natural areas is that urbanised landscapes generally have low taxonomic diversity but high species density (Blair 1996; McKinney 2002; Kark et al. 2007; Ortega-Alvareza and MacGregor-Fors 2009; Møller 2011; Sol et al. 2014; Henderson 2015; Widdows et al. 2015; Carvajal-Castro et al. 2019). The response and impacts of urbanisation processes on bird species have been widely studied by biologists (e.g., Blair 1996, 2004; Chace and Walsh 2006; Seress and Liker 2015; Reynolds et al. 2019).

Research has well documented that the response of species to processes of urbanisation significantly differ, hence the community of urban species can be categorised into three groups (i.e., *avoiders*, *exploiters*, *adapters*) (Blair 2004; McKinney 2006; Kark et al. 2007; Rogers et al. 2021). Urban avoiders are species that are more sensitive to landscape transformations and significant environmental or other disturbances within their environments (Blair 2004; McKinney 2006; Rogers et al. 2021). Urban exploiters are species that are tolerant of urbanised landscapes and can thrive in these environments because of their ability to exploit urban resources and structures (McKinney 2002, 2006; Rogers et al. 2021). Urban adapters can tolerate moderate changes to their landscapes/environments and exploit human-made structures for nesting and roosting (McKinney 2006; Rogers et al. 2021). Some of the major contributors to high species density in urbanised landscapes include high food availability (mainly as a result of humansubsidised resources) and reduced predation (Shochat 2004; Møller et al. 2012, 2015; Møller and Ibanez-Alamo 2012; Singh and Downs 2016). Furthermore, increased levels of competition for resources such as space and nesting sites (e.g., Smith 2006; Dodaro and Battisti 2014; Sumasgutner et al. 2016; Shivambu et al. 2021) are observed in urbanised landscapes (McKinney 2006; Taylor et al. 2013; Hernandez-Brito. 2014).

However, many urban landscapes are heterogeneous mosaic landscapes and are predominantly characterised by a high rate of habitat transformations, vegetated areas (e.g., natural and managed green spaces), and high- and low-density buildings and infrastructure (e.g., roads) (McKinney 2006; Ortega-Alvareza and MacGregor-Fors 2009; Soulsbury and White 2015). Some of the major challenges of urbanisation and its processes are reduced occupancy of natural habitats by native species as they dramatically decline in urbanised landscapes (Andren 1994; Marzluff and Ewing 2001; McKinney 2008; Villasenor et al. 2021). However, more recent research has highlighted how vital green spaces (remnants of natural habitats and managed green spaces) in urban mosaic landscapes are important for humans and biodiversity conservation (see Gupta et al. 2012; McPherson et al. 2016, 2019, 2021a; Maseko et al. 2019, 2020; Zungu et al. 2019, 2020a, b; Downs et al. 2021; Mansour et al. 2022). This is because the vegetation cover that is provided by the urban green spaces can mitigate some of the effects brought by processes of urbanisation (Mansour et al. 2022). For instance, urban green spaces can play a crucial role in reducing noise levels in an urban area, mitigation of climate change effects and providing cover and shade, which could be vital for reduced predation risk (Fuller et al. 2007; Møller 2012; Lafortezza et al. 2009; Mansour et al. 2021).

1.2 Raptors

Globally, raptor species are generally declining, and some may possibly go extinct in the next few years, and this is mainly because of threats such as landscape transformations and destructions, climate change, electrocution, direct or indirect poisoning, human persecution and collisions with anthropogenic infrastructure (e.g., aeroplanes, buildings, vehicles, fences) (Bildstein 2006; Hager et al. 2009; Monadjem et al. 2013; Thompson et al. 2013; Ogada et al. 2016; Amar et al. 2018; McClure et al. 2018; Mojica et al. 2018; Maphalala et al. 2020; McPherson et al. 2021b). Anthropogenic activities such as agriculture and exotic commercial plantations threaten the existence of forests globally (Hansen et al. 2013; Laurance et al. 2014), and this is detrimental to the persistence of raptors as more than 80% use forests as habitat for hunting (McClure et al. 2018). Furthermore, forests are critical for the survival and conservation of approximately 50% of all raptor species (McClure et al. 2018).

There has been an increased interest in conserving various global raptor species. Some of the main reasons for this interest are education and awareness campaigns because of the rapid loss of raptors as a result of human activities, their charisma and genuine love from the general public (and biologists), the provision of important ecosystem services, and lastly their overall conservation status worldwide and scarcity (Sergio et al. 2008; Donazar et al. 2016; McClure et al. 2018; Santangeli and Girardell 2021). The rarity, endemism and charisma of raptor species attract people from all regions of the world to visit an area where certain species of interest occur, and this is especially common among avitourists as they wish to increase their birding list (Amar et al. 2018; Miranda et al. 2021). Subsequently, this provides opportunities for accommodation places and tourist/bird guiders to benefit financially (Steven et al. 2021).

The persistence of raptors is vital for the provision of important ecosystem services and the long-term functioning of their respective environment (Şekercioğlu 2006; McClure et al. 2018). Furthermore, ecosystem services provided by raptors directly benefit humans since scavenging (i.e., removal of carcasses) significantly reduces the probability of diseases spreading (Donazar et al. 2016; Amar et al. 2018). For example, a dramatic decline in vultures (scavenging raptor species) in India resulted in an increase in disease-carrying animals such as rats (*Rattus* spp.*)* and feral dogs (*Canis lupus familiaris*), which resulted in a high number of humans and domestic animals being infected with diseases such as rabies (see Pain et al. 2003; Markandya et al. 2008; Ogada et al. 2012; Donazar et al. 2016). High food availability in urban and agricultural landscapes makes these areas ideal for rodents to thrive, but the presence of raptors, especially in agricultural areas, is crucial for controlling rodent agricultural pests (Donazar et al. 2016; Munoz-Pedreros et al. 2018 Peleg et al. 2018).

Another challenge that will significantly affect the persistence of avian species (including raptors) will be global climate change (McKinney 2008; Wiens 2016; McClure et al. 2018). Present projections show that because of climate change, range contractions for several species will happen (Pecl et al. 2017; Condro et al. 2022). Furthermore, the frequency of extreme weather conditions, including torrential rainfalls, will occur as a result of climate change, and this will significantly affect the persistence of avian species by negatively affecting breeding attempts by destroying/disturbing nests and chick mortality (Maxwell et al. 2018; Trenberth et al. 2018; McPherson et al. 2021b).

1.2.1 Raptors in urban areas

The rapid habitat alterations and the ability of raptors to persist in urban mosaic landscapes have become an interesting subject for biologists. Raptor species are typically sensitive to destruction and disturbances occurring to or within their ecosystem because of their high position in food webs and slow life history (Sergio et al. 2008; Rullman and Marzluff 2014; McClure et al. 2018). Furthermore, because of their sensitivity, raptors can be used as indicators of ecosystem health (Sekercioglu 2006; Donázar et al. 2016). However, since most raptors occur at low densities in ecosystems, it can be very challenging to efficiently research their ecology (Newton 1979; McClure et al. 2018).

Despite extensive transformations of natural landscapes in urban areas, previous research has documented how several species (including raptors) exploit and thrive in these modified environments (McKinney 2006; Møller 2009; Kettel et al. 2018; Muller et al. 2020; Mak et al. 2021; McPherson et al. 2021a). However, several factors contribute to whether a species thrives or declines in urban mosaic landscapes. For example, the high density of human-made structures such as buildings in urban built areas provides nesting opportunities (including nest boxes), and the availability of food (including supplementary feeding) increases the abundance of prey species for several raptors (Marzluff 2001; Møller and Mousseau 2009; Møller 2011; Sumasgutner et al. 2014, 2020; Kettel et al. 2018; Reynolds et al. 2019; McPherson et al. 2021a). Examples of raptor species persisting and thriving in built-up areas of urban mosaic landscapes include black sparrowhawks (*Accipiter melanoleucus*), peregrine falcon (*Falco peregrinus*), common kestrel (*Falco tinnunculus*), northern goshawks (*Accipiter gentilis*) and the main contributors to their success are the high availability of nesting sites and food availability (Solonen 2008; Kaf et al. 2015; Wreford et al. 2017; Kettel et al. 2019). On the other hand, the persistence of some raptors in urban mosaic landscapes is because of the green spaces (natural or managed areas) (Downs et al. 2021).

The increase in anthropogenic infrastructure in the urban mosaic landscape increases the chances of mortalities from collisions and electrocution (Chace and Walsh 2006; Kettel et al. 2018). Furthermore, some of the other factors contributing negatively to raptor persistence in these urban areas include competition for resources (e.g., food), nest predation and disturbance, persecution and intentional and unintentional poisoning because of human-wildlife conflict (Chace and Walsh 2006; Hager 2009; McClure et al. 2018; Mojica et al. 2018; McPherson et al. 2021a, b). However, it is important to highlight that those cases of intentional persecution and poisoning of raptor species are not a common occurrence in urban areas compared with rural areas, but they could have detrimental effects on the persistence of raptor species (Chace and Walsh 2006; Cianchetti-Benedetti et al. 2016; McClure et al. 2018; Canney et al. 2021).

1.3 Human-wildlife conflict and coexistence

Considering the global increasing human population, interactions between humans and wildlife are certain to happen. In most cases, interactions between wildlife and humans often lead to human-wildlife conflict mainly because wildlife species attack or kill humans, feed on crops, feed and attack domestic species and transmit diseases to humans and livestock (Thirgood et al. 2005; Bautista et al. 2021). The usual response of humans to solve or reduce the conflict arising from the abovementioned factors is persecution (Naha et al. 2020). This is more prevalent in mammalian predators [e.g., tigers (*Panthera tigris*) and lions (*P. leo*)], which predominantly kill humans (Thirgood et al. 2005; Naha et al. 2020). However, it is important to highlight that another taxon of species vulnerable to human-wildlife conflict is raptors, as they are associated with witchcraft (and the making of traditional medicine) and attacks on livestock and pets (Ogada et al. 2012; McPherson et al. 2021b; Salom et al. 2021). Unfortunately, the actions of humans toward wildlife could be detrimental as they could dramatically reduce the abundance of the targeted wildlife species, and possibly result in extinction, especially for species that are already threatened (Nyhus 2016).

Thus, the human-wildlife conflict between humans and raptors is one of the major challenges to effective conservation measures for global raptor species (Salom et al. 2021). This is mainly because the core threats affecting the persistence of raptors are as a result of human behaviours (e.g., persecution) and activities (e.g., habitat disturbance and degradation) (Canney et al. 2021). Although raptors have been shown to be vital for the well-being of humans and the environment, especially with regard to ecosystem services provision (Sekercioglu 2006; Buechley et al. 2019; Horgan et al. 2021), there is still some hostility towards them, which exacerbates the negative attitudes and perceptions toward them. In some parts of the world, livestock are an indicator of financial stability and crucial for human survival and perhaps the negative attitudes and perceptions could be understandable, especially if people are not well educated and lack knowledge (Miranda et al. 2022).

However, it should still be stressed that persecution is unacceptable, and this could be emphasised by stakeholders such as community leaders and biologists through awareness campaigns highlighting how persecution negatively affects ecosystem services provision and biodiversity conservation (Newton 1979; Salom et al. 2021). A change of attitude toward raptors in people is crucial for their conservation. This is because it has been shown that even a small number of people in communities can have detrimental impacts on the persistence of apex predators such as raptors (Agan et al. 2021). It is important to caution stakeholders that there could be some animosity from the public during the awareness presentations. This is because, in some cases, they are convinced that the increase of raptors in their areas is because of conservationists who provide things such as box nests (Kettel et al. 2021), consequently increasing more raptor species and/or numbers occupying their communities.

1.4 Study area- an urban mosaic landscape

The present research was conducted in eThekwini Municipality, Durban, KwaZulu Natal, South Africa, which is the 3rd largest metropolitan area in the country (Fig. 1.1). This study region is home to approximately 4 million people, with an annual population growth of 1 % and has the busiest port in Africa (EThekwini Municipality 2013; ECPDP 2015; Boon et al. 2016). The study area is usually categorised or regarded as an urban area, but a large percentage of the landscape is rural and peri-urban areas which were categorised and decreed by the apartheid regime and its segregation laws (EThekwini Municipality 2010, 2013; Boon et al. 2016). Consequently, it forms an urban mosaic landscape (Downs et al. 2021).

Urbanisation and anthropogenic activities such as agriculture, urban buildings and roads have resulted in the conversion of a large extent of natural and vegetation in eThekwini Municipality (EThekwini Municipality 2015). Consequently, these factors threaten the high diversity and persistence of species. Furthermore, other significant threats to eThekwini municipality fauna and flora include climate change, invasive species, exploitation of wildlife and habitat loss and destruction (EThekwini Municipality 2015; Boon et al. 2016). Therefore, because of the intense pressure posed by threats to biodiversity, the municipality developed a Durban Metropolitan Open Space System (D'MOSS) with the main aim of conserving the region's high diversity in the late 1980s (Roberts 1994; Adams 2005). Approximately 75 000 ha of eThekwini landscape is part of the D'MOSS area, which is primarily natural green areas, namely private nature reserves, proclaimed nature reserves, municipal nature reserves, non-user conservation servitudes and special rating areas (Adams 2005; EThekwini Municipality 2012, 2013). Furthermore, managed green areas such as parks, private gardens, golf courses, and sports fields are also under D'MOSS. Recently research has highlighted the critical role and importance of these D'MOSS areas in the conservation eThekwini Municipality biodiversity (see Maseko et al. 2019, 2020; McPherson et al. 2016a, b, 2019, Patterson et al. 2016, 2018; Zungu et al. 2019, 2020a, b).

The eThekwini Municipality is in the Indian Ocean Coastal Mist belt biome and has a sub-tropical climate with more rainfall in summer (Zungu et al. 2020a). Abiotic factors such as biogeographical position, topography (e.g., steep-sided ravines), climate, geology, soils, and physiography are the main contributors to the high diversity of aquatic and terrestrial species in eThekwini Municipality (Boon et al. 2016; McLean et al. 2016).

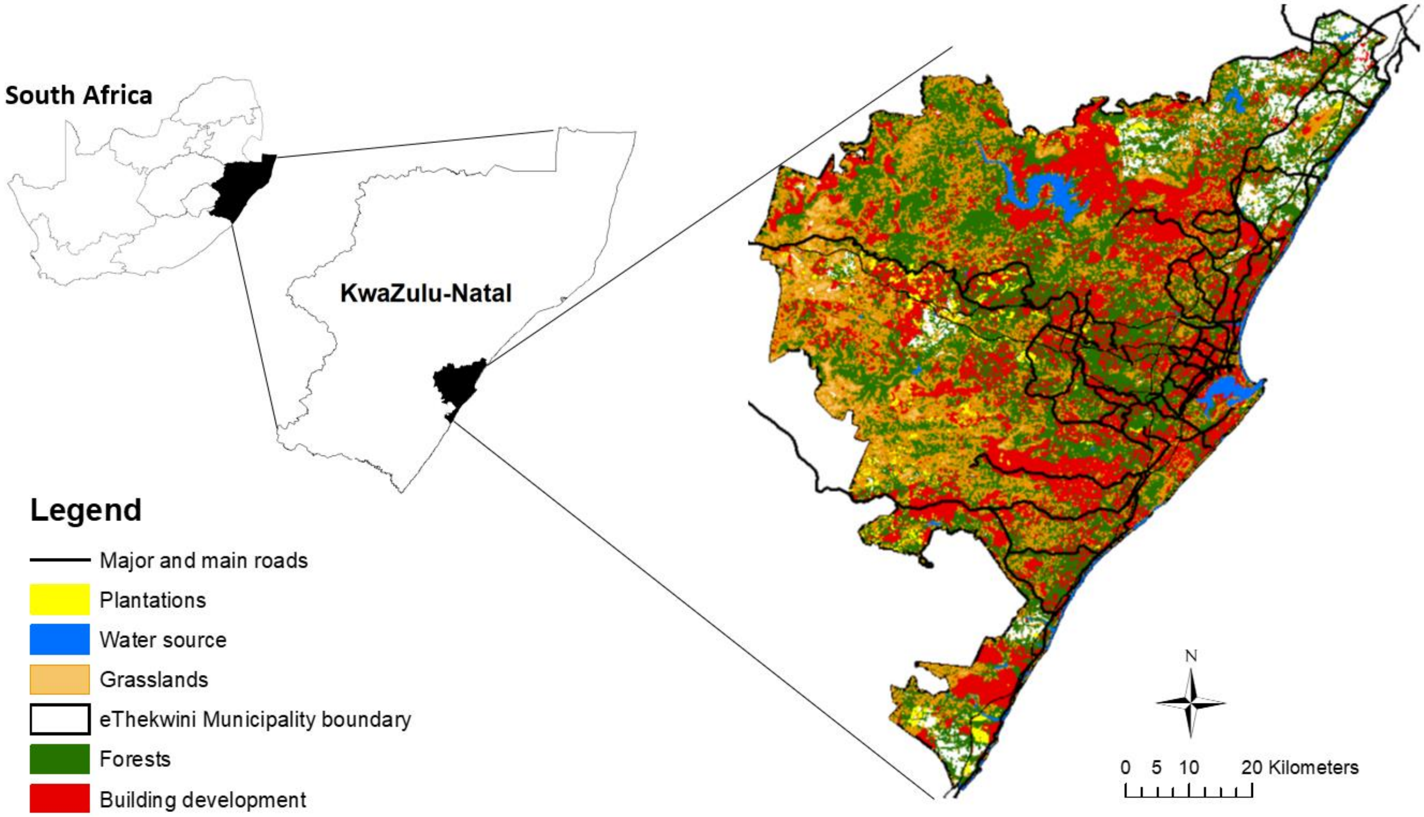

Fig. 1.1. Map of the mosaic of Durban, eThekwini Municipality, KwaZulu Natal, South Africa.

Fig. 1.2. Photographs of African crowned eagle (a) fledgling and (b) adult. (Source: Tim McClurg).

1.5 Study species

The avian species of interest in this study is the African crowned eagle (*Stephanoaetus coronatus*, hereafter crowned eagle), which is an apex predator and tree nester (Fig 1.2). Crowned eagles are technically a forest resident species, but they also occur in mature woodland environments (Sinclair et al. 2011; McPherson et al. 2015). Crowned eagles only occur in the forest and woodland of sub-Saharan African countries such as Senegal, Guinea, Ghana, Cameroon, Gabon, Democratic Republic of the Congo, Gabon, Tanzania, Zambia, Mozambique, Zimbabwe, and South Africa (McPherson et al. 2015; IUCN 2018), and where these habitat types occur in urban mosaic landscapes (McPherson et al. 2015, 2021a). Crowned eagles are a relatively large raptor species with a weight of 2.6 -5 kg, a wingspan of 1.5 – 1.8 m and a height of 80 – 98 cm (Ferguson-Lees and Christie 2005; Sinclair et al. 2011; McPherson et al. 2015). Crowned eagles have a small, rounded head, black spots on the legs and a long broad tail. The wings of the adults are dark brown, but the neck and head (with a small crest) are rufous (Sinclair et al. 2011; McPherson et al. 2015). On the other hand, the head of a juvenile crowned eagle is creamy-white, and the body is generally white and black barred. Crowned eagles are no exception when it comes to low reproduction rates and longer life spans, as portrayed by other large eagle species (Swartridge 2009; McPherson et al. 2016a, b). These large avian apex predators (i.e., crowned eagles) take care of their fledglings for approximately 14 months (McPherson et al. 2016a, b, 2019; Muller et al. 2020). Interestingly, crowned eagles are generally known to have a biennial breeding strategy, but in some environments (e.g., with high availability of prey), they breed annually (McPherson et al. 2016a, b, 2019; Muller et al. 2020). The main diet of crowned eagles includes small antelope, monkeys, hyraxes, and other mammals, but occasionally, they will also eat livestock such as chickens (*Gallus domesticus*) and goats (*Capra aegagrus hircus*) (McPherson et al. 2015, 2021b).

The primary threats to crowned eagle survival and persistence are habitat loss, eradication of nesting trees (i.e., exotic trees in urban areas), collisions with anthropogenic structures such as walls and electrocution, and poisoning or shooting by humans (McPherson et al. 2015, 2021b). According to the International Union for Conservation of Nature (IUCN), the species is globally Near Threatened (Taylor et al. 2015; IUCN 2018; McPherson et al. 2021b). In the eThekwini Municipality urban mosaic landscape, forests (i.e., forests and woodland) have been crucial in the persistence and thriving of crowned eagle population in this region (McPherson et al. 2016a, b, 2019, 2021a, b; Downs et al. 2020; Muller et al. 2020).

Table 1.1: Summary of key research studies documenting different ecological aspects of the African crowned eagle (*Stephanoaetus coronatus*) in various landscapes of sub-Saharan Africa.

Ecological aspect	**Country**	**Landscape type**	**Reference**
Diet	Tanzania	Protected area	Struhsaker and Leakey (1990)
Behaviour	Uganda	Protected area	Mitani et al. (2001)
Breeding and diet	Tanzania	Protected area	Shultz (2002)
Nesting	South Africa and Tanzania	Mixed	Malan and Shultz (2002)
Behaviour	Tanzania	Protected area	Shultz and Noe (2002)
Breeding, diet, habitat use	South Africa	Rural/farmland	Swatridge et al. (2014)
Breeding	South Africa	Urban	Malan (2005)
Diet	Ivory Coast	Protected area	McGraw et al. (2006)
Behaviour	Tanzania	Protected area	Shultz and Thomsett (2007)
Behaviour	Uganda	Protected area	Arlet and Isbell (2009)
Diet	South Africa	Urban	Malan et al. (2016)
Nesting	South Africa	Urban	McPherson et al. (2016a)
Diet	South Africa	Urban	McPherson et al. (2016b)
Diet	South Africa	Urban	Reeves and Boshoff (2016)
Diet	South Africa	Urban	McPherson et al. (2018)
Diet	South Africa	Urban	Van der Meer et al. (2018)
Habitat use	South Africa	Urban	McPherson et al. (2019)
Breeding	Tanzania	Rural/farmland	Kaneda (2020)
Breeding	South Africa	Urban	Muller et al. (2020)

Previous research on the crowned eagle population in eThekwini Municipality has highlighted the movement ecology, nest requirements, human-wildlife conflict, diet, breeding success and threats (see McPherson et al. 2016a, b, 2019, 2021a, b; Van der Meer et al. 2018; Muller et al. 2020) and they only documented the crowned eagles in forest areas of certain urban areas of eThekwini Municipality (Table 1.1). However, the main message from the abovementioned research is that crowned eagles persist in the urban mosaic landscape of eThekwini Municipality, and the major contributor to their persistence is mainly the presence of the D'MOSS areas. This is because the D'MOSS areas are a key habitat for crowned eagles (and their primary prey), and they provide large trees which they can use for nesting (see McPherson et al. 2016b, 2019). Moreover, the D'MOSS areas also include areas of exotic tree plantations (i.e., *Eucalyptus* spp.), which crowned eagles can use for nesting (see McPherson et al. 2016b). The persistence of crowned eagles in eThekwini Municipality is interesting because one would expect a specialist species such as crowned eagles to decline in numbers and partially/completely relocate to areas that are less urbanised.

1.6 Motivation for the study

Extensive research has detailed the negative impacts of urbanisation and climate change on global biodiversity (Chace and Walsh 2006; McKinney 2008; Ceccarelli et al. 2014; Reynolds et al. 2019). The vulnerability of avian species to anthropogenic activities has allowed a significant increase in the number of avian urban ecology studies. Although thriving in some environments (e.g., McPherson et al. 2021a), several raptor species will be severely affected by the long-term effects of urbanisation and climate change (Seress and Liker 2015; McClure et al. 2018). For example, because of urbanisation and an increase in anthropogenic structures such as human settlements, habitats for several raptors will be lost and fragmented into small sizes and consequently result in increased competition for resources such as space (i.e., territories) and nesting sites (Seress and Liker 2015; Reynolds et al. 2019). Also, as the human population increases, particularly in cities, the interactions between humans and wildlife will most likely increase and, in some cases, result in human-wildlife conflicts (and people having negative attitudes toward apex predators) (Cianchetti-Benedetti et al. 2016; Restrepo-Cardona et al. 2020).

In the last three decades, research has demonstrated that climate change increases temperatures and the frequency of extreme weather events (e.g., storms), which will pose challenges such as distribution range contractions (i.e., reduced ecological niches for specialist species) and destruction of nesting sites (disturbing nesting and in most cases resulting in chick and juvenile mortality) (McPherson et al. 2021b; Condro et al. 2022). In eThekwini Municipality, recent studies have shown that crowned eagles persist and thrive, especially in forest fragments, in the urban mosaic landscape (see McPherson et al. 2016a, b, 2019, 2021a, b; Muller et al. 2020). Therefore, the present study expands on the previous research on crowned eagles, especially by examining forest fragments in rural and urban areas. Furthermore, the present study observed an urgent need to research how habitat loss, competition, possible human-wildlife conflict, and climate change will affect the crowned eagle population in the eThekwini Municipality.

1.7 Aim and objectives

The overall aim of the study was to investigate the factors influencing the persistence of crowned eagles in the mosaic landscape of the eThekwini Municipality, Durban, KwaZulu Natal, South Africa. Specifically, we aimed to:

- Document the occupancy and detection probability of crowned eagles in an urban landscape mosaic with woodland/forest in Durban, EThekwini Municipality. The primary objective was to determine factors influencing the occupancy and detection probability of crowned eagles in the urban mosaic landscape, which is important for determining how this raptor responds to anthropogenic activities.

- Investigate any potential competition for nesting sites between crowned eagles and other large raptor species in the urban mosaic landscape. The main objective of this study was to compare the characteristics of nests (height of the tree, nest cover and the positioning of the nest in the tree) used by two raptor (i.e., black sparrowhawk and crowned eagles) species local landscape mosaic and then, from this, infer whether there might be potential competition for nesting site between the species.
- Use questionnaire surveys to document how the urban and rural communities perceive the presence of crowned eagles in their communities. We also investigated the general attitudes of the public towards raptors, with a focus on crowned eagles.
- Evaluate, using demographic modelling, how the population of crowned eagles would respond (i.e., decline or increase) to the rise in torrential rainfalls/thunderstorms. The main objective was to evaluate how the local population of crowned eagles would respond (i.e., decline or increase) to the increase of torrential rainfalls/thunderstorms in the study region.

1.8 Thesis structure

This thesis is presented with six chapters which are the introduction chapter, four experimental or data chapters and a final synthesis chapter. All experimental chapters are formatted for publication in international peer-reviewed journals. Overall, a certain degree of repetition and overlap in the thesis was unavoidable. Chapter 1 is the introduction which provides background information.

Chapter 2 investigated the factors influencing the occupancy and detection probability of crowned eagles. Chapter 3 compared nest characteristics of crowned eagles and black sparrowhawks to investigate if there is any potential competition for nesting sites in the urban mosaic landscape. Chapter 4 documented the attitudes and perceptions toward crowned eagles. Chapter 5 investigated the extinction probabilities and persistence of crowned eagles considering climate change effects in the urban mosaic landscape. Chapter 6 provides a synthesis of the main results and recommendations. The hypotheses or predictions are presented in each data chapter.

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CHAPTER 2

Occupancy and detectability of African crowned eagles in an urban landscape mosaic: the importance of natural forest areas

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Running header: Persistence of African crowned eagles in an urban landscape mosaic

2.1 ABSTRACT

Diminishing forests as a result of anthropogenic activities continues to negatively impact the persistence of terrestrial species. Raptors are particularly susceptible to human activities because of their low population densities and large home range sizes. In this study, we investigated the occupancy and detection probabilities of the Near-Threatened African crowned eagle (*Stephanoaetus coronatus*) in Durban, eThekwini Municipality, South Africa. Using point count surveys, we documented the presence/absence of African crowned eagles in 42 sampling sites in the urban mosaic landscape of Durban. We used the presence/absence data to model the eagles' occupancy and detection probability in our surveyed sites. The naïve occupancy of African crowned eagles was 0.6, and the estimated occupancy and detection probability were 0.78 $\pm$ 0.061 and 0.40 $\pm$ 0.085, respectively. The occupancy of African crowned eagles was positively influenced by forests ($\beta = 3.66 \pm 1.70$) and negatively influenced by disturbance ($\beta = -4.70 \pm 1.78$) and building density ($\beta = -2.65 \pm 1.34$). The detection probability of crowned eagles was positively influenced by disturbance ($\beta = 0.51 \pm 0.27$) and presence of exotic tree plantations ($\beta = 0.62 \pm 0.38$), and it was negatively influencing the type of surrounding settlements (i.e., urban or rural) ($\beta = -0.42 \pm 0.40$). Overall, our results showed the persistence of African crowned eagles in the urban landscape mosaic as a consequence of natural and managed green spaces, especially forests. This highlighted the importance of natural forests and exotic tree plantations in ensuring the survival and thriving of African crowned eagles and the key role these green spaces play in species conservation in this urban mosaic landscape.

Keywords: detection, forests, forest raptors, occupancy, urbanisation

2.2 Introduction

Globally, including South Africa, forests are a pivotal habitat for several terrestrial species, and their loss as a result of anthropogenic activities (e.g., urbanisation and fragmentation) seriously threatens their persistence and survival, leading to the exacerbation of biodiversity loss (McKinney, 2002; Lawes et al., 2007; Mckinney, 2008; Aronson et al., 2014). Over the years, this important biome has been under severe pressure from factors such as fragmentation, agriculture and unsustainable resource consumption (Geldenhuys and MacDevette 1989; Secretariat of the Convention on Biological Diversity 2010; Jewitt et al., 2015). If the present disturbance and degradation of forests persist, a dramatic decline in species (i.e., both richness and abundance) will occur, and some species could possibly go extinct (Chace and Walsh, 2006; McKinney, 2008; Maseko et al., 2019, 2020). Apart from the provision of ecological benefits, forests provide several other key benefits to societies. However, their use by various human communities varies across landscapes. For example, forests mainly provide rural people with employment, timber (for building and cooking) and medicine, whereas urban people/communities use forests for recreational purposes (e.g., birding), cultural and spiritual beliefs and ecotourism (Lawes et al., 2007; Shackleton et al., 2007, Reynolds et al., 2019). Nevertheless, with the growing human population, particularly in urban areas, it is vital to conserve the remaining natural forests that occur in the urban landscape mosaic (Maseko et al., 2019, 2020; Zungu et al., 2020a, b).

Increasing urbanisation trends, especially increased built infrastructure with reduced green spaces, will continue to cause dramatic declines in global biodiversity (McKinney, 2006; Isaac et al., 2013, Aronson et al., 2014; Marcacci et al., 2021). Presently, global human population trends suggest that more than 65% of humans occupied urban areas by 2050 (United Nations, 2014; Amaya-Espinel et al., 2019). This rapid population growth threatens environmental sustainability

(Amaya-Espinel et al., 2019) because of the extensive degradation and conversion of natural landscapes for anthropogenic purposes to provide for the socio-economic needs of the people. Human settlements/buildings (Seress and Liker, 2015) and agricultural expansion (Ceccarelli et al., 2014) are the major causes of landscape modifications, and some of the consequences of these anthropogenic activities include habitat loss and increased predation risk of species (McKinney, 2002, Reynolds et al., 2019). Furthermore, another phenomenon typically associated with urbanisation is homogenised faunal communities because of a decrease in specialist species and a significant increase in generalist species, thus causing a decline in species richness (Chase and Walsh, 2006; Isaac et al., 2013; Clergeau et al., 2016). However, as urbanisation includes the increase of anthropogenic structures (e.g., buildings), other species (usually non-natives) move/occupy urbanised landscapes which can increase biodiversity levels (McKinney, 2008). However, apex predators, such as raptors, are generally significantly affected by the effects brought about by urbanisation (Muller et al., 2020). Exceptions to these trends are some areas where the urban landscape is a mosaic of urban built areas and natural and managed green spaces that allow the persistence of a range of taxa (Downs et al., 2021).

The ever-growing human population is believed to be the main threat to raptors because anthropogenic activities have destroyed a large proportion of the habitats and that of their prey species, particularly in rural areas (Amar et al., 2018). Furthermore, in addition to primary effects, urbanisation exerts secondary effects on raptors, including collision with human-made structures (e.g., buildings) and increased risk of persecution (Hager, 2009; Kettel et al., 2018; McPherson et al., 2021a). Raptor species worldwide are also vulnerable and at risk because of human persecution, electrocution, poisoning, diseases, and climate change (Hager, 2009; Ogada et al., 2012; Kettel et al., 2018; Mojica et al., 2018; McPherson et al., 2021a, b). In agricultural landscapes, the intensification of agriculture significantly affects the persistence of raptors by reducing their nesting sites and food resources (Amar et al., 2018). Fortunately, most countries worldwide have specific laws that protect avifauna, consequently protecting raptors from the above-mentioned threats (McClure et al., 2018). The provision of important ecosystem services (e.g., rodent pest control and scavenging) by raptors make them key in the functioning of several ecosystems, and their conservation is vital to ensure the long-term functioning of ecosystems (Sergio et al., 2008; Donazar et al., 2016; Amar et al., 2018; Santangeli and Girardell, 2021).

Raptor species' ecology (and life traits) reduce their chances of persisting especially when their ecosystems are threatened. Therefore, understanding the cascading effects/threats brought by urbanisation and other anthropogenic activities to ecosystems underscores the urgent need to study how apex predators are affected (Kettel et al., 2018). Research on urban raptors has significantly increased in the last two decades (e.g. Hager et al., 2012; Rullman and Marzluff, 2014; Sumasgutner et al., 2014, 2020; Kaf et al., 2015; McPherson et al., 2016a, b, 2021a, b; Kettel et al., 2019; Muller et al., 2020;) and these studies are key considering that forests and other natural environments in urban areas are being disturbed.

Overall, most raptors in urban areas are surviving and persisting despite rapid urbanisation and various threats (e.g., persecution) by the urban dwellers (Solonen 2008; Kaf et al., 2015; McPherson et al., 2016a, 2021a, b; Kettel et al.,2018, 2019). In Durban metropolitan area, South Africa, natural forests in the landscape mosaic play a significant role in harbouring several bird species (Maseko et al., 2019, 2020), including the globally Near-Threatened African crowned eagle [*Stephanoaetus coronatus*] (hereafter crowned eagle) (Taylor et al., 2015; IUCN, 2018; Muller et al., 2020). The crowned eagle is a forest raptor that has been demonstrated to be thriving in the forest refugia in the urban landscape mosaic of this region (McPherson et al., 2016a, b, 2019). It is a sit-and-wait predator (McPherson et al. 2019). It is very challenging to detect forest-dwelling raptors mainly because of their elusive behaviour and as they occur at relatively low densities (Henneman et al., 2006; McClure et al., 2018). However, documenting their presence/absence can be crucial for effective conservation measures and urban planning.

Natural environments in highly transformed regions/ landscapes are crucial for biodiversity conservation (Maseko et al., 2019; Zungu et al. 2020a, b); hence research highlighting their importance is key to urban/city planners. Our study aimed to show the importance of forests/woodlands in the urban landscape mosaic of Durban, EThekwini Municipality, for the conservation and persistence of crowned eagles. In particular, our study aimed to document the occupancy and detection probability of crowned eagles in this urban landscape mosaic. In addition, we determined the factors influencing the occupancy and detection probability of crowned eagles, which may be key in showing how this raptor responds to anthropogenic activities. We predicted that the extent of forest habitats and forest disturbance measures would be important for the occupancy of crowned eagles. We further predicted that the presence/high density of buildings would have a negative effect on the detection probability of crowned eagles in the urban landscape mosaic.

2.3 Methods

2.3.1 Study area

Between May and August 2019, we conducted crowned eagle surveys in woodland/forest patches of Durban, eThekwini Municipality, KwaZulu Natal Province, South Africa (Fig. 2.1). EThekwini Municipality is on the eastern coast of KwaZulu-Natal and has a sub-tropical climate. The region receives an annual rainfall of 1000 mm (occurring mainly during summer), and the annual average minimum and maximum temperatures are 13.9°C and 24°C (Zungu et al., 2019; 2020a). EThekwini Municipality is the third-largest metropolitan area in the country and with a human population of ~4 million (ECPDP, 2015), so most natural landscapes are inevitably prone to be transformed or degraded because of the ever-growing human population. More than 50% of the original vegetation of EThekwini Metropolitan has been transformed for various anthropogenic activities to provide for the socio-economic needs of the escalating human population (ECPDP, 2015; Zungu et al., 2020b). The municipality had the foresight to create the Durban Metropolitan Open Space System (D'MOSS) with the aim of biodiversity conservation, protecting the remaining indigenous environments, which are mainly grasslands and forests, and various other ecosystems (Roberts, 1994; EThekwini Municipality, 2007; McPherson et al., 2016a). These natural green spaces together with managed green spaces (e.g., gardens, parks etc.), increase the persistence of several taxa (e.g., mammals) (Downs et al. 2021). Furthermore, the study region has several protected natural areas, including those in the D'MOSS. Recent research has highlighted the important role these conservation areas play in biodiversity conservation (e.g., Maseko et al., 2019; 2020; Zungu et al., 2020a, b). The eThekwini Municipality, through the D'MOSS, also protects natural open spaces, which are mostly surrounded by a network of roads and human settlements (EThekwini Municipality, 2007). The topography of our study area is generally steep, and the remaining forested areas (mostly on steep-sided ravines) may have restricted the pioneers from developing these forest areas. The protection of forest remnants in EThekwini Municipality has been shown to favour the persistence of crowned eagles (see McPherson et al., 2016a, b, McPherson et al., 2019, Muller et al., 2020) to the extent that this region has recorded the highest crowned eagle density in Africa.

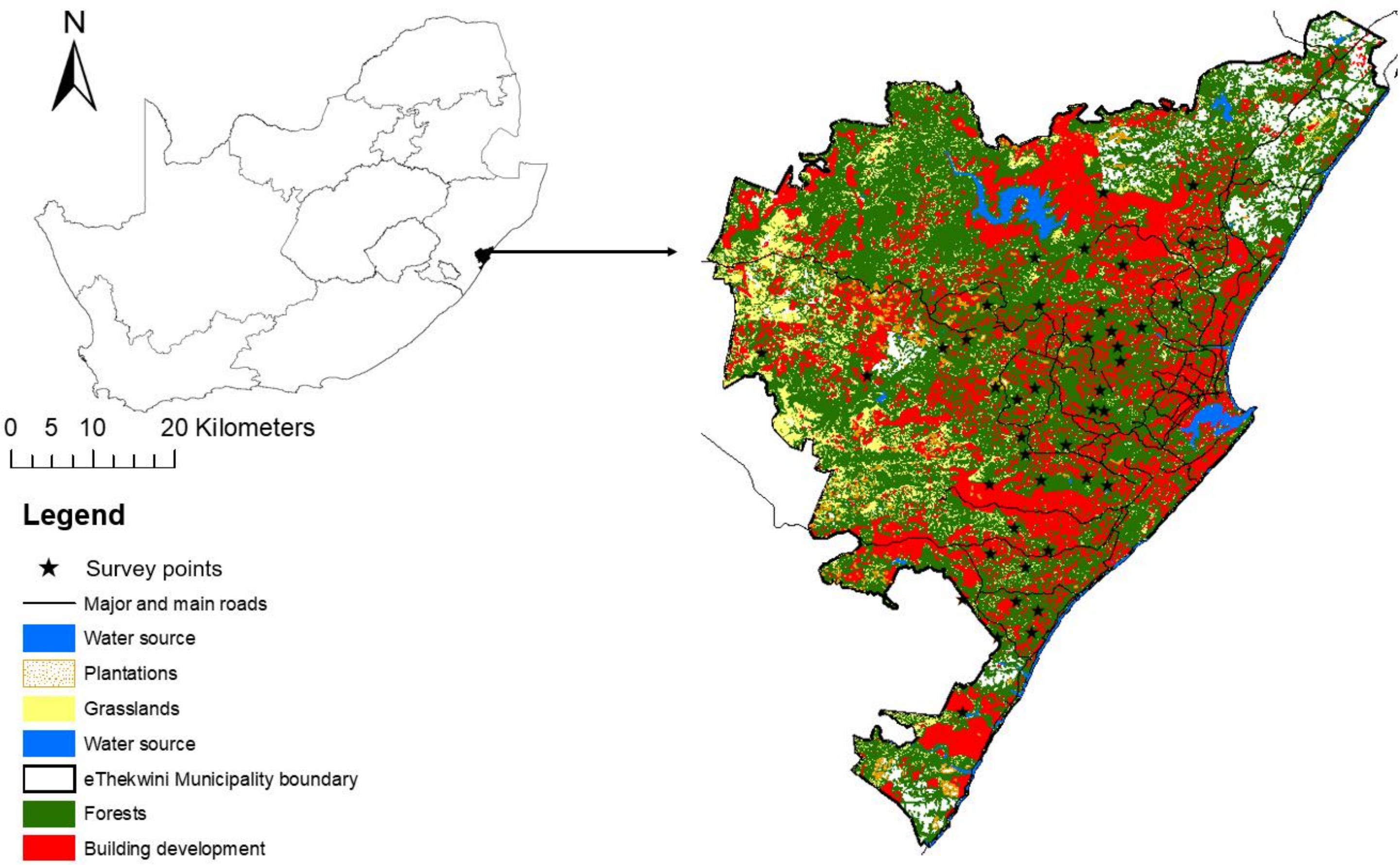

Fig. 2.1. Map of the surveyed points in the urban landscape mosaic of Durban, eThekwini Municipality, South Africa.

2.3.2 Data collection and analyses

From previous research (McPherson et al., 2016a, b, 2019), there are records of crowned eagles in forests in EThekwini Municipality, and to increase our knowledge about this species, we surveyed forest areas across the urban landscape mosaic (Fig. 2.1). Our study was conducted during the non-breeding season (i.e., May 2019 – August 2019) (McPherson et al., 2019) and the dry, austral winter period. During the dry season, the activity patterns of crowned eagles are relatively high; courtship behaviour by this species is more displayed. Furthermore, crowned eagles during this time are preparing for the next breeding cycle, as displayed by the incidence of collection and addition of new nest-building material to their nests (McPherson et al., 2019). Juveniles from the previous year rely less on their parents for food, equating to reduced parental visits to the nest (McPherson et al., 2016b). However, juveniles start to be more active as they prepare to fledge from the nest, which increases crowned eagle detection probability, offsetting the effect of reduced parental visits. We conducted one survey each month during the non-breeding season, and the average distance between the 42 surveyed sites was 5.73 km. To record the crowned eagle presence/absence data in a surveyed site, an observer selected a high-rise ground (which allows for more viewer range) to monitor any crowned eagle activity. We used audio and visual cues to detect the presence/absence of crowned eagles. Our surveys were conducted in the morning (i.e., the first 4 h after sunrise) because of high bird activity during this time, and each point survey was conducted/lasted for 1 h on days when there was no rain and <4 kph wind speed.

A considerable amount of time is spent perching by certain apex predators, particularly those that use a sit-and-wait hunting strategy. This usually means that less time is spent flying, which in most cases will result in mean daily distances/movements being short. For example, long-crested eagles (*Lophaetus occipitalis*), which also have the above-mentioned behaviour, had an average movement distance of 2.1 km d^{-1} (Maphalala et al., 2020). Furthermore, as a conservation measure for Verreaux's eagles (*Aquila verreauxii*) (3 - 5.6 kg); Murgatroyd et al. (2016) advised that at least a 3 km buffer around each nest should be protected from human disturbances as the species moved an average distance of 2.8 km away from their nests. Therefore for crowned eagles, which have a sit-and-wait hunting strategy and a body mass similar to that of the Verreaux's eagle, we estimated that they travel a daily distance of at least 2.5 km to perform their daily activities (e.g. hunting). Therefore, from our survey point, we created a 2.5 km buffer in ArcGIS v10.2 (Environmental Systems Research Institute 2011) to determine the different land-type covers (i.e., forests, building development, roads, plantations and water sources), which we presumed might influence occupancy and detection probability of crowned eagles. We then calculated the percentage of each land type in the 2.5 km buffer and recorded them as site covariates.

As crowned eagles are forest/woodland species (McPherson et al., 2019; Muller et al., 2020), we calculated the proportion of these land types, which would be very important in explaining the ideal habitat availability in relation to the occupancy and detection probability of the species. During the months of surveying (and after the survey period), we also spent time searching for nesting sites in the forests, and this allowed us to quantify the level of disturbance by humans (i.e., walking, people walking their dogs, firewood collection, etc.). We also ground-truthed the presence of gum (*Eucalyptus* spp.) trees. If we saw all three levels of disturbances in the surveyed site, the level of disturbance was recorded as high. It was considered moderate for two disturbances, while one was considered a low disturbance. Our selected covariates for analysis were forest (%), building and housing density (%), roads (%), human disturbance level (low-medium-high), water body (%), presence/absence of mature exotic plantations and surrounding settlements (suburban or rural) (Table 2.1).

Our data were analysed using the program Presence 13.1 using single-season models (Hines, 2006). The was no multi-collinearity between all the site covariates ($r < 0.7$). Species occupancy and detection probability were determined using occupancy modelling using site covariates as factors. As an indication of species detection in the surveyed site, we used the presence/absence data whereby 0 and 1 indicated presence and absence of crowned eagles, respectively. We first modelled occupancy [ψ (site covariate) p (.)] by producing a global model using site covariates and did the same procedure for detection probability [ψ (.) p (site covariate)]. We then produced models containing various combinations of the site covariates for both occupancy and detection probability. [e.g. ψ (site covariate + site covariate) *p* (site covariate)] (see Ramesh and Downs, 2014; Chibesa and Downs, 2017; Maseko et al., 2017). Our models used 10000 parametric bootstraps and a c-hat = ~ 1 was used to indicate model fit (Burnham and Anderson, 2002). Akaike information criterion (ΔAIC) ≤ 2 thresholds were used for model selection, whereby all the models with ΔAIC values ≤ 2 were top models (Burnham and Anderson, 2002; Hines, 2006). We further showed the relative importance of each variable in occupancy and detection by calculating model weights.

Table 2.1 Site covariates used in modelling occupancy and detection probability of crowned eagles in the present study.

Site covariate	Full description of site covariates
Forest (F)	Proportion of the landscape covered by forest habitat in the buffer distance.
Building density (B)	Proportion of the landscape covered by buildings in the buffer distance.
Disturbance (D)	The level of disturbance (low/medium/high) in a surveyed site.
Roads (R)	Proportion of the landscape covered by roads in the buffer distance.
Settlement (S)	The type of settlement (i.e., rural or urban) surrounding the surveyed site
Plantations (P)	Proportion of the landscape covered by plantations in the buffer distance
Water (W)	Proportion of the landscape covered by water in the buffer distance.

2.4 Results

The respective occupancy and detection probabilities of crowned eagles in our surveyed sites were 0.78 ± 0.061 and 0.40 ± 0.085 (Table 2.2). Furthermore, the naïve occupancy was 0.6. The top model showed that the occupancy of crowned eagles was positively influenced by forests (β = 3.66 ± 1.70) and negatively influenced by disturbance (β = -4.70 ± 1.78). Detection probability was positively influenced by disturbance (β = 0.51 ± 0.27) and negatively influenced by surrounding settlement type (β = -0.42 ± 0.40) and roads (β = -0.57 ± 0.22). In addition, the occupancy of crowned eagles was negatively influenced by building density (β = -2.65 ± 1.34) and detection probability was positively influenced by the presence of plantations (β = 0.62 ± 0.38). With regard to the strength of the effects of each covariate on occupancy and detection probabilities, the overall summed model weights (ωi) of the variables in the top model were; forests = 0.88, disturbance=0.78, settlement= 0.69 and roads= 0.60).

Table 2.2 Summary of model selection and parameter estimates of site occupancy and detection probability of crowned eagles in surveyed forests in EThekwini Municipality, South Africa, in the present study (see Table 2.1 for abbreviations).

Model	**AIC**	**deltaAIC**	**AIC wgt**	**Model Likelihood**	**no.Par.**	**2LL**
psi(F+D),p(D+S+R)	182.74	0	0.1791	1	7	168.74
psi(F+R+D+B),p(S+P)	183.87	1.13	0.1018	0.5684	8	167.87
psi(F+D),p(S+R)	183.96	1.22	0.0973	0.5434	6	171.96
psi(F+B+D+R),p(S+R)	184.03	1.29	0.094	0.5247	8	168.03
psi(F+B+W+R+D),p(.)	184.97	2.23	0.0587	0.3279	7	170.97
psi(F+D),p(P+S+R)	185.44	2.7	0.0464	0.2592	7	171.44
psi(F+D+P),p(S)	185.47	2.73	0.0457	0.2554	6	173.47
psi(F+W+P+D+S),p(.)	186.13	3.39	0.0329	0.1836	7	172.13
psi(F+D+P),p(F+S)	186.34	3.6	0.0296	0.1653	7	172.34
psi(F+D),p(.)	186.61	3.87	0.0259	0.1444	4	178.61
psi(F+D),p(P)	186.82	4.08	0.0233	0.13	5	176.82
psi(P),p(.)	187.72	4.98	0.0148	0.0829	3	181.72
psi(F+P),p(.)	188.01	5.27	0.0128	0.0717	4	180.01
psi(F+P),p(B+S)	188.39	5.65	0.0106	0.0593	6	176.39
psi(.),p(B)	188.44	5.7	0.0104	0.0578	3	182.44
psi(F+D+R),p(D+S)	188.74	6	0.0089	0.0498	7	174.74
psi(B+D),p(.)	188.85	6.11	0.0084	0.0471	4	180.85
psi(F+P),p(F+W)	188.88	6.14	0.0083	0.0464	6	176.88
psi(F+P),p(S)	188.89	6.15	0.0083	0.0462	5	178.89
psi(.),p(F+B)	188.98	6.24	0.0079	0.0442	4	180.98

2.5 Discussion

During these unprecedented times of rapid conversions of natural environments for built infrastructure, it is increasingly important to conduct research that will assist in the long-term conservation of natural habitats and species. Our results showed that natural forest (%) was a highly significant site covariate as it appeared in all the top models for occupancy, subsequently making this covariate essential for the occupancy of crowned eagles. Recent literature has documented the vital role of natural green spaces, particularly forests in the greater Durban area (i.e. EThekwini Municipality), in the conservation and persistence of several wildlife species (e.g. McPherson et al., 2019; Maseko et al., 2019, 2020; Zungu et al., 2020a, b; Downs et al., 2021). These findings highlight the important role of these forests in the urban landscape mosaic play in the conservation and persistence of crowned eagles in this highly urbanised region.

The forests in the urban landscape mosaic of Durban are important to crowned eagles because they are their primary habitat and usually provide nesting sites (e.g., McPherson et al., 2016a). Furthermore, forests are a habitat for several avian and mammalian species, which are prey for crowned eagles (McPherson et al., 2016b; Maseko et al., 2019, 2020; Zungu et al., 2020a, b). Consequently, these might be reasons forests positively influenced the occupancy. Recent literature showed that the forests in this urban landscape mosaic support a diverse avian community (Maseko et al., 2019; Maseko et al., 2020;), including crowned eagles (McPherson et al., 2019). Furthermore, these forests are also vital for mammals (Zungu et al., 2019, 2020a, 2020b), some of which are the main prey for crowned eagles (McPherson et al., 2016b, 2021a). Therefore, our results elucidate the significance of forests on the occupancy of crowned eagles in the urban landscape mosaic of Durban.

For several bird species, levels of disturbance at macro- or micro-levels can potentially significantly affect the dynamics of bird communities in a particular environment (Neuschulz et al., 2011; Matuoka et al., 2020). For instance, disturbance at a macro-level, which represents the conversion of natural environments for anthropogenic activities, has the potential to result in reduced (or loss) of habitat, consequently affecting the persistence of several bird species (van Vliet et al., 2020; Wilson et al., 2020). Furthermore, the levels of disturbance usually play a significant role in determining the breeding success of many bird species; areas with high human disturbance levels usually deter birds from breeding (Tarlow and Blumstein, 2007). Subsequently, high human disturbance can influence the presence/absence of birds in a particular environment (Giese 1996; Tarlow and Blumstein, 2007). It is evident that micro-human disturbances significantly affect many wildlife species, and since birds are one of the most sensitive taxa of animals (McIntyre 1995), the impacts of disturbances must be considered at the micro-level. Our study mainly documented disturbances at the micro-level, and our results showed that high levels of disturbance negatively influenced the occupancy of crowned eagles. Also, micro disturbances such as bird watching, game drives or high relative human index in an environment potentially reduce some bird activities and result in low detection and occupancy of certain bird species (Steven et al., 2011; Chibesa and Downs, 2017). However, our results showed that disturbance positively influenced the detection probability of crowned eagles. The implication from this result is that crowned eagle's detection is not necessarily affected by the level of disturbance, but there is a possibility that crowned eagles are not using these areas for occupancy, but they are seen in these sites when moving between preferred sites. Furthermore, chances of occupancy and having a nesting site in areas with light levels of disturbances are relatively low, but there is a high possibility of frequenting or using forest associated areas with relatively high levels of disturbance for activities such as hunting and collection of nest-building materials.

In the last 20 years, there has been a significant amount of research concerning the negative and positive effects urbanisation has on wildlife, particularly avian species (McKinney, 2008; Aronson et al., 2014; Seress and Liker, 2015; Marcacci et al., 2021). Our results showed that building density negatively affected the occupancy of crowned eagles. Urbanisation, especially increased built infrastructure, generally reduces natural vegetation and increases the number of building structures in a particular environment, and it has been observed that these structures kill several bird species as a result of window collisions and electrocution (Hager, 2009; Klem et al., 2009; Hager et al., 2012; Isaacs et al., 2013; Maphalala et al., 2021). Raptor research has also documented how apex predators are affected by window collisions and electrocution (Amar et al., 2018; McClure et al., 2018; McPherson et al., 2021a,b). The implication of our results is that with the increase in building structures, crowned eagles will tend to avoid the areas with high building densities and limited forest cover. However, if the crowned eagles frequent or visit high building density areas, they are more vulnerable to window collisions and electrocution, consequently reducing their population numbers (McPherson et al., 2021a,b).

Although this is viewed as a potential risk for several raptors (including crowned eagles), it is important to note that crowned eagles in our study region are documented to be thriving. This is mainly because of their relatively high breeding rate and success and the availability of forests in the urban mosaic landscape for their use (McPherson et al., 2016a, b; Muller et al., 2020; Downs et al., 2021). However, it is imperative to highlight that high building density areas might pose a considerable risk to their persistence for future conservation measures. Hence, it is important to continue research and monitor the crowned eagle's population in the urban landscape mosaic of

Durban as an indicator species of forest persistence here. Furthermore, the natural green spaces in our study region are key for biodiversity conservation. The protection of these green spaces against anthropogenic activities such as building developments increases the chances of several species to thrive in the urban landscape mosaic. For instance, degradation and loss of green spaces would cause a dramatic decline in crowned eagle's population (Downs et al., 2021; McPherson et al., 2021b). Therefore, ensuring that forests are protected, and building developments are restricted, the probability of window collisions and electrocution of crowned eagles will be reduced, consequently favouring the crowned eagles to persist in the urban landscape mosaic of Durban.

Generally, urban areas are more disturbed and developed than rural or semi-rural areas, which plays a significant role in the avian community dynamics (McKinney, 2006; Tryjanowski et al., 2015). The rural and urban areas differ mostly in biophysical attributes (e.g., biotic, climatic, and edaphic) and housing/development density. However, one of the main anthropogenic activities distinguishing rural areas and urban areas is the intensity of agriculture; with rural areas having high agricultural intensity than urban areas. In some rural communities, apex predators can potentially prey on farmers' livestock (Grande et al., 2018; Miranda et al. 2021), and this may result in farmers persecuting the raptor species they perceive as a threat to their livestock. Consequently, this might potentially deter raptors and reduce their detection probability. However, the persecution of apex predators is also evident in urban areas (Hager, 2009; Cianchetti-Benedetti et al., 2016; Amur et al., 2018; McPherson et al., 2021a,b). Our results showed that surrounding settlement type influenced detection probability; our results further showed that forests surrounded by relatively rural settlements in the urban landscape mosaic negatively affected the detection probability of crowned eagles.

Body parts of large bird species such as the crowned eagle are most likely to thrive in the traditional medicine or '*muthi*' trade, which puts the bird species at risk of being shot to make '*muthi*' or be sold to traditional healers for '*muthi*' purposes (Atuo et al., 2015; Mashele et al., 2021). Furthermore, the crowned eagles in some areas of the urban landscape mosaic of Durban are viewed as a threat to domestic pets, and in the more rural areas to chickens (*Gallus gallus domesticus*) and juvenile goats (*Capra aegagrus hircus*); hence they are often persecuted (Maseko et al., unpublished data; McPherson et al., 2021a, b). Therefore, we strongly believe that persecution of raptors either because they are a threat to livestock or used for '*muthi*' purposes in some areas of the urban landscape mosaic of Durban may be a significant contributing factor to the observed low detection probabilities here.

Our results further showed that road density negatively affected the detection probability of crowned eagles. Roads are potentially detrimental to the survival of several terrestrial wildlife species (Lambertucci et al., 2009; Dean et al., 2019), particularly urban birds. High numbers of motor vehicles, particularly in urban areas, are a threat to bird species because of an increased risk of birds colliding with cars/vehicles. Our study also highlighted the potential threat that high-density roads might pose to the persistence of urban wildlife (including crowned eagles). Roads increase the subdivision of remaining natural habitat and thus increase the number of barriers to movement, making movement between patches of suitable habitat more difficult.

Exotic tree plantations usually have a detrimental effect on environments by out-competing native species, which results in habitat loss for some wildlife species. In South Africa, initiatives such as the Working for Water Program play a significant role in ensuring that invasive species do not cause a substantial negative impact on the environment (WfW, 2009). However, exotic tree plantations (e.g., *Eucalyptus* spp.) play a significant role in providing nesting sites for raptors such as crowned eagles (Malan and Robinson, 2001; McPherson et al., 2016a; Wreford et al., 2017). Our results further elucidate that exotic tree plantations play a role in the persistence of crowned eagles because these plantations, positively influenced the detection probability of crowned eagles.

In conclusion, the forests in the urban mosaic landscape of Durban play a vital role in the persistence and conservation of crowned eagles. However, for long-term conservation and urban planning, aspects of human disturbances and urbanisation may negatively affect the persistence of these raptors in this urban landscape mosaic. Furthermore, a necessary conservation measure for these 'urban' crowned eagles is to ensure that alternative nesting sites are made available should exotic trees be removed (McPherson et al., 2016a, 2021b).

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2.7 Declarations

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Conflict of interest

The authors declare they have no conflict of interest.

Ethics approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Consent to participate

Not applicable.

Consent for publication

All authors gave consent.

Data availability

The data belong to the University of KwaZulu-Natal and are stored there. They are available from the corresponding author upon reasonable request.

Author contributions

MSTM, MMZ and CTD conceptualised the study. CTD sought funding. MSTM collected and analysed the data with assistance from STG and MMZ. MSTM wrote the draft manuscript. The other authors provided editorial input.

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CHAPTER 3

Nest characteristics of African crowned eagles and black sparrowhawks: Is there potential competition for nesting sites in an urban landscape mosaic?

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Running header: Nesting site competition between two large raptors

3.1 Abstract

The increase in human population and continuous landscape transformations, especially in urban areas, will result in most of the natural habitats being lost, significantly reduced in size and degraded. Consequently, competition for resources such as nesting sites and food may occur between species. In this study, we investigated whether there could be any potential competition for nesting sites between two raptors in an urban mosaic of Durban, KwaZulu Natal, South Africa. We visited the African crowned eagle (*Stephanoaetus coronatus*, hereafter crowned eagle) and black sparrowhawk (*Accipiter melanoleucus*) nesting sites in our study region, and compared the nest characteristics of the two raptors. Our results showed that exotic tree plantations were crucial in providing nesting sites for crowned eagles and black sparrowhawks. Furthermore, our results showed that there was no significant difference between nest height, tree cover, nest cover and distance to (i) road (ii) building and (iii) water. However, there was a significant difference between tree height and nearest neighbour distance. Large/ tall trees are easily accessible to many species, which somehow influences nest site selection for our study species. Innovative conservation measures and strategies could be vital in protecting raptor nesting sites (i.e. exotic tree plantations) in urbanised landscapes.

Keywords: Apex predators, competition, forests, plantations, urbanisation

3.2 Introduction

The increase in the global human population and continued land-use change are some of the most significant threats to biodiversity conservation globally (McKinney, 2002, 2006; Isaac et al., 2013; Sliwinski et al., 2016; Aronson et al., 2014; Reynolds et al., 2019). Loss of indigenous flora and fauna in urban areas is mainly caused by the extensive transformation of landscapes and vegetation alterations (Andren, 1994; Shochat et al., 2010). In urbanised landscapes, the size of natural habitats is significantly reduced by anthropogenic activities, resulting in the fragmentation of the remaining habitat (Fahrig, 2003), which may consequently result in increased competition for space and resources (e.g., food) among sympatric species. Urbanisation and habitat loss remain detrimental to the persistence of several wildlife species in urban areas (Chace & Walsh, 2006; McKinney, 2008; Haddad et al., 2015). Birds are among the most threatened group by anthropogenic activities (Marzluff & Ewing, 2001; Marzluff, 2001; Chace & Walsh, 2006), and recent research has highlighted the role they play in the provision of vital ecosystem services (see Amar et al., 2018; Ehlers et al., 2018), thus safeguarding the long-term functioning of the ecosystem (Maseko et al., 2019, 2020).

Alteration and disturbance of natural landscapes for anthropogenic activities such as human settlements and buildings pose a considerable threat to the persistence of most apex predators, including raptors (Amar et al., 2018; White et al., 2018). For example, the increase in human population in transformed areas increases the risk of habitat loss, building collisions, human persecution and poisoning of raptors because of human-wildlife conflict (Hager, 2009; Kettel et al., 2018; Mojica et al., 2018, McPherson et al. 2021a,b). By virtue of habitat loss, suitable habitat for wildlife is reduced, resulting in the potential loss of ideal nesting sites, particularly for specialist species. On the other hand, factors such as the provision of supplementary food by humans (through bird feeders) and the relatively high abundance of prey in urban areas allow several apex predators to persist and thrive (McPherson et al., 2016; White et al., 2018; McPherson et al., 2021). Furthermore, the availability of nests increases the chances of bird populations surviving and thriving in different ecosystems. The importance of raptor species in ecosystems cannot be questioned since they are key in the provision of vital ecosystem services such as the removal of carcasses by scavengers and reducing/controlling agricultural pests (e.g., rodents; Donazar et al., 2016; Amar et al., 2018; McPherson et al., 2021a). Despite raptors facing several urban challenges and impediments to their survival, some raptor species are thriving in urbanised landscapes (Hager, 2009; McPherson et al., 2019, 2021; Muller et al., 2020; McPherson et al., 2021a, b), which may result in species competing for nests and nesting sites (see White et al., 2018).

The ramifications of habitat loss or decreased size of natural habitats are that suitable habitats for nesting are also reduced, potentially prompting competition for nesting sites within already reduced or degraded natural habitats (Andren, 1994; Marzluff & Ewing, 2001; Fahrig, 2003; Ehlers Smith et al., 2018; Han et al., 2019; Maseko et al., 2020). Furthermore, nesting site competition between bird species is fuelled by the introduction of invasive bird species in urban landscapes as they are well known to easily exploit various resources, competing with native species (McKinney, 2006; Taylor et al., 2013; Hernandez-Brito., 2014). Competition for nesting sites in urban areas has been documented between (i) exotic and native, (ii) exotic and exotic species (iii) native and native. For example, European starlings (*Sturnus vulgaris*) and greater woodpeckers (*Dendrocops major*) (Smith, 2006), rose-ringed parakeets (*Psittacula krameri*) and starlings (Dodaro and Battisti, 2014) or native cavity nesters (Shivambu et al., 2021).

Conversion of natural landscapes for exotic tree plantations and agroforestry contributes to habitat loss and reduction (Zhang et al., 2017; Martinez-Hesterkamp et al., 2018). However, it can be argued that the presence of these plantations creates new areas and opportunities for other species to come and exploit (Zhang et al., 2017; Rogriguez et al., 2021). For example, large raptor species use these exotic tree plantations for nesting purposes (Wreford et al., 2017; McPherson et al., 2016). Hence, efficient management measures and research pertaining to the use and importance of plantations could be crucial to aid in biodiversity conservation, particularly in areas with low amounts of native habitat. A platform-built nesting strategy is commonly used by most large terrestrial raptor species; however, several factors affect raptor species before building a nest (Kruger, 2002; McPherson et al., 2016). For instance, birds will try to build /use nests or areas with reduced predation risk or nests not easily accessible to other species, including humans. Moreover, because of the time and energy required for nest building, usurpation and competition for already built nests or nesting sites may occur between species. Therefore, the increased competitive ability could potentially assist in raptor species' ability to reproduce and persist in a given area, resulting in the complete exclusion of competitively inferior species.

The African crowned eagle (*Stephanoaetus coronatus*) (hereafter crowned eagle) is a Near-Threatened raptor, and like most raptor species, its persistence in transformed anthropogenic landscapes is threatened by factors such as building collisions, shooting and human persecution (Taylor et al. 2015, IUCN 2018; McPherson et al., 2021a,b). However, this raptor species' population is thriving in the Durban, EThekwini Municipality area, South Africa (McPherson et al., 2016, McPherson et al., 2019, Muller et al., 2020). To ensure that this species continues to persist in this urban landscape mosaic, it is important to conduct research that documents present and future threats that may hinder their persistence in this region. Our study aimed to document whether there is likely to be competition for nesting sites between crowned eagles and black sparrowhawks (*Accipiter melanoleucus*) in the urban landscape mosaic of eThekwini

Municipality. Similar to crowned eagles, the black sparrowhawks also use large trees for nesting, with most of them being exotic tree plantations (e.g., *Eucalyptus* spp.), but a considerable proportion of indigenous trees are also used by both raptor species (McPherson et al., 2016; Wreford et al., 2017). Moreover, the two species use the same strategy for nesting (i.e., platform).

It is well documented that invasive tree species such as *Eucalyptus* spp. are detrimental to the environment and tend to outcompete and replace indigenous species; hence they are controlled either by cutting them down or using chemicals (WFW, 2009; Gleditsch, 2017; Harvey-Samuel et al., 2017). A significant concern from a conservation point of view arises from the present increase in the rate of habitat loss and conversion and further loss of nesting sites for raptors because of the removal of exotic trees by programmes such as Working for Water (see WFW, 2009). Therefore, the control of detrimental invasive species that provide crucial nesting sites for raptors creates a situation whereby the positive effects of removal of detrimental species are offset by the loss of potential nesting sites for raptors, which can affect their ability to persist in urban areas (McPherson et al., 2016, 2021a, b). Hence, we think this research may be potentially ground-breaking and thus worth exploring, as it would be important in informing invasive species management. Thus, ensuring that we protect the presently available nesting trees and researching any competition that may arise is crucial for the conservation of the two species under study and the conservation of other raptor species with similar nesting strategies worldwide. The main objective of our study was to compare the characteristics of nests (height of the tree, nest cover and the positioning of the nest in the tree) used by these two raptor species in an urban landscape mosaic and then, from this, infer whether there might be potential competition for nesting site between the species. Another of our objectives was to determine the importance of exotic trees for the nesting of these two raptor species in an urban landscape mosaic. We predicted that there would be no difference in the nest characteristics between those for crowned eagles and black sparrowhawks.

3.3 Methods

3.3.1 Study area

Our research was conducted in Durban, EThekwini Municipality, KwaZulu Natal, South Africa (Figure 3.1). The study region is about 2297 km^2 in extent, with a human population between 3.5 and 4 million (ECPDP, 2015). The region has a subtropical climate humid climate and receives an annual rainfall of 1000 mm (Mucina & Rutherford, 2006; Zungu et al., 2020b). Extensive landscape alterations in the region have resulted in 17% of the original vegetation being extremely degraded and 53% converted for anthropogenic activities such as buildings, agriculture, human settlements, and roads (EThekwini Municipality, 2015; Zungu et al., 2020a). The region has an urban landscape mosaic comprising high urban built development with natural (indigenous grasslands and forests) and manged greenspaces (McPherson et al., 2016; Maseko et al., 2020; Zungu et al., 2020a). EThekwini Municipality developed the Durban Metropolitan Open Space System (DMOSS), which is an open space plan aiming to protect and reduce the destruction of natural landscapes, thus ensuring biodiversity management and conservation (Roberts, 1994; Zungu et al., 2020a). The DMOSS network and Ezemvelo KZN Wildlife Protected Areas in the region have played an important role in the persistence of several avian species (Maseko et al., 2019, 2020), including raptors such as crowned eagles and black sparrowhawks (see Wreford et al., 2017; Muller et al., 2020; McPherson, 2021). For more information about the study region, see Maseko et al. (2019, 2020), Zungu et al. (2019, 2020a;2020b), and McPherson et al. (2016; 2019).

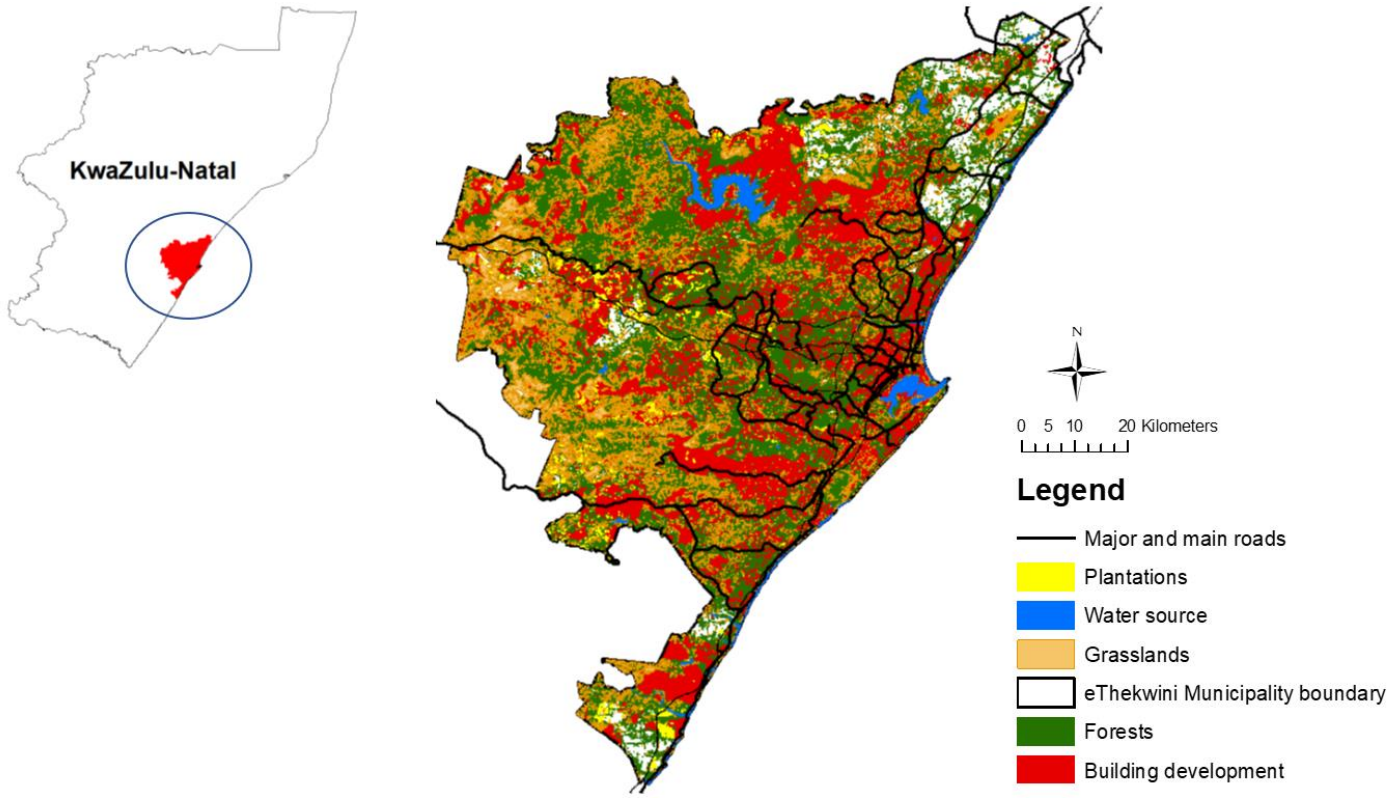

Figure 3.1. Map of the mosaic of Durban, eThekwini Municipality, KwaZulu-Natal, South Africa.

3.3.2 Data collection and analyses

Nest building is considered one of the most time-consuming activities for most avian species (Mainwaring and Hartley, 2013; Sumasgutner et al., 2016). Therefore, possible intra/inter competition for nests and nesting sites, especially in landscapes with limited remaining natural habitat, can be detrimental to population persistence through its effect on recruitment (Hakkarainen et al., 2004). Between October 2020 and July 2021, we visited a total of 52 nests (usually between morning to around midday) of both crowned eagles (n = 30) and black sparrowhawks (n = 22) to quantify and measure the nests' characteristics of all the trees that we could find (or access) in our study area. McPherson et al. (2016) and Wreford et al. (2014, unpublished) independently researched nest characteristics of crowned eagles and black sparrowhawks. However, these were conducted over a large scale (i.e. two cities [2423 km^2] and three cities [2483.94 km^2], respectively), while our research documented these characteristics in one urban landscape mosaic (with a possibility of more habitat modifications).

Table 3.1: Description of nest characteristics investigated in the present study.

Characteristic	Description
Tree height (m)	Height of the nest tree host
Nest height (m)	Height of the nest from the ground
Nearest neighbour distance (m)	Mean distance between the nest tree and the nearest potential nest tree host
Tree cover/ dense foliage (%)	This was measured as crown diameter (i.e., indication of how much dense foliage (i.e., leaves) is available on the tree
Nest cover (%)	Indication of how much the nest is exposed or covered by dense foliage (i.e. leaves)
Distance to road (m)	Distance of the nest tree host to the nearest paved road
Distance to development (m)	Distance of the nest tree host to the nearest building
Distance to water (m)	Distance of the nest tree host to the nearest permanent water source

On arrival at each nesting site, we first determined whether the nests were on an exotic or indigenous tree and whether it was inside a protected area, D’MOSS or not. Using a handheld global positioning system (GPS) (GPSMAP 64, Garmin, USA), we recorded the geographical location of each. Although some trees with nests were not accessible, in instances where we could access the tree, we measured tree the height using a measuring rod. In sites where trees were not easily accessible (e.g., very steep gorges) for us to take the measurements, we estimated the size of the tree. However, we did not measure or estimate tree width because we expected that tree height would give a general idea of the width size of the tree. We measured the nearest neighbour distance as an indication of the mean distance of the nest tree host to the nearest potential nest tree host (i.e., large tree). Tree cover or dense foliage of tree (%) was an indication of how much dense foliage (i.e., leaves) is available on the tree. We also measured nest height from the ground and measured how much the nest crown was covered or exposed by the dense foliage (%). In ArcGIS (10.3, (ESRI, Redlands, USA), we measured the nest (host tree) distance to water, distance to paved road and distance to building/human settlement. These nesting site characteristics were chosen in the present study because they were the most general and very important in nest selection for most large raptor species. Our data were analysed in IBM SPSS version 27. We tested all parameters for normality, and only nest height and distance to the road were not normal (Kolmogorov-Smirnov, $P < 0.05$). Because our sample sizes were not equal, we used Welch's t-test to test whether there were any significant differences between the nest characteristics of crowned eagles and black sparrowhawks.

3.4 Results

Of all the 52 nesting sites sampled, most trees (70%) used by both crowned eagles and black-sparrow hawks for nesting were invasive trees (e.g., *Eucalyptus* spp.). Of all the crowned eagle's nests surveyed, we found that 75% of the nests were in exotic trees, whereas 59% of the nests were in exotic trees for black sparrowhawks. There was a significant difference in nest tree height between the two raptor species ($F = 24.57$; $P = 0.0004$) and nearest neighbour distance ($F = 5.829$; $P = 0.020$) (Figure 3.2). However, there was no significant difference between nest cover ($F =$

2.444; P = 0.120), tree cover (F = 0.031; P = 0.861), nest height (F = 2.360; P = 0.134), distance to water (F = 0.004; P = 0.948), distance to road (F = 2.070; P = 0.157) and distance to development (F = 2.355; P = 0,132) (Figure 3.2). Although the was no significant difference between these species' nest characteristics, crowned eagles' nest distance to development was relatively higher than that of black sparrowhawks. The mean tree cover (%) was similar with crowned eagles 60.8%, and 61.8% for black sparrowhawks. Furthermore, the mean nest cover (%) for crowned eagles was 46% and 36% for black sparrowhawks.

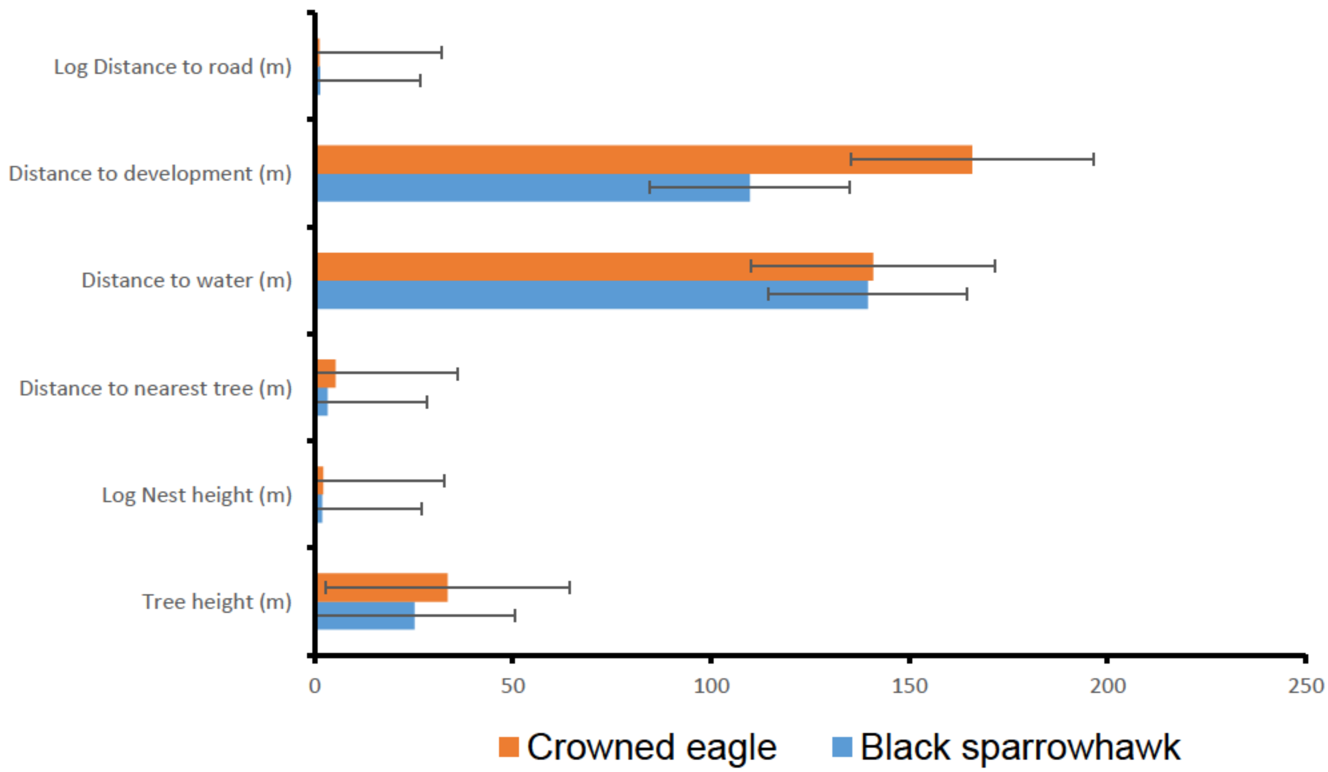

Figure 3.2. Some of the important nesting site selection variables of crowned eagles and black sparrowhawks in the urban landscape mosaic of Durban, South Africa, in the present study.

3.5 Discussion

The landscape complexity in urban areas generally reduces the survival and persistence of most terrestrial species (McKinney, 2008). However, urban landscape mosaics with natural and managed green spaces increase the persistence of mammalian, avian and herp species (Downs et al., 2021). More than 85 % of nests visited in the present study were either in protected areas or DMOSS areas, highlighting the importance of such green spaces in the urban landscape mosaic for the persistence of raptors. Although the number of nests found in protected areas and DMOSS areas was relatively high, it is vital to indicate that this is just a sample but could be more representative of a broader picture. Conservation of apex predators, especially in modified landscapes, will play an important role in the provision of ecosystem services; hence it is vital that effective conservation strategies are implemented.

A conservation conundrum arises when invasive species play a key role in the persistence of some species and biodiversity conservation. The debates and conflicts around the importance of exotic trees in some environments are crucial for conservation and could be very beneficial if all stakeholders (e.g., policymakers, managers, conservation biologists) can work together (Dickie et al., 2014) and be willing to find a solution with regards to exempting the removal of some exotic trees, particularly those that are key in aiding the persistence of other species (McPherson et al. 2016, 2021a,b). Our results highlighted the importance of exotic trees in providing nesting sites for both crowned eagle and black sparrowhawks. However, these exotic trees in South Africa are typically removed by the Working for Water Programme, which is a programme focusing on the eradication of invasive species, including *Eucalyptus* spp. used by crowned eagles and black sparrowhawks (Dickie et al., 2014; McPherson et al., 2016, 2021a, b). Furthermore, McPherson et al., 2016, 2021b) showed that ring-barking significantly affected the nesting trees of both black sparrowhawk and crowned eagles, and the continuation of both Working for Water Programme and communities' disturbances to exotic trees can have detrimental effects on the persistence of both raptor species. There should be an exception in the removal of exotic trees in areas where they benefit and aid in biodiversity conservation (Dickie et al., 2014; McPherson et al., 2016, 2021a, b). Therefore, in urban landscape mosaics where there is continued habitat transformation and significantly reduced (i.e., fragmented) natural habitats, we propose that exotic trees which are beneficial for the breeding of apex predators should be managed differently and excluded from any form of disturbance to ensure the conservation of these apex predators. However, we strictly emphasise that only the exotic trees that meet the nesting requirements of native raptors should be left intact in the urban landscape mosaic, and the excess ones should be removed as they have a suite of negative impacts on the environment.

Nesting site selection could potentially be a significant driving factor in species survival and persistence in a given environment (Bielański, 2006). For example, raptors will consider building their nests in trees not easily visible /accessible by predators (and humans), but that same nesting site should also not hinder their movement/escape plans should their nests be under attack (Bielanski, 2006). One possible characteristic of nesting that aids in the nest being hidden and not easily accessible is nesting in tall trees. We showed that there was a significant difference in tree height between trees used by crowned eagles and black sparrowhawks in the urban landscape mosaic of Durban, South Africa. Black sparrowhawk nesting trees were relatively shorter than those of crowned eagles. This result implies a relatively low chance that black sparrowhawks could potentially use trees used by crowned eagles for nesting. In our study region, there is an increase in Egyptian geese (*Alopochen aegyptiaca*) occupying crowned eagle's nests, which may hinder this raptor's persistence. Furthermore, in the Cape Peninsula, the Egyptian geese are also a problem usurping black sparrowhawks' nests (Sumasgutner et al., 2016). This could be true for sparrowhawks (Wreford, 2014) in the urban landscape mosaic of Durban, consequently affecting the persistence of both crowned eagles and black sparrowhawks. Normally, black sparrowhawks would build several nests to avoid fighting for nests, especially with Egyptian geese (Sumasgutner et al., 2016). This could result in trees available for nesting dramatically declining as Egyptian geese rapidly increase in most urban environments in South Africa (Mangnall & Crowe, 2001; Little & Sutton, 2013). Therefore, it is not ideal to completely reject the possibility of nest competition between crowned eagles and black sparrowhawks. This is because black sparrowhawks could resort to using any available tree, including those of the height preferred by crowned eagles, especially in modified environments where indigenous habitats and exotic tree plantations are vulnerable to being removed.

Hunting near water sources is pivotal for most raptor species, and having a nest near a water source could potentially reduce the distance travelled from hunting grounds to the nest (see Malan & Robinson, 2001; McPherson et al., 2016). Crowned eagles and black sparrowhawks generally prefer to nest on the lower slopes and gorges, which significantly assists when they are taking prey to the nest and collecting nest materials before the breeding season (Malan & Robinson, 2001; McPherson et al., 2016). A degree of cover provided by neighbouring trees assists with protection (i.e., reduced nest visibility) from predators, which can steal eggs and possible torrential weather conditions (Malan & Robinson, 2001). Therefore, having neighbouring trees is also crucial in increasing the chances of successful breeding. Interestingly, our results showed a significant difference between both species in the distance of the nesting tree to the nearest neighbouring tree. Although situated in a forest clump, crowned eagle nests were generally more isolated from other trees than those of black sparrowhawks (Maseko, pers. obs.). One possible explanation for this observation is that maybe because of their size, crowned eagles try to limit having other trees so close to their nesting tree with the aim of reducing/avoiding collision and being able to manoeuvre easily, especially for juveniles when they are improving their hunting skills and familiarising themselves with the surrounding nest environment. By virtue of having nesting trees somehow isolated from other trees, nest cover is compromised. Interestingly, our results showed that there was no significant difference between both tree cover and nest cover in nesting trees used by both crowned eagles and black sparrowhawks. The possible reason for nesting in trees with reduced cover could be that both species want to have a good enough view of the nest when they want to access it. It could be that they want to easily survey any activity or threats when they are returning to the nest. Furthermore, our results showed no significant difference in nest height. Malan and Robinson (2001) suggest that the aggressiveness and ability to defend nests by big raptors (e.g., crowned eagles and black sparrowhawks) renders nest height or position in a tree not too significant hence most nests are relatively lower in relation to their host tree height.

It is well documented that human land transformations and building structures have an impact on species survival (Hager, 2009; McKinney, 2006; Amar et al., 2018) and could result in species avoiding proximity with humans and anthropogenic structures. However, McPherson et al. (2016) showed that crowned eagles were not significantly affected by humans and their modified structures, indicating that they are somehow tolerant of areas in close proximity to urban built areas. The distances of the nest hosting tree to either road and human developments were similar for both crowned eagles and black sparrowhawks. Furthermore, our results showed that both species preferred nesting closer to water sources. The high availability of prey, unobstructed hunting grounds near water sources, and increased tree growth and height could be possible reasons for crowned eagles and black sparrowhawks nesting near water sources (Malan & Robinson, 2001; McPherson et al., 2016; pers. obs.).

In conclusion, our research highlights the crucial role exotic trees play in providing nesting sites for raptors in the urban landscape mosaic and how exotic trees' complete removal could hinder the persistence of crowned eagles and black sparrowhawks. Overall, characteristics influencing nest-site selection for crowned eagles and black sparrowhawks were similar, indicating that these species could potentially compete for nesting sites. This is because already the exotic trees (i.e., *Eucalyptus*) with ideal nesting characteristics are being removed from the environment, and the diminishing natural habitats could also force the two species to compete for the same nesting sites in reduced natural habitats since most of their nesting site selection characteristics are similar. Furthermore, the nests of crowned eagles and black sparrowhawks seem to attract species such as Egyptian geese to occupy them, showing that in the long-term, we could possibly observe an increase in competition for nests between the three species. Although tree size preference was not the same for crowned eagles and black sparrowhawks, we advise that this should be monitored, especially in environments where landscapes are continuously modified.

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3.7 Declarations

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Conflict of interest

The authors declare they have no conflict of interest.

Ethics approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Consent to participate

Not applicable.

Consent for publication

All authors gave consent.

Data availability

The data belong to the University of KwaZulu-Natal and are stored there. They are available from the corresponding author upon reasonable request.

Author contributions

MSTM, MMZ and CTD conceptualised the study. CTD sought funding. MSTM collected and analysed the data with assistance from MMZ. MSTM wrote the draft manuscript. The other authors provided editorial input.

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CHAPTER 4

Public perceptions of African crowned eagles in an urban-rural mosaic of eThekwini Municipality, KwaZulu Natal, South Africa

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Running header: Perceptions of African crowned eagles in an urban-rural mosaic landscape

4.1 Abstract

The increase in the human population has detrimental effects on natural landscapes through habitat transformations and degradation. Furthermore, with the increase in human population size and the presence of several wildlife species in human-dominated landscapes, interactions which could create good or bad relations are inevitable. For instance, some communities perceive raptor species as a threat to domestic animals, thus creating human-raptor conflict and impacting the species and its management. The overall aim of the study was to investigate the public attitudes and perceptions of African crowned eagles (*Stephanoaetus coronatus*, hereafter crowned eagle) in an urban-rural landscape mosaic eThekwini Municipality, KwaZulu Natal, South Africa. We created a questionnaire survey and conducted face-to-face interviews in rural areas, and sent an online survey to urban communities via neighbourhood watch groups and conservancies. We used generalised linear mixed models (GLLMs) to better explain which variables influenced respondents (i) tolerance of crowned eagles, (ii) feelings about crowned eagles, (iii) importance of crowned eagles and (iv) perceiving crowned eagles as a threat to domestic animals. Our results showed that feelings toward crowned eagles, the importance of crowned eagles and spending time in the forest positively influenced tolerance of crowned eagles. Our results further showed that feelings toward crowned eagles and education level negatively influenced whether crowned eagles were perceived as a threat to domestic animals or not. Overall, crowned eagles were 'loved' by community members of eThekwini Municipality. However, we recommend that community members are educated about crowned eagles' ecology through community and school presentations so that we can reduce some of the negative attitudes and perceptions.

Keywords: Citizen science; human-wildlife interactions; raptors importance; raptor perceptions

4.2 Introduction

The escalating urban human population continues to exacerbate land transformations and degradation, which consequently affect biodiversity (Fischer and Lindenmayer, 2007; McKinney, 2008; Concepcion et al., 2015; Zungu et al., 2020b). The provision of significant ecosystem services such as air purification, noise reduction and cooling in urban areas highlights the importance of urban green spaces and biodiversity in this human-dominated landscape (McKinney, 2008; Gupta et al., 2012; Mansour et al., 2022). The manner or scale at which urbanisation results in habitat loss through land transformations is more drastic when compared with anthropogenic activities such as traditional farming (Marzluff, 2001; McKinney, 2006). Furthermore, research has shown that urbanisation and other land transformations (e.g., agriculture and fragmentation) are at the forefront of reducing habitat for several wildlife species, which consequently results in biotic homogenisation and an increase of synanthropic species in human-dominated areas (Andren, 1994; Fahrig, 2003; Chace and Walsh, 2006; Aronson et al., 2014). Presently, more than 50% of humans occupy cities/ urban areas, and global projections show that this will continue to increase placing the small amount of earth's terrestrial surface under extreme pressure through land transformations (Aronson et al., 2014). Furthermore, the species in urban areas, particularly specialist species, are vulnerable to a decline in abundance and possibly extinction as their specific ecological niches are reduced by human activities (McKinney, 2002; Chace and Walsh, 2006; Clergeau et al., 2016; Maseko et al., 2017, 2019). Although associated with the most negative effects on biodiversity, urbanisation creates environments that certain species (mostly invasive) may exploit (Chace and Walsh, 2006; McKinney, 2008).

The reduction of suitable habitats for wildlife in urban areas because of anthropogenic activities eventually forces the coexistence of humans and wildlife (Woodroffe et al., 2005;

Thirgood and Redpath, 2008; Nyhus, 2016; McPherson et al., 2021a). Generally, the interactions in the reduced confined available spaces, especially in urban areas, result in animosity between humans and wildlife, which has led to negative human-wildlife interactions, namely conflict, becoming a topic of interest among conservation biologists (Thirgood and Redpath, 2008; McPherson et al., 2021a). Nevertheless, the formation of conservancies and the increase in supplementary feeding (e.g., bird feeding), particularly in urban areas, indicate that urban dwellers are keen on coexisting with urban wildlife and its conservation (Tryjanowski et al., 2015; Thabethe and Downs, 2018). However, it is important to indicate that the feeding of wildlife is not always a good idea as it sometimes creates problems in the long run. For instance, feeding of some non-human primates potentially results in loss of fear for humans, which leads to home raiding and sometimes may result in them directly stealing and attacking humans for food (Patterson et al., 2016, 2018) thus creating human-wildlife conflict.

One of the major concerns associated with human-wildlife conflict is that it results in the persecution of several wildlife species, which exacerbates biodiversity loss (Nyhus, 2016; Salom et al., 2021). Measures (e.g., poisoning) taken by humans to avoid or limit interactions with wildlife affect biodiversity conservation and fuel the dramatic decline and loss of globally endangered species (Salom et al., 2021). Some of the major drivers of human-wildlife conflicts include vicious attacks on humans causing injuries or fatalities, the transmission of diseases, and the loss of crops and livestock because of wildlife (Thirgood et al., 2005; Thirgood and Redpath, 2008; Bautista et al., 2021). Among bird species, apex predators are often involved in most human-wildlife conflicts, resulting in their persecution by the public (Nyhus, 2016; McClure et al., 2018; Kettel et al., 2021). The prevalence of raptor persecution shows that their importance in the provision of ecosystem services such as carcass removal is often not understood by humans

(Donazar et al., 2016; Amar et al., 2018). The major reasons for raptor persecution (e.g., shooting) are predation on livestock and use in making traditional medicine (i.e., *muthi*) (Thirgood et al., 2005; Ogada et al., 2012; Mashele et al., 2021a). However, the main reason for human-raptor conflict in human-dominated landscapes is that raptors are perceived to be a threat to domestic pets such as dogs (*Canis lupus familiaris*) and cats (*Felis catus*), and awareness and a change in human perceptions could significantly play a big role in reducing raptor persecution and conservation (Kettel et al., 2021; McPherson et al., 2021; Salom et al., 2021).

The overall aim of this study was to document how the urban and rural communities in the landscape mosaic of eThekwini Municipality, KwaZulu Natal, South Africa, perceive the presence of African crowned eagles (*Stephanoaetus coronatus*, hereafter crowned eagles) in their communities. Research exploring the perceptions and attitudes towards raptor species that are most vulnerable to persecution could be vital in coming up with ways to reduce human-wildlife conflicts, educate, and create awareness, subsequently assisting in raptor conservation. There have been reported incidences in our study area whereby members of the public report that crowned eagles attacked pets and livestock (see McPherson et al., 2016b, 2021b). Therefore, our primary objective was to investigate the general perceptions and attitudes of the public towards raptors, with a focus on crowned eagles. We predicted that tolerance of crowned eagles would be positively influenced by education and spending time in the forest either for wood collection or recreation. Furthermore, we predicted that the feelings towards crowned eagles would be negatively influenced by previous loss of pets or livestock.

Our study area is constantly under further development from various anthropogenic activities, but research studies have highlighted the high biodiversity the region comprises and the urgent need for it to be conserved (see McPherson et al., 2016a, 2016b, 2019; Maseko et al., 2019, 2020; Zungu et al., 2019, 2020a, b; Alexander et al. 2019a, b, c, 2021; Downs et al., 2021). Despite the ongoing landscape transformations, our study area included the Durban Metropolitan Open Space System (DMOSS), which is green space (i.e., protected areas, gardens, and parks) (Boon et al. 2016; McPherson et al. 2016; Maseko et al. 2019, 2020; Zungu et al.; 2019, 2020a,2020b). The natural green spaces are crucial for the persistence of raptors in the urban landscape mosaic (McPherson et al., 2016a,2016b, 2019, 2021a,2021b; Wreford et al., 2017; Muller et al., 2020). Therefore, the presence of these raptors in the urban-rural landscape mosaic could potentially lead to people having negative attitudes and perceptions toward raptors and causing harm to raptors (McPherson et al. 2021b).

There are generally mixed attitudes towards crowned eagles on social media and other online platforms particularly when a pet is missing or attacked. McPherson et al. (2016a, 2021b) indicated some concerns and the need to educate community members about crowned eagles, especially their diet. Also, during the search and monitoring of crowned eagle nesting sites in eThekwini Municipality, we noticed a combination of both good and bad attitudes and feelings about the presence of crowned eagles in their residential areas, and the need to document this to develop management and education strategies.

4.3 Methods

4.3.1 Study area and data collection

Our research was conducted in Durban, eThekwini Municipality, South Africa (29.8120^0 S, 30.8039^0 E). The eThekwini Municipality consists of a mosaic landscape including built and natural greenbelts. The latter is natural and mostly fragmented by human activities such as human settlements, including some informal settlements/housing (Mucina and Rutherford, 2011; Ehlers

Smith et al., 2017; Maseko et al., 2019; Patterson et al., 2018; Zungu et al., 2019). The human population of our study region is ~4 million people, and because the city of Durban is the main centre for most economic activities (eThekwini Municipality, 2010; ECPDP, 2015; Patterson et al., 2018 Zungu et al., 2020a), therefore, it is inevitable that the population will continue to increase rapidly.

During 2020-2021, we developed a questionnaire (Supplementary information Table S4.1) and conducted surveys in both rural (KwaMashu, KwaNdengezi, Inchanga, Ntuzuma, Umlazi etc.) and urban areas (Everton, Westville, Kloof, Gillitts etc.) of eThekwini Municipality, with the aim of documenting the overall attitudes and perceptions towards crowned eagles. Our study area mainly comprised semi-rural areas, townships, inner-city and suburban areas; therefore, we categorised semi-rural and townships as rural areas, and inner-city and suburban areas as urban areas. Furthermore, the criteria used for categorisation (i.e., urban or rural) was based on the distance from the city centre, low household income, unemployment rates and population densities, thus all areas which were found on the outskirts of the city centre or having either low household income, high unemployment rates and high population densities were categorised as rural areas. In contrast, areas with none of these abovementioned were categorised as urban areas. We conducted surveys from September 2020 to October 2021. This study was ethically reviewed and approved by the University of KwaZulu-Natal Humanities and Social Sciences Research Ethics Committee (Protocol reference number: HSSREC/ 00000868/2019).

In rural areas, we conducted our surveys by approaching community members walking on the road or standing and socialising on the side of the road, approaching people inside their homes, churches, libraries and shops, and our selection for answering the questionnaires was random for people over 18 years of age. Furthermore, after interviewing a shop or library assistant, we left some survey questionnaires for people to complete and collected these at a later stage. Access to people and their homes in urban areas was difficult, and we created an online link whereby we could send to people in urban areas either through email or social media. However, the link (https://forms.gle/B6hMPrQrvQU9KNjL8) was also shared with some people in rural areas for them to share on their social media accounts. The online link, especially in urban areas, was sent with the help of neighbourhood watch groups and conservancies. The questionnaire was designed in a way that it would take between 10 – 15 min. to be completed.

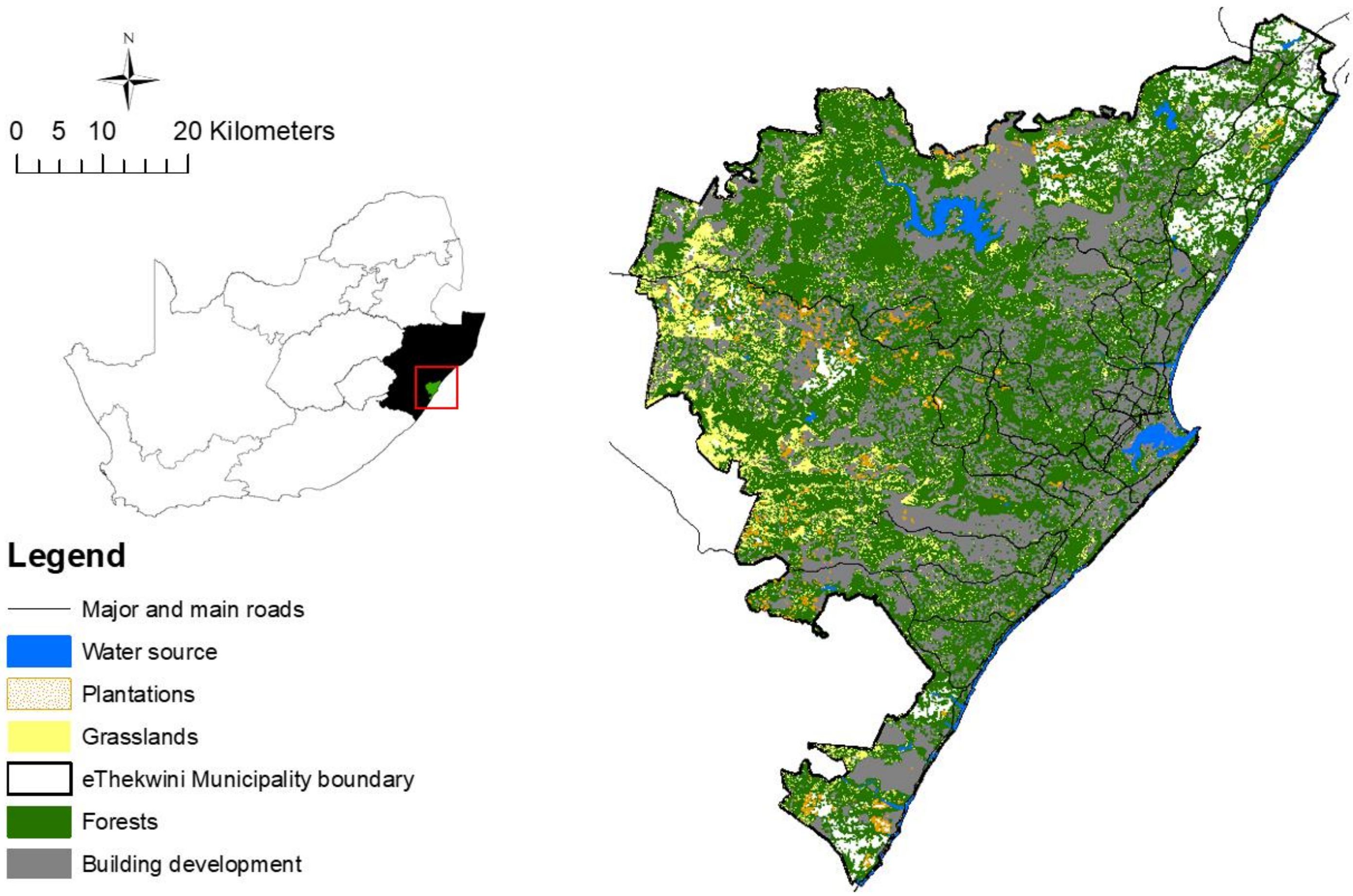

Fig 4.1 Map of the mosaic of Durban, eThekwini Municipality, KwaZulu Natal, South Africa.

4.3.2 Data analyses

We analysed our data using program R version 3.4.2. (R Core Team, 2016) using appropriate R packages. We conducted general linear mixed models (GLMMs) to determine the effect or influence of fixed effects variables on the response variables. For each response variable, we used lme4 package (Bates et al., 2015) in R to create various linear regression model combinations using fixed effects variables. Settlement type (i.e., rural and urban areas) was set as the random effect. For this study, our response variables were (a) tolerance of crowned eagles, (b) feelings about crowned eagles, (c) importance of crowned eagles, and (d) crowned eagles as a threat to pets/livestock. Our predictor variables were (1) age, (2) gender, (3) level of education, (4) employment status, (5) known crowned eagle nest in proximity to a place of residence, (6) tolerance of crowned eagles, (7) feelings about crowned eagles, (8) importance of crowned eagles, (9) crowned eagles as a threat to pets/livestock and (10) spending time in the forest. Model selection was guided by the ΔAICc (Burnham & Anderson, 2002), and this was conducted using the R package *AICcmodavg* (Mazerolle, 2016). The top model was the one with the lowest AIC, and all models in delta-AIC<2 in relation to the top model were the selected models (Burnham & Anderson, 2002).

4.4 Results

The total number of respondents in our study was 491. There was no significant difference in the proportion of females (46 %) and males (54 %) among the respondents ($\chi^2 = 2.50$, d.f. = 1, P = 0.114). There were significant differences in the proportions of respondents who completed different levels of schooling, with the majority indicating to have completed tertiary (college/university) education (47%), 27% completed matric (i.e., the highest grade for secondary school scholars), 24% attended school but did not complete matric, and lastly, only 2% of respondents had no formal education (χ^2 = 202.173, d.f. = 3, P = 0.001; Table 4.1).

Table 4.1 Demographical information of people who responded to crowned eagle survey in eThekwini Municipality, South Africa in the present study.

	Number of respondents	%
Gender		
Female	228	46
Male	263	56
Age		
18 – 25	106	22
26-35	129	26
36 and above	256	52
Education		
None	8	2
Secondary	120	24
Completed matric	134	27
Tertiary education	229	47
Employment status		
Employed	225	46
Unemployed	266	54
Settlement type		
Rural	282	57
Urban	210	43

A significant majority (73%) of our respondents indicated that they spend time in the forests for activities such as collecting wood for fire, walking, and/ birding (χ^2 = 101.281, d.f. = 1, P = 0.001). When our respondents were asked if raptors brought bad or good omens especially when they are seen on their land/properties, a significant majority (55 %) said they bring bad omens, 25% said they bring good omens and 20% responded by saying that raptors were not associated with either good or bad omen (χ^2 = 104.97, d.f. = 2, P = 0.001). Less than half (41%) of respondents said that raptors, in general, were a threat to their pets and livestock (χ^2 = 16.13, d.f. = 1, $P < 0.002$).

We asked our respondents how they feel about crowned eagles, and we found that a significant majority (56%) 'loved' them, 2% 'hated' them, and 42% said they 'neither love nor hate' crowned eagles (χ^2 = 434.77, d.f. = 4, P = 0.001). We further asked people's tolerance towards crowned eagles, and we found that the tolerance levels varied significantly: very low (4%), low (21%), neutral (23%), high (23%) and very high (41%) (χ^2 = 201.78, d.f. = 4, P = 0.001) (Figure 4.2a). When asked about what they think crowned eagles eat; respondents said wildlife animals only (58%), domestic animals only (13%), and both domestic and wildlife animals (29%) (Figure 4.2b). When asked if crowned eagles were important in society, a significant majority (76%) said they were important, and 24% said they were not (χ^2 = 138.74, d.f. = 1, P = 0.002). The response with regards to the crowned eagles' population level was decreasing (51%), increasing (28%), and the same as in the past (21%). Our respondents differed significantly with regards to the frequency with which they saw crowned eagles: daily (11%), weekly (38%), monthly (36%) and lastly, yearly (15%) (χ^2 = 114.93, d.f. = 3, P = 0.001).

When asked if crowned eagles were a threat to their pets and livestock; 40% of respondents said they were a threat and 53% said they were not, and 7% were not certain about crowned eagles being a threat or not (χ^2 = 165.65, d.f. = 2, P = 0.001). Of all our respondents, no significant differences were found in the number of those that have lost a pet or livestock to eagles, although the majority (52%) indicated having lost a pet or livestock to the bird at some point (χ^2 = 0.90, d.f. = 1, P = 0.343). The tolerance of crowned eagles was best explained by (i) spending time in the forest, (ii) feelings toward crowned eagles, and/or (iii) the importance of crowned eagles (Table 4.2). Feelings toward crowned eagles were best explained by (i) age, (ii) nest proximity, and (iii) education (Table 4.2). However, the tolerance of crowned eagles was negatively influenced by feelings toward crowned eagles (Table 4.3). The importance of crowned eagles was best explained by (i) spending time in the forest, (ii) feelings toward crowned eagles, (iii) tolerance of crowned eagles, and (iv) education (Table 4.2). However, feelings toward crowned eagles negatively influenced whether crowned eagles were important or not (Table 4.3). Lastly, crowned eagles as a threat to pets or livestock was best explained by (i) education, (ii) feelings toward crowned eagles, (iii) importance of crowned eagles, and (iv) loss of pet or livestock. However, the loss of pets or livestock negatively influenced whether crowned eagles were perceived as a threat or not (Table 4.3).

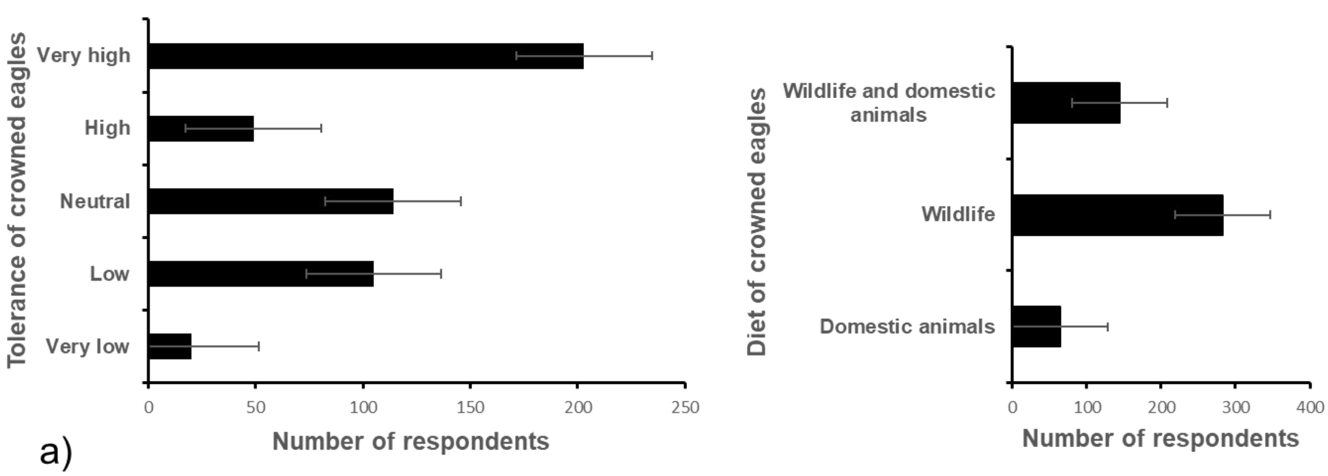

Fig. 4.2 The responses obtained from residents in the urban-rural landscape mosaic of eThekwini Municipality, KwaZulu Natal, South Africa, were asked about (a) their tolerance of crowned eagles, and (b) diet of crowned eagles.

Table 4.2 The variables from top models influencing the perceptions and attitudes towards crowned eagles in eThekwini Municipality, South Africa.

Response variable	**Fixed effects**	**K**	**AICc**	**ΔAICc**	***wi***	**logLik**
Tolerance of crowned eagles	Spending time in the forest	6	1120.34	0.00	0.62	-554.08
	Feelings about crowned eagles					
	Importance of crowned eagles					
Feelings about crowned eagles	Age	7	87.39	0.00	0.29	-50.81
	Tolerance of crowned eagles					
	Next in proximity					
	Education					
Importance of crowned eagles	Spending time in the forest	9	324.80	0.00	0.34	-153.21
	Feelings about crowned eagles					
	Tolerance of crowned eagles Education					
Crowned eagles as a threat to pets/livestock	Education	7	909.89	0.00	0.86	-447.83
	Importance of crowned eagles					
	Loss of pets/livestock					
	Feelings about crowned eagles					

k = degrees of freedom, AICc = Akaike Information Criterion (AICc), ΔAICc =Delta Akaike Information, Criterion, *wi* = Akaike weight, logLik= Log likelihood.

Table 4.3 The parameter estimates of fixed effects variables in all top models documenting the perceptions and attitudes towards crowned eagles in eThekwini Municipality, South Africa.

Response variable	**Fixed effects**	**Estimate**	**Std. Error**
Tolerance of crowned eagles	(Intercept)	0.80438	0.28723
	Spending time in the forest	0.02362	0.07881
	Feelings about crowned eagles	0.56711	0.05169
	Importance of crowned eagles	0.96880	0.08960
Feelings about crowned eagles	(Intercept)	-0.79831	0.06602
	Age	0.02812	0.01457
	Tolerance of crowned eagles	-0.02329	0.01267
	Nest in proximity	0.92987	0.01668
	Education	0.02242	0.01593
Importance of crowned eagles	Spending time in the forest	0.06321	0.03569
	Feelings about crowned eagles	-0.05621	0.02395
	Tolerance of crowned eagles	0.18627	0.01833
	Education	0.07898	0.02285
Crowned eagles as a threat to pets/livestock	Education	-0.01863	0.04220
	Importance of crowned eagles	0.23195	0.07519
	Loss of pets/livestock	0.10616	0.07409
	Feelings about crowned eagles	-0.15233	0.03680

4.5 Discussion

Research documenting the perceptions and attitudes towards wildlife species (e.g., Patterson et al., 2018; Mashele et al., 2021b) can be very important in better understanding relationships between wildlife and communities, particularly in environments experiencing severe landscape transformation and increasing human population. Furthermore, such studies can be a baseline which could be pivotal in coming up with strategies to reduce or prevent any potential human-wildlife interactions, especially negative ones, that may arise because of lack of knowledge and misunderstandings. Despite concerns such as wildlife being pests and disease carriers (Nyhus, 2016) in Africa, the respondents in our survey showed some general love and concern for the environment and wildlife. In particular, our study investigated how the communities of eThekwini Municipality perceived and felt about coexisting with crowned eagles. Although charismatic to most community members, the spreading of negative reports such as crowned eagles being responsible for the disappearance of pets and livestock [hereby referred to as domestic animals], a change of attitude towards this loved bird species is possible. Therefore, our research is pivotal in ensuring that community members are educated more about crowned eagles, consequently preventing the spreading of bad reports that could compromise the thriving of crowned eagles and other raptors in the study region. We used an online and in-person approach as an online questionnaire only may lead to biases if only select parts of the communities can access this (Streicher et al., 2021)

By providing services such as controlling agricultural pests and removing carcasses, raptors ensure the long-term functioning of the ecosystem (Şekercioğlu, 2006; Ogada et al., 2016; Amar et al., 2018). However, the negative associations most raptors have with traditional medicines (i.e. *muthi*), and bad omens could be a challenge in convincing communities to play an active role in raptor conservation (Horgan et al., 2021). Our results showed that more than 50% of our respondents indicated that raptors, in general, are associated with bad omens. However, it is important to mention that owl species were the most mentioned by respondents regarding bad omens, and the generalisation of other raptors bringing bad omens came from the fact that they are associated with strong *muthi* and witchcraft. Such statistics should be very concerning for raptor conservation in this region as this could be very detrimental to the survival of several raptor species. It is relatively common that raptor species are perceived as a threat to livestock and other domesticated animals in most human-dominated landscapes, and that usually results in community members (and usually farmers) persecuting, shooting and poisoning raptors as mitigating factors (Cianchetti-Benedetti et al., 2016; Kettel et al., 2021). Although 55% of people said that raptors bring bad omens, we found that tolerance to eagles was high which shows how complex the situation is.

The green spaces network of eThekwini Municipality has played a significant role in the persistence and thriving of crowned eagles in this highly urbanised landscape mosaic environment (McPherson et al., 2016, 2019, 2021a, 2022b; Muller et al., 2020). However, the presence and thriving of crowned eagles (especially juveniles) may have somehow resulted in some attacks on domestic animals (McPherson et al., 2021b), and such incidences may have the potential to incite vicious attacks and hatred towards crowned eagles. Despite the attacks on domestic animals, our results showed that most (56%) of our respondents 'loved' crowned eagles, and a relatively high proportion (42%) of our respondents had no good or bad feelings towards crowned eagles. Fortunately, only 2% of our respondents indicated they 'hated' crowned eagles. The appreciation of nature may significantly influence how an individual perceives and treats their surrounding environment (including wildlife) (Nisbet et al., 2009). Our results showed that most (73%)

respondents had some connection with their surrounding forest areas through various activities. Furthermore, our results showed that having a crowned eagle nest in proximity to our respondents' residents positively influenced how they felt about this raptor. Therefore, we believe that the high percentage of people who 'love' crowned eagles may have been influenced by their connection with nature (i.e., spending time in surrounding forests and having a crowned eagle nest closer to their homes) or it could be that the bird is charismatic and beautiful.

Several raptor species thrive in human-dominated landscapes. The increase in their population densities and frequent interactions with humans could increase negative attitudes towards raptors, thus leading to human-raptor conflict (Kettel et al., 2021; McPherson et al., 2021b). Our results showed that most respondents (51%) thought crowned eagle population was decreasing because of increased housing developments causing reductions to their natural habitat. Whereas 28% of respondents said the crowned eagles' population were increasing, and 21% said there had not been significant changes in crowned eagles' population. The increase in the population density of crowned eagles may lead to some community members thinking that their domestic animals are more vulnerable to crowned eagles' attacks, consequently influencing the tolerance levels and feelings towards crowned eagles. Despite our results showing that a relatively high proportion of respondents regard crowned eagles as a threat to domestic animals, our respondents also showed a generally high tolerance of crowned eagles. Most participants' high tolerance levels of crowned eagles are commendable, especially with many (more than 50%) of respondents having lost a domestic animal because of crowned eagles. Furthermore, the tolerance of crowned eagles was positively influenced by having a connection with nature (i.e., spending time in the forest), their various ecological importance in the environment and genuine love of crowned eagles. However, our results also showed that education and feelings towards crowned eagles played a considerable role in negatively influencing whether this raptor was a threat to domestic animals or not.

Lack and shortage of correct information could be detrimental and hinder any conservation efforts to save wildlife species. For example, almost half of our respondents were convinced that crowned eagles feed only on domestic animals, while others believed they fed on both wildlife and domestic animals. However, McPherson et al. (2016b) showed that crowned eagles primarily feed on wildlife species such as rock hyrax (*Procavia capensis*) and vervet monkeys (*Chlorocebus pygerythrus*), with relatively low numbers of domestic animals consumed (<2%). The latter are mainly consumed by juveniles and sub-adults which are usually at the stage of improving their hunting skills (McPherson et al., 2021b). According to our results, education positively influenced whether respondents regarded it as important or not. Also, the importance of crowned eagles in the environment was negatively influenced by feelings toward this raptor. Therefore, we strongly believe that through educating people via platforms such as community talks and school visits, we stand a better chance of availing correct knowledge for people to have a better understanding of crowned eagles' ecology, thus influencing them to regard crowned eagles as an important part of the environment.

In conclusion, most people who took part in the survey were knowledgeable about the contents of the questionnaire and showed some interest and care about the environment and wildlife. Furthermore, raptors, in general, were viewed and perceived negatively by some respondents because of their association with bad omens. However, we observed that crowned eagles were generally 'loved' by respondents despite the incidence of attacks of this raptor on domestic animals. Also, although most people embraced the coexistence with crowned eagles, the minority has the potential to cause negative impacts. For instance, a recent study showed that only a minority is needed to cause a negative interaction and the demise of a top predator (Agan et al., 2021). Furthermore, we strongly believe that thorough feedback to communities via talks and presentations may change many negative perceptions and attitudes of eThekwini Municipality residents.

4.6 Acknowledgements

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4.7 Declarations

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Conflict of interest

The authors declare they have no conflict of interest.

Ethics approval

This study was ethically reviewed and approved by the University of KwaZulu-Natal Humanities and Social Sciences Research Ethics Committee (Protocol reference number: HSSREC/ 00000868/2019).

Consent to participate

All respondents consented to participate in the study.

Consent for publication

All authors gave consent.

Data availability

The data belong to the University of KwaZulu-Natal and are stored there. They are available from the corresponding author upon reasonable request.

Author contributions

MSTM, MMZ and CTD conceptualised the study. CTD sought funding. MSTM collected and analysed the data with assistance from MMZ. MSTM wrote the draft manuscript. The other authors provided editorial input.

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4.9 Supplementary information

Supplementary information Table S1: Questionnaire designed to survey the attitudes and perceptions toward crowned eagles in eThekwini Municipality, KwaZulu Natal, South Africa.

Question	Response options
Gender	[Male / Female]
Age	[18 - 25 / 25 - 35 / 35 - above]
Are you employed	[Yes / No]
Highest level of education	[None / Grade 7- 11/ Matric /College or university]

Do you live in a Rural / Township / urban area?

What is the name of your residential area?

Do you spend much time in the forests nearby? How much time, and why (hunting/wood fuel, plant medicines, etc.)?

Do you think the forests are diminishing in size or not? If yes, please explain why?

How are forests important to you?

What is a raptor? How do you identify a raptor?

Can you identify day-time raptors and night-time raptors? If yes, how do you distinguish day-time raptors from night-time raptors?

What are the names of raptors you know?

What are your beliefs regarding the raptors mentioned above? Are they associated with good or bad omen?

When do you notice raptors (i.e., season, time of day), what are they doing when you see them?

Do you think raptors are a threat to your livestock/animals/property? Yes / No

How do you deter raptors from your property or attacking your livestock/pets? Does it work?

Are there ways in which you can get financial gain from raptors? How? How much?

In what way are raptors important to you?

Can you distinguish a crowned eagle from other birds/ raptors? Please describe crowned eagle (what it looks like and how it behaves).

How do you feel about crowned eagles? [Hate / Dislike / Neutral / Like / Love]

How do you feel about having crowned eagles or their nests around your residential area? [Hate / Dislike / Neutral / Like / Love]

What is your tolerance of crowned eagles? [Very low / Low / Neutral / High / Very high]

What do you think crowned eagles eat?

How frequently do you see crowned eagles? [Daily / Weekly / Monthly / Yearly]

Do you see crowned eagles more often or less often than in the past? [Less often than in the past / Same as in the past / More often than in the past]

Do you think their population is increasing or decreasing? Why?

Do you know where crowned eagles breed nearby?

Can you identify juvenile crowned eagles? How?

Are crowned eagles important in society, are they good or bad omens?

Have you ever seen someone selling a crowned eagle or its body parts? Where? How much was it selling for?

Do you know where they got the crowned eagle?

Do crowned eagles provide any financial gain to you? If yes, please explain how?

Do you consider crowned eagles a threat to your livestock/pets? [Yes / Maybe / No]

Have you ever lost your livestock (e.g., chickens, goats), or pets (cats, dogs) because of crowned eagles?

If yes, please tell us how many chickens/livestock over what time period have you lost because of crowned eagles?

How do you/other people deter crowned eagles from attacking your livestock/pets? Does it work?

Do you think it's important to protect crowned eagles? Why?

How do you think we can protect the current crowned eagle population?

Are there any stories associated with crowned eagles? What is the traditional knowledge of their importance in the environment, interactions with other animals?

CHAPTER 5

Population viability analysis of the Near-Threatened African crowned eagles (*Stephanoaetus coronatus*) simulated under increasing extreme weather events in a mosaic urban landscape, Durban, South Africa

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Running header: Population viability analysis of crowned eagles in an urban mosaic

5.1 Abstract

Climate change and landscape transformations as a result of the increasing human population will have detrimental impacts on biodiversity. Globally and in South Africa, the frequency of extreme weather events, such as thunderstorms, has increased, and such weather events are known to affect the persistence of several species, including raptors, significantly. Population viability analysis is vital for conservation because it assists in predicting population changes and providing the probability of survival and extinction of flora and fauna. In this study, we investigated the population viability of African crowned eagles (*Stephanoaetus coronatus*, hereafter crowned eagles) in the Durban metropole, KwaZulu-Natal, South Africa. Our main aim was to assess the sensitivity of crowned eagles to thunderstorms. We conducted population viability analyses using Vortex 10, and model scenarios were simulated for 100 years with different parameters. Our results showed that the probability of extinction was high when the frequency of thunderstorms was high. Furthermore, our results showed that increasing thunderstorm frequency would likely result in the extinction of crowned eagles population in Durban metropole, KwaZulu-Natal, South Africa, in 100 years. Education and urgent practice of climate change mitigation strategies will play an important role in the conservation and persistence of crowned eagles in the Durban metropole.

Keywords: Climate change; population viability; raptors; thunderstorms

5.2 Introduction

The global human population is projected to increase substantially in the next decade, and most of the additional people are expected to inhabit urban areas (McKinney, 2006). This rapid population growth repercussions include extensive habitat transformations resulting from various anthropogenic activities. Anthropogenic activities continue to impact global flora and fauna, resulting in biodiversity loss and increased risk of species extinction (McKinney, 2008; McClure et al., 2018). Globally, several species are declining in numbers, including species which are crucial for vital ecological processes and ecosystem services (McClure et al., 2018; Buechley et al., 2019). Raptor species important in the provisioning of important ecological functions have well been documented in previous research (e.g., Ogada et al., 2016; Amar et al., 2018). However, it has also been shown that raptor species (and populations) are significantly affected by threats such as loss of indigenous habitat, climate change, poisoning, human persecution and building collisions (Hager, 2009; Kettel et al., 2018; Mojica et al., 2018). Therefore, it is important to document how the threats presently impact the species population or how the species population could be affected by the threats in future especially in urban environments.

Modelling using Population Viability Analysis (PVA) is an important projection tool for any potential extinction risk assessment by simulating how wildlife populations respond or change under different scenarios (e.g., changes in environmental conditions) (Reed et al., 2002; Volampeno et al., 2015). One of the core mandates of PVA is to provide the calculated survival probability of wildlife should unforeseen catastrophic changes (e.g., demographic stochasticity and accidental genetic events) occur in an environment over a given period (Velevski et al., 2014; Volampeno et al., 2015). PVA further assists in estimating the future population size of wildlife and helps when devising effective conservation strategies (Volampeno et al., 2015). The several above-mentioned threats (e.g., human persecution) affecting global raptor populations have caused serious declines in several raptor populations, and this has resulted in PVAs being conducted for some raptor species (see Carrete et al., 2009; Velevski et al., 2014; Dimitriou et al., 2021) in order to assess how the populations are affected and coming with informed conservation strategies.

Our research assessed a forest raptor, the African crowned eagle (*Stephanoaetus coronatus*) [hereby crowned eagle], which according to the International Union for Conservation of Nature (IUCN), is Near Threatened (Taylor et al., 2015, IUCN, 2018; Muller et al., 2020; McPherson et al., 2019, 2021a). This species is thriving in the natural forest remnants in the mosaic urban landscape of the Durban metropole. Threats such as electrocution, shooting, building collisions, human persecution, poisoning and nest failure because of torrential rainfall and invasive tree management continue to jeopardize crowned eagles in this region (McPherson et al., 2016, McPherson et al., 2019, Muller et al., 2020; McPherson et al., 2021a, b), consequently affecting population growth of crowned eagles in the mosaic urban landscape of Durban metropole.

It is well documented that climate change has serious impacts on global fauna and flora, and projections show that several species will be extinct because of climate (Crick, 2004; Urban, 2015; Wiens, 2017; Pecl et al., 2017; Román-Palacios and Wiens, 2020). For example, range contractions are expected because of climate change, and species with specialised ecological niches will dramatically decline (and possibly be extinct) because of various changes (e.g., environmental changes such as temperature) in their ecological niches (Pecl et al., 2017; Zhang et al., 2020; Condro et al., 2022). Furthermore, climate change effects include the increase in extreme weather patterns such as thunderstorms and droughts (Leng et al., 2015; Trenberth et al., 2018). The effects of climate change are also detrimental to raptors such as crowned eagles, and this is because weather events such as storms lead to several nest failures in a breeding season and significantly impact the breeding success rate (Muller et al., 2021; McPherson et al., 2021b).

South Africa is no exception when it comes to the detrimental impacts which countries will experience as a result of climate change (Ziervogel et al., 2014; Rogerson, 2016). Already the frequencies of torrential rainfall events and average annual temperatures in South Africa (including KwaZulu-Natal) have significantly increased, and present projections show that sectors/areas such as health, water resources and biodiversity are more prone to be affected by climate change (MacKellar et al., 2014; Ziervogel et al., 2014; Engelbrecht et al., 2015). In this study, we were interested in assessing the crowned eagle population in the mosaic urban landscape of the Durban metropole to create baseline data for long-term population trends of this raptor species in a mosaic urbanised landscape. The overall aim of our study was to investigate the extinction probabilities and persistence of crowned eagles considering climate change effects in the Durban metropole, KwaZulu-Natal, South Africa. Our main objective was to evaluate how the population of crowned eagles would respond (i.e., decline or increase) to the increase of torrential rainfalls/thunderstorms in the study region. We predicted that the increase in thunderstorm frequencies would cause a dramatic decline in crowned eagle population, resulting in the extinction of this raptor in less than 100 years. Our study aimed to increase the present knowledge about the crowned eagle population in the mosaic urban landscape of Durban metropole and positively inform and improve the conservation status of crowned eagles in this relatively highly urbanised and populated region.

5.3 Methods

5.3.1 Study area

We conducted our research in the urban mosaic landscape of Durban metropole, KwaZulu-Natal, South Africa (Figure 5.1). The study region is located on the Eastern coast of KwaZulu-Natal and consists of natural environments such as natural forests (Mucina and Rutherford, 2011; Zungu et al., 2019, 2020; Maseko et al., 2019, 2020). The human population in our study region is ~4 million people (eThekwini Municipality, 2010; Boon et al., 2016), and this rapid increase in human numbers continues to increase the rapid rate of land-use change for anthropogenic activities such as roads, agriculture and building developments (EThekwini Municipality, 2015; Boon et al., 2016). The vulnerability of natural environments in our study region resulted in the eThekwini Municipality reserving or protecting various indigenous habitats under a network called Durban Metropolitan Open Space System (D'MOSS) with the aim of managing and conserving the regions of biodiversity (Roberts, 1994; Boon et al., 2016; McPherson et al., 2016, 2019; Zungu et al., 2019; Maseko et al., 2020). The green spaces under the D'MOSS network include nature reserves, parks, gardens, golf courses and cemeteries etc., and these are dispersed through urban built areas of eThekwini Municipality. For further description of the study region, see McPherson et al. (2016, 2019); Maseko et al. (2019, 2020); Zungu et al. (2019,2020a, b).

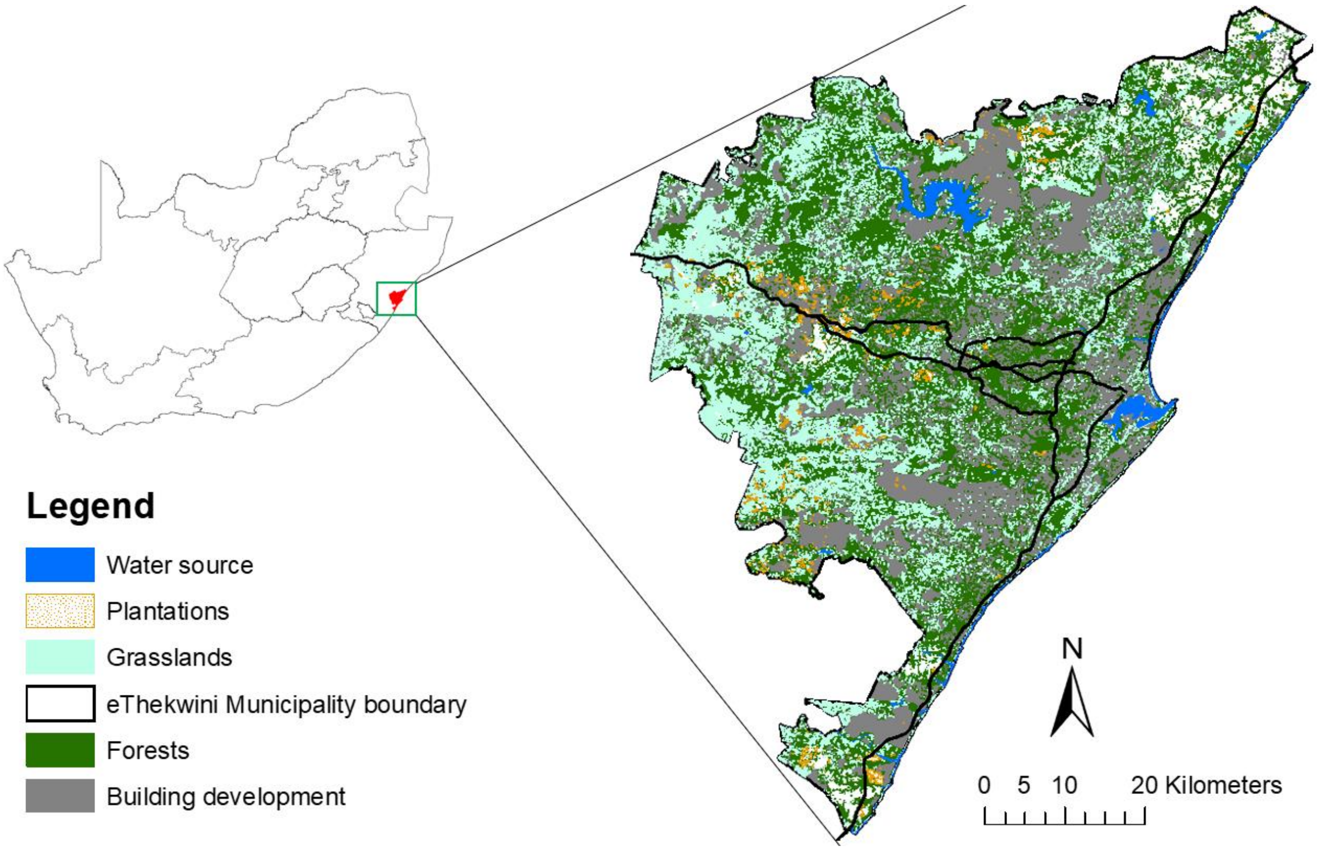

Fig. 5.1. Map of the urban mosaic landscape of Durban metropole, KwaZulu-Natal, South Africa.

5.3.2 Analyses

We conducted a population viability analysis of crowned eagles in the mosaic urban landscape of Durban metropole, KwaZulu Natal, South Africa, using the program Vortex version 10.0 (Lacy 1993; Lacy et al., 2014). The study region receives most of its rainfall during summer (McPherson 2016a; Maseko et al., 2020; Zungu et al., 2020a), and this coincides with the crowned eagle breeding season (McPherson et al., 2019). the study region has been affected by storms and torrential rainfallsand with climate change, these weather events are expected to occur frequently (Roberts and O'Donoghue 2013),. Therefore, we decided to include storms in all our models as catastrophic events because such weather events are detrimental to crowned eagle's nests and their contents (i.e., eggs or chicks). Our data for the crowned eagle PVA were from known pairs from nesting sites surveyed in 2019 – 2021 (Maseko unpublished data) and from recent research (Muller et al., 2020; McPherson et al., 2016a, b, 2019, 2021b).

We used a total of 32 known crowned eagle pairs, and because of increases in crowned eagles numbers as reported by community members and the paucity of information on the survival rate of juveniles once they leave the nest, we estimated the crowned eagle population in the study region to be 115 individuals. As documented in several raptor species, crowned eagles have a low reproduction rate, longer lifespan and usually breed biennial, but in some instances, they are seen to be breeding annually (Swartridge, 2009; McPherson et al., 2016a, 2016b; Muller et al., 2020). Therefore, we estimated the carrying capacity of crowned eagles in our study region to be 150. There is no certainty with crowned eagle's maximum reproduction age, and because of their long lifespan and tendency to remain with one breeding partner for ~10 years, we estimated the maximum reproduction age of crowned eagles to be 12. The first age of reproduction of crowned eagles is between 4 and 6 years (McPherson., 2015); hence we decided 4 years to be the first age of reproduction. Crowned eagles would sometimes not reproduce or attempt to breed hence our reproduction in models was set between 50% and 100%.

The probability of mortality in crowned eagles between the ages of 0 – 4 years is relatively high (for a species with a low reproductive rate) because of bad weather conditions and death by factors such as collision with buildings during the training stage (McPherson et al., 2021b). Therefore, we set annual mortality of 0 – 1 year to be 14 % as they are more vulnerable to threats such as extreme weather conditions. Between the ages of 1 – 2 years, crowned eagles spend their time in the nest and training for the period when they leave the nest; therefore, we set annual mortality to 11%. In addition, when juveniles disperse or leave the nest, they have a high probability of dying from anthropogenic threats such as electrocution and persecution (McPherson et al., 2021b). However, it is important to note that crowned eagles are more vulnerable to being killed or dying during the transitioning stage from juveniles to subadults. The annual mortality rate of crowned eagles for the age of 2 years was set mortality to 9%. The annual mortality rate from the ages of 3 – 4 years and after 4 years were set to be 7% and 2%, respectively. Our annual mortality rates were also deduced from the population monitored during the surveys between 2019 and 2021. For all our models, we ran our simulations using 100 iterations for over 100 years (Volampeno et al., 2015). Furthermore, extinction of our population was decided to have occurred when the number of individuals was below five.

Table 5.1 Crowned eagle scenarios used in the program Vortex to determine changes in population when there were changes in certain parameters.

Scenario	1	2	3	4	5
Female: 1st age of reproduction (year)	4	4	4	4	4
Male: first age reproduction (year)	4	4	4	4	4
Maximum reproduction age (year)	12	12	12	12	12
Mean birth rate	0.75	0.75	0.75	0.75	0.75
Maximum number of progeny	1	1	1	1	1
Sex ratio at birth	0.5	0.5	0.5	0.5	0.5
Adult female breeding (%)	90	80	75	60	50
Male's breeding (%)	90	80	75	60	50
Female mortality age 0–1 (%)	14	14	14	14	14
Female mortality age 1–2 (%)	11	11	11	11	11
Female mortality age 2-3 (%)	9	9	9	9	9
Female mortality age 3-4 (%)	7	7	7	7	7
Female mortality after age 4 (%)	2	2	2	2	2
Male mortality age 0–1 (%)	14	14	14	14	14
Male mortality age 1–2 (%)	11	11	11	11	11
Male mortality age 2-3 (%)	9	9	9	9	9
Male mortality age 3-4 (%)	7	7	7	7	7
Male mortality after age 4 (%)	2	2	2	2	2
Catastrophe type: Storm	2	4	8	10	12
Initial population size	115	115	115	115	115
Carrying capacity	150	150	150	150	150

Extinction definition = less than 5 individuals; Parameters that were changed for different scenarios are written in red.

5.4 Results

Our models simulated under different parameters indicated that crowned eagle population in the mosaic urban landscape of the Durban metropole will become extinct in 100 years (Table 5.2). For example, under model scenario 1, the crowned eagle population became extinct after 80 years (Table 5.2) when the catastrophic event frequency was low (i.e., 2%) compared with the other models. Furthermore, the number of years it took the crowned eagle population to become extinct decreased as the number of catastrophic events increased (Table 5.2). For instance, model scenario 5 had a high frequency (12%) of catastrophic events, resulting in the number of years for extinction to decrease to 68 years, which is relatively low compared with model scenario 1 (Table 5.1). In addition, our models showed that the probability of extinction of crowned eagles was relatively low when the catastrophic event frequency was low but higher as they increased (Table 5.2). Lastly, our deterministic projections also showed that the population of crowned eagles decreased as the frequency of catastrophic events increased (Table 5.3, Figure 5.2).

Table 5.2 Five scenarios showing probabilities of extinction and survival of crowned eagle population simulated at 100 years.

Model scenario	**1**	**2**	**3**	**4**	**5**
Average years to first extinction	80.84	82.21	81.36	73.09	68.73
No. simulations that went to extinction at least once	19	38	33	57	91
Extinct after 100 simulations	18	36	31	52	88
Surviving after 100 simulations	82	64	69	48	12
Probability of extinction	0.18	0.36	0.31	0.52	0.88
Probability of surviving	0.82	0.64	0.69	0.48	0.12
Means across all populations (extant and extinct)	73.32	17	20.83	8.29	1.77

Table 5.3 Crowned eagle population deterministic projections investigated under five different scenarios.

Model scenario	**1**	**2**	**3**	**4**	**5**
Population growth (r)	0.054	0.0356	0.03	0.0012	-0.0218
Lambda (λ)	1.0555	1.0362	1.0304	1.0012	0.9785
Net reproductive rate (Ro)	1.5144	1.3172	1.262	1.0096	0.8413

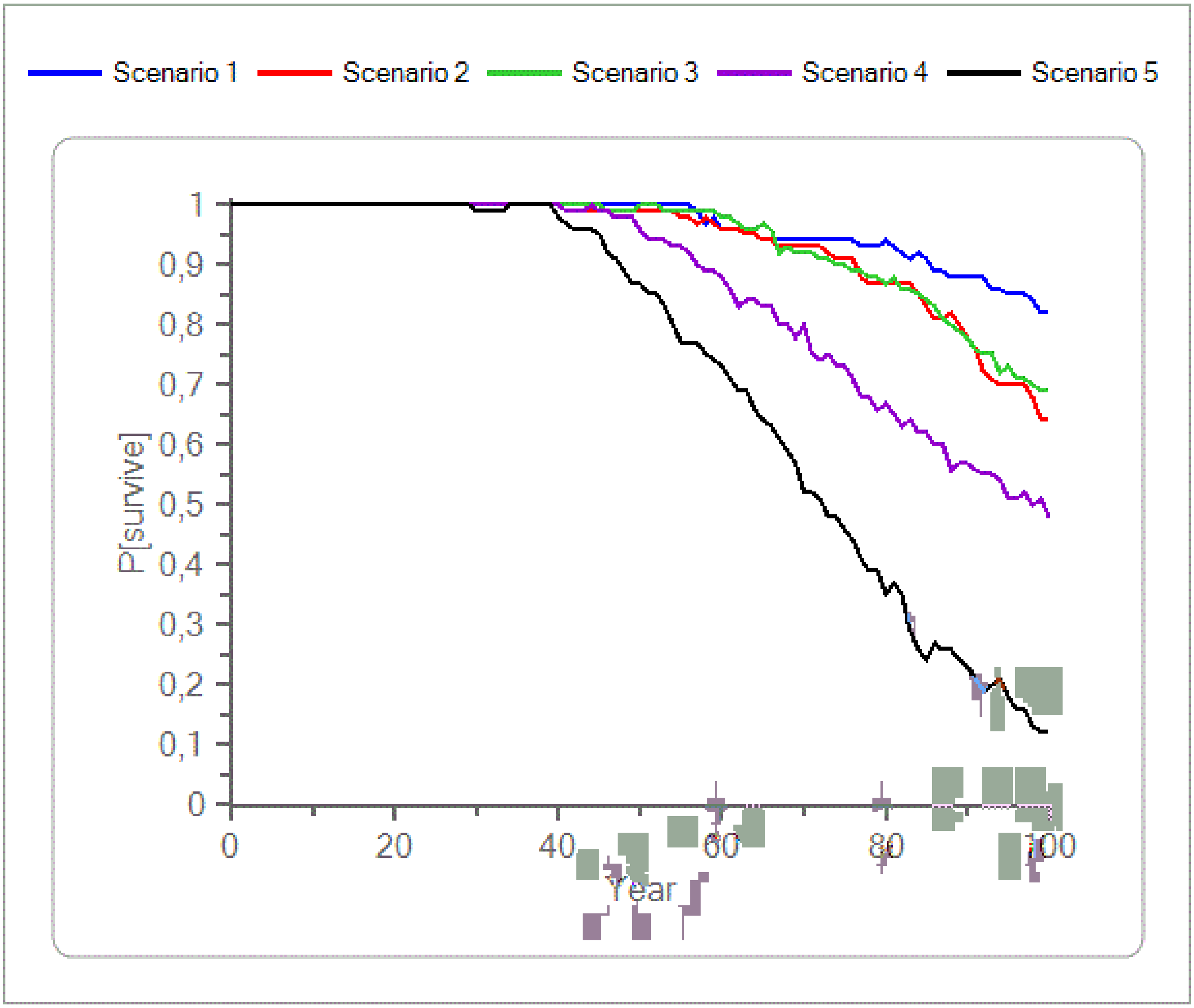

Fig. 5.2. The probability of the crowned eagle population's survival in the mosaic urban landscape of Durban metropole in 100 years under different scenarios.

5.5 Discussion

Effective and long-term conservation strategies are urgently needed to ensure that the crowned eagle population persists in the urban mosaic landscape of the Durban metropole. Presently, crowned eagles in this urbanised landscape are thriving and persisting because of factors such availability of nesting sites and forest fragments and woodlands in the landscape mosaic, which are their primary habitat (Muller et al., 2020; McPherson et al., 2016a, b; 2019; 2021a,b). However, our research highlighted that this population could be significantly affected by the long-term effects of climate change. Presently, the crowned eagles in the urban mosaic landscape of Durban metropole are mainly affected by threats such as nest site threats (i.e., ring barking exotic trees and exotic tree removal), collision with walls and windows, electrocution, poisoning and nest collapse because of torrential rainfalls (McPherson et al., 2021b). Therefore, ensuring that the probability and frequency of death by the above-mentioned threats are reduced is essential for conserving crowned eagles in this mosaic urban landscape.

Global climate change could be a serious challenge for several avian species, including raptors, when it comes to surviving and persisting (Amar et al., 2018; Condro et al., 2022). Our results showed that the present population of crowned eagles in the urban mosaic landscape of the Durban metropole is at risk of declining, especially because of the projected increase in catastrophic weather events, such as thunderstorms. Availability of nesting sites and minimum nest disturbance is crucial for the persistence of crowned eagles, and since extreme weather conditions such as torrential rainfalls already reduce the success rate of nesting and breeding (Muller et al., 2020; McPherson et al., 2021b). The projected increase in such weather could be detrimental to the persistence of crowned eagle population in our study region. Our results showed that the probability of extinction was relatively high when the frequency of thunderstorms increased; at 12% frequency of thunderstorms, our models showed that extinction would only occur after 68 years, and the probability of extinction was 0.88. On the contrary, when the frequency of thunderstorms was at a low of 2%, our results showed that the probability of survival was at a high of 0.82 and that of extinction 0.18. Therefore, the main inference from our results is that the increase in the number of thunderstorms will increase the chances of extinction of crowned eagles in the urban mosaic landscape of the Durban metropole. Also, it highlights that climate change mitigation strategies which could assist in ensuring that the effects of thunderstorms are kept at a minimum are urgently enforced and put into practice by all stakeholders (e.g., municipality, non-government organisations and public) to ensure that the population of crowned eagles in the urban mosaic landscape of Durban are protected. Furthermore, educating people more about climate change and its effects could be vital not only for crowned eagles but also for biodiversity conservation.

Although our results indicated that the extinction of the crowned eagle population could happen in 100 years, our results also showed that the probability of being viable for several years was also high, especially when catastrophic events which are detrimental to survival are not frequent. The low reproductive rate of raptors influences population growth seen in several raptor populations (Amar et al., 2018). Our results showed that from model scenario 1 to model scenario 4, the population of crowned eagles was increasing, but the population growth rate was relatively low. However, for model scenario 5 where the thunderstorm frequency was high, the population of crowned eagles was declining. The crowned eagle population in the urban mosaic landscape of Durban metropole was sensitive to thunderstorms, and we strongly believe that the increase and decrease in the crowned eagle population were mainly influenced by the frequency of thunderstorms and low reproduction rate. However, the parameters set for the different model scenarios could have been influential in the number of surviving individuals in the different models. For example, for model scenario 1, 90% of males and females are involved in reproduction, which would mean that the chances of most individuals surviving are high compared with model scenario 5 when only 50% of males and females are breeding.

One of the limitations to the population viability analysis of crowned eagles is the possibility of putting juvenile females or males in the wrong category (i.e., life stage) when setting model parameters. This is because it is very difficult to distinguish crowned eagle males from females (vice versa), especially when they are between 0 – 6 years old (McPherson et al., 2017).

In conclusion, our study investigated the population viability and sensitiveness of the charismatic crowned eagles to thunderstorms in a highly urbanised landscape. Our findings showed that the extinction of the crowned eagle population in the mosaic urban landscape of the Durban metropole could occur in 100 years, especially with the possibility of increasing thunderstorms because of climate change. Our main recommendation for conserving crowned eagles in the mosaic urban landscape of the Durban metropole is the enforcement, education, and practice of climate change mitigation strategies by different stakeholders to reduce climate change impacts.

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5.7 Declarations

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Conflict of interest

The authors declare they have no conflict of interest.

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Consent for publication

All authors gave consent.

Data availability

The data belong to the University of KwaZulu-Natal and are stored there. They are available from the corresponding author upon reasonable request.

Author contributions

MSTM, MMZ and CTD conceptualised the study. CTD sought funding. MSTM collected and analysed the data with assistance from MMZ. MSTM wrote the draft manuscript. The other authors provided editorial input.

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CHAPTER 6

Conclusions

6.1. Overview

Urbanisation is one of the predominant factors contributing to global biodiversity loss, and with the continual extreme growth in the human population size; the survival of several species is seriously threatened and could become extinct (Marzluff 2001; Chace and Walsh 2006; McKinney 2002, 2008; Aronson et al. 2014 Concepción et al. 2015; Reynolds et al. 2019). From a conservation perspective, the increase in the human population has two major implications for biodiversity conservation worldwide. Firstly, the influx of people, particularly in urban areas, basically infer that there would be an increase in anthropogenic activities and landscape transformations and modifications (McKinney 2002; Aronson et al. 2014; UN 2015; Suri et al. 2017; Guneralp et al. 2018; Reynolds et al. 2019). Consequently, the outcome would be that natural environments, which are key for the persistent and thriving of flora and fauna, could be completely lost or fragmented into smaller segments (Andren 1994; Fahrig 2003; Ehlers Smith et al. 2017; Maseko et al. 2020). Secondly, as more people reside and use the landscape for various activities, humans and wildlife species live in close proximity, and interactions between the two are usually unavoidable (Canney et al. 2021; Salom et al. 2021). In most cases, particularly when wildlife species are a threat to humans, domestic species or agricultural crops, negative attitudes and perceptions towards wildlife are inevitable and may result in humans resorting to poisoning and persecuting wildlife species (Thirgood et al. 2005; Naha et al. 2020; Canney et al. 2021; McPherson et al. 2021b).

In recent years, studies have highlighted how human activities and actions negatively affect the persistence and thriving of raptors (Hager 2009; Rullman and Marzluff 2014; McClure et al.

2018; Salom et al. 2021). For instance, the persistence of harpy eagles (*Harpia harpyja*) in the Amazon forests in South America is negatively affected by the loss of habitat and nesting sites because of anthropogenic activities (e.g., deforestation) and persecution, as they are considered to be a threat to livestock (Miranda et al. 2020, 2021).

Therefore, research addressing how human activities and negative attitudes could hinder the long-term success of raptors in both rural and urban landscapes is of vital importance. The overall aim of this study was to contribute to the conservation and understanding of the African crowned eagles (*Stephanoaetus coronatus*, hereafter crowned eagle) population in eThekwini Municipality, KwaZulu Natal, South Africa. The primary objectives were to (i) quantify the occupancy and detection probability of crowned eagles across rural and urban forests, (ii) compare the characteristics of crowned eagle and black sparrowhawk (*Accipiter melanoleucus*) nests (i.e., the height of the tree, nest cover and the positioning of the nest in the tree) with the aim of assessing the potential for nest-site competition between the two species, (iii) determine attitudes and perceptions of eThekwini Municipality residents towards crowned eagles, and (iv) use Population Viability Analysis (PVA) to evaluate how the rise in thunderstorms would affect the population of crowned eagles in eThekwini Municipality.

6.2. Summary of research

Crowned eagles generally depend on forests/woodlands for survival (Sinclair et al. 2011), but there are microhabitats which potentially play a crucial role in their occupancy and detection in these forest/woodland areas. McPherson et al. (2016a, 2019) highlighted some of the factors which could influence occupancy, but the studies only documented forests in urban areas, whereas the present study looked at the occupancy and detection across rural and urban forest areas. In 2019, from

May – August, we conducted monthly point count surveys to record the presence/absence of crowned eagles in 42 survey sites. The surveys were conducted for a period of 1 hour in the morning of days with <4 kph wind speed and no rain. Our results based on AIC weight model selection indicated that forests and the level of disturbance by humans were key variables for the occupancy of crowned eagles. However, forest had a positive influence on the occupancy, whereas disturbance had a negative influence. Furthermore, the top model showed that disturbance, surrounding settlement and roads were key for the detection of crowned eagles; with disturbance having a positive influence and both surrounding settlement and roads having a negative influence (Chapter 2). Further, the results indicated the importance of having exotic tree plantations, which some raptor species use for nesting (see McPherson et al. 2016a; Wreford et al. 2017) (Chapter 2). Therefore, competition for such nesting sites between crowned eagles and other raptors could be detrimental to the persistence of crowned eagles.

The present study then compared nest characteristics (e.g., tree height, distance to water, nest cover) of nesting sites of crowned eagles and black sparrowhawk to investigate whether there could be any competition for nesting sites (Chapter 3). The overall results showed that there was no significant difference in the characteristics of the nests of these two raptors. However, there was a significant difference in the height of trees these two raptors use, with the crowned eagle using relatively tall trees compared with those used by black sparrowhawks (Chapter 3).

Through the use of online surveys and face-to-face interviews, the present study documented the attitudes and perceptions of eThekwini Municipality residents towards crowned eagles (Chapter 4). The results showed that the tolerance of crowned eagles is mainly influenced by spending time in nature, feelings towards crowned eagles and their importance in the environment. Also, the consideration of crowned eagles as a threat to domestic animals was influenced by education, whether there was a previous loss of livestock/pets, feelings towards crowned eagles and their importance in the environment (Chapter 4).

Climate change is another potential threat that could hinder the success and persistence of crowned eagles in the study region. Studies have well documented how climate change will impact avian species, including raptors (McKinney 2008; Wiens 2016; McClure et al. 2018; Maxwell et al. 2018). Through the use of demographic modelling, our results showed that the effects of climate change, which are manifested through a rise in the frequency of torrential rainfalls/thunderstorms, would negatively affect the population of crowned eagles and could possibly lead to extinction (Chapter 5). However, if the number of torrential rainfall events remains relatively low in the study region, there is a good chance that the population of crowned eagles in eThekwini Municipality will be viable for a long period (Chapter 5). Lastly, the persecution and poisoning of raptors can easily be influenced by the negative attitudes and perceptions people have towards them.

6.3. Concluding remarks

Overall, crowned eagles are documented to be persisting and thriving in eThekwini Municipality (see McPherson et al. 2015, 2016a, b, 2019, 2021a, b; Muller et al. 2020; Downs et al. 2021). However, the crowned eagles' numbers in eThekwini Municipality have likely reached an asymptote and could either remain the same or start to decline (Fig. 6.1). One of the major results from the study with regards to the presence of forest/woodland in the study region is that they are crucial for the survival and conservation of crowned eagles, as also highlighted by McPherson et al. (2016a, b, 2019, 2021a, b). In most cases, the attention dedicated to conservation areas in rural landscapes is not the same as that dedicated to conservation areas in urban landscapes. Normally, inadequate resources and costs limit the implementation of effective conservation strategies, thus leading to high rates of poaching and the destruction of natural habitats (Kahler et al. 2012). Consequently, this results in the disturbance of species by either/both dogs (*Canis familiaris*) and humans, which could reduce the probability of occupancy. Therefore, although categorised as a forest/woodland species, the occupancy and detection of crowned eagles, especially in rural forest/woodland areas, indicate that all the forests in eThekwini Municipality are key for their persistence, thus they also require special attention so that they can also play a key role in the conservation of crowned eagles. Although there was no indication of direct competition for nesting sites, this should be closely monitored, especially because of the removal of exotic tree plantations (also preferred for nesting by both crowned eagles and black sparrowhawks) by government programmes such as working for water (see WFW, 2009).

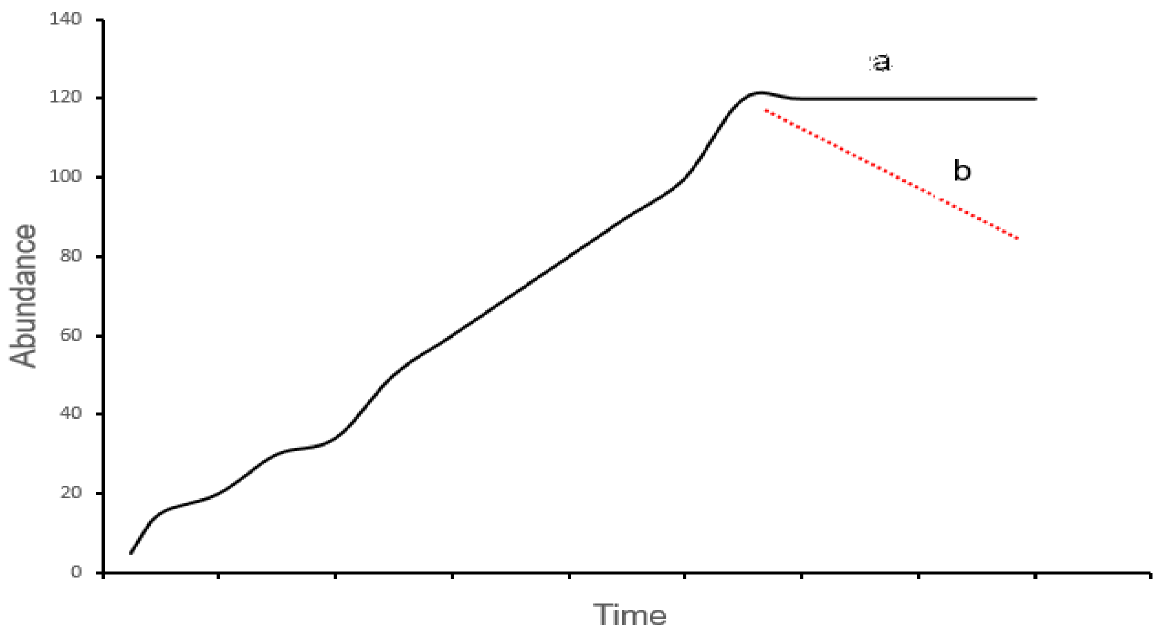

Fig. 6.1. The possible representation of crowned eagles' population numbers in eThekwini Municipality and what could happen over time. (Modified from Downs et al. 2021). The abundance has likely reached an asymptote and could either be constant (a) or decline (b) over time.

Future climate change projections for eThekwini Municipality indicate that there will be a rise in the number of torrential rainfall events, and these will have detrimental impacts on the region's infrastructure, biodiversity and agriculture (and food security) (Roberts and O'Donoghue 2013). In April 2022, the study region was affected by torrential rainfalls, and unfortunately, this resulted in more than 300 people losing their lives (see Burke 2022). The debate of whether climate change is real or not should stop, especially with the present clear signs and evidence of increased numbers of extreme weather events in eThekwini Municipality. The present study highlighted that these extreme weather events (i.e., torrential rainfalls/thunderstorms) will have a negative impact on crowned eagles' persistence. In addition, climate change will affect the survival of several species in the study region. Hence, urgent adaptation and enforcement of climate change mitigation strategies by government and municipalities are important.

6.4 Recommendations for future studies

In our study region, we have observed and received reports of Egyptian geese (*Alopochen aegyptiaca*) occupying nests previously used by crowned eagles. Egyptian geese are abundant in South Africa and continue to increase in number annually (Little and Sutton 2013; Thompson et al. 2017). Their behaviour of occupying crowned eagles' nests could lead to direct competition for nests that could be detrimental to the persistence and thriving of crowned eagles. Secondly, during face-to-face interviews, some residents mentioned that crowned eagles' body parts are used for 'strong' traditional medicine (*muthi*). However, the residents were either uncertain or could not provide the specific medicine name or its use. Therefore, studies should be expanded in future research to interview traditional healers and traditional medicine traders about their attitudes and perceptions, what traditional medicine each crowned eagle body part is used for, and how frequently people buy that particular medicine. Furthermore, visits to local *muthi* trade spots should be done to confirm the presence (and thus potential use) of particular crowned eagle body parts for *muthi* purposes.

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