Aspects of the ecology of invasive rose-ringed parakeets (*Psittacula krameri*) in eThekwini Metropolitan, KwaZulu-Natal Province, South Africa

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GENERAL ABSTRACT

Globally, the rose-ringed parakeet *Psittacula krameri* (Scopoli, 1769) has been cited as one of the world's worst gregarious invasive parrot species, having established breeding colonies successfully outside its native distribution range. The rapid expansion of its breeding population has been considered a major threat to the economy, agricultural production, biodiversity, human health and social life. To date, the rose-ringed parakeet's population has been reported in *ca.* 35 countries and the pet trade is the main introduction pathway of this species across the globe. In South Africa, rose-ringed parakeets were introduced as pets in the 1900s. Their breeding population has successfully established in several cities, particularly in Johannesburg and eThekwini Metropole. Although their population seems to be expanding at an alarming rate, little is currently known about their population size, breeding status, and feeding biology. This includes public knowledge and perception towards them as invasive species. Moreover, impacts (environmental and socio-economic) and areas that are at risk of becoming invaded by rose-ringed parakeets and other selected invasive bird species are unknown.

This study conducted monthly surveys in the greater Durban (eThekwini) Metropole, KwaZulu-Natal Province, South Africa, from August 2018 to December 2019, to determine the rose-ringed parakeet's population size, feeding biology and breeding status. A questionnaire survey was developed to determine the public knowledge and perception of parakeets. The species distribution modelling and Generic Impact Scoring Scheme were also used to investigate areas that are likely to be invaded and potential impacts (environmental and socio-economic) associated with rose-ringed parakeets, and other selected introduced bird species. A total of five major roost sites with an overall mean monthly population size of 1,783 rose-ringed parakeets were located. Most of these roost sites were found around urban (public) parks and shopping centres. Seven bird species were found sharing communal roosting sites

with rose-ringed parakeets, with the common myna *Acridotheres tristis* recorded the most. We identified 72 nests within 39 breeding sites, with the first breeding season accounting for 53 active nests and the second breeding season with 59 active nests. Rose-ringed parakeets used four tree species for nesting, with white milkwood *Sideroxylon inerme* being the most preferred tree species (71%). The recorded rose-ringed parakeet fledglings ranged between 1 – 3 per nest, and their numbers differed significantly between the seasons. A total of 63 feeding sites were identified, with most of them in the urban built land-use cover type. Rose-ringed parakeets were observed feeding on 31 fruiting/flowering trees and one insect species, with fleshy fruits (58%) and flowers (19%) primarily relied on. For our survey questionnaire, a total of 312 participants responded to the survey, with 92.5% being familiar with parakeets. A large population of rose-ringed parakeets were seen in shopping centres (38.5%), suburbia (26.3%), and golf courses (19.6%). Most survey respondents (58.3%) indicated that they provide feeding stations for these parakeets, and 57.7% did not consider them pests. In terms of invasion risk, the rose-ringed parakeets were found to have large areas in South Africa with high climatic suitability, and their impacts were both socio-economic and environmental. Agricultural production was the main impact through socio-economic, while competition and impact on other animals were the main environmental impacts.

In general, this study showed continuous growth in the rose-ringed parakeets' numbers in eThekwini Metropole, indicating that their population is breeding at an average rate. Our study also showed that rose-ringed parakeets feed on various food items, suggesting that they are generalist-opportunistic feeders. As a result, this plasticity in feeding behaviour may likely enhance competitive interactions with other species, contribute to seed dispersal, and increase damage to crops. Parakeets are not perceived as pests by most of the respondents in the eThekwini Municipality. This positive perception may have been exacerbated by the public's poor knowledge regarding their impacts on biodiversity, economy, human social life, and

health. Therefore, we recommend introducing environmental education, which involves the engagement with the community members and eThekwini Municipality. This may assist in making an informed decision regarding the control of this species in the area. Monitoring of rose-ringed parakeet's population size, breeding status, feeding biology, and movement patterns should continue so that adequate information can be acquired on their biology. In conclusion, our results highlight the importance of studying rose-ringed parakeet's ecology, which provides reliable data that can be considered in decision-making, management and eradication plans for parakeets in South Africa.

Keywords: biological invasions; fledging; competition; feeding patterns; public perceptions, climatic matching, impact assessment

PREFACE

The data described in this thesis were collected mainly in eThekwini Municipality, KwaZulu-Natal Province, Republic of South Africa, from September 2018 to December 2019. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under Prof Colleen T. Downs' supervision.

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

Tinyiko Cavin Shivambu

March 2021

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

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Prof Colleen T. Downs

Supervisor

March 2021

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DECLARATION 1 – PLAGIARISM

I, Tinyiko Cavin Shivambu, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
   a. Their words have been re-written, but the general information attributed to them has been referenced
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DECLARATION 2 - PUBLICATIONS

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

Publication 1: Published in Urban Ecosystems

Population estimates of non-native rose-ringed parakeets *Psittacula krameri* (Scopoli, 1769) in the Durban Metropole, KwaZulu-Natal Province, South Africa

Tinyiko C. Shivambu, Ndivhuwo Shivambu & Colleen T. Downs

Author contributions: TCS conceived paper with CTD. TCS and CTD sourced funding. TCS and NS collected and analysed data, and TCS wrote the paper. CTD contributed valuable comments to the manuscript.

Publication 2: Published in Journal of Ornithology

Aspects of the feeding ecology of introduced Rose-ringed Parakeets *Psittacula krameri* in the urban landscape mosaic of Durban, KwaZulu-Natal Province, South Africa

Tinyiko C. Shivambu, Ndivhuwo Shivambu & Colleen T. Downs

Author contributions: TCS conceived paper with CTD. TCS and CTD sourced funding. TCS and NS collected and analysed data, and TCS wrote the paper. CTD contributed valuable comments to the manuscript.

Publication 3: In review (Biological Invasions)

Breeding status of invasive rose-ringed parakeets *Psittacula krameri* (Scopoli, 1769) in eThekwini Metropole, KwaZulu-Natal Province, South Africa

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Author contributions: TCS conceived paper with CTD. TCS and CTD sourced funding. TCS and NS collected and analysed data, and TCS wrote the paper. CTD contributed valuable comments to the manuscript.

Publication 4: In review (African Zoology)

Citizen science survey of non-native rose-ringed parakeets *Psittacula krameri* in the Durban Metropole, KwaZulu-Natal, South Africa

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Author contributions: TCS conceived paper with CTD. TCS and CTD sourced funding. TCS and NS collected and analysed data, and TCS wrote the paper. CTD contributed valuable comments to the manuscript.

Publication 5: Published in Biological Invasions

Impact assessment of seven alien invasive bird species already introduced to South Africa

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Author contributions: TCS conceived paper with CTD. TCS and CTD sourced funding. TCS and NS collected and analysed data, and TCS wrote the paper. CTD contributed valuable comments to the manuscript.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

General introduction

1.1 Introduction

1.1.1 Biological invasion

Many non-native species have been translocated around the world accidentally and deliberately by humans from their native to non-native ranges (Mack et al. 2000; Wonham 2006; Hulme 2009; Measey et al. 2017). Over the past 200 years, the rapid expansion in human populations has facilitated an increase in globalisation, resulting in a rapid migration of humans and trade (Mack et al. 2000; Hulme 2009; Menchetti et al. 2016). These have dramatically increased the number of introduced non-native species into new geographic locations (Vitousek et al. 1997; Mack et al. 2000; Hulme 2009; Ellis 2011; Downs & Hart 2020). Many of these non-native species are either introduced for horticulture (Reichard & White 2001), ornamentation (Martin & Coetzee 2011), as part of the pet trade (Shiau et al. 2006; Bertolino 2009; Shivambu et al. 2021), hunting (Hulme 2009), for biological control (Simberloff & Stiling 1996; Fraser et al. 2015; Shivambu et al. 2020a) and food (Shivambu et al. 2020b). The process of introducing species to non-native locations where they establish populations, multiply, spread, and finally negatively impact native flora and fauna is termed biological invasion (Hulme 2009; Blackburn et al. 2011).

Biological invasions have been cited as one of the major problems occurring globally, causing declines in several native species, threatening economies, causing severe ecological instabilities, and transmitting diseases to humans and wildlife (Occhipinti-Ambrogi & Savini 2003; Pimentel et al. 2005; Fèvre et al. 2006; Crowl et al. 2008; Dove et al. 2011; Ahmad et al. 2012; Can et al. 2019; van Wilgen et al. 2020). For example, introductions of birds in Taiwan (Su et al. 2016), Burmese pythons *Python molurus bivittatus* in Florida (Dove et al. 2011), and birds and amphibians into Europe (Strubbe & Matthysen 2009a, b; Kopecký et al. 2013; Hernández-Brito et al. 2018) has led to the successful establishment of these species which subsequently caused a decline in some native species. Biological invasions have also been reported to be a single driver of the extinction of some native species on islands and mainland worldwide (Simberloff 2000; Sax & Gaines 2008; Pyšek et al. 2017). The introduced invasive brown tree snake *Boiga irregularis* caused a rapid decline in Guam forest avifauna by predating on their eggs, chicks, and parent birds during nesting and roosting (Wiles et al. 2003). The brown tree snake and Burmese python have also been reported to threaten the population of native lizards and small mammals in Pacific islands and Everglades National Park, Florida (USA) through predation (Fritts 1988; Dorcas et al. 2012). The rose-ringed parakeets *Psittacula krameri* in southern Spain, and Brussels, Belgium, have also caused a decline to a threatened greater noctule bats *Nyctalus lasiopterus* and nuthatches *Sitta europaea* through food and nest competition (Strubbe & Matthysen 2009b, 2020; Hernández-Brito et al. 2018).

1.1.2 Invasion pathways

The terms "alien", "exotic", "non-native", "non-indigenous", or "introduced species" are often used in biological invasions to describe organisms that have been accidentally or deliberately introduced in a location where they are not native (Williamson & Fitter 1996; Manchester & Bullock 2000). Sometimes, these introduced species may establish feral populations and become unwanted agricultural pests (Lockwood et al. 2019; Trouwborst et al. 2020). The term "feral" refers to cultivated or domesticated species either released or escaped confinement and established wild populations (Manchester & Bullock 2000; Butler 2005). Blackburn et al. (2011) proposed that many introduced species undergo several stages to be considered invasive, namely transport, introduction, establishment, and spread viable propagules. Similarly, most of these introduced species become invasive through one of the main six pathway categories: corridor, unaided, transport (stowaway or contaminant), escape from captivity and release into the wild (see Faulkner et al. 2020 for more details on each category). An example of such a scenario is the introduction of the common pet racoon *Procyon lotor* in Japan, which has established a self-sustaining population because of accidental pet escapes and intentional releases (MacDonald et al. 2017). Other species that have established feral populations include the world worst invasive species, such as common mynas *Acridotheres tristis*, house crows *Corvus splendens*, rose-ringed parakeets, rock doves *Columba livia* and monk parakeets *Myiopsitta monachus* (Downs & Hart 2020). These species were introduced as part of the pet trade, companion animals, biological control, and ornamentations (Avery 2020; Hart et al. 2020; Strubbe & Matthysen 2020; Shivambu et al. 2020a, b). Intentional release of unwanted or abandoned species into the wild have exacerbated unprecedented invasions worldwide, e.g. Burmese pythons, rose-ringed parakeets, marbled crayfish *Procambarus fallax* f. *virginalis*, monk parakeets, and red-eared slider *Trachemys scripta elegans* (MacGregor-Fors et al. 2011; Willson et al. 2011; Ma & Shi 2017; Pârvulescu et al. 2017; Strubbe & Matthysen 2020; Banha et al. 2019).

Some of the worst invasive species were introduced as stowaways or hitchhikers through imported horticultural and agricultural goods and plants, air and ship cargos (Faulkner et al. 2017; Shivambu et al. 2020a; van Wilgen et al. 2020). Examples include harlequin ladybirds *Harmonia axyridis*, house crows, Mediterranean mussels *Mytilus galloprovincialis*, Australasian barnacles *Austrominius modestus*, and Pacific oysters *Magallana gigas* (Work et al. 2005; Kaluza et al. 2010; Faulkner et al. 2017; Harris et al. 2017; Miralles et al. 2018; Shivambu et al. 2020a; Robinson et al. 2020). Understanding the introduction pathways associated with these species may assist in early invasion risk detection and invasive species management (Simberloff et al. 2013; Keller & Kumschick 2017).

1.1.3 Risk assessment

To understand the potential impact that the introduced species might pose, the application of risk assessment is essential (Pheloung et al. 1999; Nentwig et al. 2016; Bacher et al. 2017; Keller & Kumschick 2017; Shivambu et al. 2020c, d). Risk assessment is an evidence-based tool that attempts to identify introduced species with a high likelihood of becoming invasive and impacting biodiversity and humans (Andreu & Vilà 2010; Bacher et al., 2017). Risk assessment has been used in Australia to prevent the introduction of harmful weeds with invasion potential (Pheloung et al. 1999). Risk assessment consists of several components, including traits scoring approaches such as Environmental Impact Classification for Alien Taxa (EICAT) (Hawkins et al. 2015), Generic Impact Scoring System (GISS) (Nentwig et al. 2016) and Socio-Economic Impacts Classification of Alien Taxa (SEICAT) (Bacher et al. 2017), statistical approaches, and rapid screening (Keller & Kumschick 2017). Traits scoring approaches use features (e.g. aggression, harm, high reproduction, establishment and spread) related to the introduced invasive species. Statistical approaches use listed traits which are scored based on the invasiveness of introduced species. Rapid screening tool uses species distribution modelling, climate matching, and information on whether the species have a history of invasion elsewhere (Keller & Kumschick 2017). The species distribution modelling has been widely used to determine the potential climatic and habitat suitability of any introduced species (Thuiller et al. 2005; Keller & Kumschick 2017). These risk assessment protocols have been reported to accurately predict between 85% and 95% of the potential invasiveness of a range of taxa in many parts of world (Keller et al. 2007; Bailey et al. 2011; Burnett et al. 2012).

To date, risk assessment has become one of the essential tool used across the globe to predict the invasion potential of different taxa (Gordon & Gantz 2011; Kumschick & Richardson 2013; Nelufule et al. 2020; Shivambu et al. 2020c, d). For example, risk assessment has been mainly applied for invertebrates, including Harlequin ladybirds *Harmonia axyridis* in Belgium (D'hondt et al. 2015), Quagga mussels *Dreissena rostriformis bugensis* establishing and posing threats to native biodiversity in Britain (Roy et al. 2014), crustacean amphipods *Hyalella* spp. in Canada (Hare et al. 2003), and ants *Solenopsis invicta* and *Linepithema humile* in North America (Kenis et al. 2009). The risk assessment component (impact assessment) was also applied for terrestrial pet invertebrates such as beetles, scorpions, cockroaches, and tarantulas sold as pets in South Africa (Shivambu 2018; Nelufule et al. 2020). However, significantly less has been done on comprehensive risk assessment of invasive vertebrates, including birds globally (Vall-llosera & Sol 2009; Evans et al. 2016; Shivambu et al. 2020c). Moreover, not much has been documented on risk assessment for the introduced vertebrate animals in South Africa (Kumschick & Richardson 2013; Marr et al. 2017; Shivambu et al. 2020c). This includes the comprehensive impact assessment associated with introduced birds in South Africa, including our study species, rose-ringed parakeets. On the other hand, for taxa such as amphibians (van Wilgen et al. 2009), fishes (Marr et al. 2017), small mammals (Shivambu et al. 2020c) and invertebrates (Shivambu 2018; Nelufule et al. 2020), risk assessment has been applied. Risk assessment has been mainly applied for introduced plants than animals in South Africa (Richardson & van Wilgen 2004; Shackleton et al. 2007; Nkuna et al. 2018; Moshobane et al. 2020a). Currently, the International Union for Conservation of Nature (IUCN), government legislators, provincial conservation agencies, and various institutions from different continents have adopted the use of risk assessment as a preventive measure for potential harmful introduced species (Pheloung et al. 1999; Bomford 2008; Bomford et al. 2010; D'hondt et al. 2015; Vanderhoeven et al. 2015). The application of risk assessment has become mandatory in many parts of the world, e.g. Australia, New Zealand, and South Africa (Bomford 2008; Bomford et al. 2010; van Wilgen et al. 2008; Vanderhoeven et al. 2015; Kumschick et al. 2020). In these countries, risk assessment has been applied to screen species imported for agriculture, horticulture, pet trade, and scientific research to avoid their potential impacts (Bomford 2008; Bomford et al. 2010; van Wilgen et al. 2008; Vanderhoeven et al. 2015). In South Africa, the National Environmental Management: Biodiversity Act No. 10 of 2004 (NEMBA) requires that risk assessment be conducted for any non-native species involved in activities such as breeding, convey, display, import, possession, research, release, and selling (van Wilgen et al. 2008; NEMBA 2014; Moshobane et al. 2020b).

1.1.4 The rose-ringed parakeets

Overall, birds are the most introduced taxon compared with other animal taxa, with ~400 bird species reported introduced worldwide (Lockwood 1999; Duncan et al. 2003; Downs & Hart 2020). Amongst these birds, Psittacids (parrots) are cited as the most popular, preferred, and charismatic groups collected worldwide, mainly for ornamentation, companionship and pet trade (Cassey et al. 2004; Weston & Memon 2009; Pires 2012; Menchetti & Mori 2014). Approximately four million parrots are being collected annually from the wild, with an annual profit of US$1.4 billion (Drews 2001; Mori et al. 2013a). Moreover, the population of parrot species is decreasing, with some species vulnerable to extinction in their native ranges because of the illegal collection for pet trade purposes (Drews 2001; Wright et al. 2001; Cassey et al. 2004; Forshaw 2017; Aloysius et al. 2020). On the other hand, about 16% of the collected live parrot species have successfully established self-sustaining populations outside their native ranges (Menchetti & Mori 2014; Symes 2014; Uehling et al. 2019; Downs & Hart 2020). There are specific characteristics that influence the potential establishment of introduced non-native parrot species. This includes the ability to feed on a wide range of food items, tolerating a wide environmental range, being highly synanthropic, and the ability to proliferate from a single breeding pair to multiple breeding pairs within a short space of time (Duncan et al. 2003; Cassey et al. 2004; Menchetti & Mori 2014; Shivambu et al. 2020e; Strubbe & Matthysen

2020). Examples of parrot species that are well established and producing self-sustained populations at an alarming rate include the monk and rose-ringed parakeets (Butler 2003; Strubbe & Matthysen 2009a; Hobson et al. 2017; Avery 2020; Shivambu et al. 2020e; Strubbe & Matthysen 2020; Mori & Menchetti 2021; Viviano & Mori 2021).

This study focused on the introduced rose-ringed parakeet (*Psittacula krameri* Scopoli, 1769) known to have established in South African suburban areas through the pet trade (Hart & Downs 2014; Symes 2014; Shivambu et al. 2020f). The alternative common names for rose-ringed parakeet include ring-necked parakeet, African ring-necked parakeet, or Indian ring-necked parrot (Kinzelbach 1986; Forshaw 2010; Strubbe & Matthysen 2020). The rose-ringed parakeet is primarily distributed in the Indian subcontinent and tropical regions across sub-Saharan Africa (Forshaw 2010; Strubbe & Matthysen 2020). The rose-ringed parakeet is one of the world's worst gregarious invasive parrot species, with successfully established breeding populations outside its native distribution range (Strubbe & Matthysen 2007; Forshaw 2010; Newson et al. 2011; Strubbe & Matthysen 2020). It belongs to the family Psittacidae with four recognised subspecies, two from Asia (*Psittacula krameri borealis* and *P. k. manillensis*) and the other two from Africa (*P. k. krameri* and *P. k. parvirostris*) (Forshaw 2010; Strubbe & Matthysen 2020). The African subspecies are slightly smaller than those of Asian origin (Ali & Ripley 1969; Forshaw 1978, 2010; Strubbe & Matthysen 2020).

The rose-ringed parakeets were first introduced to Europe around 300 BC, mainly from Asia (Pakistan, Punjab regions) during the Roman Empire (Strubbe & Matthysen 2020). In those eras, the rose-ringed parakeets became the most charismatic and popular parrot widely kept as pets and were used by the military as messengers during the war and for religious purposes (Verdi 2007; Heald et al. 2019; Strubbe & Matthysen 2020). The first established breeding population of rose-ringed parakeets in Europe was reported in Kent, United Kingdom, during the 1960s (Pithon & Dytham 2002; Butler 2003; Lever 2005; Heald et al. 2019; Strubbe

& Matthysen 2020). The population of this species later expanded across the European countries, including its islands, mainly because a large number of parakeets were imported for pet trade from Asia and Africa between 1985 and 2005 (Strubbe & Matthysen 2009a; Butler et al. 2013; Menchetti et al. 2016; Grandi et al. 2018; Souviron-Priego et al. 2018; Heald et al. 2019; Rocha et al. 2020). The breeding population of parakeets in the European Union and the Mediterranean were imported through different corridors, e.g. the African rose-ringed parakeets were introduced via Senegal, while those from Asian regions were from Pakistan, Nepal, and India (Cardador et al. 2016; Pârâu et al. 2016; Heald et al. 2019: Strubbe & Matthysen 2020). A large feral population of rose-ringed parakeets in the European countries to date are of Asian descendants (Jackson et al. 2015), suggesting potential impacts and invasion by Asian parakeets as they are known to cause severe impacts and multiply rapidly (Azbdul & Ahmad 1983; Ahmad et al. 2012).

The breeding populations of rose-ringed parakeets are currently reported in *ca.* 35 countries (Strubbe & Matthysen 2009b; Hobson et al. 2017; Strubbe & Matthysen 2020). In Africa, the populations of rose-ringed parakeets have thrived in countries such as South Africa, parts of Namibia and Mauritius (Jones 1980; Hart & Downs 2014; Symes 2014; Shivambu et al. 2020f). In Europe, it has primarily invaded parts of Germany, Belgium, France, Italy, Spain, and the United Kingdom (Strubbe & Matthysen 2009a; Clergeau & Vergnes 2011; Butler et al. 2013; Fraticelli 2014; Pârâu et al. 2016; Strubbe & Matthysen 2020; Viviano & Mori 2021). Although there is insufficient global demographic data for rose-ringed parakeets, Pârâu et al. (2016) estimated a population of 85,120 parakeets in Europe alone with over 80 breeding colonies. In the Middle East and Asia, the population of rose-ringed parakeets have successfully invaded Israel, some parts of Japan, Thailand, and Indonesia (Lever 2005; Abdillah & Iqbal 2016; Menchetti et al. 2016; Yosef et al. 2016; Strubbe & Matthysen 2020). In the Americas, the growing population of rose-ringed parakeets have established in

California, Florida, and Hawaii Island (USA), while in Caracas (Venezuela), the general population is unclear (Nebot 1999; Burgio et al. 2016; Shiels et al. 2018; Uehling et al. 2019; Shiels et al. 2020). All the invaded areas have climatic conditions different to those of rose-ringed parakeet native ranges (Kottek et al. 2006; Metzger et al. 2013), making this bird one of the most successful avian global invader (Butler 2003, 2005; Ahmad et al. 2012; Menchetti et al. 2016; Strubbe & Matthysen 2020).

1.1.5 Impacts associated with rose-ringed parakeets

For a species to successfully establish self-sustaining populations after their first introduction into new environments, several invasion stages need to be undertaken, which sometimes can take some decades (Zocchi & Panella 1978; Keikl 2001; Lockwood et al. 2005; Blackburn et al. 2011). If they persist, many can rapidly increase their population and become invasive (Keikl 2001; Strayer et al. 2006; Davis 2009). On the contrary, the rose-ringed parakeets have displayed rapid expansion after their introduction, resulting in them exerting significant impacts on biodiversity, human activities, and health (Butler et al. 2013; Menchetti & Mori 2014; Strubbe & Matthysen 2009a; Shivambu et al. 2020f; Strubbe & Matthysen 2020; Mori & Menchetti 2021; Viviano & Mori 2021). The most recorded impact associated with rose-ringed parakeet is competition with native birds for nesting sites, space and food (Strubbe & Matthysen 2009b; Menchetti et al. 2016; Hernández-Brito et al. 2018; Strubbe & Matthysen 2020). During the breeding season, rose-ringed parakeets have demonstrated aggressive territorial behaviour towards native species approaching their nests (Strubbe & Matthysen 2009b; Menchetti et al. 2016; Hernández-Brito et al. 2018). For example, fatal attacks were observed on smaller birds and mammals, including the house sparrow *Passer domesticus*, blue tits *Cyanistes caeruleus*, the greater noctule bats, Leisler's bat *Nyctalus leisleri*, Savi's pipistrelle *Hypsugo savii* and black rat *Rattus rattus* in Italy and Spain (Hernández-Brito et al.

2014a; Menchetti et al. 2014; Covas et al. 2017; Hernández-Brito et al. 2018; Viviano & Mori 2021). The rose-ringed parakeet is also associated with lethal attacks on Italian red squirrels *Sciurus vulgaris italicus*, little owls *Athene noctua*, common kestrels *Falco tinnunculus* and some Corvids in Italy, France, and the UK (Cramp 1985; Dubois 2007; Mori et al. 2013b; Menchetti et al. 2014). Although it was initially thought implausible, rose-ringed parakeets were documented to mob large birds such as herons and seagulls in France (Dubois 2007). The active fatal attacks by rose-ringed parakeets on native species from their ranges are suggested to trigger conservation problems, particularly for threatened species such as the greater noctule bats and Leisler's bat (Menchetti et al. 2014; Hernández-Brito et al. 2014b).

Rose-ringed parakeets are secondary cavity nesters, using nests excavated by other bird species (Weissenbacher & Allan 1985). Consequently, they compete with native secondary hole-nesters such as tits, nuthatches, and doves for nests (Strubbe & Matthysen 2009b; Hernández-Brito et al. 2014b; Hernández-Brito et al. 2018). To date, nest displacement or destruction by rose-ringed parakeets have been documented in Europe (Cramp 1985; Hernández-Brito et al. 2014b), Israel (Shwartz et al. 2008), and Venezuela (Nebot 1999). It has been reported that the size of the nest excavated by native birds can be enlarged and elongated by rose-ringed parakeets to create a suitable nest, avoid predators and competition (Orchan et al. 2012; Menchetti et al. 2016). This behaviour has negatively affected the breeding success of native cavity-nesters (Menchetti et al. 2014; Hernández-Brito et al. 2018; Strubbe & Matthysen 2020). For example, the numbers of native threatened greater noctule bats and Leisler's bats have been negatively affected by an increased breeding population of rose-ringed parakeet in urban parks of Spain (Menchetti et al. 2014; Hernández-Brito et al. 2018). On the contrary, an increase in the nest holes used by parakeets has accelerated the breeding success of invasive common myna in Tel-Aviv, Israel (Orchan et al. 2012).

Although there is less information on the impacts of rose-ringed parakeets on flora, it has been reported to strip the bark of native trees, sometimes affecting the trees' development (Fletcher & Askew 2007; Klug et al. 2019a, b). The rose-ringed parakeet is an opportunistic generalist feeder, feeding on various food items (Juniper & Parr 1998, 2010; Newson et al. 2011; Perrin & Cowgill 2005; Shivambu et al. 2020e). Their dietary items include seeds, leaves, twigs, fruits (ripe and unripe) and flowers (Newson et al. 2011; Shiels et al. 2018; Klug et al. 20192019a, b; Shivambu et al. 2020e). Defoliation by rose-ringed parakeets on native and ornamental trees may result in death, malformation and affect carbon allocation, which reduces plants growth (Van Kleunen et al. 2010; Wiley et al. 2013; Shivambu et al. 2020e). This feeding behaviour may reduce food availability and enhance competition with native birds (Fletcher & Askew 2007; Peck et al. 2014). Although the direct effects of rose-ringed parakeets' faecal chemical composition on flora have never been assessed, this species' faecal droppings may alter understory vegetation communities and structure (Fletcher & Askew 2007). Studies by Thabethe et al. (2015) and Shiels et al. (2018) indicated that ingested smaller seeds of invasive white mulberry *Morus alba* and guava *Psidium guajava* germinated after passing through the gut of rose-ringed parakeets. This suggests that this species can potentially spread these invasive species. Other studies suggested that this species and other parrot species may carry seeds on their beaks and feathers for a distance, therefore adding to those plant species' dispersal (Tella et al. 2015; Blanco et al. 2016). It is suggested that more qualitative studies on the role of seed dispersal by Psittaciformes species are lacking. Therefore, documenting these interactions would be of great importance in terms of the role of rose-ringed parakeets on seed dispersal, especially of non-native plant species.

Damage by rose-ringed parakeets to human activities has been mainly associated with agriculture (Azbdul & Ahmad 1983; Van Kleunen et al. 2010; Ahmad et al. 2012; Shiels et al. 2018, 2020; White et al. 2021). In the United Kingdom, parakeets were previously considered urban birds but are now found in some rural settings (Butler 2003). This is of great concern as they are recognised agricultural pests in their native range and introduced ranges (Azbdul & Ahmad 1983; Strubbe & Matthysen 2009a; Ahmad et al. 2012; Shiels et al. 2018, 2020). The introduced invasive rose-ringed parakeets have caused colossal damage to the crops in Pakistan and Egypt worth US$15 million (Azbdul & Ahmad 1983; Ahmad et al. 2012; Klug et al. 2019b). In countries such as Britain, Germany, Hawaii, Pakistan, and India, the rose-ringed parakeets have negatively damaged crops of importance, sometimes feeding on them until resources were depleted (Azbdul & Ahmad 1983; Reddy 1998; Iqbal et al. 2000; Butler 2003; Tayleur 2010; Van Kleunen et al. 2010; Ahmad et al. 2011, 2012; Shiels et al. 2018). Examples include crops such as almonds *Prunus dulcis*, apples *Malus domestica*, *Citrus* spp., cherries *Prunus cerasus*, guavas *Psidium guajava*, sorghum *Sorghum bicolor*, sunflower heads *Helianthus annuus*, grapevines *Vitis* spp., peas *Pisum sativum*, pistachios *Pistacia vera*, mangos *Mangifera indica*, and maize *Zea mays* (Reddy 1998; Iqbal et al. 2000; Butler 2003; Tayleur 2010; Van Kleunen et al. 2010; Ahmad et al. 2011, 2012; Mentil et al. 2018; Shiels et al. 2018). Although detailed economic damage by parakeets has been understudied, the damage (5% – 23.3%) caused by parakeets on sunflowers in Pakistan is worth ~US$1.95 million annually (Khan & Ahmad 1983). In Germany, the damage of between 10% and 15% on grapevines is worth ~US$679,91 per annum (Fletcher & Askew 2007; Van Kleunen et al. 2010), and 30% damage on almonds in southern Europe has been reported (Mentil et al. 2018). The impacts caused by rose-ringed parakeets on crops outside their native ranges have been reported mainly in European countries, although little has been studied on their economic impacts (Dubois 2007; Latsoudis 2007; Fletcher & Askew 2007; Tayleur 2010; Van Kleunen et al. 2010). Most of these cultivated fields, orchards, and farms are often close to urban habitats, which are often linked with the potential invasion and crop predation by rose-ringed parakeets (Iqbal et al. 2000; Dubois 2007; Czajka 2011; Ahmed et al. 2012; Shivambu et al.

2020e). An increase in the human population, particularly in areas close to agricultural areas, may aggravate further establishment, invasion risk and the further introduction of rose-ringed parakeets.

The rose-ringed parakeet poses health risks to humans as it has been reported to be a reservoir of several transmittable bacterial and viral diseases (Desmidt et al. 1991; Morgan et al. 2000; Piasecki et al. 2012; Mori et al. 2018). The bacterial and viral diseases primarily associated with parakeets include avian influenza, erysipelas, salmonellosis, pseudotuberculosis, pasteurellosis, tuberculosis, and psittacosis (Gismondi 1991; Runde et al. 2007; Menchetti & Mori 2014; Mori et al. 2018). These diseases' main transmission pathway is direct contact with infected parakeet droppings and saliva through bites (Gismondi 1991; Mori et al. 2018). Practices such as unhygienic handling, inbreeding, poor transportation conditions, and uncleaned cages have increased the spread of pet parrot diseases (Morgan et al. 2000). The two respiratory diseases, avian influenza and psittacosis, are known to have a high potential risk to human health and other birds (Gregory & Schaffner1997; Runde et al. 2007). For example, influenza virus H9N2 was isolated from pet rose-ringed parakeets imported from Pakistan to Japan between 1997 and 1998 (Mase et al. 2001). Other studies also revealed that many traded parrot species tested positive for Chlamydophila, which implies transmission between traded parrots and other caged bird species, e.g. chukar partridges *Alectoris chukar* and rock doves *Columba livia* (Erbeck & Nunn 1999; Menchetti & Mori 2014; Krawiec et al. 2015). Psittacine beak and feather disease was detected in free-ranging rose-ringed parakeets in England, Britain, and six South African locations using Polymerase Chain Reaction (Kondiah et al. 2006; Sa et al. 2014). As a result, this may pose a threat to captive Psittaciform species and other wild birds (Sa et al. 2014; Mori et al. 2018). For example, Fanchette (2012) reported that bacteria and viral diseases carried by introduced rose-ringed parakeets are likely to affect native parrot species such as Vasa parrot *Coracopsis nigra* in Mahé Island, Seychelles and possibly other invaded islands.

1.1.6 Control practices for introduced rose-ringed parakeets

The population size of rose-ringed parakeets is increasing across the globe; thus, several countries have implemented different control measures for this species (Menchetti & Mori 2014; Lambert et al. 2017; Luna et al. 2019; Strubbe & Matthysen 2020). In Mahé Island, Seychelles and Canary Islands, La Palma, rose-ringed parakeets were successfully removed between 2013 and 2017 by trapping and shooting (Bunbury et al. 2019; Saavedra & Medina 2020; Strubbe & Matthysen 2020). Shooting has also been used to control parakeets in Kauai, Hawaii Island, particularly in agricultural croplands, but this method did not reduce the population size of this bird species (Gaudioso et al. 2012). Live traps have also successfully reduced the emerging population of rose-ringed parakeets in Ghent city, Belgium (Strubbe & Matthysen 2020). The removal of parakeets is also expensive (Klug et al. 2019b; Rocha et al. 2020). For example, in Mahé Island alone, the removal of 548 individuals, which took roughly five years, resulted in the government of Seychelles incurring costs of up to US$1 million (Klug et al. 2019b; Rocha et al. 2020). In the Canary Islands, La Palma, a total of US$55,962.10 was spent in eradicating only 175 individuals of rose-ringed parakeet between 2015 and 2018 (Saavedra & Medina 2020). Although there is no recent evidence of eradicating rose-ringed parakeets in the UK, Diazacon has been shown to effectively reduce captive parakeets' fertility (Lambert et al. 2010). However, controlling rose-ringed parakeets became a challenge, mainly because of the public objections to the proposed control measures (Menchetti et al. 2016; Lambert et al. 2017; Luna et al. 2019; Rocha et al. 2020). For example, in Britain and Spain, some of the residents, ecologists, bird watchers, and environmentalists are against rose-ringed parakeets' culling (Bertrand 2016; Oliver 2017; Luna et al. 2019; Williams 2021).

1.2 Rose-ringed parakeets in South Africa and motivation for the study

Rose-ringed parakeets were first introduced to South Africa in the 1900s, their populations established subsequently in the 1970s in urban areas, particularly around human habitats (Perrin & Cowgill 2005; Roche & Bedford-Shaw 2008; Hart & Downs 2014; Symes 2014; Ivanova & Symes 2019; Shivambu et al. 2020f). Their population size has increased in recent years, with many introduced as part of pet trade or companion species (Hart & Downs 2014; Symes 2014; Ivanova & Symes 2019; Shivambu et al. 2020f). Pet trade has been rendered the main introductory pathway for rose-ringed parakeets and has facilitated their establishment in South African cities, e.g. Cape Town (Dean 2000), Durban (Hart & Downs 2014; Shivambu et al. 2020f), Johannesburg (Roche & Bedford-Shaw 2008; Whittington-Jones 2017), and Pretoria (Symes 2014). Although relatively little is known about the trade volume of rose-ringed parakeets, the pet trade has resulted in unwanted release and accidental escapees of confined parakeets, forming a large feral population in urban areas, particularly in suburban areas (Symes 2014; Whittington-Jones 2017; Ivanova & Symes 2019; SABAP2 2020; Shivambu et al. 2020f). To date, the individuals of rose-ringed parakeets appear to be expanding in South Africa, predominantly across suburban areas of KwaZulu-Natal and Gauteng Provinces (Hart & Downs. 2014; Ivanova & Symes 2019; SABAP2 2020; Shivambu et al. 2020f). For example, a recent study by Whittington-Jones (2017) reported about 2,000 parakeets only in Johannesburg, Gauteng Province, between 2005 and 2016. The feral population of rose-ringed parakeets in KwaZulu-Natal Province, eThekwini Municipality, have been reported to expand (Hart & Downs 2014; SABAP2 2020). However, the previous study did not estimate the number of parakeet individuals in the reported sites, and the study suggested that the population trends and distribution of this species in South Africa are largely anecdotal (Hart & Downs 2014). Therefore, it is important to determine the population size of rose-ringed parakeets and their current distribution in urban landscape mosaic of eThekwini

Municipality. The outcome of this may be used in the management practices of this species in South Africa.

The breeding success of rose-ringed parakeets is the main contributing factor to their rapid expansion (Strubbe & Matthysen 2007; Butler et al. 2013), and they have contributed to the loss of biodiversity (Menchetti et al. 2016; Hernández-Brito et al. 2018; Strubbe & Matthysen 2020). Although the occurrence status of rose-ringed parakeets is known in South Africa (Symes 2014; Whittington-Jones 2017; Ivanova & Symes 2019; SABAP2 2020), there are relatively no information on their breeding biology in the country thus far. It is, therefore, empirical to determine the rose-ringed parakeets breeding status to fill this research knowledge gap. Therefore, the study will contribute significantly to understanding rose-ringed parakeet's population trends and inform decisions on their population control in South Africa.

The rose-ringed parakeets are generalist feeders, mainly feeding on seeds, fruits (ripe and unripe), flowers, and insects, including larvae (Juniper & Parr 1998; Perrin & Cowgill 2005). Although other studies have documented the feeding biology of rose-ringed parakeets (Azbdul & Ahmad 1983; Reddy 1998; Iqbal et al. 2000; Ahmad et al. 2011, 2012; Shiels et al. 2018), in South Africa, studies on the feeding biology of this species in the wild are lacking. However, Thabethe et al. (2015) documented the germination success of invasive plant seeds ingested by rose-ringed parakeets in South Africa. This is very important as parakeets' feeding behaviour has been documented to affect crops negatively, distress regeneration of native plants, likely to disperse seeds, and reduce the availability of food and thus increase competition with native birds (Fletcher & Askew 2007; Tella et al. 2015; Blanco et al. 2016; Shiels et al. 2018).

Although rose-ringed parakeets are primarily associated with negative impacts (Fletcher & Askew 2007; Ahmad et al. 2012; Strubbe & Matthysen 2020; Hernández-Brito et al. 2018), they are still considered charismatic species by the public (Hart & Downs 2015; Luna et al. 2019). As a result, human perceptions towards charismatic species such as invasive rose-ringed parakeets are likely to increase management related conflicts, impeding control practices (Luna et al. 2019). In South Africa, studies documenting public perceptions towards rose-ringed parakeets are lacking; therefore, acquiring this information may provide reliable data that can be used on public engagement and appropriate management of non-native invasive species.

In South Africa, there is legislation that protects native biodiversity from harm – the National Environmental Management: Biodiversity Act No. 10 of 2004 (NEMBA 2009). This legislation publishes a list of prohibited species, including rose-ringed parakeets (NEMBA 2009, 2016). The rose-ringed parakeet is listed in NEMBA under Category 2, which allows the species to be imported to the Republic of South Africa only when the permit has been issued (NEMBA 2016). The permits for parakeets are acquired for breeding, selling, possession, and transportation (NEMBA 2016; Moshobane et al. 2020b). Consequently, this may increase further introduction and dispersal of this species should the public not comply and release some of the unwanted captive parakeets. However, the permits for rose-ringed parakeets continue to be issued (see Moshobane et al. 2020b), although this species' population is expanding across South African urban landscapes (Dean 2000; Roche & Bedford-Shaw 2008; Symes 2014; Whittington-Jones 2017).

1.3 Aims and objectives

The general aim of this study was to investigate the aspects of the ecology of introduced rose-ringed parakeets (including bird species that roost or feed with them in some instances) in the eThekwini Metropole, KwaZulu-Natal Province, South Africa. The study had five main objectives:

1. To conduct monthly surveys to determine the population size, roost sites, and bird species that communally roost with rose-ringed parakeets in eThekwini Municipality. This was to estimate the relative number of parakeets and their occupancy in the urban landscapes of KwaZulu-Natal for possible control measures that the municipality is putting in place. We predicted that a large flock of rose-ringed parakeets would be located in urban landscapes, primarily in areas dominated by humans. We also predicted that rose-ringed parakeets would be sharing the roost sites with bird species occurring in the Durban Metropole, particularly non-native bird species, given that previous studies have shown them to interact with non-native birds (Gadgil 1972; Vasundriya Ranjana & Acharya 2019).
2. To locate breeding colonies of rose-ringed parakeets to determine their breeding status. Artificial nest boxes were placed to determine the occupancy between parakeets and native bird species. We predicted that the number of fledgling chicks would differ between the breeding seasons, and parakeets would occupy more artificial nests than native birds. We also predicted that tree traits such as canopy cover, diameter at breast height, the height of the nest above the ground, tree heights and nest entrance diameter would affect parakeet breeding site selection.
3. To determine the distribution of rose-ringed parakeets feeding sites and their related land-use type. The type of diet consumed by parakeets was assessed, including the patterns of associations in their diet across the seasons and interaction between different tree species fed on by parakeets and other bird species. We predicted that food items consumed by rose-ringed parakeets would differ across the seasons. We further predicted that most of the feeding sites would be primarily distributed in human-transformed habitats. Because parakeets are known to be superior

competitors, it was predicted that they would dominate most of the feeding sites compared with native or other non-native bird species.

4. To conduct an online questionnaire survey to determine the rose-ringed parakeet's sightings and associated impact on native birds. It was also determined whether residents provide supplementary food to parakeets, and the general public perceptions towards eradicating parakeets. We predicted that the general public would have knowledge about rose-ringed parakeets' existence and the impacts they pose on native birds, and many would provide supplementary feeders for them. We also expected that the general public would oppose the control of rose-ringed parakeets, particularly those who see them as charismatic.
5. To conduct species distribution modelling to determine climatically suitable areas for rose-ringed parakeet and other introduced non-native bird species in eThekwini Municipality. The Generic Impact Scoring Scheme was also used to assess the potential impacts (environmental and socio-economic) associated with rose-ringed parakeets and other selected bird species. We predicted that birds with wide natural distribution and worldwide success as an invasive species would have large potential climatic suitability covering in South Africa. Furthermore, we predicted that their impacts would be mostly socio-economic than environmental.

1.4 Description of study areas

This study was conducted in the greater eThekwini Metropole situated in KwaZulu-Natal Province on the east coast along the Indian Ocean (Fig. 1.1). The municipality spans an area of roughly 2,291 km^2. It is the home of approximately 3.5 million people of multiracial origins, of which most are African (71%), followed by Indian (19%), White (8%), and Coloured (2%) (EThekwini Municipality 2013; Chetty 2014). The annual human population growth rate is at

1% (ECPDP 2015), resulting in the municipality predominantly populated with urban structural residents surrounded the mid-city, Durban (Turco et al. 2003; Chetty 2014). Although the municipality faces environmental, economic, social injustice and governance challenges, it is considered one of the largest cities in South Africa, contributing a larger portion of its GDP (Chetty 2014; Todes 2014). It is also one of the cities with large ports of entry for a trade where goods are imported and exported, and it is also a home of many pet stores and plant sale outlets selling diverse non-native animal and plant species (Turco et al. 2003; Shivambu et al. 2021).

The climatic conditions in this area are sub-tropical (hot and moist), with an average summer temperature of 24 °C and winter temperature of 17 °C, and the annual precipitation is approximately 947 millimetres (http://en.climate-data.org/location/27097/). The municipality consists of permeable soils (clastic sedimentary), making it a very wet and moist region (Fairbanks & Benn 2000; Hlanguza 2015). The municipality consists of eight functional vegetation types: Northern Coastal Forest, Mangrove Forest, Scarp Forest, Eastern Valley Bushveld, Ngongoni Veld, KwaZulu-Natal Hinterland Thornveld, KwaZulu-Natal Sandstone Sourveld, and KwaZulu-Natal Coastal Belt (Fairbanks & Benn 2000; McLean et al. 2016; Zungu et al. 2019). Consequently, it has relatively high biodiversity, both terrestrials and aquatic (e.g. 2,267 plant species, 526 birds, 82 mammalians, 69 reptilians, and 37 amphibians reside in this area; McLean et al. 2016). Although most of the areas are reserved for human settlement, approximately 75,000 ha of protected land is demarcated as part of the Durban Metropolitan Open Space System (D'MOSS) (Roberts 1994; Adams 2005). The D'MOSS comprises areas of conservation value such as parks, sports fields, nature reserves, botanical gardens, and golf courses that provide sustainable habitats to flora and fauna and improve living standards among urban residents (Roberts 1994; Adams 2005; Zungu et al. 2019). However, these open green spaces also serve as a refuge for the invasive non-native species such as common myna, rose-ringed parakeets, house crow, rock dove, and encroachment by invasive plants (Hart & Downs 2015; Adam et al. 2017; Mugwedi et al. 2017; Downs & Hart 2020). The functional native vegetation and biodiversity within D'MOSS areas may be lost if not protected from habitat degradation and introductions of invasive species (Mugwedi et al. 2017; Zungu et al. 2019; Bitani et al. 2020).

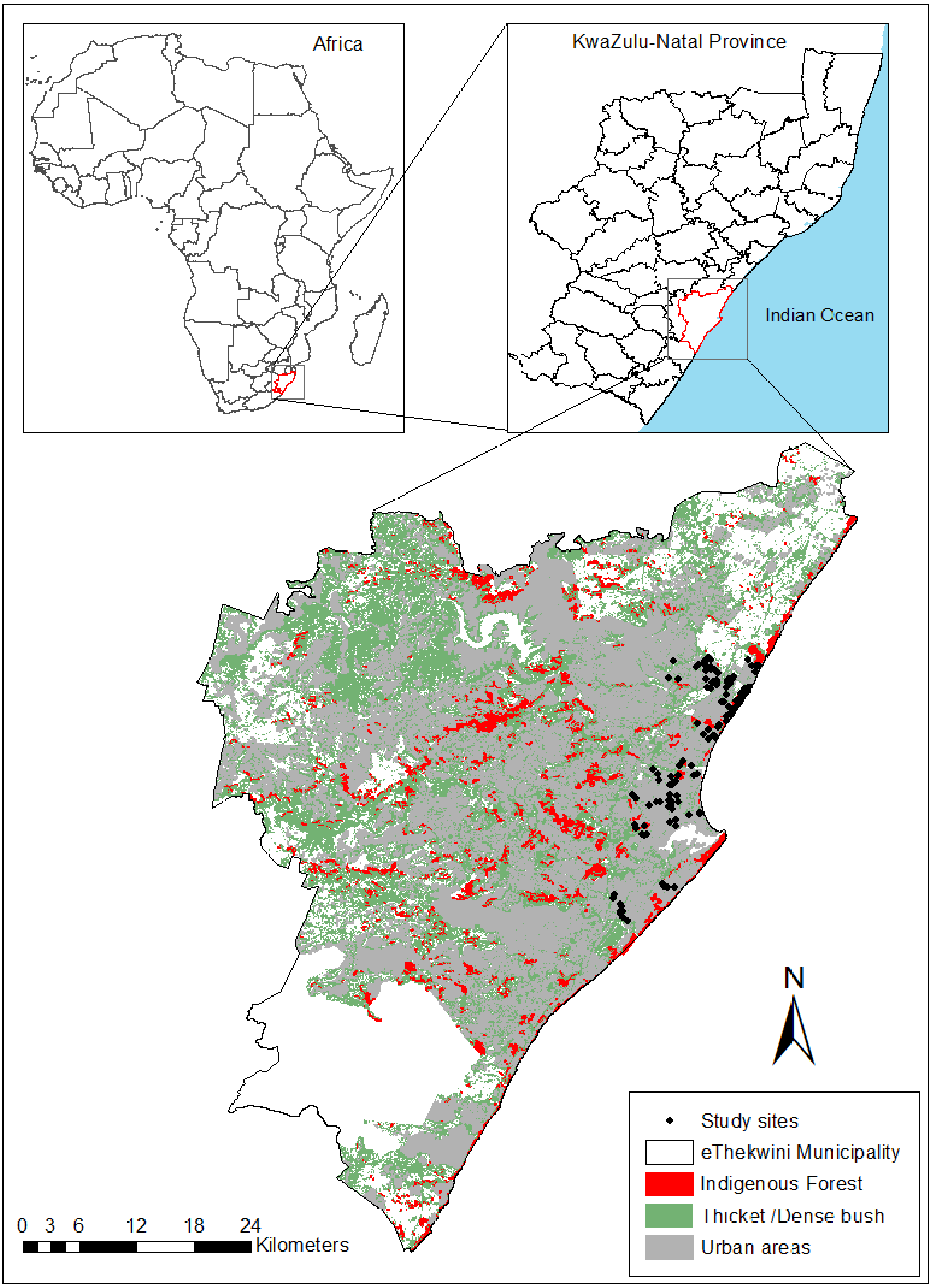

Figure 1.1 A map of eThekwini Municipality representing rose-ringed parakeets general study areas and the functional vegetation types.

1.5 Thesis outline

The study comprises a series of chapters, with the first chapter (Chapter 1) as the general introduction providing the literature review of the concepts covered by this study. The following five data chapters (Chapter 2, 3, 4, 5, and 6) are the main body, with three published and two submitted to international peer-reviewed journals. These five chapters are experimental, and each was formatted according to the journal intended or submitted to. There may be unavoidable overlaps or repetitions in some sections of some chapters. The published chapter(s) are provided with the Digital Object Identifier (DOI), which links to the article and the journal. The second chapter (Chapter 2) investigated the population size and roost sites of introduced rose-ringed parakeets in the eThekwini Municipality. Chapter 3 assessed the breeding status and biology of rose-ringed parakeets. Chapter 4 investigated rose-ringed parakeets' feeding biology in an urban landscape mosaic of eThekwini Municipality, KwaZulu Natal Province. Chapter 5 assessed public knowledge and perceptions of introduced rose-ringed parakeets in eThekwini Municipality. Finally, Chapter 6 assessed climatic suitability and the potential impacts (environmental and socio-economic) associated with rose-ringed parakeets and other selected bird species. The final chapter (Chapter 7) discusses the study's general findings and provides future research recommendations.

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CHAPTER 2

Population estimates of non-native rose-ringed parakeets *Psittacula krameri* (Scopoli, 1769) in the Durban Metropole, KwaZulu-Natal Province, South Africa

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2.1 Abstract

Rose-ringed parakeets *Psittacula krameri* are one of the most widely distributed urban avian invader species present in ~ 35 countries with population sizes increasing. These parakeets were introduced to South Africa as part of the pet trade, and feral populations have established in several urban areas since and are of concern. We, therefore, conducted monthly surveys between August 2018 – December 2019 in the greater Durban Metropole, KwaZulu-Natal Province, to determine their population size and roosting sites. In addition, we recorded bird species that communally roosted with rose-ringed parakeets, and tree species characteristics that they used for roosting. We identified five main roost site areas with an overall mean (± SD) monthly population size of 1 783.3 ± 505.2 rose-ringed parakeets. There was an increase in rose-ringed parakeet numbers, particularly in August and December after their breeding. Most rose-ringed parakeets were recorded in the north, with fewer in the south of the metropole; and many were located around shopping centres and parks. A total of seven bird species communally shared roost sites with rose-ringed parakeets, with the non-native common myna *Acridotheres tristis* being the species that frequently shared roosts with parakeets. Three tree species were used as roosts, with the Natal mahogany *Trichilia emetica* and the giant palm *Raphia australis,* so being the preferred roost tree species. The results showed variations in the measured tree traits and the number of individual parakeets roosting per tree species. The population size of non-native rose-ringed parakeets showed persistent growth, and it is, therefore, suggested that control measures for this species are introduced before its population expands further.

Keywords: Biological invasions · Avian species · Management · Urban greenspace · Urban conservation

2.2 Introduction

Urban areas have become a global hotspot where different non-native species are introduced for reasons such as pet trade, ornamentation, research, and food (Symes 2014; Gaertner et al. 2017; Padayachee et al. 2017). Consequently, some of these species establish feral populations and become invasive, often with environmental and socioeconomic impacts (Magnino et al. 2009; Hernández-Brito et al. 2018; Shiels et al. 2018; Shivambu et al. 2020). For example, parrot species such as monk parakeet *Myiopsitta monachus*, Alexandrine parakeet *Psittacula alexandri*, and rose-ringed parakeet *Psittacula krameri* have established in several cities around the world and are reported to cause agricultural, infrastructural, and ecological damage (Strubbe and Matthysen 2007; Neo 2012; Rodríguez-Pastor et al. 2012; Surender et al. 2016; Shiels et al. 2018).

The rose-ringed parakeet often occurs around human habitation (Grandi et al. 2018; Mentil et al. 2018). It is a social species and is native to parts of eastern and southern Asia and from eastern to central Africa (Parr and Juniper 2010). Humans have been responsible for translocating this species across the globe as part of the pet trade, and many are purchased for companionship (Menchetti et al. 2016; Vall-llosera et al. 2017). The rose-ringed parakeet has generally established in its invasive distribution range because of intentional release or unintentional escapes of captive populations (Strubbe and Matthysen 2009a; Vall-llosera et al. 2017). To date, populations of rose-ringed parakeets are well established, with substantial feral populations in the wild in ~ 35 countries (Menchetti et al. 2016; Strubbe and Matthysen 2020), including South Africa (Hart and Downs 2014; Ivanova and Symes 2019).

There are several potential ecological, disease and economic concerns about the establishment of feral populations of rose-ringed parakeets. They have negative impacts on crops such as almonds *Prunus dulcis, Citrus* spp., guavas *Psidium guajava,* mangos *Mangifera indica*, and common sunflower *Helianthus annuus* heads (Ahmad et al. 2012; Mentil et al.

2018). They are known to carry various parasites, including *Neopsittaconirmus lybartota* and *Tarsyopsylla octodecimdentata* (Ancillotto et al. 2018). They are a carrier of some zoonotic diseases such as parrot fever *Chlamydia psittaci* (Pisanu et al. 2018), and H9N2 Influenza A viruses (Mase et al. 2001) which can be transmitted to native animals and humans. They have also been reported to compete for food and space with native species, for example, nuthatches *Sitta europaea* (Strubbe and Matthysen 2009b) and threatened greater noctule bats *Nyctalus lasiopterus* (Hernández-Brito et al. 2018). Covas et al. (2017) reported some fatal attacks by rose-ringed parakeets on house sparrows *Passer domesticus* and blue tits *Cyanistes caeruleus*, which often resulted in these species displacement from nest cavities and reductions in their population size. The occurrence of rose-ringed parakeets in Kauai, Hawaii, has also been reported to be linked with seed predation and dispersal of invasive yellow guava *Psidium guajava* seeds to human-altered landscapes (Shiels et al. 2018).

Population sizes of rose-ringed parakeets are generally rapidly increasing in their non-native distribution ranges (Pithon and Dytham 2002; Strubbe and Matthysen 2007; Pârâu et al. 2016;). In Europe alone, a total of 80 breeding populations with an estimated overall population size of 85 120 from at least ten countries in 2015 has been recorded (Pârâu et al. 2016). Relatively little emphasis has been placed on population estimates of rose-ringed parakeets in its respective non-native distribution ranges as part of the management of the species despite established feral populations reported in various parts of the world (Hart and Downs 2014; Menchetti et al. 2016; Avery and Shiels 2017; Falcón and Tremblay 2018). Some population estimates of feral rose-ringed parakeets have been used as models of invasion success in parts of Europe (Luna et al. 2017), Italy (Grandi et al. 2018), and South Africa (Symes 2014). Most of the population estimates of rose-ringed parakeets have been documented in urban landscapes close to humans (Hart and Downs 2014; Grandi et al. 2018; Mentil et al. 2018), with fewer reported in rural landscapes despite the latter often providing commercial crops such as almonds, sunflower heads, and nuts as food sources (Butler 2003; Shiels et al. 2018).

There have been relatively few control measures proposed nor implemented for rose-ringed parakeet populations in their non-native distribution ranges. Reduction in the availability of anthropogenic food offered by humans and the wrapping of ripe crops has lowered the abundance of rose-ringed parakeets in some areas (Dhindsa et al. 1992; Butler 2003). Given the relatively rapid expansion of rose-ringed parakeet populations and its popularity in the pet trade and availability of bird feeding stations, controlling this bird species' expansion in its non-native distribution ranges has been difficult (Robb et al. 2008; Thabethe and Downs 2018). In temperate regions of Europe, feral populations of rose-ringed parakeets were maintained by supplementary feeders (Clergeau and Vergnes 2011). Catching or trapping of rose-ringed parakeets at feeding or roosting sites as part of management is generally difficult as they typically occur in densely populated suburban areas (Pithon 1998; Butler 2003; Strubbe and Matthysen 2009a).

In South Africa, the rose-ringed parakeets were introduced in the late 1900s and have expanded their feral population size and distribution range since the 1970s, mainly in urban areas (Perrin and Cowgill 2005; Hart and Downs 2014; Ivanova and Symes 2019). In addition, rose-ringed parakeets are widely kept here as part of the pet trade /companion species (Hart and Downs 2014; TC Shivambu pers. obs., unpublished data), with several feral populations established outside captivity as a result of pet release or escapees (Richardson et al. 2003; Roche and Bedford-Shaw 2008; Hart and Downs 2015; Ivanova and Symes 2019). They have established in several major South African cities, including Cape Town (Dean 2000), Durban (Hart and Downs 2014), Johannesburg (Roche and Bedford-Shaw 2008), and Pretoria (Symes 2014). To date, the population of non-native rose-ringed parakeets appears to be expanding and well-established, particularly in the greater Durban Metropole areas in eThekwini, KwaZulu-Natal Province (Hart and Downs 2014). Although they appear to be successful in their establishment, relatively little is known about the population ecology of rose-ringed parakeets in urban areas of South Africa. Consequently, we undertook monthly surveys to 1) determine their population size across the months and roost sites, 2) determine which species communally share roost sites with parakeets, 3) determine and measure roost tree traits used by rose-ringed parakeets in the greater Durban Metropole. We predicted that relatively large numbers of rose-ringed parakeets would be present and that there would be increases in their monthly numbers given that this species is known to thrive in urban landscapes (Strubbe and Matthysen 2009a; Hart and Downs 2014). We also predicted that other non-native bird species occurring in the Durban Metropole would be the most common species sharing roosts with rose-ringed parakeets. This assessment would be essential in understanding rose-ringed parakeets' ecology and their invasion success for possible control measures to be implemented for this species in South Africa at large.

2.3 Materials and methods

2.3.1 Study area

We conducted the study in the greater eThekwini Municipality located in KwaZulu-Natal Province, South Africa, situated on the eastern coast along the Indian Ocean (Fig. 2.1). The municipality is known to be a hotspot tourist destination in South Africa and throughout Africa (Turco et al. 2003). It receives an annual rainfall of ca. 980 mm (http://en.climate-data.org/location/27097/) and has average summer and winter temperatures around 13.9 °C and 24 °C, respectively (http://en.climate-data.org/location/27097/). Most of the natural land is used for human settlements, with few remaining protected natural forest patches and corridors forming part of the Durban Metropolitan Open Space System (D'MOSS), which create significant open green spaces (~ 75 000 ha) serving as refugia for native fauna and flora (Roberts 1994; Adams 2005; Zungu et al. 2019). It is one of South Africa's largest cities with a human population of ~ 3.5 million, with an annual growth of 1% (ECPDP 2015). The study was conducted mainly in three different areas of the municipality based on occurrence data for rose-ringed parakeets (Hart and Downs 2014; various pers. comm.), namely Durban North (Umhlanga Rocks: 29°44'24. 3"S, 31°04'38.5"E), Durban centre (around Cowey's Park: 29°50'18.4"S 31°00'38.7"E), and Durban South (Merebank: 29°57'06.4"S, 30°57'47.2"E) (Fig. 2.1), within the urban landscapes described above.

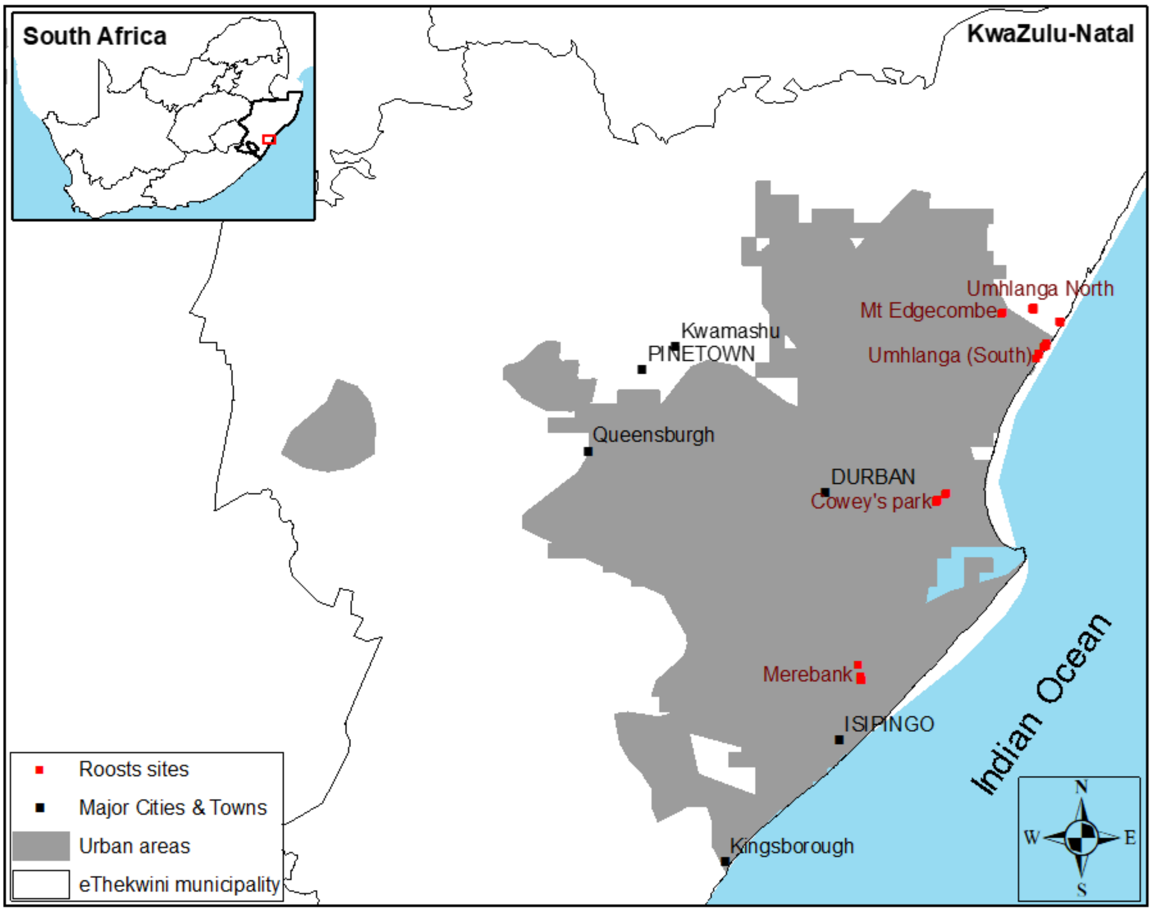

Fig. 2.1 A map showing sampling sites (red squares) where non-native rose-ringed parakeets roost in the Durban Metropole, eThekwini Municipality, KwaZulu-Natal Province, South Africa. The grey shaded areas are populated urban areas within the municipality.

2.3.2 Sampling techniques

2.3.2.1 Roost sites and population estimates

Initially, we undertook a two-week survey (3rd − 14th August 2018) to search for rose-ringed parakeets present in the Durban Metropole (Fig. 2.2). We also searched for parakeet roost sites in areas reported in Hart and Downs (2014) survey study. We obtained additional information on roost sites from public sightings reported on Facebook through contacting members from KwaZulu-Natal bird-clubs and bird forums. For housing/ eco-estates, we requested the managers to send out emails to the residents, and we also delivered the printed letters (Supplementary Material Table S2.1), which included our contact details and brief information about parakeets to acquire more information on their roost sites. Additional roost sites were acquired during sampling by asking members of the public where they have sighted or heard rose-ringed parakeets. Rose-ringed parakeets were located and recognised by their loud shrill call "kyik-kyik-kyik" or "kii-a" or "kii-ak" which they make when flying or feeding mainly (Mori et al. 2020b). The birds were also recognised by their yellow-green plumage and long progressed tail, with the curved and hooked red-pinkish bill (Fig. 2.2; Strubbe and Matthysen 2020).

We used a pair of UltraOptec® floating sports binoculars (8 × 30; Europe) for observing and identifying rose-ringed parakeets. Monthly observations commenced from August 2018 to December 2019, covering the four South African seasons (spring, summer, autumn, and winter). The sampling continued until the second breeding season (spring and summer), making the spring and summer sampled twice. The rose-ringed parakeets roost sites identified were visited, and numbers of rose-ringed parakeets in the roosts counted. The counts were conducted three times per site in a month (n = 24 days/month). Rose-ringed parakeets were counted in the late afternoons when they arrived at the roosts between 16h00– 20h30, depending on the season. We did this following a method in a previous study on parrot counts

(Seixas and Mourão 2018). We also observed the number of rose-ringed parakeets leaving the roost sites in the early mornings from dawn between 04h00–08h00 (CAT: 4 h). We conducted the morning counts to confirm the roost sites and numbers of rose-ringed parakeets present. The counts at large roost sites were conducted in the afternoons, mainly because in the mornings, rose-ringed parakeets often leave these roosts in large flocks making it difficult to count accurately. We generally counted rose-ringed parakeets during clear weather and avoided harsh climatic conditions such as heavy rains or storms. The same two observers conducted the counting throughout, and only one roost was visited per day. The numbers of rose-ringed parakeets entering the roost were recorded in singles, pairs, and number per flock (e.g. varying from five per flock to very large flocks (~ 60 birds)).

Since other bird species also use the tree species used by rose-ringed parakeets to roost (Gadgil and Ali 1975), we identified any bird species that shared the roost [also referred to as communal roosts in Gadgil (1972)] with the parakeets. We confirmed the identity of the other bird species using a bird field guide (Chittenden et al. 2016). The birds which communally shared the roost with parakeets were only identified to species level and not counted as the focus was on the number of rose-ringed parakeets. As raptors are known to prey on parakeets (Mori et al. 2020a), we also opportunistically identified any raptor species present in the vicinity of rose-ringed parakeets, particularly those that were chasing them.

2.3.2.2 Roost tree species

Tree species that rose-ringed parakeets roost on were counted and identified using a tree guidebook (van Wyk and van Wyk 2013). Tree variables such as crown cover lengths (canopy covers) in metres (m), diameter at breast height (DBH (m)), and height (m) were measured using Distance Meter software (http://distancemeterapp.000webhostapp.com/). The measurements were later quantified manually using a measuring tape and other techniques described in Khan (1999) and Butler (2003). We also identified amenities around the parakeet roost sites and grouped them as follows, beach, housing estate, cemetery, golf course, highway, manufacturing factories, railway, park, school, sports ground, and shopping centres. The number and types of amenities around each roost site were recorded to determine the amenities mostly associated with the parakeet's roost sites.

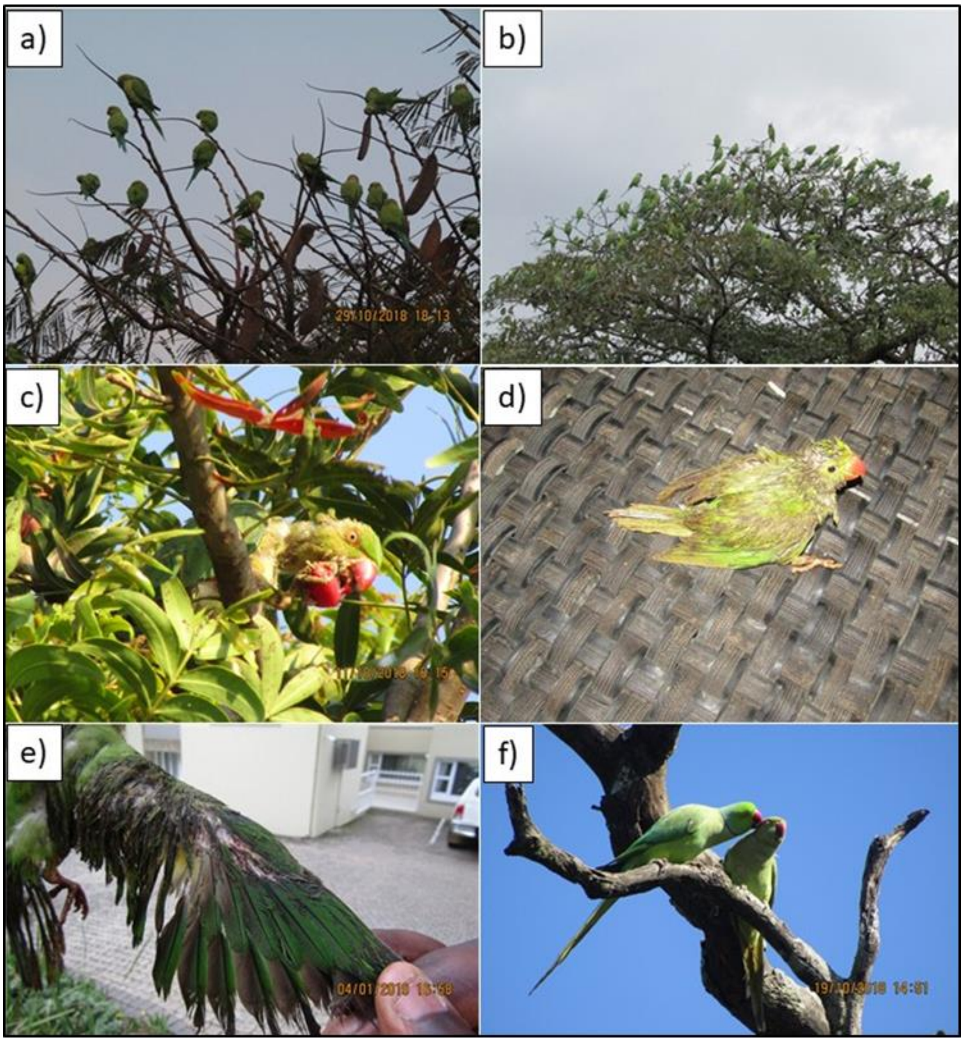

Fig. 2.2 Pictures showing rose-ringed parakeets in the greater Durban Metropole where a - b) a flock of rose-ringed parakeets in two roost trees, flat-crown tree *Albizia adianthifolia* and Natal mahogany *Trichilia emetica* in Cowey's Park, Durban North; c) an individual with symptoms of beak and feather virus feeding on wild plum tree *Harpephyllum caffrum*, and d) a wild-bred chick that fell from the nest on one of the trees used for roosting; e) an infected

parakeet's chick that had fallen from the milkwood tree *Sideroxylon inerme* in Umhlanga Rocks; f) a breeding pair of parakeets allopreening in the dry wood of Natal mahogany tree in one of the roost sites in Merebank (Photographs © TC Shivambu).

2.2.3 Statistical analyses

We performed statistical analyses using R statistical software (version 3.6.1, R Core Team 2018). We computed the mean (± SD) number of rose-ringed parakeets recorded per month. We used Repeated Measure One-Way Analysis of Variance (RMANOVA) to compare the rose-ringed parakeet population size among the sampling months. The observed number of parakeets were further validated using the Chi-squared test (χ^2) in Kruskal–Wallis. The mean, minimum and maximum recorded measurements (in metres: m) for each tree variables (DBH, height, and crown cover) were computed to determine the range sizes of trees that parakeets use for roosting. A one-way ANOVA and post hoc Tukey's HSD were computed to determine the difference in tree heights, DBH and crown cover sizes for the trees used by rose-ringed parakeets for roosting. The numbers of amenities around each of the rose-ringed parakeet roost sites were presented as percentages to display the frequency of their favourability.

2.4 Results

We identified a total of five main rose-ringed parakeets roost site areas in the Durban Metropole. The results showed significant variation in seasonal (August 2018 – December 2019) numbers of rose-ringed parakeets among the five roost site areas (Kruskal-Wallis tests: $\chi^2 = 107.2$; df = 16; n = 959; $P = 1.745e\text{-}21$). Cowey's Park recorded the largest mean population size of rose-ringed parakeets roosting throughout the 17 months of sampling with a mean (± SD) of 1,183.8 ± 607.4 rose-ringed parakeets, followed by the Gateway Mall with a mean (± SD) of 508.0 ± 215.9 rose-ringed parakeets (Table 2.1). Three rose-ringed parakeets roost site areas, namely Clarence Road, Merebank Caltex and Sherwood recorded the least seasonal monthly mean number of rose-ringed parakeets throughout the study (Table 2.1). The results showed an increase in the number of rose-ringed parakeets in Cowey's Park roost area in winter between June and August in the first and second sampling seasons following breeding (Table 2.1). A similar trend was also observed at the Gateway Mall roost area (Table 2.1). In contrast, an increase in the seasonal monthly numbers of rose-ringed parakeets at the Merebank and Sherwood roost areas occurred in summer between December and February (Table 2.1).

Table 2.1 Seasonal mean number (± SD) of rose-ringed parakeets counted between August 2018 to December 2019 at five major roost site areas in the Durban Metropole, KwaZulu-Natal Province, South Africa.

Roost site area	Coordinates		Seasons			
	Latitude	Longitude	Spring (Sep-Nov 2018 - 2019)	Summer (Dec 2018-2019 - Feb 2019)	Autumn (Mar 2019 - May 2019)	Winter (Jun 2019 – Aug 2018-2019
Clarence Road	29°50'12.1"S	31°00'52.4"E	21.7 ± 25.1	37.3 ± 34.8	24.6 ± 26.7	24.7 ± 35.9
Cowey's Park	29°50'27.6"S	31°00'32.2"E	1068.8 ± 504.5	1033.6 ± 669.1	1175.8 ± 597.5	1456.8 ± 658.6
Gateway Mall	29°43'31.1"S	31°04'02.7"E	518.1 ± 218.5	449.8 ± 285.9	506.3 ± 199.2	557.9 ± 159.9
Merebank Caltex	29°56'19.4"S	30°57'42.1"E	36.1 ± 23.5	46.1 ± 30.7	37.5 ± 22.5	29.0 ± 53.6
Sherwood	29°49'35.3"S	30°58'53.2"E	20.4 ± 18.6	43.8 ± 22.6	21.5 ± 19.6	23.2 ± 20.3

Based on the monthly sampling, combining the rose-ringed parakeet counts from all the roost site areas, the results showed significant monthly variations in the total number of rose-ringed parakeets present among months (RMANOVA: $F_{16,354} = 1.603$; $P = 0.0065$). During the first sampling months between August and December 2018, the overall population size was relatively large in August and then decreased during the breeding season (September to November), and then increased thereafter in December 2018 (Fig. 2.3). Again, in August 2019, the overall rose-ringed parakeet population was highest but decreased again during the breeding season (September - October 2019; Fig. 2.3). For the last two months of sampling, after the breeding season, the mean (± SD) population estimate of rose-ringed parakeets was about 495.9 ± 215.2, indicating that the population was rapidly increasing (Fig. 2.3).

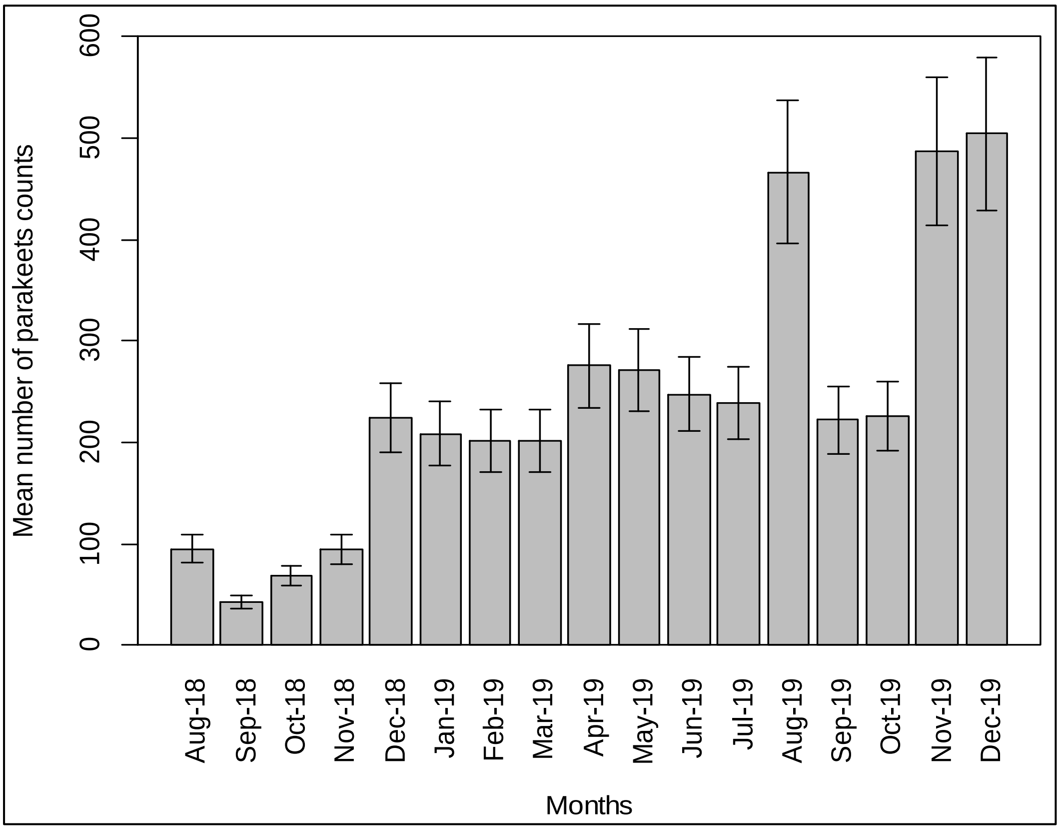

Fig. 2.3 The monthly mean (± SD) estimated rose-ringed parakeet population from August 2018 to December 2019 in the Durban Metropole. (The number used for each month labelled on the x-axis are years where 18 = year 2018 and 19 = year 2019).

We observed the changes of roosting times with seasons; in summer, the rose-ringed parakeets entered the roost in the evenings before the dark between 17h23–19h30. In spring and autumn, they entered the roost sites between 17h03–18h57, while in winter, they entered the roost between 16h58–17h50, often in the dark. In the mornings, rose-ringed parakeets left the roosting sites from sunrise between 04h00 (summer) − 07h05 (winter), depending on the month.

A total of seven bird species were observed roosting with rose-ringed parakeets in the five roost site areas in the present study. Of the seven bird species, the common myna *Acridotheres tristis* was observed sharing 60% (3 out of 5 roosts) of the roost sites with rose-ringed parakeets (Table 2.2). Species such as hadada ibis *Bostrychia hagedash*, Cape glossy starling *Lamprotornis nitens* and red-eyed dove *Streptopelia semitorquata* only shared two roost sites with rose-ringed parakeets (Table 2.2). The species that shared a single roost site area with rose-ringed parakeets included the speckled mousebird *Colius striatus*, the red-winged starling *Onychognathus morio* and the house sparrow *Passer domesticus* (Table 2.2). Of these bird species, two were non-native, the house sparrow and common myna, while the other six species are native to South Africa.

Table 2.2 A summary of non-native rose-ringed parakeets and other bird species that communally shared roost site areas within Durban Metropole, KwaZulu-Natal Province.

Bird species names	Common names	No. of tree species used for roosting (/3)	No. of roosts site areas (/5)	No. of amenities around roost sites (/8)	Types of amenities
*Acridotheres tristis**	Common myna	3	3	7	CF, EG, G, MFR, PB, SSG, SC
Bostrychia hagedash	Hadada ibis	3	2	6	CF, EG, G, PB, SSG, SC
Colius striatus	Speckled mousebird	3	1	6	CF, EG, G, PB, SSG, SC
Lamprotornis nitens	Glossy starling	3	2	6	CF, EG, G, PB, SSG, SC
Onychognathus morio	Red-winged starling	3	1	5	CF, EG, G, PB, SC
*Passer domesticus**	House sparrow	3	1	6	CF, EG, G, PB, SSG, SC
*Psittacula krameri**	Rose-ringed parakeets	3	5	8	CF, EG, G, MFR, PB, SSG, SC, Hwy
Streptopelia semitorquata	Red-eyed dove	3	2	6	CF, EG, G, PB, SSG, SC

Species with an asterisk are those known to be invasive elsewhere and in South Africa. The abbreviations in amenities types column represent amenities present around roosting sites that each species was counted.
The full description of each amenity code is as follows; **CF**: Cemetery and Farms, **EG**: Estate and Golf course, **G**: Golf course, **MFR**: Manufacturing factories and Railway, **PB**: Park and Beach, **SSG**: School and Sports ground, **SC**: Shopping centre, and **Hwy**: Highway.

Table 2.3 Four measured characteristics (mean ± SD) of the three tree species that rose-ringed parakeets used for roosting throughout (August 2018 – December 2019) the study at five roost site areas located in Durban Metropole, KwaZulu-Natal Province, South Africa.

Tree species	Common name	No. of individual tree species	DBH (metres)	Height (metres)	Crown cover (metres)	Seasonal mean (± SD) number of rose-ringed parakeets
Eucalyptus grandis	Rose gum	3	1.9 ± 0.1 m	39.0 ± 16.4 m	6.2 ± 3.9 m	12.0 ± 3.8
Raphia australis	Giant palm	21	1.1 ± 0.5 m	27.1 ± 6.9 m	1.7 ± 0.7 m	90.5 ± 84.3
Trichilia emetica	Natal mahogany	9	2.1 ± 0.9 m	28.7 ± 6.2 m	7.6 ± 6.5 m	214.0 ± 138.4

In the present study, a total of 33 trees belonging to three species were used for roosting by rose-ringed parakeets (Table 2.3). All these trees had a mean height of 28.25 m (min: 14 m; max: 42 m), a mean DBH of 1.73 m (min: 0.5 m; max: 3.5 m), and a mean crown cover of 3.9 m (min: 0.6 m; max: 20 m) (Table 2.3). There was a significant difference in the mean height of the tree species used by rose-ringed parakeets (ANOVA: $F_{2,60}$ = 0.043; P = 9.474e-28), with rose gum *Eucalyptus grandis* having a high mean height compared with the giant palm *Raphia australis* and Natal mahogany *Trichilia emetica* (Table 2.3). When comparing the crown cover size for the three species, it was found out that there was a significant difference between them (ANOVA: $F_{2,60}$ = 3.065; P = 0.05). A post hoc Tukey's HSD comparison showed that Natal mahogany had a significantly large crown cover than the giant palm and rose gum. The DBH size of the three tree species was also significantly different (ANOVA: $F_{2,60}$ = 7.389; P = 0.001). A post hoc Tukey's HSD comparison showed that the DBH size for giant palm was not different, but the DBH of the latter was different when compared with the rose gum tree. In terms of the mean number of parakeets per tree species, Natal mahogany and giant palm were the most preferred species for roosting when compared with rose gum (Table 2.3). The roost site areas used by the parakeets were located around eight amenities, with shopping centres (41%), parks and beaches (19%), and cemetery and farms (17%) being the dominant amenities (Table 2.2).

In the presence of rose-ringed parakeets at the five roosting site areas, two raptor species, namely the black sparrowhawk *Accipiter melanoleucus* (monthly mean number ± SD: 3.4 ± 1.2) and the yellow-billed kite *Milvus aegyptius* (monthly mean number ± SD: 3.8 ± 1.1, only present from September to March) were recorded.

2.5 Discussion

We predicted that a relatively large number of rose-ringed parakeets would be present and that there would be increases in their monthly numbers, given that the population size of this species is known to thrive in urban landscapes where they are commensal. As predicted, the present study recorded a relatively large number of rose-ringed parakeets in the urban landscape of Durban Metropole, particularly in the suburb of Durban North, with persistence in their monthly numbers. Rebele (1994) and Butler (2003) showed that the proportion of rose-ringed parakeet populations in non-native ranges was higher in the urban landscapes than suburban or rural ones. Rose-ringed parakeet's primary occurrence in urban landscapes has since been reported globally (Butler 2005; Strubbe and Matthysen 2007; Ivanova and Symes 2019), particularly in Europe (Pârâu et al. 2016; Grandi et al. 2018), and in its native distribution range, especially in Pakistan (Khan 1999; Khan et al. 2004). The social behaviour may explain the occurrence of rose-ringed parakeets in these anthropogenic dominated urban landscapes. These areas generally offer parakeets a relative abundance and variety of foods and space to roost (Parr and Juniper 2010; Mentil et al. 2018). Plasticity in behaviour displayed by rose-ringed parakeets has enabled them to persist in such anthropogenic landscapes (Butler 2003; present study). It has been reported that homeowners have supplementary bird feeders for native bird species; however, non-target non-native bird species, such as rose-ringed parakeets and common mynas, also utilised the supplementary bird food (Thabethe and Downs 2018; Mori et al. 2020b; TC Shivambu. pers. obs.).

Urbanisation has been reported to facilitate an increase in rose-ringed parakeets, with humans contributing largely by providing discarded waste or supplementary food which sustains these feral populations (Clergeau and Vergnes 2011). This has resulted in increased numbers of rose-ringed parakeets, with Europe alone recording a total of 80 colonies established in ten countries, with an estimated population size of ~ 85 000 feral parakeets

(Pârâu et al. 2016). In South Africa, the overall population of rose-ringed parakeets occurring in Cape Town (Dean 2000), Durban (Hart and Downs 2014), Johannesburg (Roche and Bedford-Shaw 2008), and Pretoria (Symes 2014) was not known. However, Whittington-Jones (2017) reported ~ 2 000 rose-ringed parakeets in Gauteng Province (Johannesburg and Pretoria Metropoles) alone between 2015 and 2016. This population size is close to that reported in the present study of ~ 1 783. The population of rose-ringed parakeets in Gauteng Province was shown to increase by 18% in one of the parks, Victory Park, Johannesburg (Whittington-Jones 2017). In the present study, increased numbers of rose-ringed parakeets mainly followed their breeding season and increased by two-fold. Similarly, previous population estimate studies of parrots have observed decreased numbers during the breeding season and increased numbers thereafter (e.g., Berg and Angel 2006; Seixas and Mourão 2018).

The continued increase of the rose-ringed parakeet population in the Durban Metropole (Hart and Downs 2014; present study) displays their behavioural plasticity and their invasion success. Of concern is their potential of impacting native bird species as displayed in other countries (Strubbe and Matthysen 2009b; Covas et al. 2017; Hernández-Brito et al. 2018). The introduction of rose-ringed parakeets in South Africa as part of the pet trade, including their establishment and population increase as displayed in the present study, is a good illustration of the propagule pressure process (Lockwood et al. 2005). The population of rose-ringed parakeets in South Africa may continue to grow and spread to other urban areas if not controlled. Furthermore, the role played by the pet trade in introducing parrot species in the cities is of great concern as most of them accidentally escape or intentionally released into the environment and cause impacts (Symes 2014; Rodríguez-Pastor et al. 2012; Falcón and Tremblay 2018; Shivambu et al. 2020).

We also predicted that other non-native bird species occurring in the Durban Metropole would be the most common species sharing roosts with rose-ringed parakeets. As predicted, common myna, which is a non-native invasive species, was found to share 60% of the roost sites with parakeets when compared with the native species. The behaviour of communal roosting by parakeets and other invasive species is relatively understudied but has enabled many invasive birds to become successful invaders, especially in urban areas (Gadgil and Ali 1975; Beauchamp 1999; Strubbe and Matthysen 2009a). Invasive species in South Africa such as the house crow *Corvus splendens* and common myna have been reported to share urban roost sites with rose-ringed parakeets in India (Gadgil and Ali 1975). It is therefore not surprising to find non-native invasive common myna and rose-ringed parakeets sharing the roosts in South Africa. This communal roosting behaviour is reported to provide potential benefits for these species, such as increased predator detectability, sharing body heat, and enhanced mating opportunities (Weatherhead 1983; Beauchamp 1999; Blanco and Tella 1999). Although it is relatively rare for some urban bird species such as black-billed magpies *Pica hudsonia* (Beauchamp 1999) and red-billed choughs *Pyrrhocorax pyrrhocorax* (Blanco and Tella 1999) to share roosts with other bird species, other species such as rose-ringed parakeets, common myna, house crow, and house sparrow share roosts with other bird species for the above-mentioned potential benefits (Gadgil and Ali 1975). In the present study, we also observed the presence of one avian predator and one avian scavenger species near rose-ringed parakeet roost sites. They were observed preying on other bird species that communally roost with parakeets, such as doves (TC Shivambu pers. obs.). The presence of raptor species in any space has shown to affect individuals' bird of prey's fitness and its community processes such as interactions which have resulted in lowering their fecundity (Cresswell 2008). Shwartz et al. (2009), using the enemy-release hypothesis, also suggested that predation might be the main contributing factor to the rose-ringed parakeet's relatively low fecundity in India. Control of any invasive species tends to be more effective at their early establishment stage (Manchester and Bullock 2000), so given that the non-native rose-ringed parakeet's population is at a local select urban level (Dean 2000; Hart and Downs 2014; Symes 2014) and not extensively established across South Africa like common mynas (SABAP2 2020), control measures may need to be implemented relatively soon.

In the present study, rose-ringed parakeet counts were made in five communal roost site areas; however, no aggressive behaviours were observed between parakeets and other bird species present (TC Shivambu unpublished data). In Europe, however, rose-ringed parakeet flocks were reported to impact native nuthatches (Strubbe and Matthysen 2009a), noctule bats (Hernández-Brito et al. 2018), and other bird species, including invasive species in their roost sites (Hernández-Brito et al. 2014).

The rose-ringed parakeets roosted in two different native tree species, particularly Natal mahogany and giant palm in the Durban Metropole in the present study. Similarly, in the Western Ghats Region of Kerala, southern India, and Hawaii, rose-ringed parakeets have been reported to roost in coconut palm trees *Cocos nucifera* and royal palm trees *Roystonea regiaas* with other bird species (Basheer and Aarif 2013; Klug et al. 2019). Rose-ringed parakeets use of another select evergreen, tall tree species maybe because they provide camouflage, their height and relatively large canopy cover that provide suitable roosting space. The presence of different tree species in the Durban Metropole and surroundings with similar variables to those used by parakeets for roosting may provide the possible roost sites for this bird should it expand its distribution range further.

The roost site areas used by rose-ringed parakeets in the present study were generally associated with anthropogenic infrastructure, including areas around shopping centres, beaches and parks. Similarly, in Italy (Grandi et al. 2018) and in Gauteng Province, South Africa (Whittington-Jones 2017; Ivanova and Symes 2019), rose-ringed parakeet roost sites were recorded in parks and golf courses.

2.6 Conclusions

The present study reported a total of five rose-ringed parakeet roost sites in the Durban Metropole urban landscape with an increased population size of parakeets, mainly after the breeding season. This suggests a continued expansion of the non-native rose-ringed parakeet's population in this urban area. It is suggested that control measures for rose-ringed parakeets, particularly targeting their roosts sites, be implemented. Pet stores also need to be monitored as many feral parakeets are likely escapees or intentional releases of captive pets (Roche and Bedford-Shaw 2008; Hart and Downs 2014; Symes 2014). There is a need to regulate pet stores selling of any parakeet species as this could reduce further invasion of parakeets in urban landscapes, including their potential risk to native bird species and crops as they expand their non-native distribution range.

2.7 Acknowledgements

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2.9 Supplementary material

Table S2.1. Copy of the letter with rose-ringed parakeet brief description sent to eThekwini Municipality residents to acquire information on parakeets roost sites.

Aspects of the ecology of the invasive rose-ringed parakeets (*Psittacula krameri*) in eThekwini Municipality

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Brief overview

The rose-ringed parakeet (*Psittacula krameri*) is considered one of the world's worst invasive bird species. It belongs to the parrot family. It is native to sub-Saharan Africa, India, and Asia. Globally it is a popular pet and in many countries, escaped ones have become feral. This species is reported to have established in approximately 25 countries, with approximately 85 000 population in Europe alone. The rose-ringed parakeets have been reported to cause destruction to crops of agricultural importance, compete with native bird species for nesting sites, carry diseases and parasites that are transmittable to humans and other animals, and cause fatalities to native birds, bats, and other small mammal species.

Rose-ringed parakeets were introduced to South Africa in the 1970s as part of the pet trade, and they are now considered an invasive bird species here. They are known to occur in various cities and surrounds, including Cape Town, Durban, Johannesburg, and Pretoria. Their populations appear to be expanding, particularly in the greater Durban Metropolitan areas, and their population estimate is currently unknown in South Africa as a whole.

Cavin Shivambu from the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg campus, is conducting a study on rose-ringed parakeets as part of his PhD. Part of his study is locating where rose-ringed parakeets roost with the objective to estimate their population size in the greater Durban area. He is also interested in their nesting sites in the greater Durban area. He is undertaking a survey as part of his project to understand aspects of their ecology. Please see the link (https://goo.gl/forms/acWHmc2SowjNF7re2) to complete the survey should you wish to assist in his study.

Photo by Cavin Shivambu

For more information on this project, feel free to contact Prof Colleen Downs at downs@ukzn.ac.za or Mr Cavin Shivambu (PhD candidate) at shivambucavin@gmail.com.

Further readings

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CHAPTER 3

Breeding status of invasive rose-ringed parakeets *Psittacula krameri* (Scopoli, 1769) in eThekwini Metropole, KwaZulu-Natal Province, South Africa

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Running header: Breeding biology of invasive rose-ringed parakeets

3.1 Abstract

The rose-ringed parakeet *Psittacula krameri* has established feral populations in South African suburban areas. The breeding biology of the parakeets remains poorly documented here. We assessed their breeding status and behaviour in eThekwini Metropole, KwaZulu-Natal Province. We also determined distances travelled by parakeets between roost and breeding sites. We placed artificial nest boxes to determine occupancy by the parakeets or other bird species. We identified 39 breeding sites with a total of 72 nests. There was no significant difference between the number of active nests in the first (n = 53 nests) and second breeding seasons (n = 59). Four tree species were used for nesting, with white milkwood *Sideroxylon inerme* used the most (71%). Only East African lowland honey bees *Apis mellifera scutellata* and common mynas *Acridotheres tristis* used our artificial nest boxes. Parakeet fledglings recorded ranged between 1- 3 per nest, and their numbers differed significantly between the seasons. The number of fledglings was not influenced by any tree variables. The distance travelled by parakeets between the roost and breeding sites ranged from 1.43 - 5 km. Our study provides essential data for an overall management strategy and to inform decisions on the eradication of this species in South Africa.

Keywords: Fledging; Invasive species; Nest-site competition; Tree cavity; Nest cavity; Urban habitations

3.2 Introduction

The rose-ringed parakeet *Psittacula krameri* (Scopoli, 1769) is one of the world's worst invasive bird species and has successfully established in many countries, including South Africa (Hart and Downs 2014; Symes 2014; Ivanova and Symes 2019). It was first introduced in South Africa in the late 1900s through the pet trade (Hart and Downs 2014; Symes 2014; Ivanova and Symes 2019). The species was first reported breeding in the 1970s and has since established feral populations in urban areas of Gauteng, KwaZulu-Natal and Western Cape Provinces (Perrin and Cowgill 2005; Hart and Downs 2014). The population of this species has increased at a disturbing rate, particularly in urban landscapes (Dean 2000; Roche and Bedford-Shaw 2008; Hart and Downs 2014; Ivanova and Symes 2019). An estimated population of *ca.* 2 500 birds in Victoria Park, Gauteng Province alone was reported in 2016 (Whittington-Jones 2017). The overall population size of rose-ringed parakeets in South Africa is poorly known particularly in the provinces where the species is known to occur (Dean 2000; Roche and Bedford-Shaw 2008). The rapid increase of rose-ringed parakeets in South Africa has raised concern from both conservation and economic perspectives because of their impacts, including them being a pest to crops in their native and invaded ranges (Ahmad et al. 2011; Ahmad et al. 2012; Mentil et al. 2018; Shiels et al. 2018; Klug et al. 2019). Rose-ringed parakeets have been reported to outcompete native species for nests, e.g. nuthatches *Sitta europaea*, threatened greater noctule bats *Nyctalus lasiopterus*, and blue tits *Cyanistes caeruleus* (Strubbe and Matthysen 2009; Covas et al. 2017; Hernández-Brito et al. 2018). As a result, these various native species have been displaced from their nest cavities, sometimes resulting in the decline of those species (Covas et al. 2017; Hernández-Brito et al. 2018).

Understanding species breeding biology is useful in evaluating potential reproductive success, particularly for invasive bird species (Hyman and Pruett-Jones 1995; Burger and Gochfield 2000). Avian breeding biology includes nest site selection which involves bird identifying habitat with characteristics it requires to breed (Jones and Robertson 2001). Secondary cavity nesters are bird species that use nests excavated by other bird species (Rendell and Robertson 1994). They include several invasive bird species such as rose-ringed parakeets, common myna *Acridotheres tristis* and European starlings *Sturnus vulgaris* (Koenig 2003; Grarock et al. 2013; Charter et al. 2016). To date, in South Africa, relatively little research has been conducted on the breeding biology of such secondary cavity nesters, especially rose-ringed parakeets, including factors influencing their nest selection and reproductive success. In other countries, however, the breeding biology of rose-ringed parakeets has been studied, e.g., in Britain (Butler et al. 2013), Turkey (Şahin and Arslangündoğdu 2019), and Belgium (Strubbe and Matthysen 2009b; Strubbe and Matthysen 2011).

An increase in rose-ringed parakeet's population has been reported to be influenced by the richness of nesting cavities excavated by other birds (Strubbe and Matthysen 2007). Given that the population size of rose-ringed parakeets is increasing in South Africa (Dean 2000; Symes 2014; Whittington-Jones 2017; TC Shivambu pers. obs.), particularly in eThekwini Metropolitan areas (Hart and Downs 2014). Consequently, it would be valuable to study the breeding biology of parakeets to understand their breeding success and potential to expand their population size here. In this study, we surveyed several areas in eThekwini Municipality where the feral population of rose-ringed parakeets are established to determine 1) their breeding status, 2) the types of trees used for nesting, and if the measured tree variables can influence the number of parakeet's fledglings, 3) determine the nest occupancy between parakeets and native bird species, and 4) evaluate the distances between breeding and roosting sites. We predicted that there would be differences in the number of parakeet's fledglings between breeding seasons, given an increase in their population size (Hart and Downs 2014; Symes 2014; Whittington-Jones 2017). The canopy cover, diameter at breast height, the height of the nest above the ground, tree heights and nest entrance diameter would influence the number of parakeet's fledglings. We also predicted that parakeets would occupy more of the artificial nest boxes compared with native bird species. Finally, we predicted that the distance between breeding and roosting sites would be relatively short, given that most of the trees with nest holes excavated by native birds are in the surroundings.

3.3 Material and methods

3.3.1 Study sites

Our study was conducted in eThekwini Municipality, located in the eastern coastal areas of KwaZulu-Natal Province (29.8120° S, 30.8039° E), South Africa (Fig. 3.1). The size of the municipality is ~2 292 km², and most of its land is used for human settlements (Musvoto et al. 2016). The municipality is one of the largest in South Africa, with the human population estimated at 3.5 million (EThekwini Municipality 2013; Todes 2014). Approximately 75 000 ha of areas in this municipality is part of the Durban Metropolitan Open Space System (D'MOSS) (Zungu et al. 2019). This open space system forms part of the urban green spaces, which serve as unique habitats for both flora and fauna, including humans who use it for relaxation and other activities such as sport (Roberts 1994; Adams 2005). The climate is categorised as subtropical, with a mean annual rainfall of 948 mm p.a. (http://en.climate-data.org/location/27097/). The mean yearly ambient temperature ranges from a minimum of 14 °C to a maximum of 24 °C (http://en.climate-data.org/location/27097/). The climate is described by long humid, sunny and hot summer, mild winter, short spring and autumn. The type of vegetation cover found within the municipality includes Coastal Belt, Eastern Valley Bushveld, Hinterland Thornveld, Ngongoni Veld, Mangrove Forest, Northern Coastal Forest, and Scarp Forest (McLean et al. 2016).

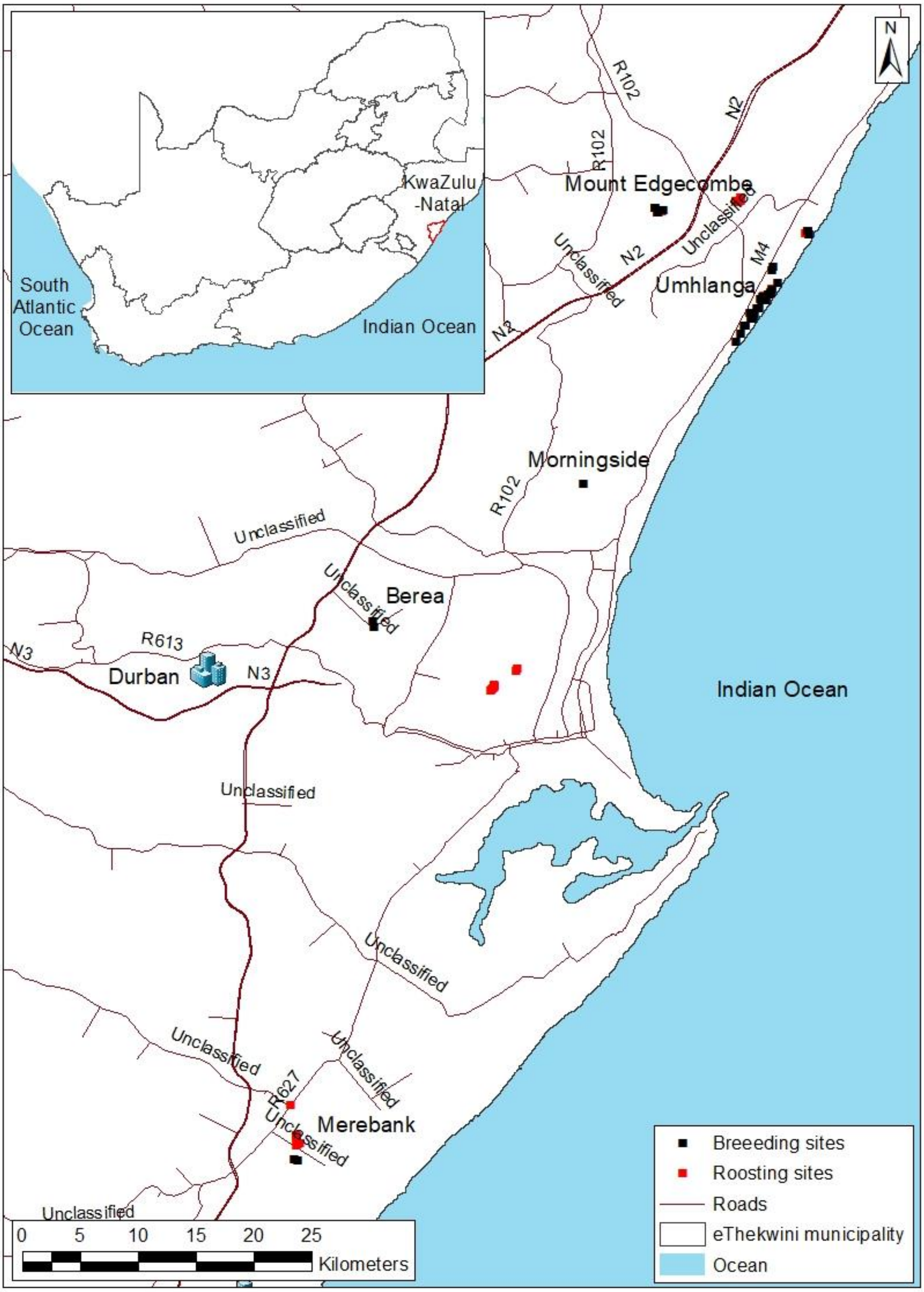

Fig. 3.1 A map showing study sites where invasive rose-ringed parakeets were located breeding in eThekwini Municipality, KwaZulu-Natal Province, South Africa in the present study.

3.3.2 Sampling techniques

Our study started in early August 2018 to late December 2019 to determine the specific time of the year that rose-ringed parakeets bred. A monthly search was conducted throughout eThekwini Municipality for evidence of breeding in areas where the species were sighted feeding or roosting (Hart and Down 2014; TC Shivambu unpublished data). We also acquired information on rose-ringed parakeet breeding sites from various KwaZulu-Natal bird-clubs, as well as residents in our study area who were mainly Facebook users. Some of the residents who were keen to assist with our study joined a WhatsApp group that was created so that anyone who saw or located parakeets breeding sites or nests could share the location.

The located rose-ringed parakeet breeding sites (Fig. 3.1) were visited three times a month per site. We recorded the number of breeding pairs and the number of nest holes used (Fig. 3.2). Each tree species used for breeding was identified to species level using a field guidebook (van Wyk and van Wyk 2013). We also identified nest cavities used by native bird species then used by the parakeets. Nest tree variables such as nest height above the ground, tree height, diameter at breast height (DBH), and crown cover (canopy cover) length were measured manually using measuring tape and Distance Meter software (http://distancemeterapp.000webhostapp.com/). The nest hole diameter was also measured manually using a desk ruler. The measuring techniques applied here were adopted following tree guidelines (Khan 1999; Butler 2003; Butler et al. 2013; Leverett and Bertolette 2014). All measurements were in metres (m), and the few in centimetres were converted to metres. We used these variables to determine if they influenced the number of fledglings. The clutch sizes and hatchlings were difficult to assess as the nest interiors were challenging to access; however, we were able to document the number of fledglings per nest. The nest interiors we did observe typically had a narrow entrance passage that then turned sideways into a nesting chamber. This made viewing directly into nesting chambers difficult. Parakeets chicks were considered to have fledged when we could see them out of the nest after two months (~8 weeks). We assumed incubation to have started when the female did not leave the nest for more than 20 min, and when the male was feeding the female. During this time, only males were seen flying back to roosts and feeding sites. The roost site that each of the breeding pairs used was located (Fig. 3.2), and the distances that parakeets travelled (in kilometre - km) from roost to breeding sites were measured using google earth distance ruler (Google Earth Pro 2019). We used UltraOptec® floating sports binocular (8 x 30; Europe) to observe parakeets as they flew from roost or breeding sites. We created a map showing the study areas (nest and roost site locations) using ArcGIS (version 10.4.1: ESRI 2018).

A total of 65 artificial nest boxes were placed in five locations namely Ballito (n = 8), Berea (n = 4), Merebank (n = 9), Mount Edgecombe (n = 10), and Umhlanga Rocks (n = 34) (Fig. 3.1). The nest boxes were placed in known rose-ringed parakeet breeding areas to determine the nest occupancy between parakeets and native bird species. We placed the nest boxes in the following areas, forest patches, a golf course, a guest house garden, a park, a private residence, a restaurant garden, a school garden, and a shopping centre (Supplementary Information Fig. S3.1). The nest boxes were placed in August 2018, and they were monitored by checking the boxes directly on a monthly (n = 12) basis, once a week until December 2019. The nest boxes were made of pinewood, and the top was covered with aluminium sheeting to prevent rot. The nest boxes were painted with brown waterproof paint to blend in the environment (see Supplementary Information Fig. S3.1). Each artificial nest box height was 41.3 cm, width 20.3 cm, breadth 30 cm and nest hole diameter 2.1 cm. Each nest box was placed at approximately ± 6.7 m above the ground in the following trees, white seringa *Kirkia acuminate*, flat-crown *Albizia adianthifolia*, white milkwood *Sideroxylon inerme* and Natal fig *Ficus natalensis*.

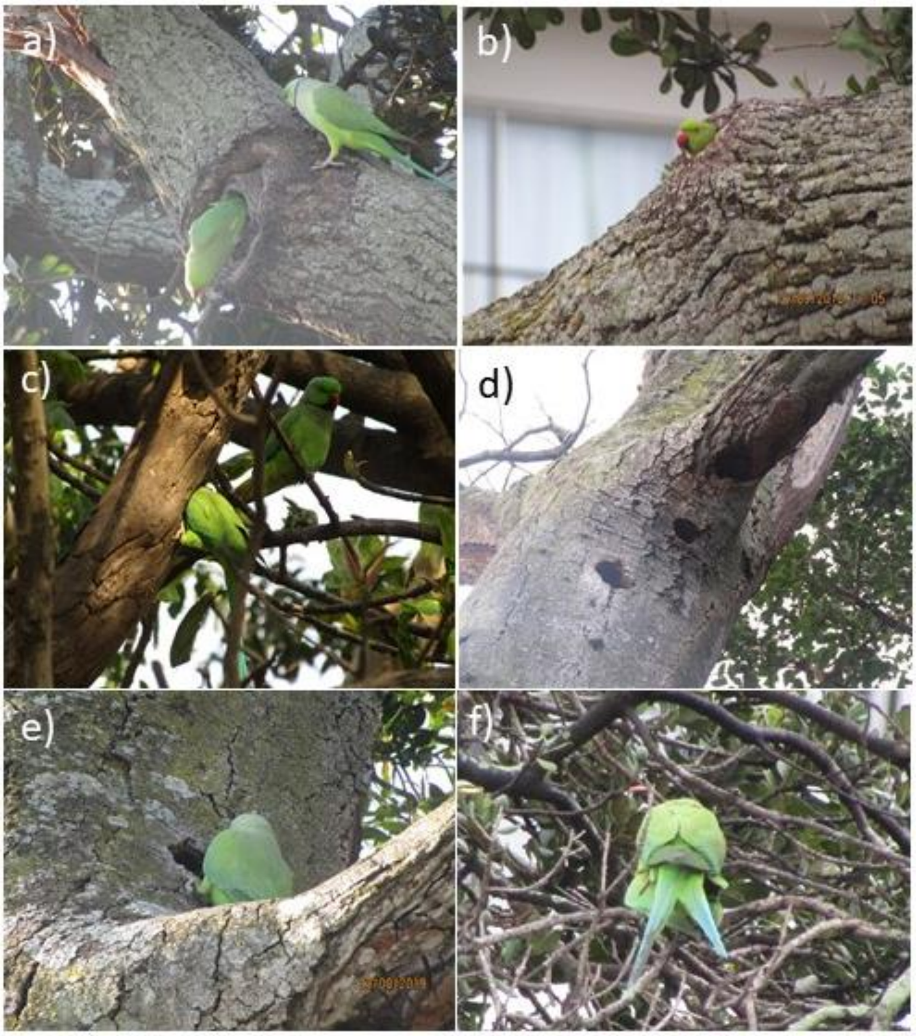

Fig. 3.2 Examples of rose-ringed parakeets at several nesting sites in our study, where a) and b) show parakeets coming out of the nest excavated by native cavity-nesting birds in white milkwood tree *Sideroxylon inerme* (L.), c) parakeets entering a cavity in the river red gum tree *Eucalyptus camaldulensis* (Dehnh.), d) nests holes in flat-crown tree *Albizia adianthifolia*, e) female parakeets entering a nest in a flat-crown tree, and f) a breeding pair of parakeets mating in early September 2019 near one of the nest sites (©Photographs: TC Shivambu).

3.3.3 Statistical analyses

We determined the mean (± SD) for each of the following: the number of rose-ringed parakeet breeding pairs, fledglings, tree variables, and distance travelled parakeets between the nest and roost sites. We compared the observed number of active nests, breeding pairs, and fledglings, respectively, using the Kruskal-Wallis test. The number of active nests was counted and converted to percentile units (%). We used Generalised Linear Modelling (GLM) with backwards eliminations procedures to predict the effects of each of the tree variables (i.e. crown cover, DBH, the height of nest above the ground, nest diameter, and tree height) on the number of parakeet fledglings produced per breeding season. The analyses were performed separately for each season (first breeding season one coded "A", while second breeding season coded "B"). Before model analyses, collinearity within the independent variables was checked. We checked if the residuals were independent, identical and normally distributed using residual plots. These were tested using the Kolmogorov–Smirnov normality test and Levene's tests (Zar 1999). As a result, we found that there was no evidence of violations of the assumptions. We used the Kruskal-Wallis test to determine if the differences between the distance travelled by parakeets from roost to breeding sites were significant. We performed all statistical analyses using R statistical software (version 3.6.1, R Core Team 2018).

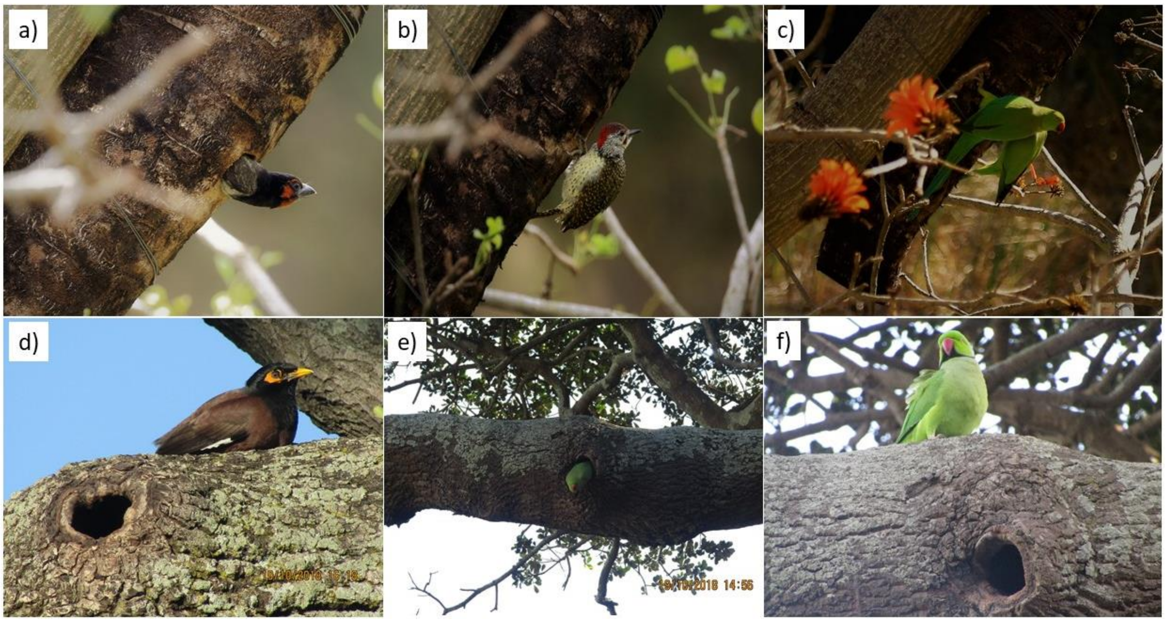

Fig. 3.3 Photographs showing a) a black-collared barbet *Lybius torquatus* and b) a golden-tailed woodpecker *Campethera abingoni* using privately owned artificial nests, and c) rose-ringed parakeets' pair *Psittacula krameri* taking-over privately owned artificial nest of the respective native species; d) an alien invasive common myna *Acridotheres tristis* using similar natural nest as used by e) and f) invasive rose-ringed parakeets during the breeding seasons in our study. ©Photographs a), b) and c) by Mike du Trevou, d), e) and f) by TC Shivambu.

3.4 Results

The breeding season for rose-ringed parakeets in our study in eThekwini Municipality, South Africa, started at the beginning of September and continued until the first week of November each year (~69 days). A total of 39 breeding sites were identified, with a total of 72 nests used (natural nests = 69; privately-owned artificial nests from residential = 3) [Note: privately owned artificial nest boxes are those in residential areas that private owners placed]. Of the 65 artificial nest boxes we placed, 65% (n = 42) were used by East African lowland honey bee *Apis mellifera scutellata*, 27% (n = 18) were not used by parakeets nor other bird species, and only 8% (n = 5) were used by the invasive common myna *Acridotheres tristis* (Supplementary Information Table S3.1). We recorded the most parakeet nests in the suburb of Umhlanga

Rocks, with 30 sites. Other areas had only one to four breeding sites with less than ten nests (Supplementary Materials Table S3.1). Most of the parakeet nests were found in resident's gardens, followed by parks and forest patches. A few nests were found in school grounds, a cemetery, a golf course and a hotel garden (Supplementary Materials Table S3.2). In total, parakeets used 53 nests in the first (2018) breeding season, and 59 in the second breeding season (2019) (Table 3.1). We found no significant difference in the observed number of nests used between breeding seasons (Kruskal–Wallis test: $\chi^2 = 0.59$; $F_{1,76} = 0.72$; $P = 0.398$).

In our study, rose-ringed parakeets nested in a total of four tree species (Table 3.1, Fig. 3.2, Supplementary Information Table S3.2). Most parakeets (71%) used the white milkwood tree *S. inerme* for nesting, followed by invasive river red gum *Eucalyptus camaldulensis* (14%) and native flat-crown *Albizia adianthifolia* (13%) (Table 3.1). Observed parakeet's nests included natural cavities (n = 26), nests formerly used by native birds, namely, crested barbet *Trachyphonus vaillantii* (natural nests = 12), African hoopoe *Upupa africana* (natural nests = 16), black-collared barbet *Lybius torquatus* (privately owned artificial nest box = 1, natural nests = 8) and golden-tailed woodpecker *Campethera abingoni* (privately owned artificial nest boxes = 2, natural nests = 7) (Fig. 3.3). The nests in 39 breeding sites were all-natural except for three privately owned artificial nest boxes in Mount Edgecombe Estate and Umhlanga Rocks (Fig. 3.3). During our observations, common mynas *Acridotheres tristis* also used some of the nests (n = 3) that rose-ringed parakeets used (Fig. 3.3). We recorded this at two sites, Durban View Park and Ridge Road, both located in Umhlanga Rocks (Fig. 3.3). The mean (± SD) height of the nests was 10.84 ± 3.79 m above the ground with a diameter size of 0.81 ± 0.22 m. The mean tree height was 22.9 ± 8.25 m, with the mean crown cover size of 8.37 ± 10.98 m. Lastly, the mean DBH was 4.15 ± 0.82 m.

The number of rose-ringed parakeet fledglings recorded in the first breeding season (1.13 ± 0.83 mean ± SD; n = 44) was significantly lower than the number of fledglings observed in the second breeding season (1.59 ± 0.81; n = 62) (Kruskal-Wallis test: χ^2 = 5.99; df = 1; P = 0.021). Most (84%, 44 out of 53) had either one to three fledglings in the first breeding season with only 16% unsuccessful in their breeding attempt. In contrast, only four nests did not have any fledglings in the second breeding season out of 59 nests, i.e. 6.8% unsuccessful. The Generalised Linear Modelling showed that none of the measured tree variables (tree height, the height of the nest above the ground, nest diameter, DBH and crown cover) had a significant influence on the number of fledglings produced in both breeding season (P > 0.1; Table 3.2).

The mean (± SD) distance travelled by rose-ringed parakeets from nest sites to three major roost sites (Cowey's Park, Umhlanga Rocks, and Merebank –Table 3.3) was 2.64 ± 0.76 km (Table 3.3). The longest distance travelled was from Durban North to Cowey's Park (5 km), and the shortest (1.43 km) travelled was from Merebank Muslim cemetery to Merebank Caltex (Table 3.3). We found a significant difference between distances that rose-ringed parakeets travelled from roosts to breeding sites (Kruskal-Wallis test: χ^2 = 8.99; df = 5; P = 0.001).

Table 3.1 Tree species used by rose-ringed parakeets as nest sites during the breeding seasons in our study. Tree species with an asterisk are invasive to South Africa. The number in the brackets in the fledgling column is the actual number of fledging chicks recorded during the breeding seasons.

Scientific names	Common names	No. of nests	Active nests used by parakeets		No. of breeding pairs		Mean (±SD) No. of fledgling chicks	
			1st breeding	2nd breeding	1st breeding	2nd breeding	1st breeding	2nd breeding
Albizia adianthifolia	Flat-crown	9 (13%)	8 (15%)	9 (15%)	6 (11%)	6 (12%)	1.6 ± 1.14 (n = 8)	1.6 ± 0.55 (n = 8)
*Eucalyptus camaldulensis**	River red gum	10 (14%)	6 (8.1%)	9 (15%)	8 (14%)	8 (15%)	1.25 ± 0.5 (n = 5)	1.75 ± 0.96 (n = 7)
Ficus natalensis	Natal fig	1 (2%)	1 (2%)	1 (2%)	1 (2%)	1 (2%)	0.55 ± 0.67 (n = 1)	0.03 ± 0.14 (n = 1)
Sideroxylon inerme	White milkwood	49 (71%)	38 (72%)	40 (68%)	40 (73%)	37 (71%)	1.03 ± 0.82 (n = 30)	1.59 ± 0.87 (n = 46)

Table 3.2 A summary of the GLM predicting the number of fledglings in the first and second breeding season against measured tree variables. "A" represents procedure performed using first breeding season datasets, and "B" shows results from analyses using second breeding season datasets.

A	**Estimates (β)**	**Std. Error**	**t-value**	**P-value**
Intercept	0.49	1.21	0.41	0.684
Height	0.01	0.02	0.32	0.75
DBH	0.13	0.18	0.69	0.49
Nest height above the ground	0.15	0.13	1.21	0.23
Nest diameter	-0.05	0.65	-0.07	0.95
Crown cover	0.01	0.01	0.08	0.94

B	**Estimates (β)**	**Std. Error**	**t-value**	**P-value**
Intercept	0.67	1.18	0.41	0.17
Height	-0.01	0.02	-0.34	0.73
DBH	-0.06	0.18	-0.32	0.75
Nest height above the ground	-0.05	0.13	-0.43	0.67
Nest diameter	0.33	0.64	0.51	0.61
Crown cover	0.02	0.01	0.27	0.79

Table 3.3 Summarised measured distances (km) that rose-ringed parakeets travelled between roosts and nest sites located in eThekwini municipality, KwaZulu-Natal Province.

Breeding sites	Coordinates		Roost sites	Coordinates		Distance travelled (km)
	Latitude	**Latitude**		**Latitude**	**Longitude**	
Merebank	-29.951600	30.962529	Merebank Caltex	-29.938705	30.961724	1.43
Merebank	-29.951958	30.963511	Merebank Caltex	-29.938705	30.961724	1.48
Mt Edgecombe	-29.728205	31.049168	Gateway Mall	-29.725825	31.066771	1.72
Lady Allen	-29.733201	31.083331	Gateway Mall	-29.725825	31.066771	1.80
Lady Allen	-29.733201	31.083332	Gateway Mall	-29.725825	31.066771	1.80
Lady Allen	-29.734023	31.083430	Gateway Mall	-29.725825	31.066771	1.85
Mt Edgecombe	-29.728643	31.047961	Gateway Mall	-29.725825	31.066771	1.85
Mt Edgecombe	-29.727539	31.047417	Gateway Mall	-29.725825	31.066771	1.88
Mt Edgecombe	-29.727566	31.047390	Gateway Mall	-29.725825	31.066771	1.89
Lady Allen	-29.741625	31.075126	Gateway Mall	-29.725825	31.066771	1.93
Lady Allen	-29.742240	31.074799	Gateway Mall	-29.725825	31.066771	1.98
Lady Allen	-29.745454	31.076178	Gateway Mall	-29.725825	31.066771	2.34
Lady Allen	-29.746944	31.074747	Gateway Mall	-29.725825	31.066771	2.45
Lady Allen	-29.747632	31.074508	Gateway Mall	-29.725825	31.066771	2.51
Lady Allen	-29.747928	31.074098	Gateway Mall	-29.725825	31.066771	2.53
Lady Allen	-29.748012	31.074074	Gateway Mall	-29.725825	31.066771	2.54
Lady Allen	-29.747814	31.074656	Gateway Mall	-29.725825	31.066771	2.54
Lady Allen	-29.748679	31.072742	Gateway Mall	-29.725825	31.066771	2.60
Lady Allen	-29.749114	31.072160	Gateway Mall	-29.725825	31.066771	2.61
Lady Allen	-29.748697	31.073228	Gateway Mall	-29.725825	31.066771	2.61
Lady Allen	-29.749289	31.072238	Gateway Mall	-29.725825	31.066771	2.64
Lady Allen	-29.749177	31.073086	Gateway Mall	-29.725825	31.066771	2.66
Lady Allen	-29.749363	31.073389	Gateway Mall	-29.725825	31.066771	2.67
Lady Allen	-29.751427	31.071243	Gateway Mall	-29.725825	31.066771	2.85

Breeding sites	Coordinates		Roost sites	Coordinates		Distance travelled (km)
	Latitude	Latitude		Latitude	Longitude	
Lady Allen	-29.751417	31.071740	Gateway Mall	-29.725825	31.066771	2.87
Lady Allen	-29.752480	31.070125	Gateway Mall	-29.725825	31.066771	2.94
Lady Allen	-29.752583	31.070750	Gateway Mall	-29.725825	31.066771	2.99
Lady Allen	-29.752529	31.069760	Gateway Mall	-29.725825	31.066771	3.0
Lady Allen	-29.753433	31.070085	Gateway Mall	-29.725825	31.066771	3.04
Lady Allen	-29.753093	31.070313	Gateway Mall	-29.725825	31.066771	3.06
Lady Allen	-29.753515	31.069962	Gateway Mall	-29.725825	31.066771	3.07
Lady Allen	-29.753786	31.070178	Gateway Mall	-29.725825	31.066771	3.12
Sherwood	-29.826395	30.981317	Cowey's Park	-29.841022	31.008941	3.12
Clare Hills	-29.824971	30.981173	Cowey's Park	-29.841022	31.008941	3.24
Lady Allen	-29.755387	31.068382	Gateway Mall	-29.725825	31.066771	3.25
Lady Allen	-29.755472	31.068507	Gateway Mall	-29.725825	31.066771	3.26
Lady Allen	-29.757165	31.067555	Gateway Mall	-29.725825	31.066771	3.47
Lady Allen	-29.759305	31.066378	Gateway Mall	-29.725825	31.066771	3.71
Durban North	-29.792505	31.030596	Cowey's Park	-29.841022	31.008941	5.72

3.5 Discussion

In this study, we found that most of the rose-ringed parakeet breeding sites were distributed in the suburb of Umhlanga Rocks, typically in residents' gardens and parks. In South Africa, these parakeets are generally distributed in human-dominated areas and typically occupy urban parks with their roosting sites also found in the urban areas (Dean 2000; Roche and Bedford-Shaw 2008; Hart and Downs 2014; Ivanova and Symes 2019). Most of the urban parks have different tree species used by most cavity nesters, including parakeets (Strubbe and Matthysen 2007; Strubbe and Matthysen 2009a; Orchan et al. 2013; Mori et al. 2017; Rocha et al. 2020). Rose-ringed parakeets mostly used secondary cavities in the native white milkwood tree for nesting when compared with other tree species. This tree had most of the dead branches enabling native cavity-nesting bird species to excavate nest holes. In addition, the white milkwood tree is the most common tree species in the coastal areas where Umhlanga Rocks is situated (Govender 2000). The invasive river red gum tree *E. camaldulensis* was the second most used for nesting by parakeets in our study. The number of river red gum trees used by parakeets in this study was lower than the number reported in Yarkon Park, Tel Aviv, Israel (Orchan et al. 2013). This may be explained by the river gum tree being the most abundant species in Orchan et al. (2013) study. The mean nest height above the ground and tree height was larger than that reported in Butler et al. (2013), which recorded 8.1 m and 19.5 m, respectively. This indicated that parakeets likely prefer to use secondary cavities in taller trees for nesting. Trees with such similar characteristics may provide nest sites for rose-ringed parakeets resulting in a loss of habitat and/or nest sites for native cavity-nesting bird species (Strubbe and Matthysen 2009a; Covas et al. 2017). In addition, parakeets preference to breed in urban landscapes could be further explained by the availability of food and warmer temperature (Hart and Downs 2015).

We found an increase in the number of nest sites used between breeding seasons. This may be explained by that parakeets breeding pairs utilised similar nest throughout the breeding season, and their population size is increasing (Shivambu et al. 2020a). This was also observed in previous studies where parakeets were seen using the same nest hole (Orchan et al. 2013; Rocha et al. 2020). In our study, the recorded number of parakeets' fledglings ranged between one and three chicks. Similarly, the number of fledgeling chicks produced in the Indian subcontinent (n = 1.7 – 3.0; Shivanarayan et al. 1981), Israel (n = 1; Orchan et al. 2012) and Britain (n = 0.8 – 1.4; Butler 2003; Butler et al. 2013), suggesting that the breeding success of parakeets in South Africa is within the range reported for other areas. The number of fledglings fluctuated between the seasons, and our results did not show a decline in their breeding success. In addition, we observed no raptors preying on the parakeets during our survey, which may also be the reason why their fledglings were not declining. The small percentage of nests where fledging was unsuccessful were the secondary nests used by both common mynas and parakeets, and artificial nests as they were also used by native birds.

If rose-ringed parakeets utilise similar nest sites over the years, their numbers will likely increase, as reported in Hart and Downs (2014), Symes (2014), and Whittington-Jones (2017). In a British study conducted by Butler (2003), the reproductive rate of rose-ringed parakeets increased over the sampled years, which showed that fledglings had matured and contributed to the reproduction success of this species. However, despite covering two breeding seasons, it appears that the rose-ringed parakeets' reproductive rate is succeeding as in their non-native range.

The breeding seasons for rose-ringed parakeets differ between the continents. In our study, the parakeets bred between September and November. While in Europe (Butler et al. 2013; Rocha et al. 2020) and its native range, including Bangladesh, India, and Pakistan (Simwat and Sidhu 1973; Krishnaprasadan et al. 1988; Hossain et al. 1993), they breed between

February and June. The similarity of breeding seasons between the countries is supported by some parts having matching climate stratification (Metzger et al. 2013; Shivambu et al. 2020b). Consequently, this has created a similar breeding match, which may increase the invasion success of rose-ringed parakeets (Luna et al. 2017).

None of the tree parameters influenced the number of rose-ringed parakeets' fledglings produced in both breeding seasons in our study. However, we reported a large number of the nests that fledged in this study, indicating that the parakeets are successful breeders in KwaZulu-Natal Province. In a study by Butler et al. (2013), it was shown that nest cavity size influenced the parakeet's clutch size produced. This may also explain the reproductive success of this species in our study. In other studies, the selection of nest sites was influenced by artificial nest boxes placed for native bird species but taken over by parakeets, resulting in their feral populations being sustained (Butler 2003; Braun and Wink 2013). Out of 69 natural nests recorded in our study, 43 nests were previously used by native birds, including three privately owned artificial nest boxes. Species replaced by parakeets in their nests included the crested barbet, African hoopoe, black-collared barbet, and golden-tailed woodpecker. Although we did not observe parakeets directly replacing native birds from the remaining 26 natural nests, it is likely that native birds also used those nests before parakeets used them. Some of the nests were expanded by parakeets so that they could use them. Only non-native or alien invasive species that we observed using the same nest sites as the parakeets were common mynas. This may result in complex competition between native and non-native bird species. The nest sites competition between common myna and parakeets was also observed by Orchan et al. (2013). In Belgium, rose-ringed parakeets have been implicated in the displacement of the native blue tits and nuthatches (Strubbe and Matthysen 2009a; Covas et al. 2017). In other studies, species of woodpecker such as great spotted woodpecker *Dendrocopos major,* green woodpeckers *Picus viridis* and Syrian woodpecker *Dendrocopos syriacus* have had their nest sites taken by parakeets (Butler et al. 2013; Braun and Wink 2013). This may negatively impact the population of native bird species and cause their decline in natural areas, including South Africa.

In this study, native bird species or rose-ringed parakeets did not use our artificial nest boxes, but African honey bees and common mynas used them. A study by Downs (2005) also found that similar bee species occupied artificial nest boxes placed for wild endangered South African Cape parrots *Poicephalus robustus* with an occupation percentage of 20% between 2000 and 2003. Occupation by bees or common mynas in our study may have impeded native bird species or parakeets from using the nests. Given that bees can use nest boxes (MacIvor 2017), it is likely that African honey bees will take artificial nest boxes placed for native birds. The common myna was reported to affect the breeding success of the eastern rosella *Platycercus eximius* and crimson rosella *Platycercus elegans* by taking over their nest boxes in Canberra, Australia (Grarock et al. 2013). In a study by Charter et al. (2016) in Tel Aviv, Israel, it was found that common mynas occupied the majority (62-74%) of artificial nest boxes when compared with the rose-ringed parakeets (5-14%). It is possible that common myna will continue to use artificial nest boxes, given their population size in South Africa and their aggressive behaviour towards other bird species (Harper et al. 2005; Lowe et al. 2011; Peacock et al. 2007).

The distances that rose-ringed parakeets travelled from roost sites to breeding sites differed as some were close (~1.3 km) or far (~5 km). We found most of the parakeet nesting sites relatively close to roosting sites, and many were observed also feeding on tree species that they nested in, e.g., white milkwood fleshy fruits (Shivambu et al. 2020c). It is suggested that this behaviour may be to save the energy needed to fly long-distances, as indicated in Ettinger and King (1980) for the willow flycatcher *Empidonax traillii*. In Britain, Butler (2003) found parakeets travelled ± 6 km between nest and roost sites, while in Brussels, Belgium, Pârâu et al. (2016) found that they travelled ± 9 km. This explains the similar behaviour by rose-ringed parakeets' in South Africa. However, they have also been travel for more that 10 km, e.g. 12 km in Amsterdam and 15 km in Germany (Keijl 2001; Kahl-Dunkel and Werner 2002).

3.6 Recommendations

We recommend further studies on the breeding biology of rose-ringed parakeets, given that their population is increasing indifferent provinces of South Africa (Dean 2000; Roche and Bedford-Shaw 2008; Hart and Downs 2014; Ivanova and Symes 2019). In addition, a long-term study on the parakeets breeding biology may provide a robust breeding status, including its breeding behaviour and population trends. These parakeets are secondary cavity-nesting species and have displaced native cavity users in other countries and South Africa (Strubbe and Matthysen 2009a; Covas et al. 2017; TC Shivambu pers. comm.; present study). It is therefore essential to assess parakeets' impact on native cavity-nesting birds, primarily through competition. Our study reported a total of 39 parakeet breeding sites, fewer than the number of parakeets estimated (~2 000, Shivambu et al. 2020a) in eThekwini Municipality; it is therefore recommended that their movement patterns be assessed using radiotelemetry to locate additional breeding sites. Given that nest boxes have been used successfully by rose-ringed parakeets (Butler et al. 2013; Charter et al. 2016) and other psittacid species such as macaws *Ara* spp. (Munn 1992; Nycander et al. 1995), green-rumped parrotlet *Forpus passerinus* (Beissinger and Bucher 1992), and the yellow-crowned Amazon *Amazona ochrocephala* (Sanz et al. 2003), it is recommended that parakeets be monitored to determine if they may use artificial nest boxes in the long run.

3.7 Conclusions

We concluded that the rose-ringed parakeets breeding is contributing to their population growth as their reproductive success was relatively at an average rate in eThekwini Municipality. They successfully found and used secondary nest cavities and likely compete with some native species for nest sites. Moreover, the findings of this study provide essential data for an overall management strategy and can be used to inform decisions on eradicating this species in South Africa.

3.8 Acknowledgements

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3.9 Authors' contribution

TCS and CTD conceptualised the study. TCS and CTD sourced funding. TCS and NS collected and analysed the data. TCS wrote the manuscript draft. CTD and NS reviewed and edited the manuscript.

3.10 Declaration of competing interest

The authors declare that they have no conflict of interest.

3.11 References

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3.12 Supplementary material

Supplementary Figure S3.1 An example of a) nest boxes type been painted in the University of KwaZulu-Natal, Pietermaritzburg campus, and b) one of the nest box placed in white seringa *Kirkia acuminata* that rose-ringed parakeets breed in Durban North, KwaZulu-Natal Province. ©Photographs: TC Shivambu.

Supplementary Material Table S3.1 Information on areas where artificial nest boxes were placed in eThekwini Municipality for rose-ringed parakeets and native bird species during breeding seasons. Other animals are those organisms that were using artificial nest boxes, and a number 0 indicate unoccupied nest boxes. The common and scientific names of "other animals" are East African lowland honey bees *Apis mellifera scutellata* and common myna *Acridotheres tristis*.

Locations	**Coordinates**		**Amenities**	**No. of parakeets nesting**				**Other animals**
	Latitude	**Longitude**		**Spring**	**Summer**	**Autumn**	**Winter**	
Leo Boyd Highway, Ballito	-29.545289	31.196889	Forest patch	0	0	0	0	Bees
Compensation Beach Road, Ballito	-29.549850	31.206769	Forest patch	0	0	0	0	Bees
Driftwood Drive, Ballito	-29.548919	31.204761	Forest patch	0	0	0	0	Bees
Ballito 1	-29.546481	31.204619	Forest patch	0	0	0	0	Bees
Ballito 2	-29.543550	31.204069	Forest patch	0	0	0	0	Bees
Compensation Beach Road, Ballito	-29.547069	31.207611	Residence	0	0	0	0	Bees
Ashley Road 54/53, Ballito	-29.546181	31.208581	Forest patch	0	0	0	0	Bees
Yellowwood Drive, Ballito	-29.555425	31.189167	Residence	0	0	0	0	Bees
Homeford Drive 13/18, Durban	-29.749261	31.073431	Residence	0	0	0	0	Bees
Ganges secondary school	-29.948020	30.963540	School	0	0	0	0	0
Ganges secondary school	-29.948150	30.964030	School	0	0	0	0	Bees
Ganges secondary school	-29.947980	30.963940	School	0	0	0	0	Bees
Ganges secondary school	-29.947830	30.964020	School	0	0	0	0	Bees
Allipore primary	-29.946183	30.963251	School	0	0	0	0	0
Allipore primary	-29.946235	30.963195	School	0	0	0	0	0
Allipore primary	-29.945881	30.963371	School	0	0	0	0	Bees
Allipore primary	-29.945490	30.963134	School	0	0	0	0	0
Sneezewood Lane	-29.751100	31.031800	Shopping centre	0	0	0	0	Bees
Forest Drive 26/55, Durban	-29.753200	31.068980	Residence	0	0	0	0	Bees
Lady Ellen Crescent 36/21, Durban	-29.753283	31.070392	Park	0	0	0	0	0
Lady Ellen Crescent 34/19, Durban	-29.753460	31.070030	Park	0	0	0	0	0
Lady Ellen Crescent 36/21, Durban	-29.753310	31.070440	Park	0	0	0	0	0
Lady Ellen Crescent 16/9, Durban	-29.755440	31.068660	Residence	0	0	0	0	Common myna

Locations	Coordinates		Amenities	No. of parakeets nesting				Other animals
	Latitude	Longitude		Spring	Summer	Autumn	Winter	
Lady Ellen Crescent 16/9, Durban	-29.755500	31.068550	Residence	0	0	0	0	Bees
Lady Ellen Crescent 16/9, Durban	-29.755390	31.068410	Residence	0	0	0	0	Bees
Umhlanga Rocks, 4320	-29.753187	31.069196	Park	0	0	0	0	Bees
Umhlanga Rocks, 4320	-29.752826	31.069687	Park	0	0	0	0	0
Umhlanga Rocks, 4320	29.752529	31.069800	Park	0	0	0	0	Bees
Forest Drive 27, Durban	-29.757340	31.067500	Residence	0	0	0	0	Bees
Forest Drive 17, Durban	-29.758170	31.066480	Residence	0	0	0	0	Bees
Homeford Drive 13/18, Durban	-29.749230	31.073410	Forest patch	0	0	0	0	0
Homeford Drive 13/18, Durban	-29.749300	31.073470	Residence	0	0	0	0	Common myna
Seafern Road, Durban	-29.749080	31.073350	Forest patch	0	0	0	0	Bees
Seafern Road, Durban	-29.748650	31.073400	Guest house	0	0	0	0	Bees
Forest Drive 54/87, Durban	-29.749320	31.072290	Residence	0	0	0	0	Bees
Eastmoor Crescent 16/9, Durban	-29.742970	31.077510	Park	0	0	0	0	Common myna
Durban view park	-29.734050	31.083310	Park	0	0	0	0	Bees
Durban view park	-29.733710	31.082970	Park	0	0	0	0	0
Marine Drive 41, Durban	-29.733680	31.082750	Park	0	0	0	0	Bees
Marine Drive 37/36, Durban	-29.733400	31.083150	Park	0	0	0	0	Bees
Marine Drive 35, Durban	-29.733040	31.083140	Residence	0	0	0	0	Bees
Marine Drive 37/36, Durban	-29.733400	31.083150	Park	0	0	0	0	Common myna
Umhlanga Rocks, Umhlanga, 4320	-29.733190	31.083330	Park	0	0	0	0	Bees
Hawthorne Drive 13/24, Durban	-29.726630	31.043510	Residence	0	0	0	0	0
Hawthorne Drive 13/24, Durban	-29.726840	31.043290	Residence	0	0	0	0	Bees
Hawthorne Drive 9/20, Durban	-29.726020	31.043830	Residence	0	0	0	0	Common myna
Hawthorne Drive 15/26, Durban	-29.727290	31.043280	Residence	0	0	0	0	Bees
Hawthorne Drive 17/28, Durban	-29.727630	31.043180	Residence	0	0	0	0	0
Hawthorne Drive 19/30, Durban	-29.727940	31.043230	Residence	0	0	0	0	0
Carolina Vista 35/46, Durban	-29.728360	31.049050	Residence	0	0	0	0	Bees
Carolina Vista 35/46, Durban	-29.728390	31.048970	Residence	0	0	0	0	0
Carolina Vista 35/46, Durban	-29.728330	31.049070	Residence	0	0	0	0	Bees
Umhlanga Rocks, 4250	-29.748504	31.073115	Residence	0	0	0	0	Bees
Umhlanga Rocks, 4320	-29.748999	31.072187	Residence	0	0	0	0	Bees
Umhlanga Rocks 4320	-29.748813	31.071908	Residence	0	0	0	0	Bees

Locations	**Coordinates**		**Amenities**	**No. of parakeets nesting**				**Other animals**
	Latitude	**Longitude**		**Spring**	**Summer**	**Autumn**	**Winter**	
Essenwood, Berea, 4001	-29.840801	31.009278	Shopping centre	0	0	0	0	0
Essenwood, Berea, 4001	-29.840593	31.009433	Shopping centre	0	0	0	0	0
Essenwood, Berea, 4001	-29.836788	31.014647	Shopping centre	0	0	0	0	0
Morningside, Durban, 4001	-29.836181	31.015107	Shopping centre	0	0	0	0	0
Mount Edgecombe Estate 2	-29.728415	31.049038	Restaurant	0	0	0	0	Bees
Mount Edgecombe Estate 2	-29.728498	31.048920	Restaurant	0	0	0	0	Bees
Mount Edgecombe Estate 2	-29.728229	31.043127	Golf course	0	0	0	0	Bees
Mount Edgecombe Estate 2	-29.727244	31.043233	Golf course	0	0	0	0	Bees
Mount Edgecombe Estate 2	-29.726994	31.043395	Golf course	0	0	0	0	Bees
Mount Edgecombe Estate 2	-29.726972	31.043250	Golf course	0	0	0	0	Bees
Mount Edgecombe Estate 2	-29.725582	31.043938	Golf course	0	0	0	0	Bees

Supplementary Material Table S3.2 Summary table showing breeding sites, tree species used for nesting, localities and types of amenities around the study areas.

Sites	Tree species	Common name	Place name	Amenities	Latitude	Longitude
1	*Albizia adianthifolia*	Flat-crown	Mt Edgecombe	Residence	-29.728643	31.047961
2	*Albizia adianthifolia*	Flat-crown	Mt Edgecombe	Residence	-29.728205	31.049168
3	*Albizia adianthifolia*	Flat-crown	Mt Edgecombe	Residence	-29.727539	31.047417
4	*Eucalyptus camaldulensis*	River red gum	Sherwood	School	-29.826395	30.981317
5	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Park	-29.752480	31.070125
6	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Forest patch	-29.752529	31.069760
7	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Park	-29.753093	31.070313
8	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Forest patch	-29.752583	31.070750
9	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Hotel	-29.753433	31.070085
10	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Hotel	-29.753515	31.069962
11	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.755387	31.068382
12	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.753786	31.070178
13	*Eucalyptus camaldulensis*	River red gum	Windsor Golf Course	Golf course	-29.817151	31.031077
14	*Sideroxylon inerme*	White milkwood	Sherwood	School	-29.824971	30.981173
15	*Ficus natalensis*	Natal fig	Mt Edgecombe	Residence	-29.727566	31.047390
16	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.755472	31.068507
17	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.757165	31.067555
18	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.759305	31.066378
19	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.751427	31.071243
20	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.749289	31.072238
21	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.748679	31.072742
22	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Forest patch	-29.749114	31.072160
23	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.748697	31.073228
24	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.749363	31.073389

Sites	Tree species	Common name	Place name	Amenities	Latitude	Longitude
25	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.749177	31.073086
26	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.751417	31.071740
27	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Forest patch	-29.748012	31.074074
28	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Forest patch	-29.747928	31.074098
29	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Forest patch	-29.747814	31.074656
30	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.747632	31.074508
31	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.746944	31.074747
32	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Residence	-29.745454	31.076178
33	*Albizia adianthifolia*	Flat-crown	Umhlanga Rocks	Park	-29.742240	31.074799
34	*Albizia adianthifolia*	Flat-crown	Umhlanga Rocks	Park	-29.741625	31.075126
35	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Park	-29.733201	31.083331
36	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Park	-29.733201	31.083332
37	*Sideroxylon inerme*	White milkwood	Umhlanga Rocks	Park	-29.734023	31.083430
38	*Eucalyptus camaldulensis*	River red gum	Merebank	Cemetery	-29.951958	30.963511
39	*Eucalyptus camaldulensis*	River red gum	Merebank	Cemetery	-29.951600	30.962529

CHAPTER 4

Aspects of the feeding ecology of introduced Rose-ringed Parakeets *Psittacula krameri* in the urban landscape mosaic of Durban, KwaZulu-Natal Province, South Africa

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4.1 Abstract

The Rose-ringed Parakeet Psittacula krameri is one of the world's commonest invasive bird species and has established in the South African urban landscapes. However, relatively little is known about the feeding biology of parakeets here. We surveyed areas in eThekwini Municipality, Durban, South Africa, to determine their feeding sites and the related land-use types. Patterns of the association were explored using Correspondence Analysis to determine parakeets' diet across seasons and interaction between different tree species fed on by parakeets and other bird species. Dietary items were determined visually using binoculars. We identified a total of 63 feeding sites, with many in the urban built land-use cover type. The parakeets' diet differed significantly across the seasons, with spring accounting for 33% of annual food items. We identified 31 fruiting/flowering tree species fed on by the parakeets, with fleshy fruits and flowers accounting for 58% and 19%, respectively. Native tree species (63%) were mostly relied on compared with non-native (27%). They also fed on carpenter ants *Camponotus cinctellus,* which contributed 3% of their diet. The forest fever-berry *Croton sylvaticus* (fleshy fruits) and African star-chestnut *Sterculia africana* (flowers) were the most preferred tree species in autumn and summer. The observed number of bird species that communally fed with parakeets were significantly different across the sampled seasons. The diets for the Common Myna *Acridotheres tristis* and the Speckled Mousebird *Colius striatus* overlapped with parakeets for most tree species. Parakeets were observed actively feeding in the early mornings and late afternoons before roosting. Our study supports that parakeets are generalist-opportunistic feeders. The assessment of Rose-ringed Parakeets feeding ecology may help understand their potential impact on native tree and bird species within an urban landscape.

Keywords: Alien invasive species · Competition · Generalist species · Feeding patterns · Urban landscape

4.2 Introduction

Studying the feeding ecology of invasive bird species has facilitated understanding of their species-specific diets around the world (Khan 2003; Fraticelli 2014). This has enabled a better understanding of the impacts posed by introduced bird species, especially on crops of economic importance such as apple *Malus domestica*, citrus *Citrus* spp., cherry *Prunus cerasus*, yellow guava *Psidium guajava*, mango *Mangifera indica*, sunflower *Helianthus annuus*, and maize *Zea mays* (Ahmad et al. 2011; Canavelli et al. 2013; Fraticelli 2014; Symes 2014; Menchetti and Mori 2014). Some parrot species, for example, are regarded as one of the agricultural pests in both their native and invaded areas (Mukherjee et al. 2000; Kale et al. 2014; Shiels et al. 2018). The invasive Monk Parakeet *Myiopsitta monachus* in Barcelona, Spain, has been associated with damage to commercial crops such as tomato *Lycopersicon esculentum*, maize, and pear *Pyrus communis* (Senar et al. 2016). In India and Hawaii, Rose-ringed Parakeets *Psittacula krameri* feed on crops of agricultural importance, which include citrus, guava, mango, sorghum, and maize (Reddy 1998; Ahmad et al. 2012; Shiels et al. 2018).

The agricultural impacts associated with Rose-ringed Parakeets are of concern as these can cause significant economic losses (Shiels et al. 2018). These parakeets also destroy seeds of native trees, are sometimes seed dispersers, and they can also strip bark on the native trees resulting in the death of those trees (Fletcher and Askew 2007; Tella et al. 2015; Thabethe et al. 2015; Klug et al. 2019). There is also a potential for the parakeets to spread alien and invasive plant species, especially small seeds that can pass through their digestive tract (Thabethe et al. 2015; Shiels et al. 2018; Klug et al. 2019). In addition, Peck et al. (2014) showed that these parakeets negatively affect the foraging behaviour of native bird species through food competition, and they may adversely affect native species accessing food in urban domestic gardens.

Humans have been the only contributing factor in the introduction of Rose-ringed Parakeets from their native to non-native ranges through the exotic pet trade (Symes 2014; Jackson et al. 2015). Rose-ringed Parakeets show plasticity in feeding behaviour and are generalist-opportunistic feeders consuming a variety of foods, including insects and plant components such as flowers, seeds, twigs, fruits, and leaves (Eason et al. 2009; Ahmad et al. 2011; Clergeau and Vergnes 2011; Fraticelli 2014; Symes 2014; Tella et al. 2015; Borray-Escalante et al. 2020). Although the feeding ecology of Rose-ringed Parakeets has been reported in other countries (Ahmad et al. 2012; Fraticelli 2014; Shiels et al. 2018), relatively little has been documented in South Africa (Thabethe et al. 2015; Ivanova and Symes 2019). Given the evidence of environmental and socio-economic impacts associated with Rose-ringed Parakeets (Shivambu et al. 2020a), it is important to understand their feeding biology in South Africa.

The populations of non-native Rose-ringed Parakeets are established in the urban areas, particularly around human habitations in South Africa (Hart and Downs 2014; Symes 2014; Ivanova and Symes 2019; Shivambu et al. 2020b). The pet trade has been the main contributing factor that has facilitated to the introduction and establishment of parakeets in South Africa, with unwanted pets released and some escaping captivity and forming wild populations in urban areas (Symes 2014; Ivanova and Symes 2019; SABAP 2020). To date, the wild populations of this species appear to be increasing and occurring in different urban areas in South Africa (Hart and Downs 2014; Symes 2014; SABAP2 2020; Shivambu et al. 2020b). The potential impacts associated with Rose-ringed Parakeets feeding ecology in other countries is well documented (Ahmad et al. 2012; Fraticelli 2014; Shiels et al. 2018; Shivambu et al. 2020a). Given this, we studied aspects of their feeding ecology to (1) determine the distribution of Rose-ringed Parakeets feeding sites, and their associated land-use types, (2) determine types of food items consumed and patterns of association in Rose-ringed Parakeets diet across the seasons, (3) identify bird species that fed communally with the Rose-ringed Parakeets, and explored the associations of different tree species between them, and (4) determine daily feeding times of Rose-ringed Parakeets. We predicted that the Rose-ringed Parakeets diet would differ across the seasons and feed on a variety of food types, but mainly seeds and fleshy fruits of both native and non-native plants. We also predicted that Rose-ringed Parakeets land-use cover type for feeding activities would be associated with human-transformed habitats, as previously reported (Butler 2005; Fraticelli 2014). Given that Rose-ringed Parakeets is a superior competitor (Le Louarn et al. 2016; Peck et al. 2014; Strubbe and Matthysen 2007), we expected that parakeets would dominate the feeding study sites when compared with native species.

4.3 Materials and methods

4.3.1 Study area

We conducted our study in the KwaZulu-Natal Province, South Africa, particularly in the Durban Metropolitan areas, which form part of eThekwini Municipality (29.8120° S, 30.8039° E). It is in the eastern coastal regions of South Africa (Fig. 4.1a). The size of the municipality is ~ 2 291 $km^{2,}$ with the human population estimated at ~ 3.4 million (EThekwini Municipality 2013). It is known to be one of the largest cities in South Africa and the busiest municipalities in terms of business with urban structural areas surrounding it (Todes 2014). Its climate is subtropical, with an annual minimum mean temperature ranging from 14 °C to a maximum of 24 °C (http://en.climate-data.org/location/27097/). Its climate is characterised by humid, sunny, and hot summer, mild cold winter, short autumn, and spring; collectively with the mean annual rainfall of ~ 948 mm (http://en.climate-data.org/location/27097/). The types of vegetation found here include those associated with Coastal belt, Eastern Valley Bushveld, Hinterland Thornveld, Ngongoni Veld, Mangrove Forest, Northern Coastal Forest, and Scarp

Forest biomes (McLean et al. 2016). The eThekwini Municipality is a mosaic of habitat types ranging from built to natural (Zungu et al. 2019). The study area includes part of the Durban Metropolitan Open Space System (D'MOSS), which provides significant open green space (~ 75 000 ha) such as conservation areas, golf courses, nature reserves, and parks which serve as a refuge for native fauna and flora (Roberts 1994; Adams 2005; Zungu et al. 2019). The study area was selected as it was reported to have introduced wild populations of Rose-ringed Parakeets (~ 2 500 parakeets), particularly around human habitations (Hart and Downs 2014; SABAP 2020; Shivambu et al. 2020b).

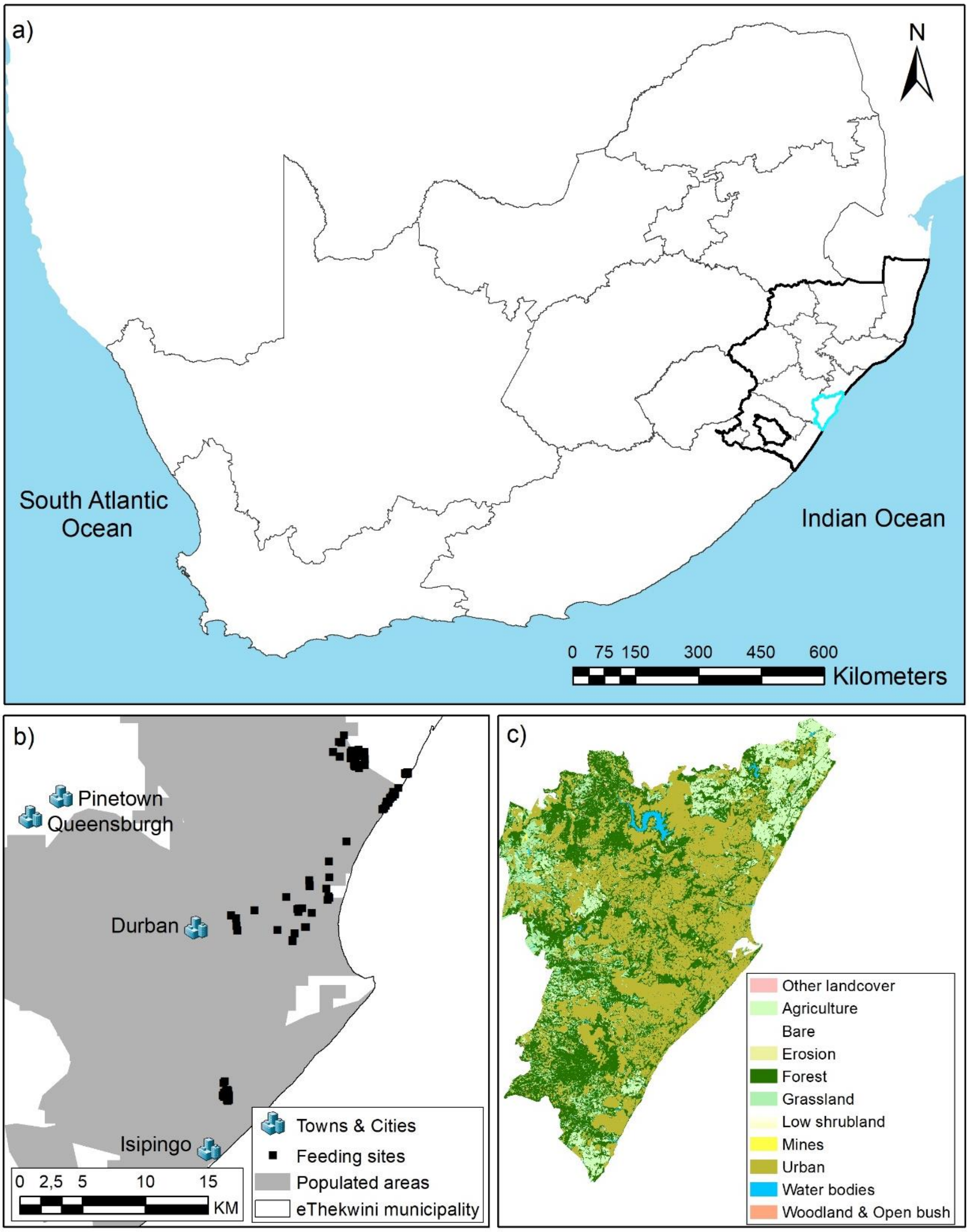

Fig. 4.1 A map showing the general study area of Rose-ringed Parakeets where **a)** indicates eThekwini Municipality (highlighted in blue), **b)** the distribution of feeding sites, and **c)** the land-use cover types in eThekwini Municipality, KwaZulu-Natal Province, South Africa. (The grey area in b indicates the populated urban area)

4.3.2 Sampling techniques

In this study, we undertook a 2 weeks' survey (from 3rd to 17th September 2018) to search for the presence of Rose-ringed Parakeets in the urban mosaic of eThekwini Municipality. We searched for parakeets in the parks, golf courses, forests patches, domestic properties, and agricultural areas around urban areas. We were granted access to privately-owned household properties from landowners. These areas, mainly domestic gardens, form part of the urban green spaces available (Patterson et al. 2018). The flowering and fruiting vegetation planted within the area provides parakeets with potential food items (pers. obs.). In addition, we obtained more information on where parakeets were observed feeding in the vicinity from residents through face-to-face interviews, and via online platforms (e.g. Facebook, KwaZulu-Natal birds-clubs and bird-forums).

We then undertook monthly surveys from September 2018 to September 2019 (12 months) with 3 days of sampling per month per particular area identified. The months were separated into seasons, namely autumn (Mar–May), winter (Jun–Aug), spring (Sep–Nov) and summer (Dec–Feb). The sampled areas or general locations included the suburbs of Merebank, Durban North, Umhlanga Rocks, including Forest Drive, and Mount Edgecombe Estates in eThekwini Municipality (Fig. 4.1). Each of the respective general locations ($n = 4$) had~15 feeding sites that were closer to each other (between 200 m, 800 m and 1 km) and were separated into either morning or afternoon. The morning sites were a few kilometres away from the parakeet roosts (~ 3.34 km), while the afternoon sites were closer to the roosts (~ 340 m). This allowed us to sample each location the whole day by following parakeets as they shifted feeding sites. In the mornings, we sampled from 06h00 until 14h00, while in the afternoons, we sampled from 14h30 until dusk. Three days' observations were made per location in 15 days, each once per week in a month. Feeding was determined by visual inspection (~ 3 m away from the trees), typically using UltraOptec® floating sports binoculars (8×30; Europe) and a camera (Canon PowerShot SX430 IS, HD 45X optical zoom; China). We recorded the number of parakeets foraging in pairs or flocks (~ 5 – 50). We recorded the daily feeding times of the Rose-ringed Parakeets and all food items that they fed on. These generally included flowers, seeds, fruits, twigs, barks, leaves, and insects. In terms of fleshy fruit consumption, we checked for any dropped seeds and stripped fruits/seeds below the trees (e.g. Fig. 4.2d). We also recorded if the plant species was native or non-native (hereafter alien). Alien or native bird species that fed communally with Rose-ringed Parakeets were also documented at the same time if in the same tree as parakeets. We confirmed the identification of bird species that fed communally with parakeets to species level using a bird field guide (Chittenden et al. 2016). The tree species that parakeets fed on were identified using a tree field guide (van Wyk and van Wyk 2013). We collected samples of insects observed ingested by the parakeets opportunistically. We later verified their identification using the reference collection housed at the University of KwaZulu-Natal, Pietermaritzburg campus.

The specific geographic localities coordinates (latitude and longitude in decimal degrees) of all Rose-ringed Parakeet feeding sites were identified using Google maps (https://maps.google.com). We then determined the land-use cover types [downloaded from the Department of Environmental Affairs—Geographic Information System Data (DEA-GIS Data 2019)] associated with the parakeets feeding sites. The Rose-ringed Parakeet feeding site distribution map and land-use cover layout were produced using ArcGIS (version 10.4.1: ESRI 2018).

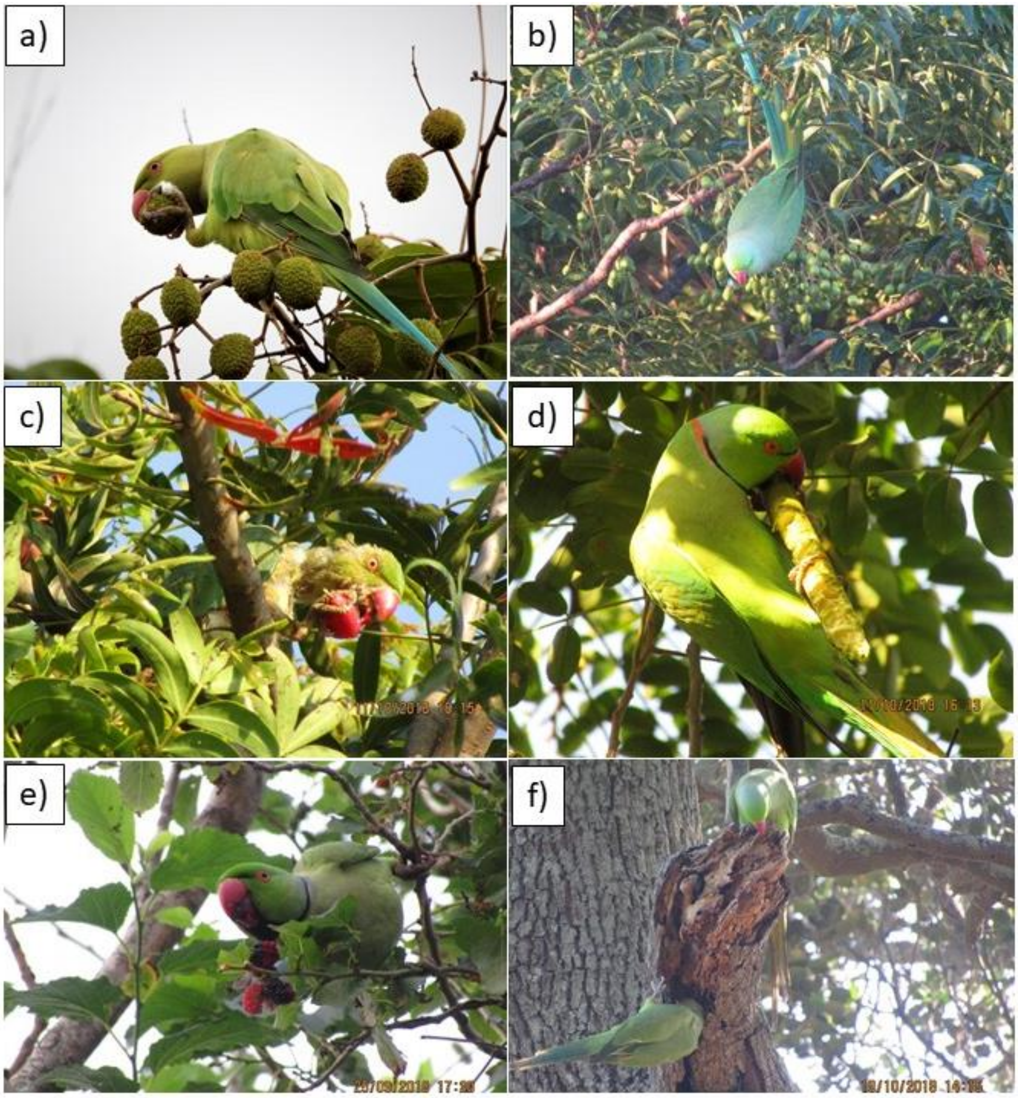

Fig. 4.2 Rose-ringed Parakeets observed in eThekwini Municipality in the present study feeding on fruits of the following trees **a** lychee fruits *Litchi chinensis*, **b** alien syringa *Melia azedarach*, **c** wild plum *Harpephyllum caffrum*, **d** wild cassia *Senna singueana*, **e** alien white mulberry *Morus alba*; as well as on insects **(f)** carpenter ants *Camponotus cinctellus* found on the dry wood of a milkwood tree *Sideroxylon inerme* consumed by parakeets (photographs © TC Shivambu)

4.3.3 Statistical analyses

We performed all statistical analyses using R statistical software (version 3.6.1, R Core Team 2018). We grouped months into seasons and determined the seasonal mean number (± SD) of observed Rose-ringed Parakeet individuals feeding on specific food items. We compared the seasonal mean number of parakeets feeding on each food item using the Repeated Measure Analysis of Variance (RMANOVA). The mean number of individual parakeets that fed on a specific food item throughout the sampling was computed and used to calculate the mean percentage (%) of preferred diet composition.

We determined the monthly total number of observed individuals of the bird species that communally fed with Rose-ringed Parakeets on a particular food item per feeding site. The mean number of these bird species was determined, and seasonal variance was tested using a Kruskal–Wallis test. We used Correspondence Analysis to determine patterns of association of Rose-ringed Parakeets diet types across the seasons. The variables for each correspondent analysis were grouped according to seasons, namely spring, summer, autumn, and winter. We also explored the associations of different tree species between parakeets and bird species that communally fed with them throughout the study period. A total of 31 tree species were grouped into six diet types, i.e. bark, dry seeds, fleshy fruits, fleshy seeds, flowers, and twigs. Eigenvalues were examined using Correspondence Analysis. Factors with an eigenvalue greater than one were considered. All these analyses we performed using ggbiplot in R statistical software (version 3.6.1, R Core Team 2018). The hours of parakeets feeding activity were categorised on an hourly basis from 6h00 to 18h30, and the yearly mean for each hour was determined. The mean numbers of parakeets feeding at a specific time of a day all year-round were used to test for the differences in the feeding time patterns using the Kruskal–Wallis test.

4.4 Results

We located a total of 63 Rose-ringed Parakeet feeding sites in the urban mosaic of eThekwini Municipality. Most of these feeding sites were distributed in the coastal lands (Fig. 4.1b). About 60% (n = 38) of the located feeding sites were in the central Durban surrounds. The suburban areas of Umhlanga Rocks followed with a total of 15 feeding sites, while in Merebank, we recorded a total of 10 feeding sites (Fig. 4.1b). In terms of land-use cover types, we found that most of the feeding sites were in urban built areas, particularly in suburbia with domestic gardens and with a few around indigenous forest patches (Fig. 4.1b, c). No feeding sites were recorded in agricultural areas within the urban mosaic landscape.

Table 4.1 Food items that introduced Rose-ringed Parakeets fed on during the present study

Species name	Common name	Food item	Status
Albizia adianthifolia	Flat-crown albizia	Flowers	Native
*Bauhinia variegata**	Butterfly tree	Flowers	Alien
Camponotus cinctellus	Carpenter ants	Insect	Native
Carica papaya	Pawpaw	Fleshy fruits	Alien
Croton sylvaticus	Forest fever-berry	Fleshy fruits	Native
Cupressus arizonica	Arizona cypress	Twigs	Alien
Cussonia zuluensis	Zulu cabbage tree	Flowers	Native
Erythrina lysistemon	Common coral tree	Flowers	Native
Euclea undulata	Small-leaved guarri	Fleshy fruits	Native
Euphorbia ingens	Candelabra tree	Fleshy fruits	Native
Ficus burkei	Common wild fig	Fleshy fruits	Native
Ficus craterostoma	Bastard Natal fig	Fleshy fruits	Native
Ficus lutea	Giant-leaved fig	Fleshy fruits	Native
Ficus natalensis	Natal fig	Fleshy fruits	Native
Ficus trichopoda	Swamp fig	Fleshy fruits	Native
Harpephyllum caffrum	Wild plum	Fleshy fruits	Native
*Jacaranda mimosifolia**	Jacaranda tree	Flowers	Alien
Mangifera indica	Mango tree	Flowers	Alien
*Melia azedarach**	Syringa	Fleshy fruits	Alien
*Morus alba**	White mulberry	Fleshy fruits	Alien
Phoenix reclinata	Wild date palm	Fleshy fruits	Alien
Piliostigma thonnigii	Camel's foot	Dry seeds	Native
Raphia australis	Kosi palm	Fleshy fruits	Native
Senna singueana	Wild cassia	Fleshy seeds	Alien
*Sesbania punicea**	Spanish gold	Dry seeds	Alien
Sideroxylon inerme	White milkwood	Fleshy fruits	Native

Species name	Common name	Food item	Status
Sterculia africana	African star-chestnut	Flowers	Alien
Syzygium cordatum	Water berry	Fleshy fruits	Native
Syzygium guineense	Woodland waterberry	Fleshy fruits	Native
Widdringtonia nodiflora	Mountain cypress	Bark	Native
Erythrophleum lasianthum	Maputaland ordeal tree	Fleshy fruits	Native
*Eucalyptus grandis**	Blue gum	Bark	Alien

The status of the species depicts whether these species are native or alien in South Africa. An asterisk (*) indicate species invasive to South Africa

The Rose-ringed Parakeet diet comprised mainly of plant items: 58% fleshy fruits, 19% flowers, 7% dry seeds and barks, 3% for fleshy seeds, twigs and insects (Table 4.1, Fig. 4.2). In total, 31 fruiting/flowering tree species were recorded consumed by the parakeets, with 63% native and 37% alien tree species (Table 4.1). Fleshy fruits formed a large part of the parakeets' diet and were mainly from 18 tree species, most of which were native (Table 4.1). Alien tree species from which fleshy fruits were consumed included the alien invasive white mulberry *Morus alba* that has relatively small seeds (Fig. 4.2). Most of the tree species were fed on when the fruits were green as well as when ripe, e.g. syringa berries and white mulberries (Fig. 4.2). Parakeets consumed flowers from at least seven different tree species, of which three were native and four alien species (Table 4.1, Fig. 4.2). They were also observed feeding on the bark of two tree species, namely the native mountain cypress *Widdringtonia nodiflora* and the alien invasive blue gum *Eucalyptus grandis* (Table 4.1). Twigs formed a small percentage of the parakeets' diet and were consumed from only one tree species, the alien Arizona cypress *Cupressus arizonica* (Table 4.1). Parakeets were observed depredating on the fleshy seeds of wild cassia *Senna singueana* and dry seeds of camel's foot *Piliostigma thonnigii* and Spanish gold *Sesbania punicea* until they were exhausted.

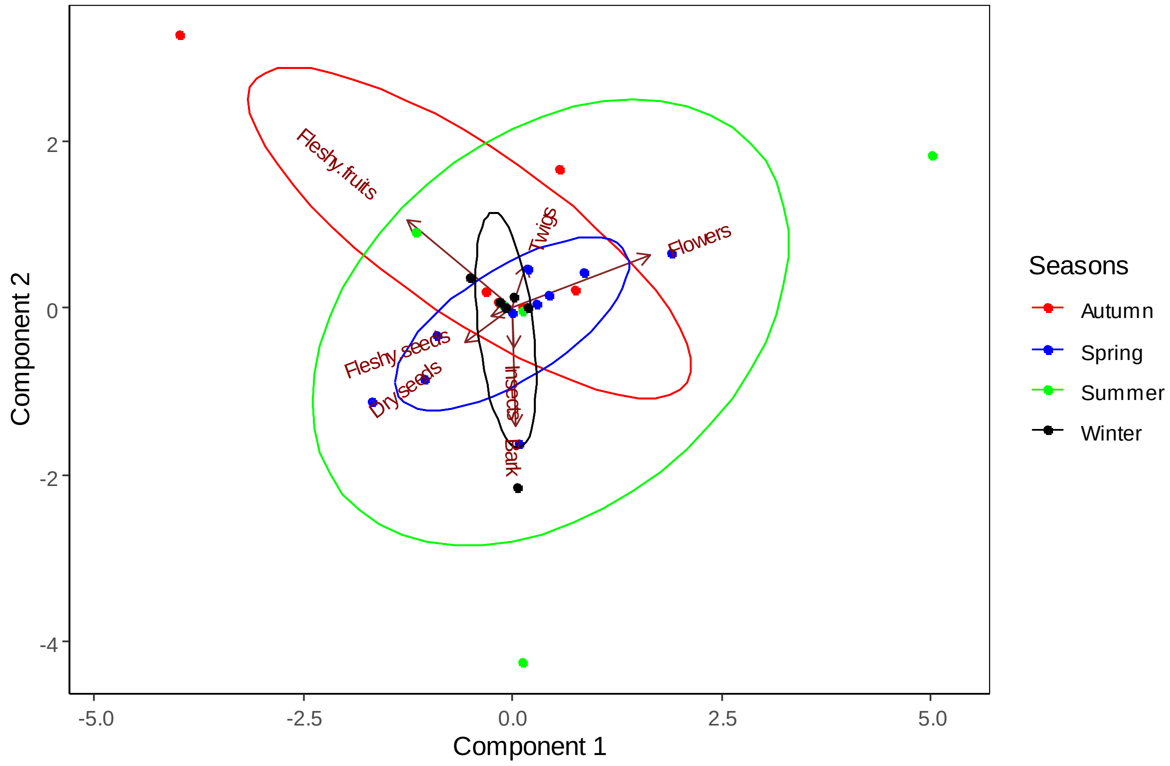

Fig. 4.3 The first two components of Correspondence Analysis representing the patterns of association in Rose-ringed Parakeets' diets for 31 tree and one insect species across the seasons. The axes explained 49.3% of variance using components 1 and 2, while the ellipses indicate the seasons

The Correspondence Analysis distinguished patterns of association in the Rose-ringed Parakeets' diet across the seasons. The first component from the Correspondence Analysis explained 32.1% of the variance, while the second component explained 17.2% of the variance in the seasonal diet. The Rose-ringed Parakeet diet differed significantly across seasons (RMANOVA: $F_{3,344}$ = 2.23, P = 0.007; Fig. 4.3), with spring accounting for 33% of the different food items. Autumn, winter and summer only accounted for between 20 and 22% of the different food items. In all the seasons, parakeets mostly relied on fleshy fruits and flowers (Fig. 4.3). Fleshy fruits of the forest fever-berry *Croton sylvaticus* and flowers of the African star-chestnut *Sterculia africana* were mainly consumed in autumn and summer (Fig. 4.3).

Rose-ringed Parakeets fed on the fruits of some tree species throughout the year, such as the alien invasive syringa *Melia azedarach*, Natal fig *Ficus natalensis*, and pawpaw *Carica papaya* (Fig. 4.3; Supplementary information Table S4.2). The bark of mountain cypress *Widdringtonia nodiflora* and insects *Camponotus cinctellus* residing on blue gum *Eucalyptus grandis* were consumed in winter and spring (Fig. 4.3).

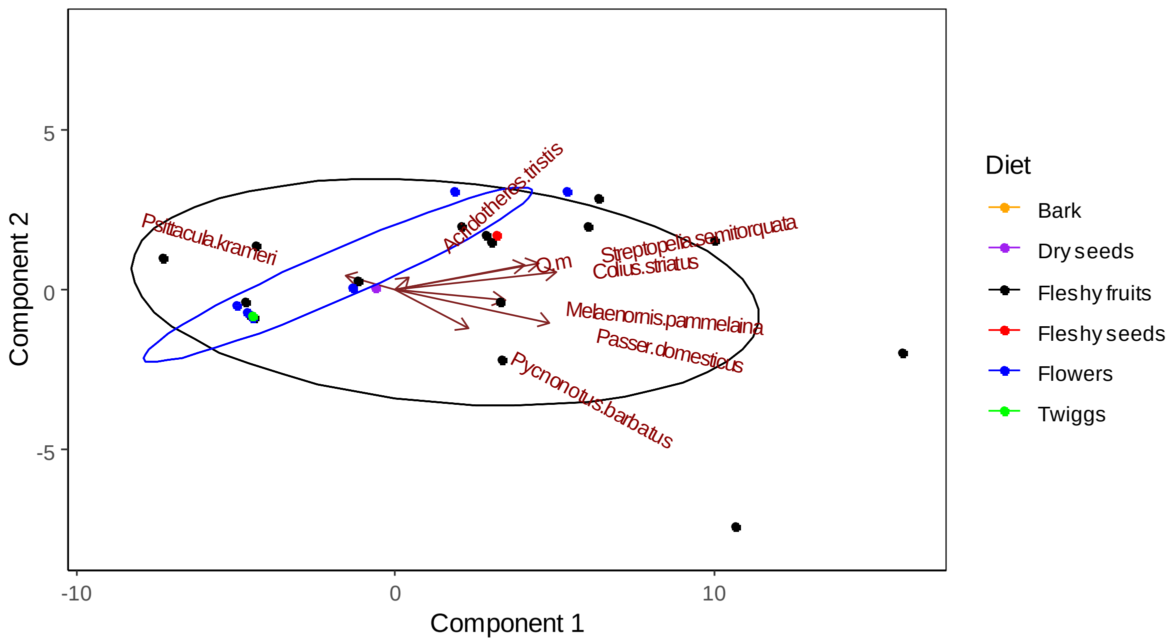

Fig. 4.4 The first two components of the Correspondence Analysis representing the patterns of associations between Rose-ringed Parakeets diet types and the seven bird species that fed communally with them in Durban Metropole, KwaZulu-Natal Province. The abbreviation "O. m" represents the Red-winged starling *Onychognathus morio*. Both axes explained 47.5% of variance using components 1 and 2, while ellipses indicate the diet types belonging to 31 tree and one insect species

We recorded a total of seven bird species that fed communally with Rose-ringed Parakeets (Fig. 4.4). Of these, five were native species while the other two, the Common Myna

Acridotheres tristis and the House Sparrow *Passer domesticus* were alien invasive species in South Africa. The Correspondence Analysis revealed patterns of association of different tree species and diet between parakeets and seven bird species that communally feed with them. The first component explained 29.8% of the variance, and the second component explained 17.7% of the variance in types of diet consumed by eight bird species. The results showed an overlap between parakeets' diet and the other seven bird species for 17 tree species (Fig. 4.4). Tree species with fleshy fruits were mostly consumed when compared with other food items (Fig. 4.4). We found that there was a significant difference between the observed number of bird species that communally fed with parakeets (Kruskal–Wallis: χ^2 = 759.7, df = 7, P = 0.0021). The diets for the Common Myna and the Speckled Mousebird *Colius striatus* overlapped with parakeets for most tree species and food items when compared with other bird species (Fig. 4.4). Tree species where the parakeets' diet did not overlap with other bird species included dietary items such as bark, dry seeds, and twigs (Fig. 4.4). We observed the Rose-ringed Parakeets deterring other bird species from entering the same tree species they were feeding on. This was observed at all the times when parakeets were feeding with other birds. We did not observe parakeets injuring other bird species, though.

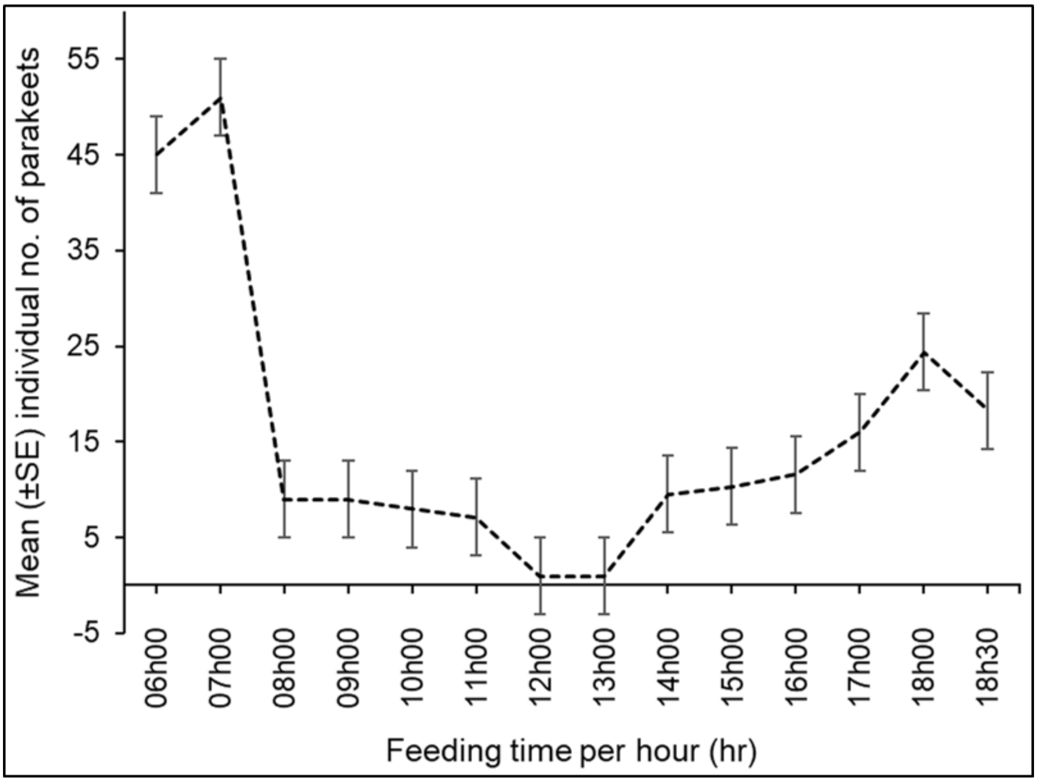

Fig. 4.5 A time series representing typical daily feeding activity patterns of Rose-ringed Parakeets in the present study

The feeding times for Rose-ringed Parakeets differed significantly through the day (χ^2 = 719, df = 13, P < 0.05; Fig. 4.5). They showed higher feeding activity in the morning between 06h00 to 08h00, which then decreased between 09h00 and 11h00 (Fig. 4.5). In our study, parakeets were rarely observed feeding in the midday except on cloudy or overcast days, mainly between 12h00 and 13h00 (Fig. 4.5). During this period, parakeets were typically resting in the shade in trees. Parakeets became active again and fed generally from 14h00 until dusk when they flew to their roosts (Fig. 4.5).

4.5 Discussion

The Rose-ringed Parakeets land-use cover type for feeding activities was associated with human-transformed habitats as reported in other studies (Butler 2005; Clergeau and Vergnes 2011; Fraticelli 2014; Shiels et al. 2018). This may be explained by that parakeets are generally pet releases or escapees (Hart and Downs 2014; Symes 2014; Ivanova and Symes 2019). In addition, urban green spaces, especially domestic gardens, provided food year-round in the present study. In Britain and Italy, where they are introduced (Lambert et al. 2009; Fraticelli 2014), and in Pakistan and India, where they are native and introduced to cities through trade (Iqbal et al. 2000; Ahmad et al. 2012), the parakeets typically forage and roost in the urban mosaic landscape. In our study, their feeding sites were scattered through the urban mosaic landscape of eThekwini Municipality but were mainly in the city centre, suburbia, and coastal areas.

As predicted, Rose-ringed Parakeets showed that they are generalist, opportunistic omnivores (mainly frugivores and to a lesser extent granivores), as their main diet comprised mainly of fleshy fruits, with flowers and dry seeds also taken. This is because most plant species have flowers and fruits in different seasons, e.g. syringa *Melia azedarach*, Natal fig *Ficus natalensis*, and pawpaw *Carica papaya* fruit/flower throughout the year. Similar studies also found that parakeets are mainly frugivores and granivores (Clergeau and Vergnes 2011; Klug et al. 2019; Shiels and Kalodimos 2019; Borray-Escalante et al. 2020). We also observed the parakeets feeding on insects such as carpenter ants throughout the year as a supplementary dietary item. Although these insects accounted for a relatively small portion of the parakeets' diet (3%), this would have been a relatively high protein source. Rose-ringed Parakeets showed plasticity in their feeding behaviour in our study, feeding mainly on fleshy fruits and flowers, particularly in spring and summer. However, in the dry seasons, they also fed on dry seeds, insects, and tree bark. Fletcher and Askew (2007) also indicated that parakeets consumed and stripe bark. In Hawaii, the parakeets fed on similar food items reported in our study, although they were mainly foraging in agricultural landscapes (Shiels et al. 2018). The feeding sites for the parakeets in the present study were not distributed in agricultural landscapes, but we observed them feeding on crops such as litchis, apricots *Prunus armeniaca*, invasive mulberries, and mangos in domestic gardens in suburbia. As parakeets have broad diets and found to have a high potential impact on agriculture (Shivambu et al. 2020a), we should expect them to cause impacts should they expand to agricultural landscapes and other urban areas. The parakeets were also observed feeding on the flowers and seeds of some native plants, such as the common coral tree *Erythrina lysistemon*, African star-chestnut, and camel's foot. These trees were fed on until resources were exhausted. A study by Clergeau and Vergnes (2011) in Europe also found that Rose-ringed Parakeets fed on the same tree species until resources were depleted. Feeding on these tree species may likely affect their regeneration processes (Thabethe et al. 2015; Klug et al. 2019), or their seeds may be dispersed (Tella et al. 2015; Blanco et al. 2016).

In our study, Rose-ringed Parakeets also fed on seeds of alien wild cassia and Spanish gold, and the flowers of invasive jacaranda *Jacaranda mimosifolia*. This may potentially limit the spread of these alien species in South Africa. However, Shiels and Kalodimos (2019) reported that parakeets could reduce the tree's ability to reproduce when they forage in large flocks. Little has been reported on the parakeets spreading alien invasive species as they typically predate on seeds with a diameter ≥ 2.5 cm (Dhindsa et al. 1992; Ahmad et al. 2011; Shiels et al. 2018). However, in Hawaii, a study by Shiels et al. (2018) found that parakeets had intact seeds of invasive yellow guava in their gizzards and, therefore, have the potential to spread this invasive plant. We found that the parakeets fed on invasive white mulberry fruit with seeds smaller than those of guava (Henderson 2001), and this may lead to the potential spread of this species. Thabethe et al. (2015) showed that when Rose-ringed Parakeets ingested alien fruit species (white mulberry, guava, camphor *Cinnamomum camphora*, and bugweed *Solanum mauritianum*), ~ 8% of seeds germinated. Although parakeets are known to destroy fruits to eat the pulp, they can disperse the seeds when transporting them in their bills (Tella et al. 2015).

We found that Rose-ringed Parakeets fed communally with seven bird species on 17 of 31 tree species. At all times, during the observations, parakeets chased other birds visiting the same tree species they were feeding on. This interaction may negatively affect native avian frugivore species' foraging behaviour and sometimes lead to their displacement (Krüger 2002). This was evident in Europe, particularly in Britain and Belgium, where Rose-ringed Parakeets were shown to be superior competitors against native Common Starlings *Sturnus vulgaris*, Great Tits *Parus major*, European Robins *Erithacus rubecula* (Le Louarn et al. 2016), Eurasian Nuthatches *Sitta europaea* (Strubbe and Matthysen 2007), and Great Spotted Woodpeckers *Dendrocopos major* (Peck et al. 2014). The Rose-ringed Parakeets were reported to have an overlapping feeding niche with these native bird species, as observed in the present study (Peck et al. 2014; Le Louarn et al. 2016). None of the native bird species were killed or severely injured by parakeets in our study (pers. obs.). However, Covas et al. (2017) observed parakeets killing House Sparrows and Eurasian Blue Tits *Cyanistes caeruleus* during feeding.

We found that Rose-ringed Parakeets foraged throughout the day, except midday, but fed more in the early morning and late afternoon. Most bird species typically rest in the shade during the heat of the day to avoid water loss (Robbins 1981; Wolf 2000; Bouchard and Anderson 2011). Other frugivore species show similar biphasic feeding activity patterns that may be related to digestive constraints or total energy intake and/or food availability (Symes and Downs 2001; Wirminghaus et al. 2002; Brown and Downs 2003; Rollinson et al. 2013). Other parrot species such as the Grey-headed Parrot *Poicephalus fuscicollis suahelicus* and the

Cape Parrot *P. robustus* typically forage in the early mornings and late afternoons (Wirminghaus et al. 2001; Symes and Perrin 2003).

4.6 Conclusions and recommendations

Rose-ringed Parakeets showed behavioural plasticity in feeding behaviour and were generalist-opportunistic feeders with their feeding sites distributed in the urban mosaic landscape. This species would likely compete with other bird species, mainly native species, as reported in Europe (Strubbe and Matthysen 2007; Peck et al. 2014; Le Louarn et al. 2016). The parakeets' foraging behaviour may potentially impact native and agricultural plant species if they expand further to other areas. In our study, the parakeets were mainly feeding on flowers, seeds, and fruits of different plant species, and, therefore, this may negatively affect the reproductive success of native plants. The introduced Rose-ringed Parakeets have successfully established in eThekwini Municipality and other cities around South Africa, and the assessment of their feeding ecology may assist in understanding the potential negative impacts associated with this species (see Shivambu et al. 2020a). We also recommended continued monitoring of Rose-ringed Parakeets feeding ecology in eThekwini Municipality as their population is increasing (~ 2 500 parakeets) (Hart and Downs 2014; Shivambu et al. 2020b). As the parakeets are known to be urban commensal species (Strubbe and Matthysen 2007; Hart and Downs 2014; Ivanova and Symes 2019), movement patterns may need to be assessed for this species to identify other foraging areas and possibly areas at risk of crop damage as they are known to feed on crops (Ahmad et al. 2012; Shiels et al. 2018; Klug et al. 2019).

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4.9 Supplementary material

Supplementary information Table S4.1 A summary table indicating food type and mean number (±SD) of invasive rose-ringed parakeets feeding throughput four sampling seasons. Where zero (0) indicate, no parakeets were seen feeding on particular species. Species with an asterisk (*) are those invasive to South Africa.

Species name	Common name	Means seasonal (± SD) species number			
		Spring	**Summer**	**Autumn**	**Winter**
Albizia adianthifolia	Flat-crown albizia	4.0 ± 2.5	26.8 ± 9.12	0	0
*Bauhinia variegata**	butterfly tree	4.0 ± 3.2	5.0 ± 2.9	0	24.7 ± 16.0
Camponotus cinctellus	Carpenter ants	3 ± 2.1	8.7 ± 2.8	5.0 ± 2.3	3.3 ± 1.3
Carica papaya	pawpaw	3.5 ± 4.5	11 ± 4.3	6.0 ± 9.9	5.5 ± 2.9
Croton sylvaticus	Forest fever-berry	75.0 ± 55.7	275 ± 115.7	0	0
Cupressus arizonica	Arizona cypress	2.0 ± 0.14	1.0 ± 1.1	0	0
Cussonia zuluensis	Zulu cabbage tree	2.5 ± 1.4	3.5 ± 5.1	0	0
Erythrina lysistemon	Common coral tree	11.5 ± 9.8	0	0	0
Euclea undulata	Small-leaved guarri	0	9.3 ± 6.1	6.3 ± 3.1	0
Euphorbia ingens	Candelabra tree	0	0	13 ± 10.1	2.7 ± 3.4
Ficus burkei	Common Wild Fig	0	70.8 ± 10.3	20 ± 16.3	7.8 ± 4.3
Ficus craterostoma	Bastard Natal fig	0	6.0 ± 9.9	3.0 ± 6.5	0
Ficus lutea	Giant-leaved fig	5.5 ± 2.9	0	0	5.5 ± 2.9
Ficus natalensis	Natal fig	6.4 ± 22.12	10.5 ± 9.8	9.7 ± 10.2	10.6 ± 6.6
Ficus trichopoda	Swamp Fig	6.6 ± 3.6	10.4 ± 8.9	0	0
Harpephyllum caffrum	Wild plum	7.8 ± 22.3	5.7 ± 4.5	5.8 ± 5.5	0
*Jacaranda mimosifolia**	Jacaranda tree	33.2 ± 21.9	0	0	43.8 ± 25.4
Mangifera indica	Mango tree	5.7 ± 23.2	0	8.0 ± 1.2	10.2 ± 5.1
*Melia azedarach**	Syringa berrytree	11.2 ± 3.9	12.6 ± 14.8	20.6 ± 10.8	7.6 ± 6.8
*Morus alba**	de-pulped	5.0 ± 23.1	0	10.1 ± 7.9	12.1 ± 24.3

Species name	Common name	Means seasonal (± SD) species number			
		Spring	Summer	Autumn	Winter
Phoenix reclinata	Wild date palm	12.5 ± 10.2	0	26.9 ± 17.6	11.2 ± 7.6
Piliostigma thonnigii	Camel's foot	0	1.5 ± 2.2	0	0
Raphia australis	Kosi palm	0	3.5 ± 1.9	2.0 ± 1.6	0
Senna singueana	Wild cassia	5.5 ± 3.9	0	11.6 ± 6.3	0
*Sesbania punicea**	Spanish gold	3.0 ± 3.9	0	7.7 ± 5.2	0
Sideroxylon inerme	White milkwood	5.0 ± 6.2	7.8 ± 8.2	0	7.0 ± 2.3
Sterculia Africana	African star-chestnut	76.0 ± 45.3	23.7 ± 10.9	0	0
Syzygium cordatum	Water berry	4.5 ± 2.4	15.8 ± 11.6	0	9.7 ± 5.2
Syzygium guineense	Woodland waterberry	0	4.8 ± 7.8	6.8 ± 4.8	0
Widdringtonia nodiflora	Mountain cypress	2.8 ± 1.9	8.8 ± 2.9	8.2 ± 5.9	6.4 ± 4.2
Erythrophleum lasianthum	Maputaland ordeal tree	6.2 ± 3.4	5.4 ± 4.2	0	35.3 ± 12.8
*Eucalyptus grandis**	Bluegum	4.5 ± 2.4	3.5 ± 1.9	5.8 ± 5.5	3.0 ± 9.4

Supplementary information Table S4.2 Descriptive seasonal feeding data for rose-ringed parakeets and other bird species that fed communally with them. The data were collected between September 2018 – September 2019. For full list see Electronic Supplementary Table at https://static-content.springer.com/esm/art%3A10.1007%2Fs10336-020-01841-1/MediaObjects/10336_2020_1841_MOESM1_ESM.docx)

Species name	Common name	Food species type	Food parts	Location name	latitude	Longitude	Seasons	Date	Time
Acridotheres tristis	Common Myna	*Erythrina lysistemon*	Flowers	Alipore Primary School	-29.946258	30.963682	Spring	12-09-2018	15:20-16:30 PM
Acridotheres tristis	Common Myna	*Mangifera indica*	Flowers	Alipore Primary School	-29.946258	30.963682	Winter	18-07-2019	14:30-15:50PM
Acridotheres tristis	Common Myna	*Mangifera indica*	Flowers	Alipore Primary School	-29.946258	30.963682	Winter	27-07-2019	14:20-15:55PM
Acridotheres tristis	Common Myna	*Mangifera indica*	Flowers	Alipore Primary School	-29.946258	30.963682	Winter	30-07-2019	15:30-16:00PM
Acridotheres tristis	Common Myna	*Mangifera indica*	Flower	Alipore Primary School	-29.946258	30.963682	Spring	05-08-2019	10:00-12:00AM
Acridotheres tristis	Common Myna	*Erythrina lysistemon*	Flower	Alipore Primary School	-29.946258	30.963682	Spring	05-08-2019	10:00-12:00AM
Acridotheres tristis	Common Myna	*Mangifera indica*	Flower	Alipore Primary School	-29.946258	30.963682	Spring	13-08-2019	10:00-11:00AM
Acridotheres tristis	Common Myna	*Erythrina lysistemon*	Flower	Alipore Primary School	-29.946258	30.963682	Spring	13-08-2019	10:00-11:00AM
Acridotheres tristis	Common Myna	*Mangifera indica*	Flower	Alipore Primary School	-29.946258	30.963682	Spring	16-08-2019	08:00-11:40AM
Acridotheres tristis	Common Myna	*Erythrina lysistemon*	Flower	Alipore Primary School	-29.946258	30.963682	Spring	16-08-2019	08:00-11:40AM
Acridotheres tristis	Common Myna	*Phoenix reclinata*	Fleshy fruits	Alipore Primary School	-29.946248	30.963186	Autumn	15-03-2019	18:00-19:30PM
Acridotheres tristis	Common Myna	*Sterculia quinqueloba*	Flower	Alipore Primary School	-29.945307	30.963535	Autumn	15-03-2019	18:00-19:30PM
Acridotheres tristis	Common Myna	*Morus alba*	Fleshy fruits	Clerence Rd	-29.836617	31.014771	Spring	16-09-2018	16:00-16:40 PM
Acridotheres tristis	Common Myna	*Euclea undulata*	Fleshy fruits	Clerence Rd	-29.836617	31.014771	Spring	22-09-2018	15:07-16:40 PM
Acridotheres tristis	Common Myna	*Erythrina lysistemon*	Flower	Cowey's park surroundings	-29.845462	31.007050	Winter	16-07-2019	14:23-16:40PM
Acridotheres tristis	Common Myna	*Erythrina lysistemon*	Flower	Cowey's park surroundings	-29.846067	31.009646	Winter	22-07-2019	14:45-15:45PM
Acridotheres tristis	Common Myna	*Erythrina lysistemon*	Flower	Cowey's park surroundings	-29.819254	31.012207	Winter	25-07-2019	16:00-17:10PM
Acridotheres tristis	Common Myna	*Erythrina lysistemon*	Flower	Cowey's park surroundings	-29.819254	31.012207	Spring	06-08-2019	08:09-10:30AM
Acridotheres tristis	Common Myna	*Sterculia africana*	Flowers	Cowey's park surroundings	-29.845462	31.007050	Summer	09-01-2019	18:25-18:40 PM
Acridotheres tristis	Common Myna	*Sterculia africana*	Flowers	Cowey's park surroundings	-29.826437	31.007946	Summer	15-01-2019	18:00-18:20 PM
Acridotheres tristis	Common Myna	*Sterculia africana*	Flowers	Cowey's park surroundings	-29.819254	31.012207	Summer	28-01-2019	18:07-18:15 PM
Acridotheres tristis	Common Myna	*Erythrina lysistemon*	Flowers	Durban park view	-29.736401	31.080269	Spring	07-09-2018	16:00-16:43 PM
Acridotheres tristis	Common Myna	*Ficus trichopoda*	Fleshy fruits	Durban park view	-29.736401	31.080269	Spring	08-10-2018	17:32-17:56 PM

Species name	Common name	Food species type	Food parts	Location name	latitude	Longitude	Seasons	Date	Time
Acridotheres tristis	Common Myna	*Ficus trichopoda*	Fleshy fruits	Durban park view	-29.733802	31.083316	Spring	14-10-2018	17:38-17:50 PM
Acridotheres tristis	Common Myna	*Ficus trichopoda*	Fleshy fruits	Durban park view	-29.734938	31.083016	Spring	19-10-2018	16:18-17:00 PM

CHAPTER 5

Citizen science survey of non-native rose-ringed parakeets *Psittacula krameri* in the Durban Metropole, KwaZulu-Natal, South Africa

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5.1 Abstract

The rose-ringed parakeet *Psittacula krameri* has become invasive in several countries, including South Africa, mainly through the pet trade and escapees. We conducted an online questionnaire survey targeting the residents in Durban, eThekwini Municipality, KwaZulu-Natal Province, South Africa. We aimed to determine the public's knowledge of the distribution, habitat type and supplementary feeding of rose-ringed parakeets. We also determined if the public perceived the parakeets as pests and if control measures were supported. We found that many parakeet sightings were reported in Durban North and primarily in and around shopping centres. A significant number of respondents provided feeding stations for parakeets, with most provisioning seeds and grains. A large number of respondents considered parakeets as a pest. Rose-ringed parakeets were reported to chase nine bird species, of which seven were native and two non-natives. Most respondents stated that parakeets should not be controlled. However, most of those who supported their control suggested shooting and destruction of eggs. We concluded that parakeets' distribution is expanding and associated with anthropogenic activities in this urban mosaic landscape. However, public perceptions make invasive parakeet management difficult.

Keywords: alien invasive species; questionnaire survey; supplementary feeding; public perceptions; urbanisation

5.2 Introduction

Alien invasive species are regarded as a major threat to biodiversity loss, and they globally represent a significant impact on economies and human social life (Lockwood et al. 2009; Sharp et al. 2011; Early et al. 2016; Luna et al. 2019). The significant threats associated with alien invasive species are typically limited by policy and management responses (Bax et al. 2003; Early et al. 2016; Moshobane et al. 2020). The management issues of alien invasive species are increasingly becoming social in as much as they are increasingly becoming scientific and political (Verbrugge et al. 2013; Crowley et al. 2019; Luna et al. 2019). Politics and society have become part of the management of invasive species, and support from the public may play an essential role in the management of these species (Bertolino and Genovesi 2003; Schüttler et al. 2011; Mentil et al. 2018; Pisanu et al. 2018; Crowley et al. 2019).

General public perceptions towards the control of invasive species may be guided by the type of eradication method proposed for a particular species (Fraser 2006; Courchamp et al. 2017). In addition, social benefits such as hunting for-profit or cultural advantages such as medicinal use of the species can positively influence public perceptions (Perrings et al. 2002; Pejchar and Mooney 2009). Effective actions for invasive species control can also be impaired by public objections (Sharp et al. 2011; Fischer et al. 2014). In particular, objections to the control of charismatic species such as the invasive rose-ringed parakeet *Psittacula krameri* have been documented (Lambert et al. 2017; Luna et al. 2019).

The rose-ringed parakeet is amongst the world's worst invasive species established in *ca.* 35 countries through the pet trade (Menchetti et al. 2016; Ivanova and Symes 2019; Strubbe and Matthysen 2020). It is also recognised as one of the species with increasing management related conflict issues because of public perceptions (Carrete and Tella 2008; Luna et al. 2019). This is despite its increased populations having impacts on crops, negatively affecting the biodiversity through competition with native species, and carrying zoonotic diseases transferrable to humans and wildlife (Ahmad et al. 2012; Strubbe and Matthysen 2009a; Mentil et al. 2018; Pisanu et al. 2018).

The rose-ringed parakeet was first introduced to South Africa in the 1900s as part of the pet trade (Perrin and Cowgill 2005; Roche and Bedford-Shaw 2008; Hart and Downs 2014). This has resulted in accidental escapees and intentional releases of caged parakeets into the wild in Gauteng (Pretoria and Johannesburg), KwaZulu-Natal (Durban), and Western Cape (Cape Town) Provinces (Dean 2000; Roche and Bedford-Shaw 2008; Hart and Downs 2014; Symes 2014; Shivambu et al. 2021a). The population size of rose-ringed parakeets in Gauteng Province has been estimated at 2 000 (Whittington-Jones 2017), while in KwaZulu-Natal Province was estimated at 1 783; Shivambu et al. 2021a). However, there is a lack of information on its overall numbers and distribution in South Africa.

Given this background, our study aimed to determine the public's knowledge of the distribution, habitat type and supplementary feeding of rose-ringed parakeets. We also determined if the public perceived the parakeets as pests and if control measures were supported. We predicted that the public would provide bird feeders as feeding birds is a well-known phenomenon, especially in urban landscapes (Galbraith et al. 2014; Tryjanowski et al. 2015; Galbraith et al. 2017). We also expected that the residents do not support the management of rose-ringed parakeet given that is it perceived as charismatic (Hart and Downs 2014; Luna et al. 2019).

5.3 Materials and methods

5.3.1 Study area

The study areas were selected based on rose-ringed parakeet observations from parallel studies in eThekwini Municipality, KwaZulu-Natal Province, South Africa (Shivambu et al. 2021a, b; Figure 5.1). The human population size in this municipality is estimated at 1.34 million (eThekwini Municipality 2013; Zungu et al. 2019; Maseko et al. 2020). It has a unique dedicated network of green corridors, the Durban Metropolitan Open Space System (D'MOSS) (Roberts 1994; Zungu et al. 2019). These areas (i.e. parks, conservation sites, golf courses, and nature reserves) are conserved for native flora, fauna, and human outdoor activities (Roberts 1994; Zungu et al. 2019; Maseko et al. 2020). The urban landscapes are comprised of different vegetation structures (both native and non-native) of which some provide breeding, roosting and feeding sites for rose-ringed parakeets (Hart and Downs 2014; Shivambu et al. 2021a). The climatic conditions in the municipality are characterised as subtropical, with an annual minimum average temperature of 27 °C and the maximum average temperature of 34 °C (http://en.climate-data.org/location/27097/). The recorded yearly rainfall is *ca.* 940 mm (http://en.climate-data.org/location/27097/).

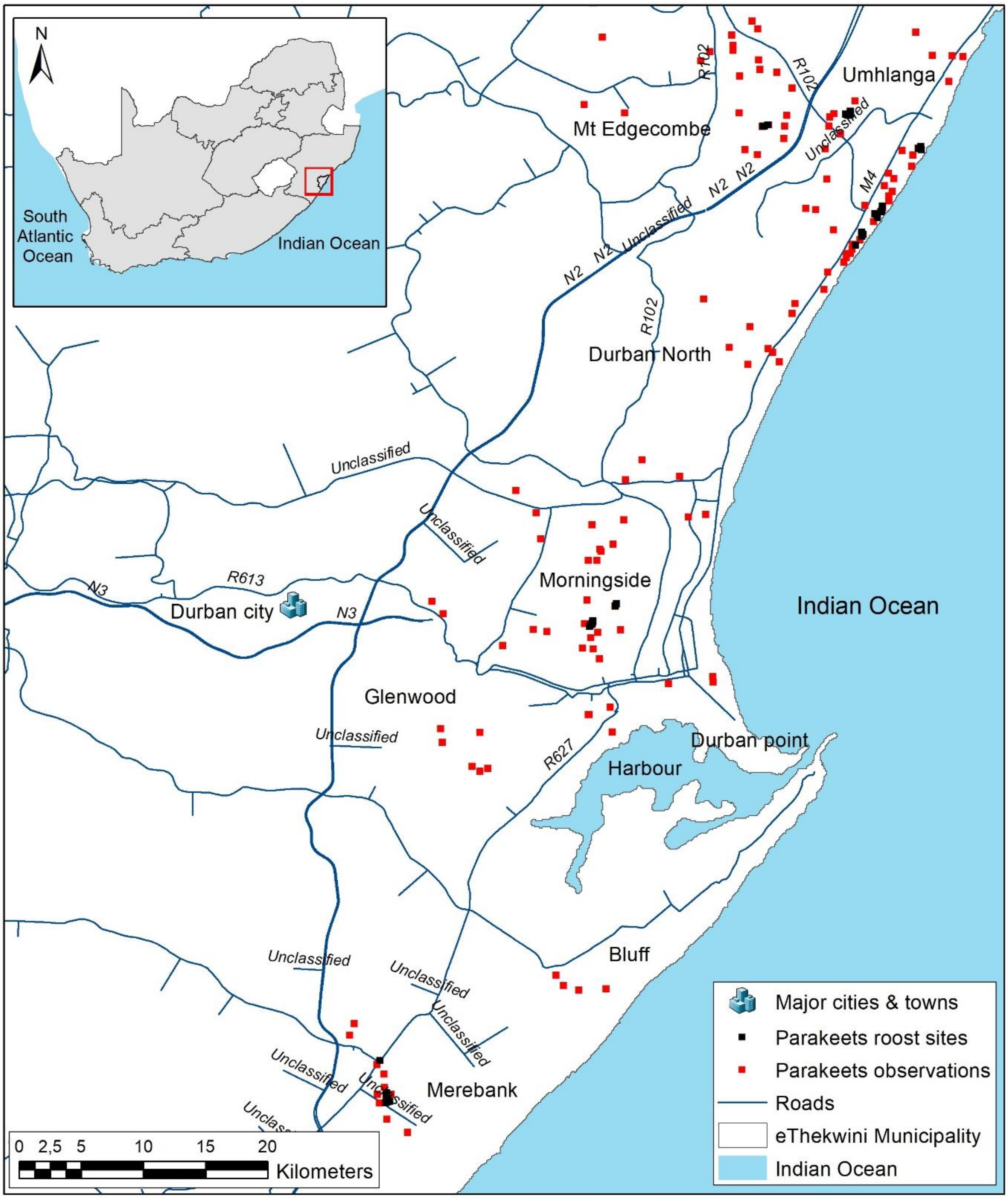

Fig. 5.1 A map showing various areas where rose-ringed parakeets were observed by survey participants (red square dots) and roost sites (black square dots) from Shivambu et al. (2021a) in eThekwini Municipality (outlined by the red square in the map on the top left), KwaZulu-Natal Province, South Africa. Names and coordinates of rose-ringed parakeets observed sites are provided in Supplementary Material Table S52.

5.3.2 Questionnaire survey design and data collection

We developed an online-based questionnaire survey using Google forms (https://www.google.com/forms/about/). The questionnaire survey had a brief description of rose-ringed parakeets and the study aims, followed by 15 questions, of which many were closed-ended (Supplementary Material Table S5.1). The questionnaire was designed to collect information on rose-ringed parakeets' distribution, habitat and food types, and if respondents considered them as pests and what their perceptions of control measures were (Table 5.1). The survey was active from 12 August 2018 until 10 July 2020 (699 days: 1 year ten months) to obtain adequate responses.

The survey link (https://forms.gle/52h21wKv7esZ34aQ8) was distributed through Facebook, WhatsApp, local estate newsletters (n = 3), pet shops (n = 32), and printed letters (n = 420) targeting residents in eThekwini Municipality. Letters were distributed to the eco-estates managers and residents during sampling for parallel studies (Shivambu et al. 2021a, b, c) and presentations. The ethical clearance to conduct this study was granted by the University of KwaZulu-Natal Humanities and Social Research Ethics Committee (number: HSS/0678/018D).

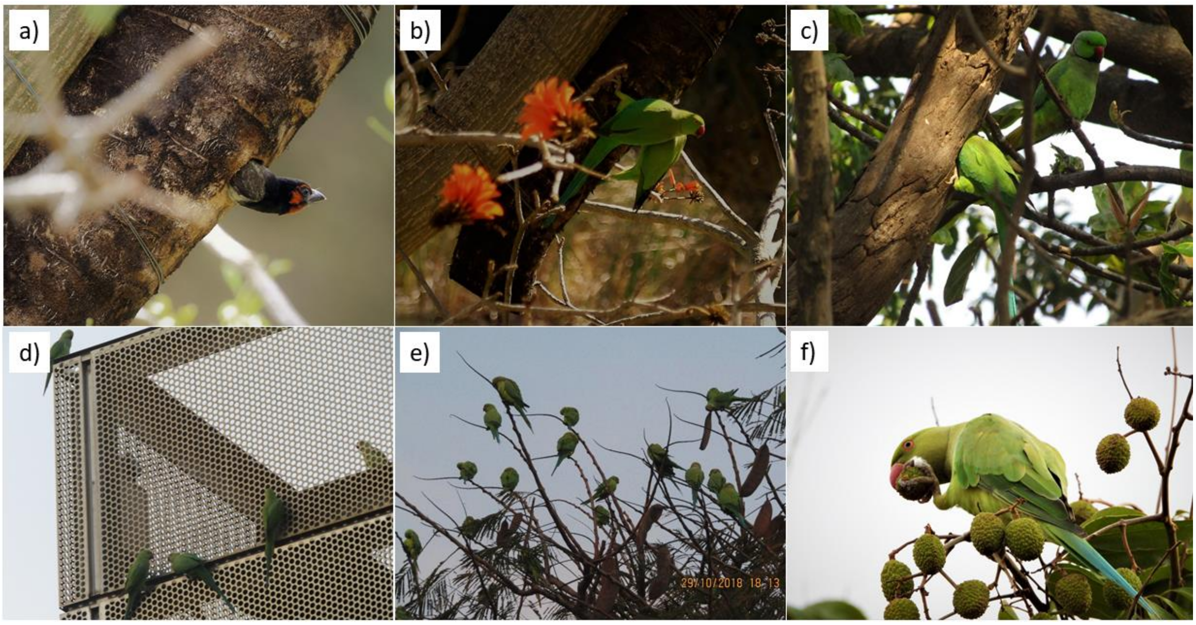

Fig. 5.2 Pictures showing a) a black-collared barbet *Lybius torquatus* leaving an artificial nest in a private garden in Mount Edgecombe Country Club, Durban North, b) rose-ringed parakeets *Psittacula krameri* pair taking-over an artificial nest placed for black-collared barbets in Mount Edgecombe, c) male, and female rose-ringed parakeets entering a natural nest excavated by native bird species in Merebank, d) and e) rose-ringed parakeet flocks in Gateway Mall, Umhlanga Rocks, and in a flat-crown tree *Albizia adianthifolia* in Cowey's Park Shopping Centre, Durban North, and f) rose-ringed parakeets feeding on lychee fruits *Litchi chinensis* in a Mount Edgecombe garden. (©Photographs a) - b) by Mike du Trevou, c) - e) by TC Shivambu, and f) by G. Frans).

5.3.3 Statistical analyses

We performed all statistical analyses using R statistical software (version 3.6.1, R Core Team 2018). We plotted the distribution of rose-ringed parakeets' sightings using ArcGIS (version 10.4.1, ESRI 2018). We only conducted descriptive and non-parametric statistics due to the nature of the survey data obtained from this study. We performed the Kruskal-Wallis test to determine if the number of respondents differed between the habitat types. We also used the

Kruskal-Wallis test to determine the difference between the number of respondents who regarded rose-ringed parakeets as pests and those who did not. We further used the Kruskal-Wallis test to determine the difference between the number of respondents who support the control for rose-ringed parakeets and those who did not.

5.4 Results

A total of 312 participants completed the survey, with 93.5% (*n* = 290) having seen rose-ringed parakeets in different locations in the urban mosaic landscape. A total of 137 rose-ringed parakeets' distribution sites were reported (Figure 5.1, Supplementary Material Table S5.2). A large number of rose-ringed parakeets' sightings were in Durban North, particularly Umhlanga areas, followed by Durban central (Figure 5.1). We found a significant difference between the median number of respondents in habitat types (Kruskal-Wallis test: χ^2 = 31.13; df = 6; *P* = 0.001). Most respondents indicated to have seen rose-ringed parakeets in and around shopping centres (38.5%; *n* = 120 participants), followed by suburbia (26.3%; *n* = 82) and golf courses (19.6%; *n* = 61) (Table 5.1, Figure 5.2 and 5.3). The majority of respondents reported to have seen rose-ringed parakeets feeding (43.9%, *n* = 137), followed by nesting (26.3%, *n* = 82), flying around (16.0%, *n* = 50), and roosting (13.8%, *n* = 43) (Table 5.1).

Many respondents (58.3%; *n* = 182) provided supplementary feeding stations for rose-ringed parakeets at their residences (Table 5.1). Most respondents provided seeds (71.4%; *n* = 130) and grains (22%; *n* = 40) to parakeets (Table 5.1). There was no significant difference between the number of respondents who regarded rose-ringed parakeets as pests and those who do not regard them as pests (χ^2 = 20.45; df = 1; *P* = 0.062). A total of 173 respondents (55.4%) did not consider rose-ringed parakeets as pests, while 44.6% (*n* = 139) considered them as pests (Table 5.1). The majority of participants (60.6%, *n* = 189) had seen rose-ringed parakeets chasing other bird species (Table 5.1). Seven native and two invasive bird species were reported being chased by rose-ringed parakeets (Supplementary Material Table S5.3). Alien invasive species included the common myna *Acridotheres tristis* and the house sparrow *Passer domesticus.* The native species chased included the African hoopoe *Upupa africana,* Knysna turaco *Tauraco corythaix*, red-winged starling *Onychognathus morio,* crested barbet *Trachyphonus vaillantii*, golden-tailed woodpecker *Campethera abingoni*, black-collared barbet *Lybius torquatus*, and the southern black flycatcher *Melaenornis pammelaina* (Supplementary Material Table S5.3). In addition, respondents indicated that parakeets chase woodpeckers and barbets from their nests during the breeding season (Figure 5.2; Supplementary Material Table S5.3). Some of the respondents indicated that they used to see black-collared barbet (37.4%, n = 55), crested barbet (34%, n = 50), and golden-tailed woodpecker (28.5%, n = 42) before the presence of rose-ringed parakeets (Table 5.1).

We found a significant difference between the number of respondents who indicated that rose-ringed parakeets should be controlled and those who indicated that they should not be controlled (χ^2 = 12.13; df = 1; P = 0.002). Most respondents (57.7%, n = 180) indicated that rose-ringed parakeets should not be controlled (Table 1). However, the majority of respondents who supported control suggested shooting (45.5%, n = 60), followed by the destruction of eggs during the breeding season (25.7%, n = 34) (Table 5.1). On a question to provide additional information, respondents suggested that common mynas, house crows *Corvus splendens,* and starlings should be controlled instead of rose-ringed parakeets (Supplementary Material Table S5.3). In addition, some respondents indicated that rose-ringed parakeets make noise, disturb golfers, and a few stated that they did not know that they were non-native (Supplementary Material Table S5.3).

Table 5.1 Summary information showing numbers of responses per question asked during the rose-ringed parakeet's survey.

Questions	No. of responses provided *N* (%) out of 312 participants	
	Answers	**No answers**
What best describes your dwelling?	**100% (312)**	**0%**
Townhouse	23.6% (70)	
Suburb	72.4% (215)	
Other	8.6% (27)	
Have you seen rose-ringed parakeets?	**100% (312)**	**0%**
Yes	92.5% (290)	
No	6.5% (20)	
If yes, can you please specify the location	**100% (312)**	**0%**
Shopping centres	38.5% (120)	
Suburban residence	26.3% (82)	
Golf course	19.6% (61)	
Park	8.0% (25)	
Cemetery	2.8% (9)	
Townhouse	2.6% (8)	
School	2.2% (7)	
Do you feed them?	**90.4% (282)**	**9.6% (30)**
Yes	58.3% (182)	
No	32.1% (100)	
What do you feed them/it?	**58.3% (182)**	**41.7% (130)**
Seeds	71.4% (130)	
Grains	22% (40)	
Other	6.6% (12)	
Do you consider parakeets as pests?	**100% (312)**	**0%**
Yes	44.6% (139)	
No	55.4% (173)	
Do you see parakeets chasing other birds?	**312 (100%)**	**0%**
Yes	60.6% (189)	
No	39.4% (123)	

Questions	No. of responses provided *N* (%) out of 312 participants	
	Answers	**No answers**
Which birds did you used to see before parakeets were introduced in areas where you have seen them? please list them	**47% (147)**	**0%**
Golden-tailed woodpecker *Campethera abingoni*	28.5% (42)	
Black-collared barbet *Lybius torquatus*	37.4% (55)	
Crested barbet *Trachyphonus vaillantii*	34.0% (50)	
Which activities were parakeets doing when you saw them?	**312 (100%)**	**0%**
Feeding	43.9% (137)	
Nesting	26.3% (82)	
Roosting	13.8% (43)	
Flying around	16.0% (50)	
As alien species, do you think the number of parakeets should be controlled?	**100% (312)**	**0%**
Yes	42.3% (132)	
No	57.7% (180)	
If yes explain how	**42.3% (132)**	**57.7% (180)**
Shooting	45.5% (60)	
Egg destruction	25.7% (34)	
Trapping	15.1% (20)	
Poisoning	7.6% (10)	
Fogging	6.1% (8)	

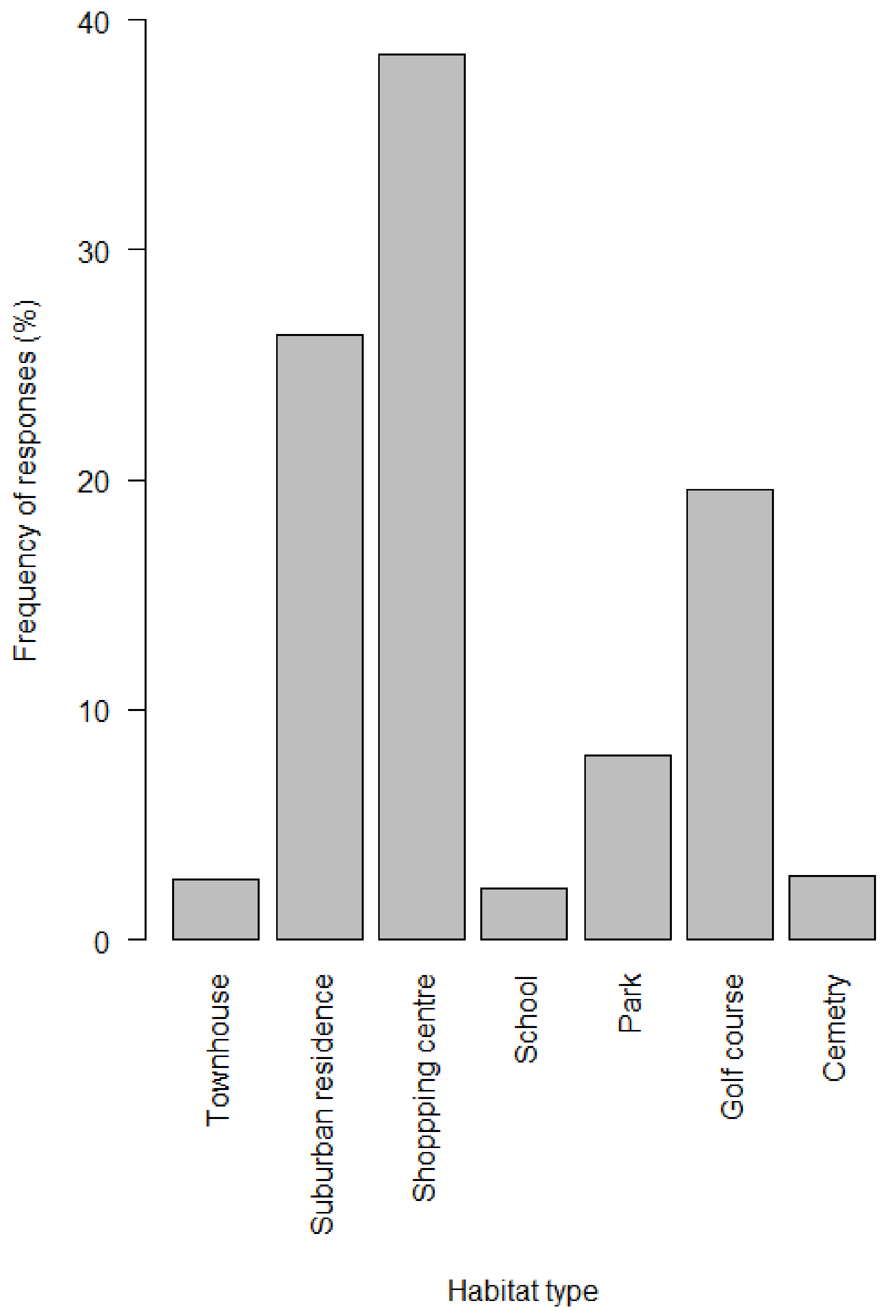

Fig. 5.3 The percentage number of survey respondents who reported sightings of rose-ringed parakeets in seven habitat types in Durban Metropole, KwaZulu-Natal Province, South Africa.

5.5 Discussion

Previous studies have underlined the possible complications and challenges associated with charismatic alien invasive species such as rose-ringed parakeets (Carrete and Tella 2008; Blackburn et al. 2010; Luna et al. 2019). It has been emphasised that studies on biological invasions are mainly impeded by public perceptions towards charismatic species (Courchamp et al. 2017). This often results in the public's dislike to participate in studies on biological invasion, resulting in reduced participation in this study.

In our study, 93.5% of participants reported having seen rose-ringed parakeets in different locations and habitat types in Durban Metropole. The most rose-ringed parakeet sightings were reported in Durban North, particularly in the Umhlanga areas. This shows that the population of rose-ringed parakeets is expanding away from the city centre, as reported in Hart and Downs (2014). Most of the locations reported in our study were around and within the confirmed roost and feeding sites (Shivambu et al. 2021a, b), indicating the reliability of citizen science data. Reported sightings away from roost sites could indicate unconfirmed roosts, especially sightings in Bluff and Glenwood areas (Figure 1). This warrants further investigation to confirm other roost sites.

Many respondents indicated to have seen rose-ringed parakeets in and around shopping centres, followed by suburban residences and golf courses. The rose-ringed parakeets' major roosts are in a shopping centre in Durban North and central Durban (Shivambu et al. 2021a; Figure 1), suggesting that most respondents could have seen them visiting the centre. Overall, our study indicated that rose-ringed parakeets are associated with urban landscapes with relatively high human density. Typically, such rose-ringed parakeets are pet escapees or releases and have evolved to live with humans (Roche and Bedford-Shaw 2008; Symes 2014; Strubbe and Matthysen 2020; Shivambu et al. 2021a, b). In addition, urban areas have relatively high food availability for this species, especially in gardens and parks (Scalliet 1999; Wegener 2004; Strubbe and Matthysen 2007; Wolff and Touratier 2010; Shivambu et al. 2021b). Parakeets prefer urban habitat in their native ranges; as a result, they seem to benefit from urbanization, and such prior adaptation to anthropogenic environments may explain their success when introduced to structurally similar anthropogenic environments elsewhere (Strubbe and Matthysen 2009b).

Our study revealed that many respondents provide supplementary feeding stations for rose-ringed parakeets, and the food types provided were mainly seeds and grains. This further supports rose-ringed parakeets' persistence in suburban areas of the Durban Metropole. Rose-ringed parakeets are mainly granivores; hence supplementary feeding stations with grains and seeds support their persistence in urban areas as found in other studies (Sol et al. 2012; Clergeau and Vergnes 2011; Clergeau and Yésou 2006; Shivambu et al. 2021b). As a result, this species is likely to increase in numbers and become a pest with potential environmental and socio-economic impacts (Shivambu et al. 2020).

More respondents did not consider rose-ringed parakeets as pests. This could indicate a knowledge gap about alien invasive species in the urban areas, and therefore introducing this topic to the public is necessary. Rose-ringed parakeets were reported chasing other bird species, of which the majority were native species. Although no fatal attacks were reported in our study, there might be impacts posed by rose-ringed parakeets, possibly through competition for nests. For example, respondents reported that rose-ringed parakeets chase woodpeckers and barbets out of the nest (Figure 2; Supplementary Material Table S3). In Seville (Spain), Tel Aviv (Israel), Barcelona (Spain), and Brussels (Belgium), rose-ringed parakeets have been reported to outcompete native species such as the great tits *Parus major*, blue tits *Cyanistes caeruleus*, nuthatches *Sitta europaea*, and greater noctule bats *Nyctalus lasiopterus* for their food, nests, and space (Strubbe and Matthysen 2009a; Charter et al. 2016; Covas et al. 2017; Hernández-Brito et al. 2018).

Most respondents indicated that rose-ringed parakeets should not be controlled, but with some suggesting rather controlling common mynas, house crows, and starlings. These results could be explained by the positive perceptions towards alien invasive species kept as pets and considered charismatic. Similarly, Hart and Downs (2014) study in South Africa also indicated positive perceptions by the public towards rose-ringed parakeets compared with common mynas. Respondents who indicated that rose-ringed parakeets should be controlled suggested shooting and destroying eggs during the breeding season. In general, controlling rose-ringed parakeets would be difficult, given many respondents opposing their control. In Seville (Spain), public members objected to the management of rose-ringed parakeets, which has led to their increased population, particularly in urban areas (Luna et al. 2019). In addition, some control programmes of charismatic alien invasive species have been unsuccessful in South Africa, e.g., the control of invasive mallard duck *Anas platyrhynchos* in the city of Cape Town was opposed by the public (Gaertner et al. 2015). The objection of any control measures to reduce charismatic invasive species highlights the ecological knowledge gap in identifying the environmental and socio-economic impacts of such species (García-Llorente et al. 2008; Pett et al. 2016; Luna et al. 2019). As a result, the population of these species may increase and subsequently affect biodiversity, the economy, and humans negatively.

5.6 Conclusions and recommendations

This study showed that the distribution of rose-ringed parakeets is expanding in the Durban Metropole, and it is associated with urban areas where there are anthropogenic activities. A high percentage of respondents provided feeding stations for rose-ringed parakeets, which may sustain their population in these areas. In addition, many respondents had positive perceptions of rose-ringed parakeets and did not support their control. Some of the respondents did not know that parakeets were invasive species in South Africa. Therefore, we recommend that researchers, policymakers, and municipality managers engage with the public to discuss the impacts associated with invasive species and their management. This study's results can be used to understand social dilemmas in managing charismatic alien invasive species in urban landscapes.

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5.8 Ethics approval

Ethics was approved by the University of KwaZulu-Natal – Humanities and Social Research Ethics Committee (ethic number: HSS/0678/018D).

5.9 Authors' contributions

TCS and CTD conceptualised and did the sample design. TCS implemented the study. TCS and NS analysed the data. TCS wrote the manuscript draft while CTD and NS edited the manuscript before submission.

5.10 Conflict of Interest

The authors declare that they have no conflict of interest.

5.11 References

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5.12 Supplementary Material

Supplementary Table S5.1 The questionnaire survey distributed to members of the public in Durban Metropole between 2018 and 2020.

Questionnaire survey on rose-ringed parakeets (Psittacula krameri)

The rose-ringed parakeets are considered among the world's worst invasive bird species. They have become cosmopolitan and been associated with human habitation. This species have been reported to cause destruction of stored grains and crops, spread diseases, and kill native species. Parakeets have been seen in KwaZulu-Natal Province, particularly in the eThekwini Municipality metropolitan areas. However, the presence, impacts and ecology associated with this species are relatively unknown. This survey forms part of PhD study from the University KwaZulu-Natal. Should you wish to complete this anonymous survey, it will take only 8 minutes of your time. For more information please contact Prof Colleen Downs at downs@ukzn.ac.za or Mr Cavin Shivambu (PhD candidate) at shivambucavin@gmail.com.

Name & email address of the participant (Optional)

Your answer

1. What best describes your dwelling?

- ◯ Townhouse
- ◯ Suburb
- ◯ Village
- ◯ Other:

2. Have you seen rose-ringed parakeets?

- ◯ Yes
- ◯ No

3. If yes, can you please specify the location

Your answer

4. Where did you see them/it?

- [ ] House
- [ ] Garden
- [ ] Backyard
- [ ] Parks
- [ ] Mall
- [ ] Work place
- [ ] Other: ____________________

5. Do you feed them?

- ○ Yes
- ○ No

6. What do you feed them/it?

- [ ] Grains
- [ ] Seeds
- [ ] House food
- [ ] Snacks
- [ ] Other: ____________________

7. How many individuals of rose-ringed parakeets have you seen?

- ◯ 2
- ◯ 6
- ◯ 10
- ◯ 15
- ◯ Other:

8. At what time did you see them?

- ☐ Morning (between 06:30 – 10:30 AM)
- ☐ Midday (between 12:00 – 13:00 PM)
- ☐ Afternoon (between 16:30 – 18:30 PM)
- ☐ Other: ____________

9. Do you consider parakeets as pests?

- ◯ Yes
- ◯ No

10. If yes, do they feed on any of the following?

- [ ] Garden fruits
- [ ] Stored grains
- [ ] Insects
- [ ] Seeds
- [ ] Flowers
- [ ] Other: ______________________

11. For how long has this been happening?

- ◯ 1 month
- ◯ 2 months
- ◯ 3 months
- ◯ 1 year
- ◯ Other:

12. Do you see parakeets chasing other birds?

- ◯ Yes
- ◯ No

13. Which birds did you used to see before parakeets were introduced in areas where you have seen them? please list them

Your answer

14. Which activities were parakeets doing when you saw them?

- [ ] Feeding
- [ ] Roosting
- [ ] Nesting
- [ ] Other:

15. As alien species, do you think the number of parakeets should be controlled?

- ◯ Yes
- ◯ No

16. If yes explain how:

Your answer

17. Do you want to add anything?

Your answer

Submit

Page 1 of 1

Table S5.2 A summary table showing specific locations where rose-ringed parakeets were sighted by residents in eThekwini Municipality. Amenities are types of habitat types where parakeets were sighted.

Location names	Amenities	Coordinates	
		latitude	longitude
Umhlanga Rocks, Umhlanga, 4320	Park	-29.742091	31.075136
Umhlanga Rocks, Umhlanga, 4320	Forest patch	-29.740462	31.077317
Umhlanga Ridge, Umhlanga	Forest patch	-29.746519	31.070765
La Lucia, 4051	Forest patch	-29.740552	31.062172
La Palmer, La Lucia, Umhlanga, 4051	Park	-29.747492	31.059722
Virginia Bush Nature Reserve, Durban North, 4051	Forest patch	-29.768564	31.055022
Umhlanga Rocks, Umhlanga, 4319	Residence	-29.739280	31.076107
Herrwood Park, Umhlanga, 4319	Residence	-29.712891	31.090388
Herrwood Park, Umhlanga, 4319	Park	-29.712733	31.085925
Hawaan, Blackburn, 4319	Residence	-29.707543	31.082213
Umhlanga Lagoon Nature Reserve	Nature reserve	-29.713094	31.092769
Umhlanga, 4320	Residence	-29.718619	31.089612
Mount Edgecombe Country Estate 2, Mount Edgecombe, 4302	Residence	-29.728358	31.049126
Mount Edgecombe Country Estate 2, Mount Edgecombe, 4302	Residence	-29.728760	31.047729
Mount Edgecombe Country Estate 2, Jimmy Jungles	Golf course	-29.728657	31.052778
Mount Edgecombe Country Estate 2, Mount Edgecombe, 4302	Residence	-29.725713	31.042553
Mount Edgecombe, 4302	Golf course	-29.734013	31.043776
Mount Edgecombe, 4302	Residence	-29.735075	31.046598
Fairways Reach, Mount Edgecombe Country Estate 2, Mount Edgecombe, 4302	Residence	-29.731498	31.052563
Mount Edgecombe Country Estate 2, Mount Edgecombe, 4302	Residence	-29.726234	31.053228
Montgomery Dr., Mount Edgecombe Country Estate 2, Mount Edgecombe, 4302	Residence	-29.720150	31.054451
The Open Rd, Mount Edgecombe Country Estate 1, Mount Edgecombe, 4302	Residence	-29.716581	31.050964
The Hilbre Dr., Mount Edgecombe Country Estate 1, Mount Edgecombe, 4302	Forest patch	-29.713814	31.046844
Mount Edgecombe Country Estate 1, Mount Edgecombe, 4302	Golf course	-29.715920	31.047166

Location names	Amenities	Coordinates	
		latitude	longitude
Mount Edgecombe Country Estate 2, Mount Edgecombe, 4302	Forest patch	-29.717467	31.042596
Muirfield Cir, Mount Edgecombe Country Estate 1, Mount Edgecombe, 4302	Residence	-29.710516	31.041137
Mount Edgecombe Country Estate 2, Mount Edgecombe, 4302	Residence	-29.708233	31.040847
Blackburn Estate, Blackburn, South African Sugarcane Research Institute	Institution	-29.705074	31.045353
Blackburn Estate, Blackburn, South African Sugarcane Research Institute	Institution	-29.706835	31.046694
Rockford, Phoenix, 4068	Cemetery	-29.711988	31.035944
Rockford, Phoenix, 4068	Park	-29.713963	31.033884
Long croft, Phoenix, 4068	Forest patch	-29.708691	31.011735
Stonebridge, Phoenix, 4068	Forest patch	-29.723851	31.007680
Centenary Park, Phoenix, 4068	Forest patch	-29.725718	31.016792
Dumat Pl, Mount Edgecombe Country Estate 2, Mount Edgecombe, 4302	Business place	-29.708242	31.040876
Muirfield Cir, Mount Edgecombe Country Estate 1, Mount Edgecombe, 4302	Residence	-29.711668	31.041131
Somerset Park, Umhlanga, 4319	Business place	-29.733813	31.061884
Somerset Park, Umhlanga, 4319	Park	-29.728698	31.062689
Somerset Park, Umhlanga, 4051	Park	-29.730480	31.065286
Umhlanga Ridge, Umhlanga, 4319	Park	-29.726623	31.062883
Gateway Ave, Umhlanga Ridge, Umhlanga, 4319	Business place	-29.725859	31.063816
Umhlanga Ridge, Durban, 6940	Business place	-29.725313	31.067446
Umhlanga Ridge, Umhlanga, 4319	Business place	-29.723041	31.068528
Moore street CBD, Durban, 4094	Park	-29.860978	31.008714
Durban Central, Durban, 4001	Cemetery	-29.859272	31.013464
Albert Park, Durban	Park	-29.864857	31.013973
Gugu Dlamini park, Durban Central, Durban, 4001	Park	-29.854009	31.026586
South Beach, Durban, 4001	Park	-29.853656	31.036644
Victoria park, North Beach, Durban, 4063	Park	-29.852372	31.036585
Moore street CDB, Durban, 4094	Park	-29.860967	31.008575
Risk Management Services, Mazisi Kunene Rd, Glenwood, Berea, 4001	Residence	-29.864993	30.984259

Location names	Amenities	Coordinates	
		latitude	longitude
Durban botanical gardens, Musgrave, Berea, 4001	Botanical garden	-29.846032	31.007254
Berea Park Rd, Musgrave, Berea, 4001	Park	-29.842320	30.999266
Musgrave, Berea, 4001	Forest patch	-29.845472	30.989315
Musgrave, Berea, 4001	residence	-29.841842	30.996240
Lena Ahrens Rd, University, Berea, 4041	Cricket field	-29.872578	30.982424
West ridge, Berea, 4091	Institution	-29.864174	30.975399
UKZN Howard campus, Berea	Institution	-29.867215	30.975766
Grosvenor, Bluff, 4052	Institution	-29.921822	31.002958
St Patricks Rd, Grosvenor, Bluff, 4052	Park	-29.919572	31.001335
Bluff golf course	Golf course	-29.922582	31.012587
The Dutch club, Bluff, Durban, 4052	Golf course	-29.922852	31.006442
Ninapur Pl, Merewent, Bluff, 4052	Residence	-29.946288	30.964201
Ganges, Alipore Rd, Merewent, Bluff, 4052	institution	-29.946472	30.963152
Sport ground, Merewent, Bluff, 4052	Park	-29.948304	30.961651
Mobeni East, Durban, 4060	Residence	-29.941794	30.962669
Woodlands, Durban, 4004	Forest patch	-29.933066	30.954900
Woodlands, Durban, 4004	Park	-29.930398	30.955968
Allipore primary school, 30 Alipore Rd, Merewent, Bluff, 4052	Institution	-29.946460	30.963150
Barrackpur Rd, Merewent, Bluff, 4052	Institution	-29.944759	30.962741
Chenab Rd, Merewent, Bluff, 4052	Residence	-29.946335	30.961115
Mobeni, Durban, 4060	Business place	-29.939599	30.961099
Muslim cemetery, Merewent, Bluff, 4052	Cemetery	-29.951851	30.963309
Raj Mahal Rd, Merewent, Bluff, 4052	Forest patch	-29.954878	30.967904
Gladys Manzi Rd, Musgrave, Berea, 4001	Institution	-29.848438	31.011037
Grayville, Berea, 4001	Golf course	-29.841948	31.015780
Avondale Rd, Grayville, Berea, 4001	Business place	-29.846185	31.009658
Avondale Rd, Essenwood, Berea, 4001	Park	-29.843714	31.009136

Location names	Amenities	Coordinates	
		latitude	longitude
Avondale Rd, Essenwood, Berea, 4001	Business place	-29.842458	31.010713
Essenwood, Berea, 4001	Park	-29.840508	31.007693
Essenwood, Berea, 4001	Institution	-29.835217	31.008326
Cowey's park, Problem Mkhize Rd, Essenwood, Berea, 4001	Business place	-29.840577	31.009402
Avondale Rd, Essenwood, Berea, 4001	Business place	-29.836623	31.014572
Durban girls high, Lena Ahrens Rd, Glenwood, Berea, 4001	Institution	-29.873016	30.986024
Glenwood, Berea, 4001	Forest patch	-29.873706	30.984259
Jameson park, Morningside, Berea, 4001	Park	-29.826297	31.008555
Mitchell park, Morningside, Berea, 4001	Park	-29.826283	31.010569
Mitchell park, Morningside, Berea, 4001	Park	-29.824273	31.011417
Sir Arthur Rd, Morningside, Berea, 4001	Residence	-29.822669	31.014189
Burman bush, Morningside, Berea, 4001	nature reserve	-29.817209	31.016553
Windsor golf course, Stamford Hill, Durban, 4025	Golf course	-29.816536	31.031112
Stamford Hill, Durban, 4025	Golf course	-29.815950	31.034932
Thames Pl, Umgeni Park, Durban North, 4051	Residence	-29.807399	31.029117
Umgeni Park, Durban North, 4051	Park	-29.808198	31.016904
Intersite Ave, Umgeni Business Park, Durban, 4001	Business place	-29.810622	30.992334
Havelock Cres, Morningside, Berea, 4001	Residence	-29.823802	31.011177
Morningside village, Morningside, Berea, 4001	Park	-29.818312	31.009367
Sherwood, Durban, 4091	Forest patch	-29.835510	30.973410
King Cetshwayo Hwy, Sherwood, Durban, 4091	Residence	-29.838262	30.975987
Riverside retirement village, Umgeni Park, Durban North, 4051	Residence	-29.803716	31.020685
Springfield, Durban	Park	-29.821422	30.997888
Ribes Pl, Springfield, Durban, 4091	Forest patch	-29.815597	30.996823
Northlands girls high, Durban North, 4051	Institution	-29.778395	31.040234
Red Hill, Durban North, 4051	Forest patch	-29.767556	31.034482
Northwood school, 144-140 Adelaide Tambo Dr., Durban North, 4051	Institution	-29.773752	31.044956

Location names	Amenities	Coordinates	
		latitude	longitude
Hoylake Dr., Durban North, 4051	Residence	-29.782195	31.044488
Beachwood, Durban North, 4051	Golf course	-29.781667	31.051570
Danville park, Somerset Park, Durban North, 4319	Park	-29.770791	31.054418
La Lucia growth point, Umhlanga, 4051	Park	-29.752055	31.063671
Old Bush Rd, Umhlanga, 4051	Residence	-29.747134	31.057508
Durban view park, Umhlanga Rocks, Umhlanga, 4320	Park	-29.733203	31.083357
Durban view park, Long beach, Umhlanga Rocks, Durban, 4319	Park	-29.733618	31.082727
Umhlanga Rocks, Umhlanga, 4319	Residence	-29.735153	31.081572
Ridge Rd, Umhlanga Rocks, Umhlanga, 4320	Residence	-29.734156	31.079173
Umhlanga Rocks, Umhlanga, 4320	Forest patch	-29.737695	31.081272
Forest Dr., Umhlanga Rocks, Umhlanga, 4320	Park	-29.743325	31.076944
Forest Dr., Umhlanga Rocks, Umhlanga, 4320	Forest patch	-29.744373	31.076139
Umhlanga Rocks, Umhlanga, 4320	Forest patch	-29.745542	31.076187
Forest Dr., Umhlanga Rocks, Umhlanga, 4320	Residence	-29.747046	31.074765
Seafern Cres, Umhlanga Rocks, Umhlanga, 4320	Residence	-29.747889	31.074266
Homeford Dr., Umhlanga Rocks, Umhlanga, 4320	Forest patch	-29.749142	31.073413
Homeford Dr., Umhlanga Rocks, Umhlanga, 4320	residence	-29.750153	31.072753
Lady Allen Cres, Umhlanga Rocks, Umhlanga, 4320	Park	-29.752477	31.070039
Forest Dr., Umhlanga Rocks, Umhlanga, 4320	Park	-29.753478	31.070023
Lady Ellen Cres, Umhlanga Rocks, Umhlanga, 4320	Park	-29.753064	31.070377
Lady Ellen Cres, Umhlanga Rocks, Umhlanga, 4320	Residence	-29.754205	31.069647
Lady Ellen Cres, Umhlanga Rocks, Umhlanga, 4320	Forest patch	-29.755476	31.068612
Forest Dr., Umhlanga Rocks, Umhlanga, 4320	Forest patch	-29.755243	31.068022
Lady Ellen Cres, Umhlanga Rocks, Umhlanga, 4320	Residence	-29.756351	31.067883
Lady Ellen Cres, Umhlanga Rocks, Umhlanga, 4320	Residence	-29.757324	31.067470
Forest Dr., Umhlanga Rocks, Umhlanga, 4320	Residence	-29.757305	31.066708
Trevor Pl, Umhlanga Rocks, Umhlanga, 4320	Forest patch	-29.758260	31.066601

Location names	Amenities	Coordinates	
		latitude	**longitude**
Forest Dr., Umhlanga Rocks, Umhlanga, 4320	Forest patch	-29.759229	31.065984
Glen Ashley, Durban North, 4051	Forest patch	-29.761469	31.062363
Ypsilanti Ave, Glen Ashley, Durban, 4051	Residence	-29.765370	31.061609
Fairway St, Durban North, 4051	Golf course	-29.779567	31.050070
Jim Fouche Dr., Durban North, 4051	Forest patch	-29.778734	31.049002

Table S5.3 Additional information provided by rose-ringed parakeet survey respondents in eThekwini Municipality, KwaZulu-Natal Province.

Number of respondents	**Responses**
1	Even though they are pests they are not yet a problem
2	I keep as a pet
3	These birds are beautiful but make noise and chase our native barbets from the nests
4	They are beautiful birds
5	What a lovely exotic bird
6	Why controlling them? These are beautiful birds man
7	I can’t say they must be controlled
8	I know they are pests but not annoying as the mynas
9	Kill house crows and mynas and leave this special exotic bird
10	Love all wildlife and no easy answer to take out any birds
11	The bird is beautiful and unique exotic
12	They should not be killed now
13	Their number is not that large or is of concern
14	They took woodpecker nest
15	They use my woodpecker nest during the breeding season
16	They chased southern black flycatcher and mynas coming next to their nest
17	They chased Knysna turaco feeding on natal fig
18	They chase barbet during breeding
19	They are using my woodpecker nest, I don’t know how to keep them away
20	Saw them doing nothing except chasing mynas
21	I saw them chasing African hoope and common mynas
22	My golden tailed woodpecker never returned after parakeets took its nest
23	I saw them chasing and fighting red-winged starling next to Durban beach
24	Crested barbet & black collard barbet were chased from the nest we made
25	I did not know they were alien birds. This has been very informative thanks
26	I had no idea that they were invasive could not believe my wife
27	I honestly didn’t know they were aliens, the newsletter was helpful
28	Thought they were our native birds
29	Thanks for the study now I know that they are not ours
30	Very much needed survey I did not know that they were aliens
31	They make irritating noise
32	They make helluva a noise
33	They make considerable noise
34	Their make a lot of noise
35	They disturb golfer’s in the estate

Number of respondents	Responses
36	They disturb while playing golf
37	Their noise is so unpleasant
38	They make a lot of noise
39	I hate these birds they make helluva a noise
40	They make noise and defecate on chairs and tables
41	Very fast breeding alien bird
42	They visits in large numbers in weekends
43	rapidly increased population over the past few years
44	The number of this species has increased
45	Their number is increasing enormously in uMhlanga crescent
46	Their numbers have increased dramatically
47	There are so many in this place
48	There are too many already I wish you luck trying to reduce this problem
49	As aliens they should be controlled
50	Common myna and starlings are also a problem
51	Control mynas and starlings first
52	Government should not do anything on them, just kill mynas
53	I regard them as a pest that should be removed
54	These are lovely birds why killing them? Control mynas and black starlings
55	We also have a problem with Starlings and House Crows
56	Why don't you control mynas number? And leave these beautiful birds alone
57	Why don't you kill common mynas first
58	Why must they be controlled?
59	I put up a feeder for them, just to watch different breeds coming and going. I saw a yellow one the other day, but it got away before taking a picture. They are a bit aggressive and chase away other birds
60	I do not see Parakeets where I live in PMB but do see them when I visit Durban which is once every few months
61	We will also have a problem with Common Starling and House Crow if they are not controlled as well
62	Worthwhile, much needed survey
63	I am happy to help do any research you may need at Durban View Park as I live right here in front view of them
64	See attached photo
65	We no longer have moosebirds but connecting their absence to the rose-ringed parakeets is not possible.
66	They are quite sturdy birds that can adapt well in different environments. A lot of these wild birds use to be someone's pet at one stage, they then adapted & survived. Formed their own flocks & then bred to keep their species alive. They are beautiful & highly intelligent. If there is to be any blame or accusations of classing these birds or any other animal as pests, then maybe we humans should take a long hard look at ourselves as we have interfered with nature. We've destroyed most of the natural habitats

Number of respondents	**Responses**
	that once were homes to all animals & creatures. Human population is increasing drastically & our animals are dwindling. So who are really the pests here?

CHAPTER 6

Impact assessment of seven alien invasive bird species already introduced to South Africa

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6.1 Abstract

Globally, various avian species have been introduced accidentally and deliberately by humans through different pathways. Some of these species were able to establish, multiply, and become invasive. In this study, we identified areas that are climatically suitable for seven introduced invasive bird species and assessed the environmental and socio-economic impacts associated with the selected bird species in South Africa. We used present distribution records to predict potential climatic suitability distributions and used the Generic Impact Scoring Scheme to assess the impacts associated with seven invasive bird species in South Africa. We found that all the seven species were climatically suitable to South Africa, and *Passer domesticus*, *Sturnus vulgaris*, and *Anas platyrhynchos* each had relatively large climatic suitability distributions. The climatic suitability for all the species was within their occurrence ranges in and outside South Africa. For impact assessments, we found that all seven selected species had impacts, with *A. platyrhynchos*, *Acridotheres tristis*, *Columba livia*, and *Psittacula krameri* having the highest overall impacts, respectively. The socio-economic impact ranked higher than environmental impact for all species. The socio-economic impacts were frequently through agricultural production and human infrastructure, while the environmental impact was mostly through impacts of birds on other animals and competition. These need to be incorporated in decision-making and eradication plans for these alien invasive birds in South Africa.

Keywords: Alien invasive birds · Climatic matching · GISS · Environmental impact · Socioeconomic impacts · Impact assessment

6.2 Introduction

Human activities have moved and translocated many species around the world, accidentally and deliberately (Hulme 2009). As a result, live animals have been transported from one location to another for centuries (Mori et al. 2017; Lockwood et al. 2019). Many of these species were introduced as part of the pet trade (Kawai et al. 2015; Mori et al. 2017; Lockwood et al. 2019), for biological control (Brook et al. 2003; Fraser et al. 2015), for research (Jojola et al. 2005), and as food sources, e.g. feral pigs *Sus scrofa* (Jean Desbiez et al. 2011) and waterfowl (Pingel 2011). In addition, some of the animals were introduced to new areas as hitchhikers, stowaways and/or as transport contaminants (Buck and Marshall 2008; Faulkner et al. 2017).

The process of introducing species to non-native locations where they establish, multiply, spread and finally negatively affecting native flora and fauna is termed as a biological invasion (Hulme 2009; Blackburn et al. 2011). Globally, biological invasions are a major problem as in most parts they cause a decline in many native species (Dove et al. 2011), impact on economies (Pimentel et al. 2005; Ahmad et al. 2012), and facilitate the transmission of diseases to humans, animals and plants (Crowl et al. 2008). For example, the introduction of non-native birds globally (Martin-Albarracin et al. 2015), the Burmese python *Python bivittatus* in Florida (Dove et al. 2011), and the African clawed frog *Xenopus laevis* into Europe (Kopecký et al. 2013).

The impacts associated with any introduced or not yet introduced species can be assessed using standardised impact assessment schemes (Kumschick and Nentwig 2010; Nentwig et al. 2016; Keller and Kumschick 2017). The impact assessment schemes are essential because they ease impact detection and invasion management (Simberloff et al. 2013; Keller and Kumschick 2017). The application of impact assessment requires evidence which is based on impacts that the introduced species have caused (Andreu and Vila` 2010; Bacher et al. 2018). Impact assessment has been applied to many taxa using approaches such as the Environmental Impact Classification for Alien Taxa (EICAT) (Hawkins et al. 2015), the Generic Impact Scoring System (GISS) (Nentwig et al. 2016), the Socio-Economic Impact Classification of Alien Taxa (SEICAT) (Bacher et al. 2018), and rapid screening tools such as species distribution modelling and information on history of invasion elsewhere (Bomford 2006; Keller and Kumschick 2017). The species distribution modelling (SDMs) has increasingly become one of the widely used tools to predict organisms' climatic suitability using presence occurrence records (Estrada-Peña et al. 2007; Di Febbraro et al. 2013). The SDMs has been used to create watch lists used to identify species with potential invasion threats and required for monitoring (Faulkner et al. 2014). The use of SDMs with formal impact assessment scheme is novel, and these two approaches have shown to reveal potential areas at risk of invasion, environmental and socio-economic impacts associated with modelled species (Foxcroft et al. 2007; Chown et al. 2012; Keller and Kumschick 2017).

In South Africa, several introduced avian bird species have become invasive. These include the rose-ringed parakeet *Psittacula krameri* (Hart and Downs 2014), the common myna *Acridotheres tristis* (Peacock et al. 2007), the common starling *Sturnus vulgaris* (Mokotjomela et al. 2013), the rock dove *Columba livia* (Harris et al. 2016), the mallard duck *Anas platyrhynchos* (Stafford 2010), the house crow *Corvus splendens* and the house sparrow *Passer domesticus* (Hart and Downs 2015). Some of these species are amongst the world worst invasive species (Lowe et al. 2000). Most of these species are considered urban, but many are now occurring in rural, peri-urban and agricultural areas (Butler 2003; Shwartz et al. 2009; van Rensburg et al. 2009; Ahmad et al. 2012; Old et al. 2014).

The populations of these alien invasive bird species in South Africa are increasing and well established in major towns and surroundings (Peacock et al. 2007; van Rensburg et al.

2009; Stafford 2010; Hart and Downs 2014; Harris et al. 2016). Given the increasing number of these alien invasive birds, not much is known about their impacts. Understanding the impact associated with introduced invasive birds is important so that appropriate management can be implemented. In this study, we aimed to (1) investigate areas that are likely to be climatically suitable for the selected introduced invasive bird species in South Africa and other parts of the world, and (2) use the Generic Impact Scoring System to assess the environmental and socio-economic impacts associated with the selected alien invasive bird species in South Africa. Given that the selected invasive bird species are often associated with humans (van Rensburg et al. 2009; Harris et al. 2016) and can generally persist over a wide distribution range (Michaelsen and Refvik 2003; Ryall 2003); we, therefore, predicted that those species with large occurrence records worldwide would be the species with large potential climatic suitability distributions and that their impacts would be more socio-economic than environmental.

6.3 Materials and methods

6.3.1 Species distribution records

To develop the climatic match, occurrence records from either native or introduced ranges are required (Steiner et al. 2008). In this study, updated distribution records for seven invasive bird species in South Africa (native and introduced ranges) were downloaded from the Global Biodiversity Information Facility (GBIF; https://www.gbif.org) using rgbif package in R statistical software (version 1.2.5019; R Core Team 2018). The distribution records from museums/ herbariums and those that overlapped were automatically cleaned and removed in R using Biogeo package (Robertson et al. 2016) to prevent data autocorrelation. Exclusion of records from museums or herbariums was done as there was no certainty regarding the accuracy of datasets provided (Rowe 2005). The cleaned datasets were converted to spatial points datasets readable in R.

6.3.2 Model evaluation and climatic matching

The species distribution modelling (SDM) package by Naimi and Araújo (2016), which works in R was used to build a model for seven respective bird species invasive to South Africa. The 19 updated bioclimatic variables downloaded from WorldClim (https://www.worldclim.org) at 10-min spatial resolution were used as predictor variables to describe each species suitability. The predictor variables that collinear with each other were excluded from the model to prevent autocorrelation, as this can affect model prediction and performance (Dormann et al. 2013). The correlation tests were performed using adjusted mean squared (R^2) of multiple correlation coefficient using the Variance Inflation Factor function in R (VIF; Marquardt 1970), variables greater than 0.7 indicated high collinearity and were removed prior to model fitting. To fit the model satisfactorily, the species distribution model requires both presence and absence records (Naimi and Araújo 2016). In this study, the recommended pseudo-absence records (n = 1000 at average runs of 100 bootstrap replications) were drawn randomly from the background of present records (Barbet-Massin et al. 2012).

To predict the climatic match, six methods were fitted to determine the model performance and relate the predictor variable that best described the respective avian species distribution suitability. The methods were isolated from 15 methods supported by the SDM package with the following methods; boosted regression tree (BRT: Friedman 2001), classification and regression trees (CART: Breiman 1984), generalised linear model (GLM: McCullagh 1989), multivariate adaptive regression spline (MARS: Friedman 1991), random forest (RF: Breiman 2001), and support vector machine (SVM: Vapnik 1995). The models were evaluated at 100 runs of bootstrap replication to give the model adequate time to converge.

The independent-threshold statistics such as the area under the curve (AUC) and dependent-threshold statistic (true skill statistic: TSS) were used to evaluate model performance. To build one model for each species using all six methods, the independent AUC thresholds were weighted to mean and later used to adjust the climatic suitability threshold. In the present study, the randomised correlation (COR) procedure described by Thuiller et al. (2009) was used to measure between the predicted values, and the variables under predictions were permutated randomly. The AUC, TSS, and COR values closer to 1 indicated which predictor variables contributed highly to the respective species suitability using the selected six methods. The model outputs included AUC, TSS, and COR values which showed each method's mean performance per species using test datasets generated using partitioning. The model outputs were viewed using the mapview function in R and later downloaded for analyses. The variables performance figures for each method used were displayed to determine which of the selected predictor variables contributed most in predicting climatic suitability (Supplementary information Table S6.1).

6.3.3 Impact assessment

6.3.3.1 Species selection and literature search

Although there are approximately 400 alien bird species introduced around the world (Kumschick et al. 2016), in this study, the impacts were assessed for seven species that have been reported as invasive species in South Africa. Selection of these species was based on the following criteria (1) species listed under the National Environmental Management: Biodiversity Act (NEMBA), and (2) those with present large records outside South Africa. Since impact assessment is assessed based on published evidence (Nentwig et al. 2016), here we searched for published impact observed outside South Africa. The scientific and e-literature were found on the biological invasion websites, Google Scholar, Clarivate (https://clarivate.com/), as well as Global Invasive Species Databases Compendia such as the Animal Diversity Web (ADW: https://animaldiversity.org/), the International Union for Conservation of Nature (IUCN: https://www.iucnredlist.org/), the Global Invasive Species Database (GISD: www.iucngisd.org/gisd), the Centre for Agriculture and Biosciences International (CABI: www.cabi.org/isc), and the Invasive Species Specialist Group (ISSG: www.iucngisd.org/gisd). To search the impacts, the common and scientific names were used for each species together with impact phrases. For example, phrases used included ''rose-ringed parakeet's impacts'', ''rose-ringed compete with native bird'', ''diseases associated with rose-ringed parakeets'', ''rose-ringed parakeet's hybrids'', agricultural impacts by rose-ringed parakeets'', and ''impact of rose-ringed parakeets on infrastructure'' for this species. For the species where we could not find much literature, we used their previous scientific names or synonyms obtained from Integrated Taxonomic Information System (ITIS: www.itis.gov). The relevant scientific literature related to the respective avian species assessed were selected and used in this study (Supplementary information References S6.1).

6.3.3.2 Impacts assessment

Several impact schemes have been developed, including EICAT (Hawkins et al. 2015), GISS (Nentwig et al. 2016) and SEICAT (Bacher et al. 2018). All these schemes exclusively rely on published literature (Hawkins et al. 2015). In this study, we used GISS (Nentwig et al. 2016) to assess the impacts associated with the selected invasive bird species. This impact scheme was used because it generally includes both the environmental and socio-economic impacts (Nentwig et al. 2010, 2016).

The GISS system used comprised of 12 impacts categories, six under socio-economic and environmental impacts, and each category represented an impact mechanism (Nentwig et al. 2016). The impact intensity of each category ranged from 0 (no impacts) to 5 (highest impacts) (Nentwig et al. 2016). The impact categories for both environmental and socioeconomic were summed to get the maximum overall impacts score per species. The latter was out of 60 (12 impacts categories 9 5 (highest impact score)) (for more details see Nentwig et al. 2016). The overall maximum impact score for each category in both environmental and socio-economic impacts was used to rank the impact of a species from low or high impact.

6.3.4 Statistical analyses

The maximum overall impacts scores used to rank species were computed in SPSS (version 25, IBM 2016). To compare the sum of overall impact scored for each avian species and means between environmental and socio-economic impacts, student paired t-tests were used with the *P*-value set to 0.05 significance level. The overall impact between environmental and socio-economic categories was compared for each avian species scored. We also used Kendall's tau (s) test to determine the correlation between the overall impacts scored per avian species and the number of publications used for each species. We used ANOVA and Turkey HSD method with the least squared means *P*-values adjusted to determine the significant differences between the levels of mechanism for both environmental and socio-economic impacts. For these statistical analyses, we used R (version 3.4.4, R Core Team 2018).

6.4 Results

6.4.1 Distribution modelling

The model performed well for all seven invasive bird species with a mean independent AUC threshold ranging from 0.83 to 1 (Table 6.1, Supplementary information Fig. S6.1 – 6.7). The models fitted well under all six methods, with random forest (RF), support vector machine (SVM), and multivariate adaptive regression spline (MARS) being the top three methods that contributed the most in fitting the models (Table 6.1).

Table 6.1 A summary of the mean model performance of six fitted methods generated using presence records for seven invasive bird species in South Africa using partitioning in the present study

Methods	Common myna *Acridotheres tristis*				Mallard duck *Anas platyrhynchos*				Rock dove *Columba livia*				House crow *Corvus splendens*			
	AUC	COR	TSS	Variables	AUC	COR	TSS	Variables	AUC	COR	TSS	Variables	AUC	COR	TSS	Variables
BRT	0.83	0.63	0.65	9,3	0.88	0.65	0.73	9,19,3	0.93	0.7	0.82	19,3,4	0.88	0.68	0.74	9,3,8
CART	0.84	0.74	0.66	9,3,2	0.82	0.72	0.62	9,19,13,3	0.93	0.83	0.82	19,3,4,10	0.84	0.77	0.67	3,8,9
MARS	0.95	0.69	0.8	3,2,9	0.94	0.76	0.77	19,3,9	0.96	0.84	0.82	4,3,10,2	0.97	0.83	0.87	3,15,14
GLM	0.88	0.6	0.64	9,13,15	0.79	0.84	0.66	15,9,19	0.9	0.7	0.64	4,3,19	0.96	0.77	0.82	9,13,19
RF	1	0.92	0.96	3,2,19	1	0.91	0.97	19,3,9	1	0.93	0.95	3,4,19	1	0.95	0.98	3,15,2
SVM	0.95	0.75	0.89	9,3,2	0.94	0.83	0.89	15,9,3	0.99	0.92	0.94	4,10,3	0.99	0.91	0.96	3,2,15

Methods	House sparrow *Passer domesticus*				Rose-ringed parakeet *Psittacula krameri*				Common starling *Sturnus vulgaris*			
	AUC	COR	TSS	Variables	AUC	COR	TSS	Variables	AUC	COR	TSS	Variables
BRT	0.89	0.68	0.74	3,4,9	0.85	0.66	0.69	4	0.91	0.68	0.81	19,9
CART	0.86	0.75	0.7	4,19,8	0.9	0.79	0.78	4,10,2	0.9	0.82	0.79	19,9,3
MARS	0.94	0.74	0.74	4,3,19	0.96	0.8	0.86	10,4	0.96	0.83	0.83	13,19,3,9
GLM	0.9	0.55	0.63	4,3,2	0.94	0.75	0.77	4,10,3	0.89	0.62	0.72	9,3,15
RF	1	0.92	0.96	4,15,19	1	0.94	0.97	2,3,4	0.99	0.93	0.95	9,3,15,19
SVM	0.96	0.85	0.9	4,15,19	0.96	0.87	0.91	4,10,2	0.97	0.86	0.92	14,9,19

Numbers in the variable columns represent predictor variables that best explain each species suitability, and each variable is described below

The full names for predictor variables numbers are as follows: 1: BIO1 = annual mean temperature, 2: BIO2 = mean diurnal range (mean of monthly (max temp - min temp)), 3: BIO3 = isothermality (BIO2/BIO7) (* 100), 4: BIO4 = temperature seasonality (standard deviation * 100), 5: BIO5 = max temperature of warmest month, 8: BIO8 = mean temperature of wettest quarter, 9: BIO9 = mean temperature of driest quarter, 10: BIO10 = mean temperature of warmest quarter, 13: BIO13 = precipitation of wettest month, 14: BIO14 = precipitation of driest month, 15: BIO15 = precipitation seasonality (coefficient of variation), and 19: BIO19 = precipitation of coldest quarter

6.4.1.1 Common myna Acridotheres tristis

The model performed well in predicting the climatic suitability for the common myna with mean AUC values for all methods of 0.91 (Table 6.1, Supplementary information Fig. S6.1). The projected climatic suitability distribution of the common myna was relatively large, covering a large extent of the globe except for Antarctica and some dry desert areas in Africa (Fig. 6.1). South Africa had large predicted climatic suitability for this species except for some parts in Northern Cape and Western Cape Provinces (Fig. 6.1). The predicted climatic suitability in South Africa overlapped with presence records of occurrence, but in some parts, it occurred in uninvaded areas (Fig. 6.1). The predictor variables that described this species' climatic suitability were temperature related and were mainly Bio 2 (mean diurnal range (mean of monthly (max temp - min temp)), Bio 3 (isothermality (BIO2/BIO7), and Bio 9 (mean temperature of driest quarter) (Table 6.1, Supplementary information Fig. S6.1).

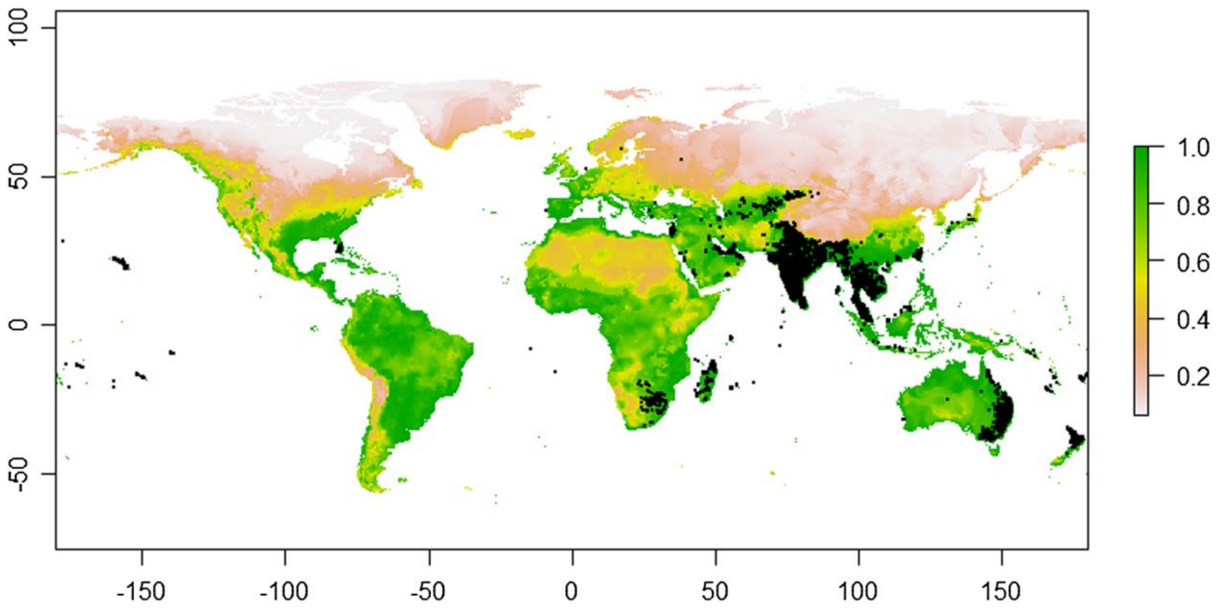

Fig. 6.1 The species distribution modelling showing predicted climatically suitable areas for the common myna *Acridotheres tristis* in South Africa and other parts of the world in the present study. (Note: The suitability measured is shown by a colour ramp threshold on the right;

the greener the suitability, the more suitable areas are. Black dots in the map represent species presence data used for modelling)

6.4.1.2 Mallard duck Anas platyrhynchos

The projected climatic suitability distribution for the mallard duck was relatively large in North America, and Central Europe, extending towards central Russia and southern Asian regions (Fig. 6.2). In South America, the largest climatic suitability for the mallard duck was found in Argentine, Chile and Uruguay. In Africa, the largest climatic suitability for the mallard duck was in central Africa and South Africa except for the Northern Cape and some parts in the Limpopo and North West Provinces (Fig. 6.2). In South Africa, the climatic suitability for this species overlapped largely with presence records than areas not currently invaded (Fig. 6.2). Australia and New Zealand also had broad climatic suitability for the mallard duck, and this extended to include relatively small parts of East Asia (Fig. 6.2). Only two predictor climatic variables (Bio 9: mean temperature of the driest quarter and Bio 19: precipitation of coldest quarter) contributed the most in projecting climatic suitability of the mallard duck (Table 6.1, Supplementary information Fig. S6.2).

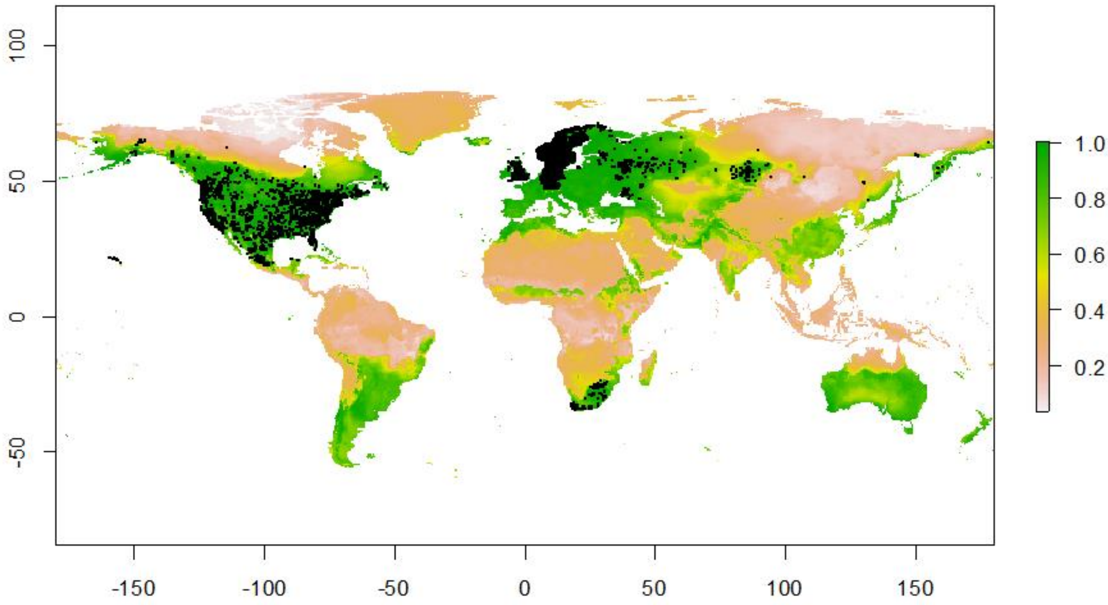

Fig. 6.2 The species distribution modelling showing predicted climatically suitable areas for the mallard duck *Anas platyrhynchos* in South Africa and other parts of the world in the present study. (Note: The suitability measured is shown by a colour ramp threshold on the right; the greener the suitability, the more suitable areas are. Black dots in the map represent species presence data used for modelling)

6.4.1.3 Rock dove Columba livia

The climatic suitability distribution of the rock dove occurred largely in North America, Australia, central Europe, New Zealand, and South America (particularly in three regions; Argentine, Chile, and Uruguay) (Fig. 6.3). Central Asia had scattered suitability, especially in east China (Fig. 6.3). The predicted climatic suitability in South Africa for the rock dove was relatively large, covering all provinces, including invaded and uninvaded areas (Fig. 6.3). The climatic suitability distribution for this species was best described by three predictor variables, namely isothermality (Bio 3), temperature seasonality (Bio 4), and precipitation of coldest quarter (Bio 19) (Table 6.1, Supplementary information Fig. S6.3).

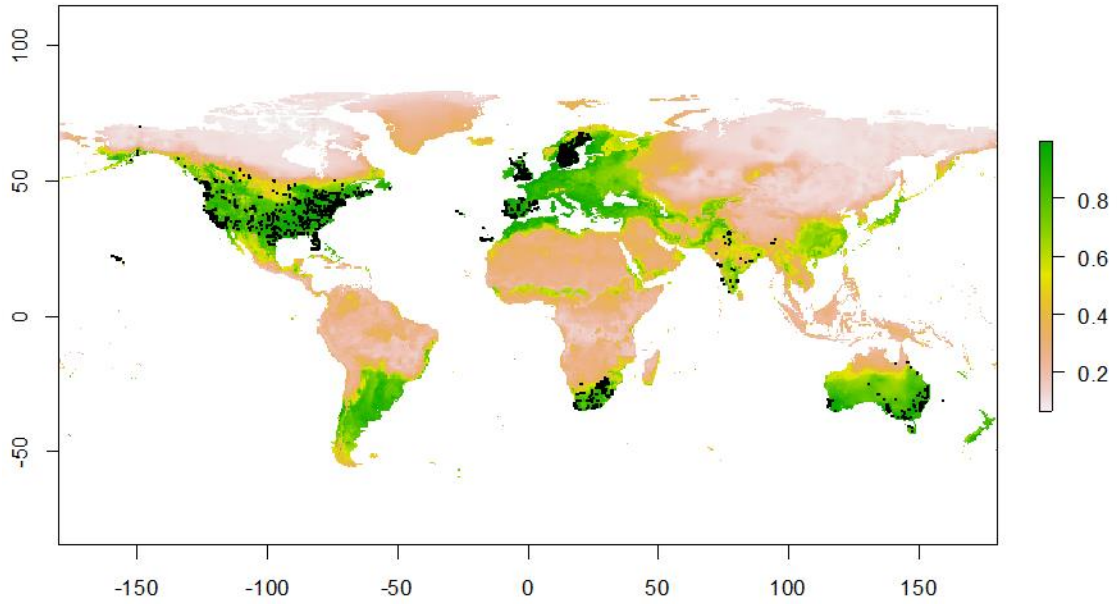

Fig. 6.3 The species distribution modelling showing predicted climatically suitable areas for the rock dove *Columba livia* in South Africa and other parts of the world in the present study. (Note: The suitability measured is shown by a colour ramp threshold on the right; the greener the suitability, the more suitable areas are. Black dots in the map represent species presence data used for modelling)

6.4.1.4 House crow Corvus splendens

The projected climatic suitability distribution for the house crow differed from other species as its suitability was more in the southern hemisphere, southern Asia, and the Middle East (Fig. 6.4). In South Africa, the predictions were concentrated in the western and eastern coastal areas of the KwaZulu-Natal, Eastern Cape, Western and the Northern Cape Provinces (Fig. 6.4). The predictions overlapped with presence records of the house crow but in some areas, it also included currently uninvaded areas (Fig. 6.4). The climatic suitability for this species was best described by the predictor variables isothermality (Bio 3), mean temperature of driest quarter (Bio 9), and precipitation seasonality (coefficient of variation) (Bio 15) (Table 6.1, Supplementary information Fig. S6.4).

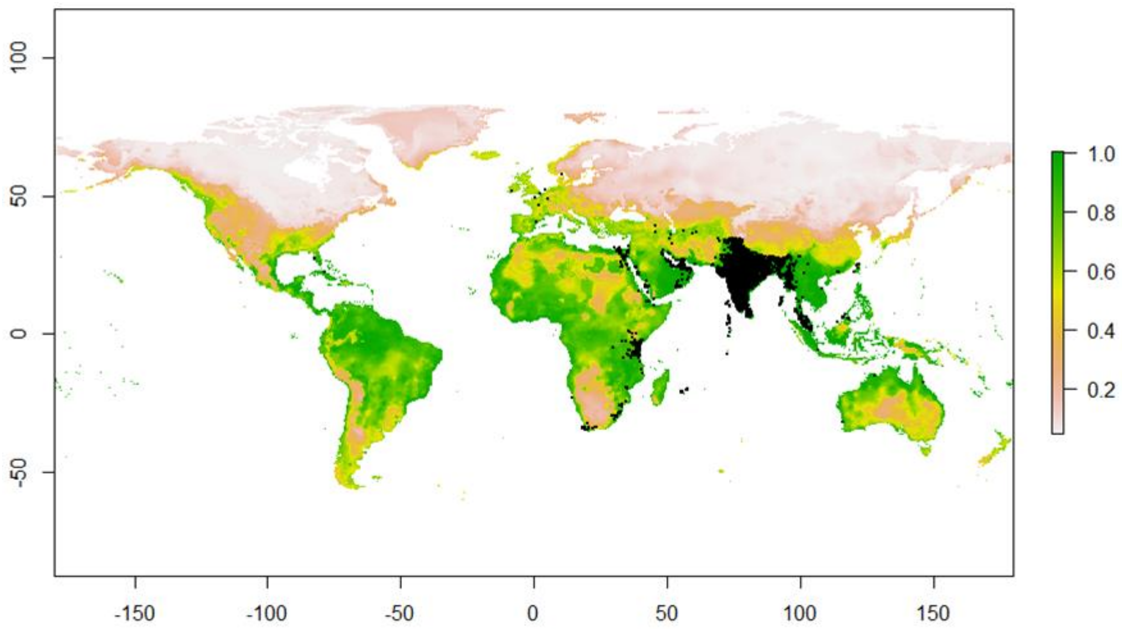

Fig. 6.4 The species distribution modelling showing predicted climatically suitable areas for the house crow *Corvus splendens* in South Africa and other parts of the world in the present study. (Note: The suitability measured is shown by a colour ramp threshold on the right; the greener the suitability, the more suitable areas are. Black dots in the map represent species presence data used for modelling)

6.4.1.5 House sparrow Passer domesticus

The house sparrow was one of the species with the largest projected climatic suitability distribution worldwide of the various species assessed (Fig. 6.5). In South Africa, the climate suitability distribution for the house sparrow was projected to include all the provinces, including the largest portion of both invaded and currently uninvaded distribution ranges (Fig. 6.5). The predictor variables that contributed most to this species' climatic suitability were similar to those reported for the rock dove (Table 6.1, Supplementary information Fig. S6.5).

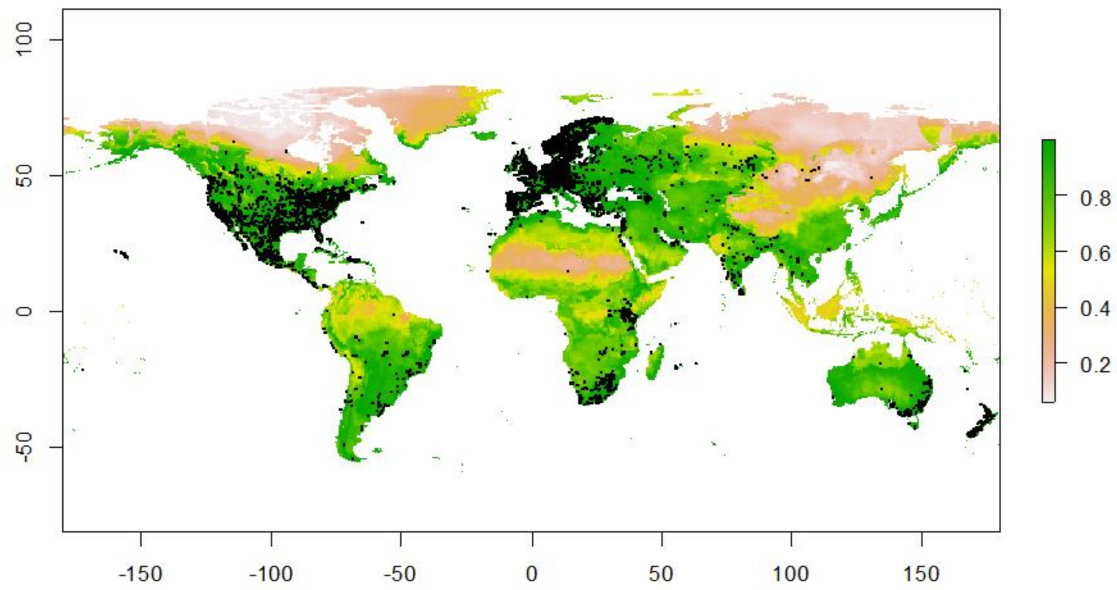

Fig. 6.5 The species distribution modelling showing predicted climatically suitable areas for the house sparrow *Passer domesticus* in South Africa and other parts of the world in the present study. (Note: The suitability measured is shown by a colour ramp threshold on the right; the greener the suitability, the more suitable areas are. Black dots in the map represent species presence data used for modelling)

6.4.1.6 Rose-ringed parakeet Psittacula krameri

The projected climatic suitability distribution of rose-ringed parakeets was scattered across the globe (Fig. 6.6). In North and South America, the western and eastern coastal areas were more suitable for this species (Fig. 6.6). In South America, the suitability was particularly in the coastal regions of Mexico, some regions of Brazil, Argentina, Paraguay, and Uruguay (Fig. 6.6). The regions with the largest climatic suitability distribution for these parakeets included western European countries, the Middle East and the southern parts of Asia (Fig. 6.6). In Africa, the largest distribution suitability was predicted in the sub-Sahara, especially the eastern regions (Fig. 6.6). Australia and New Zealand also had a large predicted climatic suitability distribution for these parakeets (Fig. 6.6). In South Africa, the western and eastern coastal regions, particularly the Western Cape, Eastern Cape, and KwaZulu-Natal Provinces, had relatively large predicted climatic suitability distribution for rose-ringed parakeets (Fig. 6.6). This included some inland regions of the Free State, Gauteng, Mpumalanga, and KwaZulu-Natal Provinces and extended from Limpopo Province to East African countries (Fig. 6.6). The predicted suitability distribution for this species in South Africa overlapped with the known occurrence records, while in some parts, suitability occurred in currently uninvaded distribution ranges (Fig. 6.6). The predictor variables temperature seasonality (Bio 4) and mean temperature of warmest quarter (Bio 10) contributed most in predicting the climatic suitability distribution for this species (Table 6.1, Supplementary information Fig. S6.6).

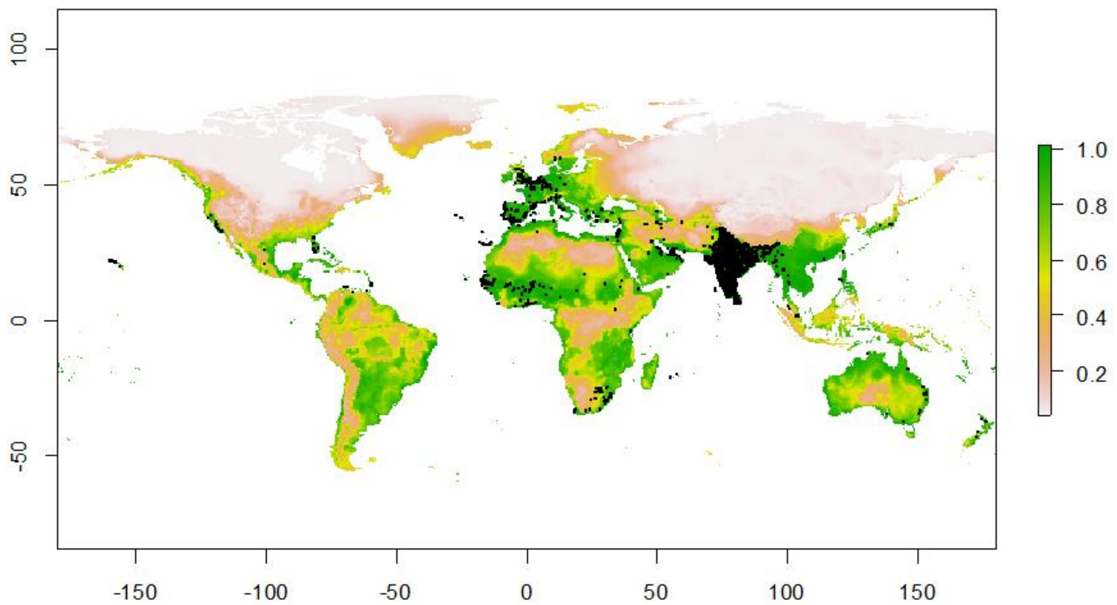

Fig. 6.6 The species distribution modelling showing predicted climatically suitable areas for rose-ringed parakeets *Psittacula krameri* in South Africa and other parts of the world in the present study. (Note: The suitability measured is shown by a colour ramp threshold on the right; the greener the suitability the more suitable areas are. Black dots in the map represent species presence data used for modelling)

6.4.1.7 Common starling Sturnus vulgaris

The northern regions of the northern hemisphere, particularly North America and Europe, had large climatic suitability distribution for the common starling (Fig. 6.7). In South America, particularly Argentine, Chile, and Paraguay had larger suitability. In South Africa, the Eastern Cape, Western Cape, and KwaZulu-Natal Provinces also had relatively large projected climatic suitability distributions for this species (Fig. 6.7). In South Africa, the predicted climatic suitability of starling overlapped with presence records while suitability in Free State occurred in currently uninvaded distribution ranges (Fig. 6.7). The southern regions of Australia (particularly Western Australia and New South Wales), and New Zealand had relatively large projected climatic suitability distribution for the common starling (Fig. 6.7). The northern regions of the Middle East and eastern parts of China also had suitable climatic distribution ranges for this species (Fig. 6.7). The predictor variables isothermality (Bio 3), mean temperature of driest quarter (Bio 9), and precipitation of coldest quarter (Bio 19) described the common starling climatic suitability distribution (Table 6.1, Supplementary information Fig. S6.7).

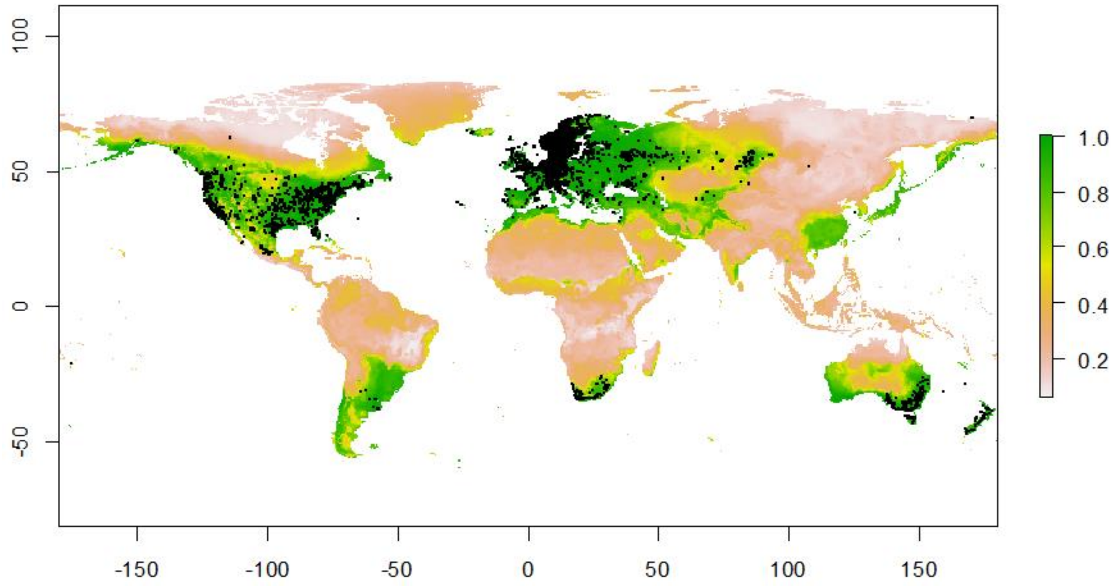

Fig. 6.7 The species distribution modelling showing predicted climatically suitable areas for the common starling *Sturnus vulgaris* in South Africa and other parts of the world in the present study. (Note: The suitability measured is shown by a colour ramp threshold on the right; the greener the suitability, the more suitable areas are. Black dots in the map represent species presence data used for modelling)

6.4.2 Impact assessment

6.4.2.1 Species ranked by impacts

A total of 129 published references from the scientific literature were used to assess the impact of the seven selected invasive bird species in South Africa (Supplementary information References S6.1). The number of literature references used in scoring these species differed per species, and ranged from a minimum of 12 to a maximum of 27 papers (Table 6.2). Several impacts exerted by some of these species were reported by single literature; as a result, there was a negative correlation (Kendall's tau: τ = -0.15, $P > 0.05$) between overall impact scored per species and the number of literature references used for scoring. All seven selected avian invasive species were found to have impacts (Table 6.2). The mallard duck, common myna, rock dove, rose-ringed parakeet, and house crow were the avian invasive species with the highest overall impact ranging from 35 to 39 (Table 6.2). The house sparrow and common starling had impact magnitudes between 25 and 29 (Table 6.2). However, some of these avian species scored a maximum impact of five across the different levels of mechanisms. For example, these high scoring mechanisms (shown in parentheses) for the different species were as follows: the mallard duck (competition, hybridisation, agricultural production, human infrastructure, and human social life); the common myna (animals, competition, agricultural production, and human social life); the rock dove (hybridisation, agricultural production, human infrastructure, human health and human social life); the house crow (animals, agricultural production, and human social life); the house sparrow (agricultural production and human health); the rose-ringed parakeet (agricultural production); and the common starling (agricultural production, animal production, and human infrastructure) (Table 6.2).

6.4.2.2 Impact levels across the mechanisms

Most of the bird species scored in this study had previous records resulting in relatively large environmental impacts (maximum possible score of 5) through effects on other animals (which included predation and/or parasitism), competition, and hybridisation. They also caused relatively large socio-economic impacts through effects on agricultural production, human infrastructure, human health, and human social life (Table 6.2). Most of these species have previously caused impacts through socio-economic mechanisms rather than environmental mechanisms (Table 6.2; Supplementary Fig. S6.8). The impact mechanism recorded with the maximum possible score across all the respective avian species was agricultural production (Table 6.2). There was a significant difference between the levels of socio-economic categories (ANOVA: $F_{6.015} = 15.32$, $P = 0.05$) and no significant difference between the levels of mechanisms for the environmental categories (ANOVA: $F_{1,154} = 1.26$, $P = 0.0017$). The overall impacts between the levels of mechanisms scored for environmental and socio-economic categories differed significantly (Turkey HSD: $P = 0.00019$; Fig. 6.8).

Table 6.2 A summary of the Generic Impact Scoring System showing the overall environmental and socio-economic impact scores assessed for seven avian invasive bird's species introduced to South Africa in the present study

Species	Common names	Environmental								
		Plants or vegetation	Animals	Competition	Diseases transmission	Hybridisation	Ecosystems	Environmental total		
Anas platyrhynchos	Mallard duck	2	2	5	2	5	2	18		
Acridotheres tristis	Common myna	4	5	5	4	0	3	21		
Columba livia	Rock dove	2	3	3	2	5	3	18		
Corvus splendens	House crow	0	5	4	2	0	0	11		
Passer domesticus	House sparrow	1	2	0	2	3	2	10		
Psittacula krameri	Rose-ringed parakeet	2	4	4	4	3	3	17		
Sturnus vulgaris	Common starling	0	2	3	1	0	0	6		
Level overall scores		11	23	24	17	16	13	101		
Species	Common names	Socio-economic							Overall scores	Number of references used
		Agricultural production	Animal production	Forestry production	Human Infrastructure	Human health	Human social life	Socio-economic total		
Anas platyrhynchos	Mallard duck	5	3	0	5	3	5	21	39	16
Acridotheres tristis	Common myna	5	0	0	4	3	5	17	38	18
Columba livia	Rock dove	5	0	0	5	5	5	20	38	18
Corvus splendens	House crow	5	4	0	3	3	5	20	31	18
Passer domesticus	House sparrow	5	1	0	4	5	0	15	25	21
Psittacula krameri	Rose-ringed parakeet	5	3	2	2	3	3	18	35	27

Sturnus vulgaris	Common starling	5	5	0	5	4	4	23	29	12
Level overall scores		35	16	2	28	26	27	134	235	130

The mechanism levels ranked per species according to the maximum scores are also indicated. (References used for the respective species impact assessments are presented in Supplementary References S6. 1)

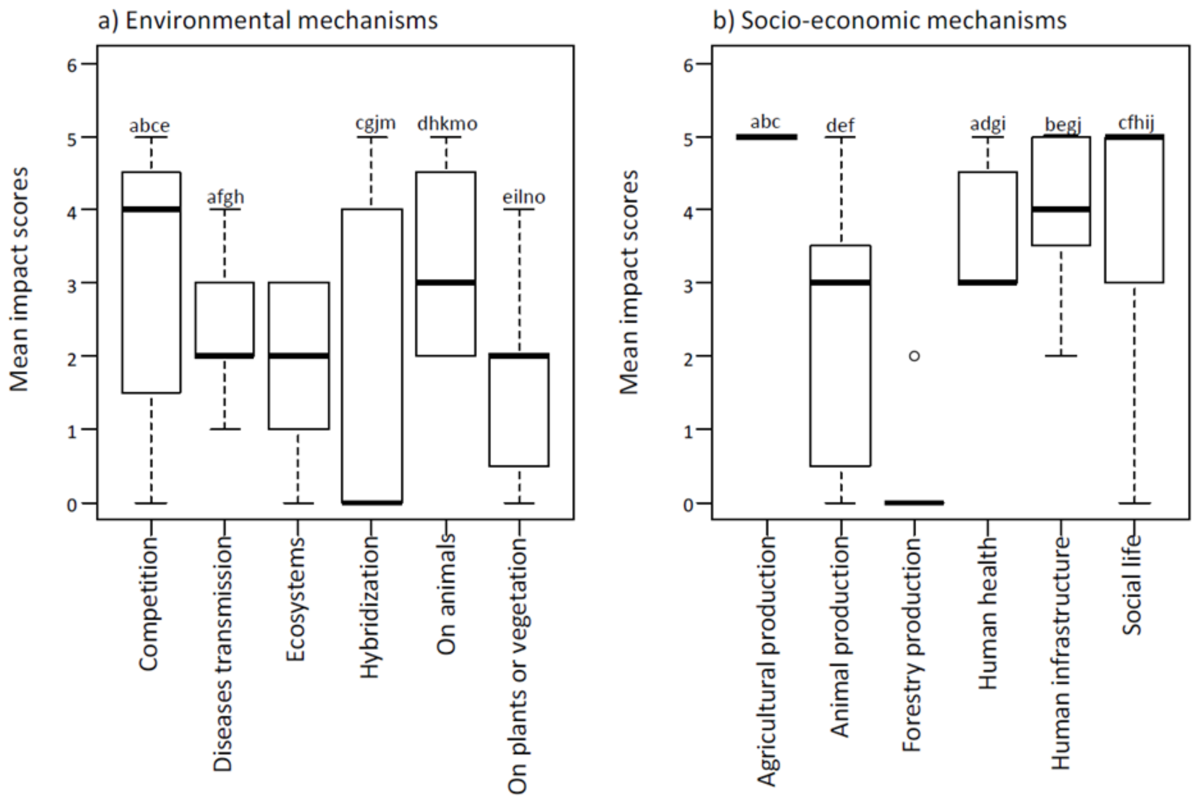

Fig. 6.8 The overall impacts magnitude between levels of mechanisms scored for seven selected invasive bird's species in South Africa for **a)** environmental and **b)** socio-economic categories in the present study. (Letters in each boxplot are level of grouping indicating the significant differences amongst the mechanism, where same letters indicate significant differences between the levels of mechanism, comparisons are Turkey HSD least squared means P-values adjusted)

6.5 Discussion

6.5.1 Climatic suitability

In this study, we report on the potential predicted climatic suitability distribution ranges for seven invasive avian species introduced to South Africa and other parts of the world. It was shown that some of the species with relatively large occurrence records tended to have relatively large climatic suitability distribution ranges. This was particularly evident for the common myna, house sparrow, and mallard duck in the present study. The availability of large climatic suitability distribution for these species was robust as modelling was performed covering larger areas, and this has been similarly reported by Estrada-Peña et al. (2007). Conversely, some species, such as the common starling, house crow, rose-ringed parakeet, and rock dove, despite having relatively large occurrence records, had relatively low climatic suitability distributions in comparison. This was particularly because their present distribution did not cover large extents, and this may have limited their distribution predictions as found in other studies (Estrada-Peña et al. 2007; Lee-Yaw et al. 2016). The climatic suitability for most of these species was within their present occurrence ranges, and this suggests that their distribution is dependent on climatic conditions.

The occurrence of some of these avian invasive species, particularly in South Africa and other parts of the world, overlapped with the predicted climatic suitability distributions for each, but in some areas, the predicted suitability included currently uninvaded areas. This may contribute to the potential likelihood of establishment should the species depend on climatic conditions. Species such as the house sparrow in North America, the rose-ringed parakeet in Italy (Di Febbraro and Mori 2015), and the house crow in New Zealand and Australia (Fraser et al. 2015) all depended on the climatic conditions for successful colonisation. This indicates that species with present distribution records in climatically suitable areas may pose a risk of further invasion. The respective alien invasive bird species reported in the present study have established across the globe with wide distribution ranges across Asia, Australia, Europe, and North America (Lowe et al. 2000; Pithon and Dytham 2002; Pinto 2005; Peacock et al. 2007). In some areas, species such as the rock dove (Michaelsen and Refvik 2003) and the house crow (Ryall 2003) have been reported to survive extreme conditions different to those in their native ranges, e.g. the house crow has survived in Hoek van Holland, Netherlands, where their breeding colony persist in extreme cold periods with ambient temperatures less than - 8 °C (Ryall 2003). Species that are reported to survive in areas of relatively wide climatic ranges might be more opportunistic and have phenotypic plasticity to make their survival possible in a wide environmental range, e.g. the rose-ringed parakeet and the monk parakeet *Myiopsitta monachus* (Spreyer and Bucher 1998; Strubbe and Matthysen 2009a, b; Thabethe et al. 2013).

For some of the invasive avian species, climatic suitability alone cannot explain species occurrence and colonisation as some are highly social and have evolved to live in association with humans, e.g. the house crow (Owino et al. 2004), the house sparrow (Shaw et al. 2008), and the rose-ringed parakeet (Butler 2003; Hart and Downs 2014). In addition, avian species introduced in areas, either rural or urban, where human habitation exists generally provide them with supplemental food, space, and shelter (Layton 2009; Shimba and Jonah 2017), and those with relatively large potential climatic suitability may pose a relatively high risk of becoming invasive. However, climatic matching and/or species distribution modelling alone cannot fully justify the impact associated with species but can be applied with impact scoring assessment to quantify their impacts as suggested in other studies (Keller and Kumschick 2017).

6.5.2 Impact assessment

All seven invasive birds assessed in the present study scored higher for socio-economic impacts than environmental impacts. Other studies, however, found higher environmental impacts than socio-economic, or no difference between the two impacts (Evans et al. 2014; Kumschick et al. 2015). We found higher socioeconomic impacts likely because many of the species assessed in the present study are associated with human habitation (Owino et al. 2004; Layton 2009), especially in the city centres where there is generally an abundance of anthropogenic food and infrastructure for their persistence (Soh et al. 2002; van Rensburg et al. 2009). Factories, shopping malls, agricultural sectors and domestic gardens also provide suitable habitats for these species (Suliman et al. 2011; Magudu and Downs 2015; Menchetti et al. 2016; Senar et al. 2016). As a result, all the seven alien invasive birds scored in this study had maximum impacts on agricultural production, resulting in major economic losses, e.g. the rose-ringed parakeet damage is worth approximately ~ US$11,5 Million in Pakistan alone (Khan and Ahmad 1983; Ahmad et al. 2011) and the crop damage by common starlings was estimated at ~ US$800 million per annum in the USA (Pimentel et al. 2000). Some of the species scored the maximum on human infrastructure; this is because the damage associated with those birds included both control and damage costs. For example, the airstrike damage by mallard ducks was estimated at over US$100 million, and about US$200,000 was spent in clean-up costs associated with common starlings in Omaha, Nebraska, USA (Linz et al. 2007; Cummings 2016). Species such as the house crow and the rock dove have been reported to pollute various anthropogenic infrastructure and water bodies with their excreta (Xi 2009; Sacchi et al. 2002; Jerolmack 2008; Shimba and Jonah 2017), resulting in more financial expenditure. For example, in the USA alone, feral pigeons in some urban areas have caused impacts of ~ US$1.1 million annually (Pimentel et al. 2005). Most of the invasive bird species included in the present study have impacts on human health as many are vectors of zoonotic diseases, e.g. the mallard duck (Gunnarsson et al. 2012), house crow (Ryall and Meier 2008), rock dove (Dolz et al. 2013), and rose-ringed parakeet (Mase et al. 2002). Some of the diseases carried by these invasive birds are transmittable to animals; as a result, farmers may have production losses. The common starling has been documented to carry *Mycobacterium avium paratuberculosis*, which is the main cause of Johne's disease in cattle (Corn et al. 2005). This disease has cost the USA dairy industry ~ US$200–250 million annually (Beard et al. 2001). Only the rose-ringed parakeet was associated with impact on forestry production, and the reported impact was through bark stripping and defoliation (Strubbe and Matthysen 2009a, b). The impacts on forest production by these seven species were relatively low because most of the alien invasive bird species examined have adapted to live, roost, and feed on food around human habitation. This included species such as the common starling (Mennechez and Clergeau 2001), house crow (Shimba and Jonah 2017), rock dove (Spennemann and Watson 2017), and house sparrow (Magudu and Downs 2015).

The impacts on the environment of the seven invasive avian species were mostly in terms of competition and effects on other animals. For example, rose-ringed parakeets have been reported to compete with native nuthatches *Sitta europaea* (Strubbe and Matthysen 2009b) and the threatened greater noctule bat *Nyctalus lasiopterus* (Mattia et al. 2014; Hernández-Brito et al. 2018). Sometimes the competition may result in fatal attacks on native avifauna (Mattia et al. 2014; Covas et al. 2017). The common myna was also reported to attack common coati *Nasua nasua* in Victoria, Australia (Fitzsimons 2006). Diseases carried by some of these birds can negatively affect other birds, e.g. mallard ducks are natural carriers of infectious duck virus enteritis (DVE) that can be transmitted to other ducks in the wild (Dhama et al. 2017). Species that scored maximum under hybridisation were rock dove and mallard duck; these species have been implicated in changing the genetic pool of native or endangered species. For example, the mallard duck affects the genetic pool of endangered species such as Hawaiian duck *Anas wyvilliana*, the African black duck *A. sparsa*, and the Meller's duck *A. meller* (Fowler et al. 2009). Some of the species assessed in the present study, such as the rose-ringed parakeet, are bred in captivity, and the wild populations of hybrids for this species are relatively rare or have few populations (Postigo 2016).

In the present study, some mechanisms examined recorded low impacts, and this could be attributed to the paucity of literature and that there are relatively few studies of invasive bird impacts. For example, the score for impact on ecosystems, and plants or vegetation were relatively low as a consequence. Although there were a few of the invasive alien species in the present study that scored relatively low impacts, which represented minimal or no impacts, the impacts reported for these species should not be underestimated (Hawkins et al. 2015). The minimal impacts scored can change to be large for some species once introduced to areas that meet their colonisation traits, as explained in Blackburn et al. (2009). This is evident for species such as common mynas in South Africa (Peacock et al. 2007) and monk parakeets in Spain (Rodríguez-Pastor et al. 2012) which have large densities in their invasive ranges compared with their native ranges, and their impacts are relatively large.

6.6 Conclusions and recommendations

We found that all the seven avian invasive species had climatically suitable distributions in South Africa. The climatic suitability for all the species was within their occurrence ranges in and outside South Africa. From the impact assessments, we found that all seven selected species had impacts, with the mallard duck, common myna, rock dove, rose-ringed parakeet, and house crow having the highest overall impacts, respectively. The socio-economic impact ranked higher than the environmental impact for all species. The socio-economic impacts were frequently through agricultural production and human infrastructure, while the environmental impact was mostly through impacts of birds on other animals and competition.

It is recommended that the seven invasive bird species assessed in the present study should be eradicated, given that they have relatively large potential climatic suitability distributions and have both environmental and socio-economic impacts. For areas that are climatically suitable for these respective species but presently no occurrence records, surveillance in these areas is needed to ensure they are detected as soon as they appear and that mitigation measures are implemented. Those species not yet included in NEMBA with the highest possible recorded impacts and potential climatic suitability range should not be neglected in decision making for policy implementation. In addition, long term management strategies are needed to address the impacts associated with invasive species already established, but not yet controlled (Garcia-Diaz et al. 2021). The present study provides baseline data towards the management of invasive avian species in southern Africa and globally.

6.7 Acknowledgements

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6.8 Compliance with ethical standards

Conflict of interest – The authors declare that they have no conflict of interest.

6.9 References

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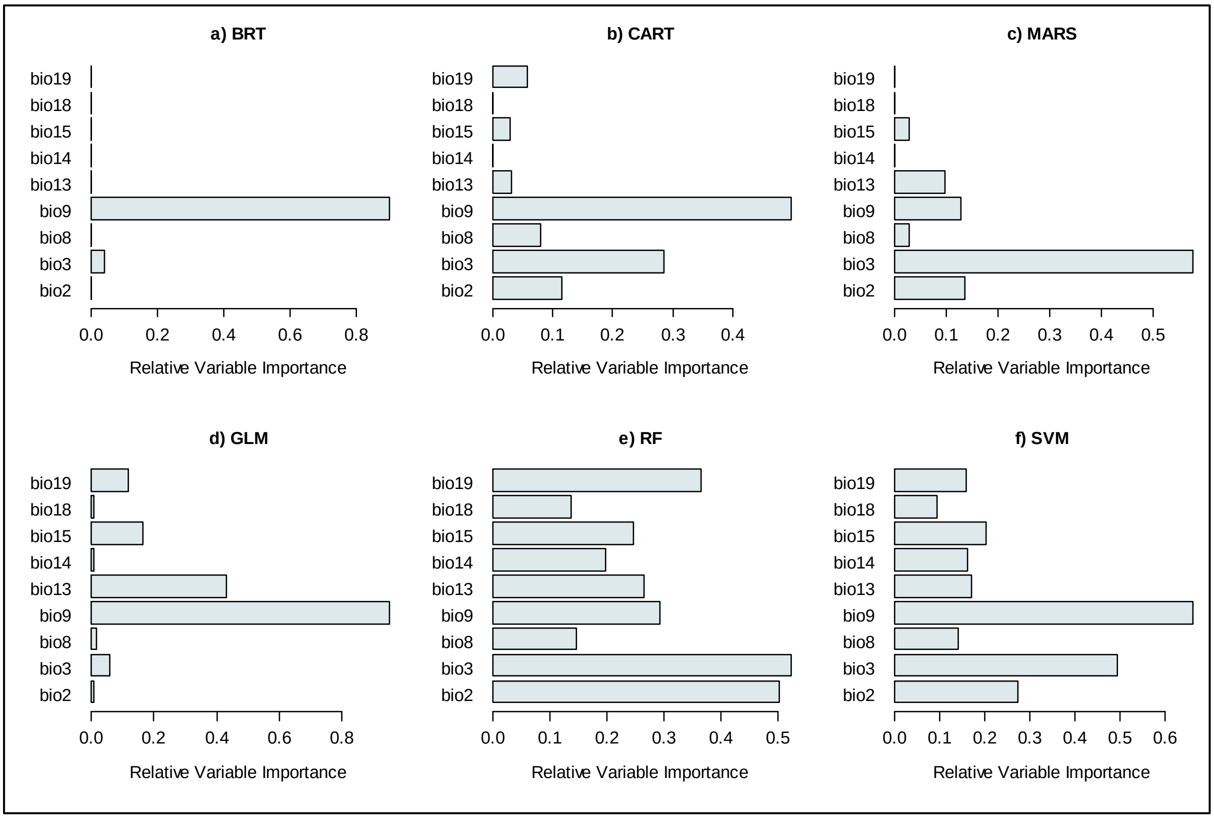
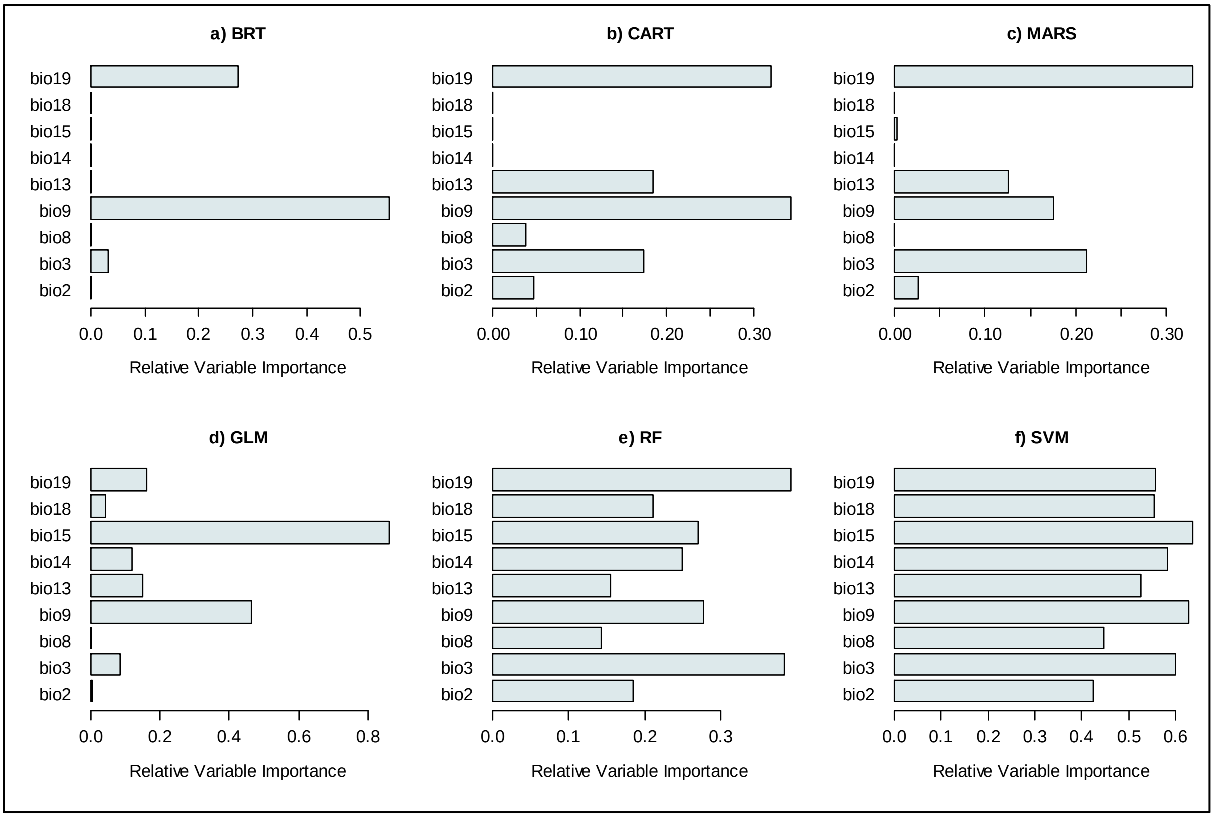
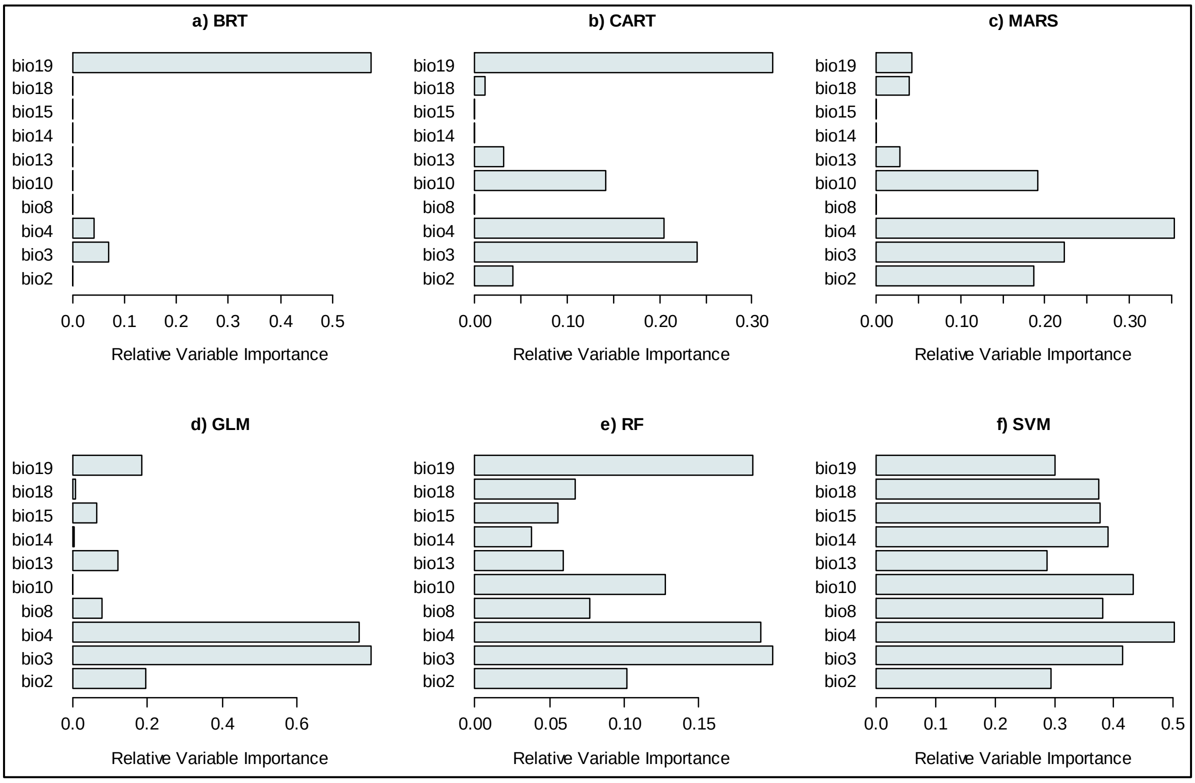
6.10 Supplementary material



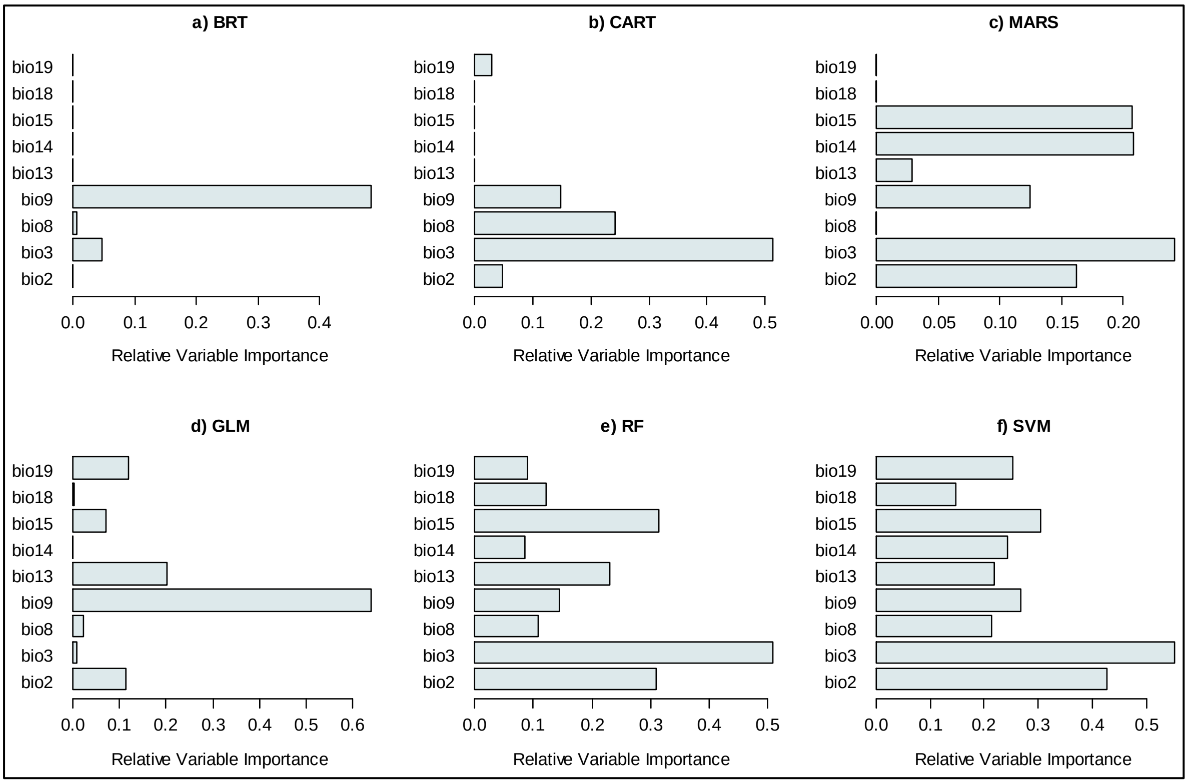
Supplementary Figure S6.1 Predictor variables that contributed most to the common myna *Acridotheres tristis* distribution modelling using the seven methods in the present study.



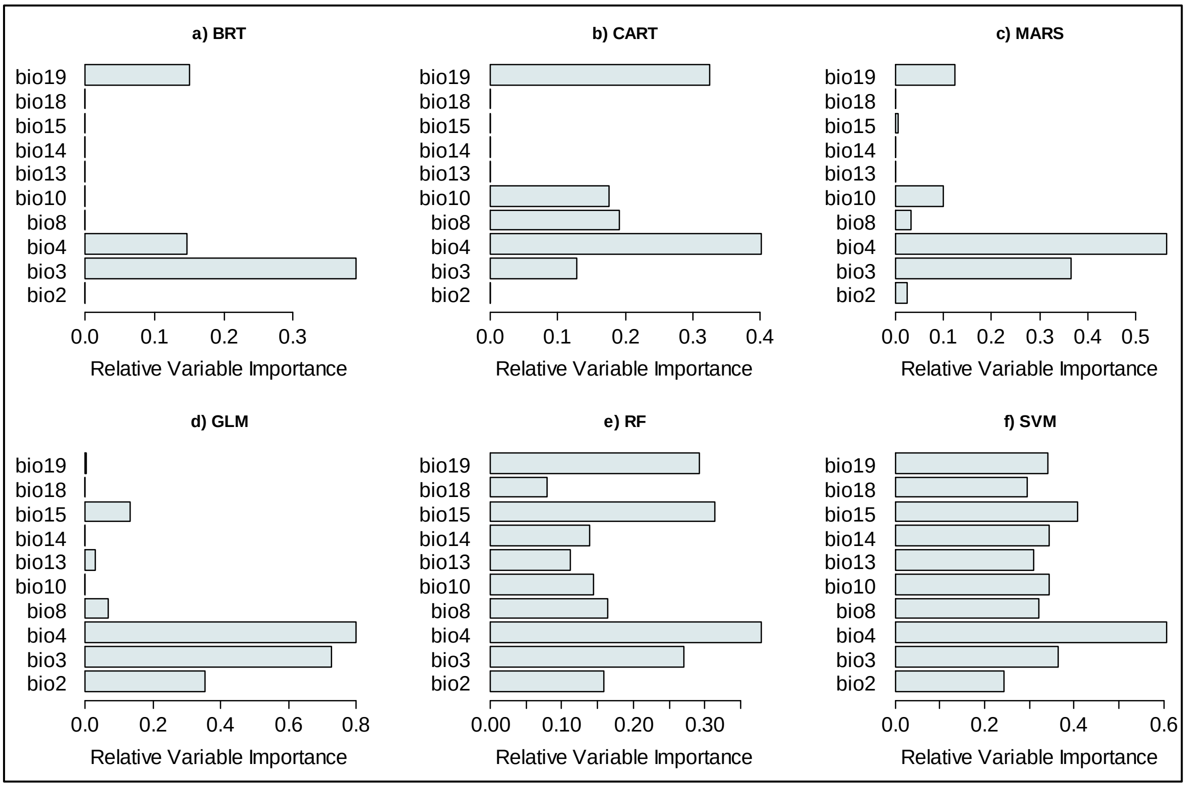
Supplementary Figure S6.2 Predictor variables that contributed most to the mallard duck *Anas platyrhynchos* distribution modelling using the seven methods in the present study.



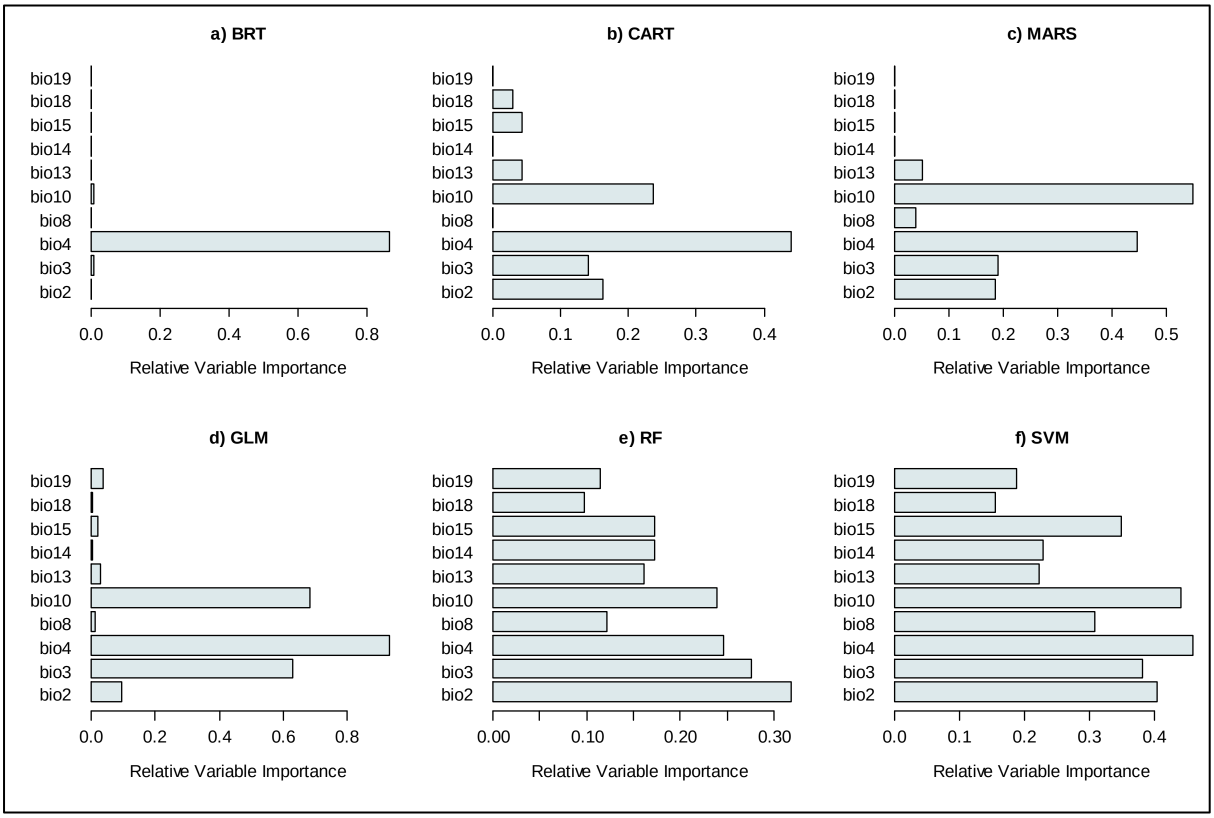
Supplementary Figure S6.3 Predictor variables that contributed most to the rock dove *Columba livia* distribution modelling using the seven methods in the present study.



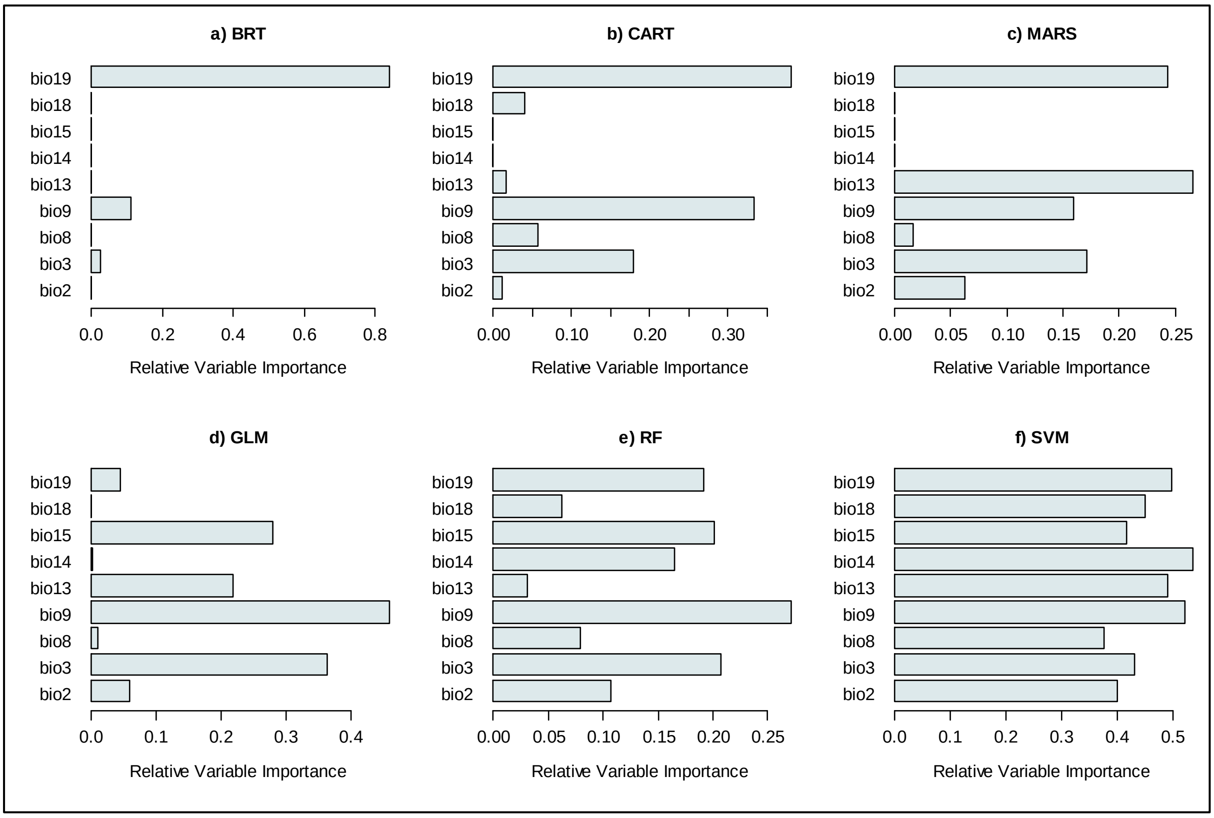
Supplementary Figure S6.4 Predictor variables that contributed most to the house crow *Corvus splendens* distribution modelling using the seven methods in the present study.



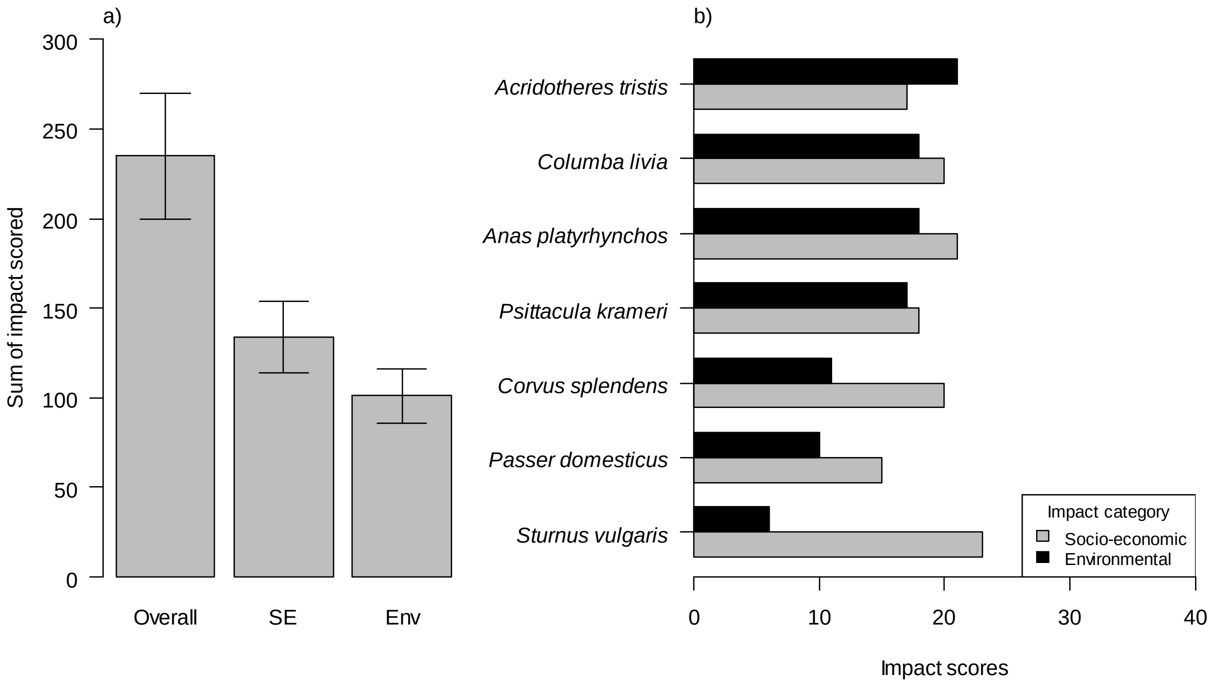
Supplementary Figure S6.5 Predictor variables that contributed most to the house sparrow *Passer domesticus* distribution modelling using the seven methods in the present study.



Supplementary Figure S6.6 Predictor variables that contributed most to the rose-ringed parakeets *Psittacula krameri* distribution modelling using the seven methods in the present study.



Supplementary Figure S6.7 Predictor variables that contributed most to the common starling *Sturnus vulgaris* distribution modelling using the seven methods in the present study.



Supplementary Figure S6.8 Comparisons of the overall impacts scored between a) socio-economic "SE" and environmental "Env" impact categories, and b) for the seven alien avian species in South Africa in the present study.

Supplementary Information Table(s)

See Electronic Supplementary Table S6.1 excel sheets at https://static-content.springer.com/esm/art%3A10.1007%2Fs10530-020-02221-9/MediaObjects/10530_2020_2221_MOESM2_ESM.xlsx

See Electronic References used for the respective impact assessments at https://static-content.springer.com/esm/art%3A10.1007%2Fs10530-020-02221-9/MediaObjects/10530_2020_2221_MOESM1_ESM.docx

CHAPTER 7

General discussion and conclusions

7.1 Background and brief discussion

Non-native species are known to adapt, colonise, and multiply their propagules in their introduced ranges, with the risk of becoming invasive (Lockwood et al. 2009; Blackburn et al. 2011). Several characteristics influence the establishment of many non-native species (Lockwood 1999; Duncan and Blackburn 2002; Britton & Gozlan 2013; Downs et al. 2021). For example, the ability to feed on various food items, survive a wide range of environmental conditions, highly synanthropic, and the ability to proliferate from single breeding pair within a short space of time (Lockwood 1999; Duncan and Blackburn 2002; Britton & Gozlan 2013). Studying the biology (i.e. population dynamics, breeding, and feeding) of the introduced species can be useful in determining their potential to establish and cause impact (Luna et al. 2016; Pârâu et al. 2016; Per 2018).

7.1.1 Population estimates

The rose-ringed parakeet is regarded as one of the world's most introduced gregarious parrot species with a thriving breeding colony outside its native ranges (Strubbe & Matthysen 2007; Forshaw 2010; Strubbe & Matthysen 2020). In South Africa, the breeding population of rose-ringed pparakeetswas introduced in the 1900s. Their population size started to establish in the 1970s, particularly in major cities such as Durban and Johannesburg (Perrin & Cowgill 2005; Roche & Bedford-Shaw 2008; Hart & Downs 2014; Symes 2014; Whittington-Jones 2017). However, it is not known when the population started to expand and if there were any failed populations. As a result, a monthly survey was conducted between August 2018 and December 2019 to determine the population size of rose-ringed parakeets in eThekwini Municipality

(Durban) (see Chapter 2; Shivambu et al. 2020a). The population size of rose-ringed parakeets increased after the breeding season (between September and December), with an overall mean population size of 1,783 individuals. When comparing the results from this chapter to other studies within South Africa, the population size of parakeets in Victoria Park, Johannesburg, was roughly 2,000 parakeets (Whittington-Jones 2017). This indicates that the population of rose-ringed parakeets is expanding in the urban landscape; therefore, expected to invade other areas in the country. Other studies also indicated that parakeets establish well in the urban landscape; for example, 1,355 (Per 2018) individuals were recorded in Turkey, 981 (Orchan et al. 2012) in Israel (Tel Aviv), 644 (Luna et al. 2016) in Portugal (Lisbon), and over 30,000 individuals in the United Kingdom (Peck 2013). Overall, the results obtained from this chapter showed continuous growth in the population size of rose-ringed parakeets, indicating that their population is breeding success is not negatively affected in the wild.

7.1.2 Breeding biology

Studies on the breeding biology of rose-ringed parakeets are limited globally (Butler 2003; Butler et al. 2013). As a result, this chapter studied the breeding status of rose-ringed parakeets in eThekwini Municipality (see Chapter 3). The breeding season for rose-ringed parakeets in our study started at the beginning of September 2018 and continued until the first week of November 2019. A total of 39 breeding sites were identified, with a total of 72 nests. The recorded number of parakeet’s fledglings ranged between one and three chicks. The recorded number of parakeet’s fledglings in this study was within the range recorded in the Indian subcontinent (n = 1.7 – 3.0; Shivanarayan et al. 1981), Israel (n = 1; Orchan et al. 2012) and Britain (n = 0.8 – 1.4; Butler 2003; Butler et al. 2013). This species' breeding is at an average rate, and this explains the increased population size of parakeets, e.g. in Chapter 2, the size of parakeets counted increased after the breeding season between September and December

(Shivambu et al. 2020a). During the breeding period, parakeets were observed displacing native cavity-nesters such as black-collared barbet *Lybius torquatus* and golden-tailed woodpecker *Campethera abingoni*. It is suggested that this aggressive behaviour may pose a severe threat to native hole-nesters, thus affecting their reproductive success, particularly for the species which breed during the same season as parakeets (see Dodaro & Battisti 2014; Charter et al. 2016; Hernández-Brito et al. 2018). Some of the nests occupied by rose-ringed parakeets were taken over by invasive common myna *Acridotheres tristis*. Consequently, this may reduce the availability of nests used by wider native cavity-nesters. The artificial nest boxes (n = 65) arrayed to determine the nest occupancy by rose-ringed parakeets were used by the common myna (8%) and the African lowland honey bees *Apis mellifera scutellata* (65%). Consequently, this may further exacerbate the impact caused by parakeets on native cavity-nesters in eThekwini Municipality as they cannot use both artificial and natural nests.

7.1.3 Feeding biology

Documenting the feeding biology, particularly of invasive bird species, provide a better understanding of their specific diets and impacts they pose on plants, crops, and insects (Reddy 1998; Iqbal et al. 2000; Tayleur 2010; Van Kleunen et al. 2010; Shivambu et al. 2020b; Strubbe & Matthysen 2020). For example, an increase in rose-ringed parakeets' population has led to a major threat to agriculturally significant crops (Fletcher & Askew 2007; Ahmad et al. 2010, 2011; Van Kleunen et al. 2010; Khan et al. 2011; Shiels et al. 2018). In this chapter, rose-ringed parakeets were recorded feeding on 32 food items, of which fleshy fruits (ripe and unripe) and flowers contributed the most to their daily diet (see Chapter 4; Shivambu et al. 2020b). Parakeets also fed on insects, twigs, and barks (Chapter 4; Shivambu et al. 2020b). They predate on these food items in a flock of about 60 parakeets, until resources were depleted. This behaviour may also affect plants' regeneration as they predate on seeds, leaves, and barks

(Fletcher & Askew 2007; Peck et al. 2014; Shivambu et al. 2020b). This plasticity behaviour suggest that rose-ringed parakeets are generalist-opportunistic feeders and likely to reduce natural resources used by other native birds as they are a superior competitor. The invasive white mulberry *Morus alba* with smaller seeds was amongst the fruits consumed by parakeets (see Chapter 4; Shivambu et al. 2020b). As a result, this plant may be dispersed as the seeds pass through their digestive tract (see Thabethe et al. 2015). Although there are relatively few qualitative studies on seeds dispersal by parrots, it was suggested that parakeets might be dispersing seeds on their beaks and/or feathers as they fly between sites (Tella et al. 2015; Thabethe et al. 2015; Blanco et al. 2016; Shiels et al. 2018). In this chapter, we did not document parakeets feeding on crops. However, given that their population is increasing (Chapter 2), they may likely expand to agricultural landscapes and may cause significant impacts on crops in the farms, orchards, and gardens. For example, in southern Europe, Hawaii, Pakistan, and India, rose-ringed parakeets' feeding behaviour has caused enormous economic losses on significant crops (see Ahmad et al. 2010, 2011; Van Kleunen et al. 2010; Khan et al. 2011; Mentil et al. 2018; Shiels et al. 2018).

7.1.4 Public perceptions and knowledge

Perceptions, opinion and knowledge of the public towards non-native invasive species differs, particularly for those species found to be charismatic, e.g. rose-ringed parakeets (Lambert et al. 2017; Luna et al. 2019). This often results in conflicts that prevent the eradication of these introduced charismatic species (Estévez et al. 2015; Crowley et al. 2017; Lambert et al. 2017; Crowley et al. 2019). In this chapter, a total of 312 survey participants reported having seen parakeets around shopping centres, suburban areas, and parks (see Chapter 5). Most of the respondents did not consider rose-ringed parakeets as pests. As a result, most of them opposed the control measures associated with parakeets in the municipality but suggested that common mynas should be controlled first. Consequently, this attitude may impede control programs for rose-ringed parakeets in the country. Similarly, in Seville (Spain), public members opposed the management measures for parakeets mainly because they are kept as pets and are found to be attractive and perceived not having impacts (Luna et al. 2019). Most respondents did not consider parakeets as pests, which suggests a lack of knowledge of their impacts on native species and humans as they carry zoonotic diseases (see Chapter 6). Nonetheless, in South Africa, permits are issued for rose-ringed parakeets even though their numbers are increasing remarkably in urban landscapes (Shivambu et al. 2020a; Moshobane et al. 2020). For example, permits are issued to public members to breed, sell, possess, and transport parakeets (see Moshobane et al. 2020). This may exacerbate the increased ownership of rose-ringed parakeets and promote positive attitudes towards this pet parrot. As a result, many unwanted parakeets may accidentally escape or intentionally released into the wild, therefore expanding the current population and possibly colonising new areas (see Symes 2014).

7.1.5 Impact assessment

One of the characteristics influencing the introduced species to be more detrimental is its ability to cause severe impacts, either environmental or socio-economic (Reaser et al. 2007; Hernández-Brito et al. 2014; Keller & Kumschick 2017). In this chapter (Chapter 6, Shivambu et al. 2020c), the Generic Impact Scoring Scheme was applied to assess the potential impacts (environmental and socio-economic) associated with introduced rose-ringed parakeets and other six selected non-native birds. All the selected bird species had impacts, with socio-economic ranked higher than environmental. For socio-economic, rose-ringed parakeets was primarily associated with impacts on agricultural production and human infrastructure. These results suggest that parakeets are likely to cause these impacts in South Africa, given their increased population (Chapter 2) and feeding behaviour which is mainly fleshy fruits (Chapter

4). For environmental impact, the main impacts for rose-ringed parakeets was mainly through impacts on other animals (predation) and competition. Parakeets were mainly associated with these impacts because they are known as the most aggressive bird species and superior competitors, sometimes displacing and killing other bird species for nests and food (Dodaro & Battisti 2014; Charter et al. 2016; Hernández-Brito et al. 2018). In addition, the results for impact assessment were consistent with the results found in Chapter 3, where it was found that parakeets replace native cavity nesters during the breeding season.

This chapter also showed that parakeets and other selected six non-native bird species have large climatic suitability in South Africa (Chapter 6). Therefore, it was suggested that the population of these species might increase, given that their current distribution was within the projected climatic suitability, indicating that they also depend on the climate to colonise, e.g. rose-ringed parakeets, common myna, rock dove *Columba livia*, and house sparrow *Passer domesticus* (see Chapter 6 or Shivambu et al. 2020c).

7.2 Recommendations for future studies

In general, the present study provides a comprehensive assessment of the ecology of the established rose-ringed parakeets' population in the urban landscape mosaic of eThekwini Municipality. Regardless of the insight gained in this study, considerable more work needs to be done. Therefore, the following future studies were recommended:

1. Given that rose-ringed parakeets' population size was comprehensively documented only in eThekwini Municipality (Durban city), and little has been recorded in Pretoria, Johannesburg, and Cape Town (Perrin & Cowgill 2005; Roche & Bedford-Shaw 2008; Symes 2014; Shivambu et al. 2020a). It is recommended that the general population size of rose-ringed parakeets be assessed in a larger extant to understand their potential establishment and demographic trends.

2. Due to constraints of funds, the movement patterns of rose-ringed parakeets were not assessed in this study. Therefore, we recommend that wild-caught parakeets be collared with transmitters to obtain their detailed movement patterns. This may help locate new roosts, breeding and feeding sites.
3. The rose-ringed parakeets are one of the charismatic pet parrots, and permits are issued for their sales (Hart & Downs 2014; Symes 2014; Moshobane et al. 2020). Therefore, there is a need for online stores and physical pet shops to be monitored regularly to understand their trade volume, which may be linked to their potential releases or escapes.
4. In this study, the breeding status of rose-ringed parakeets was documented; however, only the number of fledglings were counted. As a result, we suggest that future studies establishing parakeet's breeding biology (e.g. breeding phenology and physiology) be conducted in order to understand their reproductive success in detail.
5. An experimental study for nest-site competition between rose-ringed parakeets and native cavity-nesters may need to be conducted to determine the impacts associated with its competitive behaviour during the breeding season (see Strubbe & Matthysen 2009). It will be essential to assess this because documenting parakeet's competitions in the wild is challenging, and it is unlikely to observe this behaviour in the field.
6. It is also recommended that camera-traps be placed in each breeding site to determine their behavioural pattern during breeding seasons, including their potential natural enemies or nest competitors.
7. The rose-ringed parakeets are generalists opportunistic-feeders predating on various food items (Reddy 1998; Iqbal et al. 2000; Tayleur 2010; Van Kleunen et al. 2010; Shivambu et al. 2020b). It will be ideal for performing stable isotope analyses using

stomach contents to assess the nutritional benefits acquired from food items consumed and estimate the parakeet's trophic position.

8. Rose-ringed parakeets belong to four subspecies, with those of Asian origin known to be associated with severe impacts and can multiply rapidly (Morgan 1993; Ahmad et al. 2012; Jackson et al. 2015). Therefore, it is recommended that a genetic study assess the parakeet's ancestral origins, genetic structure, and invasion routes.
9. Several bacterial and viral diseases have been isolated from wild parakeets. Many of these diseases cause threats to human health, particularly respiratory diseases such as Avian influenza and Psittacosis (see Menchetti et al. 2016; Mori et al. 2018). It is, therefore, suggested that bacterial and viral diseases from wild-caught and pet parakeets be screened to highlight potential health risks associated with these zoonotic diseases on humans and animals.

7.3 Concluding remarks

In conclusion, the population size of rose-ringed parakeets is increasing in an urban landscape mosaic of eThekwini Municipality. Although their population size has never been documented in eThekwini Municipality previously, their numbers may be increasing by two-fold, given that they are reproducing at an average rate. To successful implement eradication programs, public members must be involved when making decisions associated with eradication plans. Reducing the numbers of rose-ringed parakeets may help maintain biodiversity, particularly for native cavity-nesters whose nests were taken during breeding seasons. The results obtained from this thesis provide a baseline towards understanding the rose-ringed parakeet's ecology, human perceptions towards them, and their potential impacts. Therefore, local or provincial conservation agencies, government legislation bodies, and invasive species programmes can use this study's findings to formulate effective management strategies to protect native biodiversity from harm. In addition, we recommend rapid response for areas across South Africa where the parakeets are currently not yet present but climatically suitable. Rapid-response would also be useful given that parakeets populations are still very small compared to the UK, with over 30,000 individuals (Peck 2013).

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