Aspects of the urban ecology of the Spotted Thick-knee (*Burhinus capensis*)

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ABSTRACT

With the increase in urbanisation and the negative impact it has had on biodiversity globally, there has been a recent trend in studying species responses to the unnatural changes in their habitats. Avian species are suitable for response studies because they have the greatest mobility to move in and out of fragmented areas that compose of varying intensity in anthropogenic development and human activity. However, there is a paucity of research on specific species or select groups of species with increased urban presence, thus information about their urban ecology is relatively limited. In Africa, one such avian species that lacks urban ecological information is the Spotted Thick-knee (*Burhinus capensis*). The Spotted Thick-knee is a ground-nesting species that appears to be persisting in urban areas of South Africa.

This thesis aimed to evaluate aspects of the Spotted Thick-knee's urban ecology in Pietermaritzburg, KwaZulu-Natal, South Africa. The objectives of this thesis were to: (1) determine whether Spotted Thick-knees have experienced changes in range, distribution and abundance across South Africa; (2) assess and collect novel information on human-wildlife interactions that result from the presence of Spotted Thick-knees across a fragmented and human-modified landscape, which consists of varying anthropogenic developments; and (3) determine whether different land-use and anthropogenic activities influence the nesting ecology of Spotted Thick-knees breeding across an urbanised landscape.

Firstly, we extracted and examined data collected from the Southern African Bird Atlas Project (SABAP) in project one (SABAP1), which consists of data records between 1987–1993; and project two (SABAP2), which consists of data records from 2007 and is currently ongoing as of 2021. We used the geospatial data from species sightings in both project databases to analyse historical and current trends in range and distributions of the Spotted Thick-knee across South

Africa. We associated changes in Spotted Thick-knee sightings to changes in species abundance in that specific area. Furthermore, we associated areas of absence in sightings or areas where Spotted Thick-knee have only recently been sighted, as changes in range and distributions. Results suggest that there is currently an overall decrease in abundance of Spotted Thick-knees across South Africa. There has been a perceived increase in population and distribution of Spotted Thick-knees, because of the recent increase in reports of the species presence in urban areas. However, this trend likely results from the increase in intensity and scale of urban developments across South Africa, which has led to easier sighting of Spotted Thick-knees present in urban and peri-urban areas.

Secondly, we conducted monthly presence-only surveys between July 2019 and December 2020, excluding 3 months between March–May 2020 because of Covid-19 National lockdown regulations in South Africa. Direct observations were carried out at known locations of Spotted Thick-knees across the urbanised landscape of Pietermaritzburg, KwaZulu-Natal. Locations were discovered through active surveying as well as public participation. We carried out pilot observations between April–June 2019, in public areas and other areas of access where the species was observed before commencement of the study and areas determined to be suitable for the species to occur based on existing literature. For the public participation approach, we distributed newspaper articles in June 2019, with requests for information regarding Spotted Thick-knee sightings. We included 52 locations in the study, with 47 locations identified before fieldwork commenced in July 2019. Four more locations were identified during the data collection period, because of late responses from public participants. For the ‘human-wildlife interactions’ component of the study, we sent out questionnaires to participants from the newspaper article request, in an attempt to collect qualitative information regarding their perception of Spotted Thick-knees in Pietermaritzburg.

Results from the Spotted Thick-knee monthly-presence study suggest that their occurrence at known locations was not random with Spotted Thick-knee present at 30 out of 52 sites for more than 75% of the number of months in the study period; and the movements of individuals and/or pairs could be seasonally influenced because there were generally less sites with Spotted Thick-knee present during known non-breeding months compared to breeding months. Results from questionnaire feedback supported the limited existing literature pertaining to behaviours of Spotted Thick-knee. Furthermore, frequent observations highlighted Spotted Thick-knee response, or lack thereof, to the novel pressures associated with attempts to persist in anthropogenically influenced environments. Domestic dogs (*Canis lupus familiaris*) were identified as the most common threat followed by 'pool drownings', as the major 'known' causes of injury or death to urban-dwelling Spotted Thick-knees.

Lastly, we carried out active observations and remote monitoring of Spotted Thick-knee nest sites, which were identified through a corollary study that assessed their presence across the urbanised landscape of Pietermaritzburg. Data were collected between July 2019 and December 2020. Data were collected in the breeding season that began in July 2019. We continued to monitor sites until February 2020 as Spotted Thick-knee were historically documented to be breeding until April in this part of South Africa. However, Covid-19 National lockdown regulations prevented data collection between March–May 2020. Data collection resumed between June–December 2020 for direct observation of sites to determine whether nest site re-use took place in a subsequent breeding season. We collected information regarding clutch size and the outcome of a nesting attempt regarding whether the nesting attempt was the first or second attempt by the breeding pair;

the land-use of each site; and the month of initiation for each nesting attempt. A nesting attempt was considered to be a success if at least one hatchling was observed. A nesting attempt was considered to have failed if there were no hatchings observed; nests were inactive or abandoned; nest or eggs were destroyed; or eggs failed to hatch after the maximum incubation period known for Spotted Thick-knees which was 30 days. Results showed a significant difference between the 21 nesting attempts that succeeded and the 12 nesting attempts that failed. We investigated nest-site selection by collecting data on specific nest-site characteristics and habitat variables at each site, including the land-use each nest site was located. Data were collected within a study-defined nest-plot of 10 m in radius with the nest in the centre. The area's general land-use was recorded because land-use differs in development and anthropogenic activity, which was predicted to influence nest-site selection. We compared characteristics and measured variables associated with nest-plots to random sites that were considered to be suitable for nesting. Results showed that for select habitat variables, Spotted Thick-knee were preferential in their selection of nest sites. These preferences include: greater use of shrub-like species for nest site placement compared with nests with tree species and nests with no cover structure; more grass cover; shorter grass; shorter vegetation; and flatter slopes at nest sites, compared to random sites.

By use of an information-theoretic approach, we investigated Spotted Thick-knee nest survival as a function of daily nest survival in program MARK. Habitat variables and nest-site characteristics were considered predictor variables in nest survival and analysed in conjunction with data relevant to nest ages; nesting attempt date within a season; and independent variables such as temperature, precipitation, and observer effect on nest sites during visits. Results from this section showed the most support for models with nest age; nest date in season; the proportion of bare ground cover in nest-plot; and the use of shrub-like nest-cover structures, as the most influential prediction variables relating to daily nest survival.

We remotely monitored a subsample of Spotted Thick-knee nest sites using camera-traps to investigate incubation activity within human-modified habitats. We recorded the duration of incubation in min. h^{-1} where the duration of the incubating adult present were summed for each hour within a 24-h period. We compared incubation activity over 12-h (day vs night) and hourly over 24-h periods. We recorded the number of disturbance events and the disturbance duration in min. h^{-1} within the field of view for each captured image and carried out regression analyses to determine whether these disturbances and durations influenced incubation activity. Furthermore, we identified the cause of these disturbance events where possible and categorised them as: human-; domestic animal-; motor vehicle-; or wild animal-induced events. Results showed that incubation activity was significantly longer during the ‘day’ (12 h; 6:00 to 17:59) compared with the ‘night’ (12 h; 18:00 to 5:59); but shortest during the ‘17:00 to 17:59’ hour, over the 24-h period. We found that 32.6% of disturbance events were caused by domestic animals or pets. We found a significant relationship between disturbance events and incubation activity. Incubation activity decreased as a result of an increase in the number and duration of disturbance events.

We revisited sites between July–December 2020 to determine whether Spotted Thick-knee re-used nest-sites and found that 75.8% of Spotted Thick-knee nest sites from the 2019–2020 breeding season were re-used in the 2020–2021 breeding season, and that 80% of the re-used nest sites had a successful nesting attempt in the 2019–2020 breeding season.

Data collection for this section was notably constrained by the Covid-19 National lockdown and severity of the pandemic in South Africa. Some public participants and property owners were hesitant to have the observer visit sites frequently. Therefore, sites were visited less frequently at 14-day intervals until the end of the data collection period.

The study of Spotted Thick-knee nesting ecology highlighted the habitat and nest-site characteristics that were preferred by breeding pairs; the impact these selections have on nest survival in anthropogenically transformed environments; and some of the major risks and novel pressures associated with nesting in human-modified habitats. The main findings in this thesis provide novel information on Spotted Thick-knee in an urban ecological context. Each component of the study comprised of aspects relevant to their response to anthropogenic developments and human activity. Insights from this study are essential to providing a framework and understanding of the many terrestrial-dependent bird species that may be behaviourally similar. This study improved on our understanding of changing land-use on ground-nesting species, especially considering the paucity of current scientific literature on this group. The baseline data and preliminary findings from this study will become increasingly relevant in the future because the natural landscape continues to be removed and destroyed for human 'benefit'. It has been suggested that many species will be at risk because of loss of habitat; therefore, conservation will be more difficult or too late if there is insufficient information and understanding of the species.

PREFACE

The data described in this thesis were collected in Pietermaritzburg, the Republic of South Africa from February 2018 to January 2020. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Professor Colleen T. Downs.

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

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Kyrone K. Josiah

January 2021

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

[redacted]

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Professor Colleen T. Downs

Supervisor

January 2021

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DECLARATION 1 - PLAGIARISM

I, Kyrone Kent Josiah, 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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5. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

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Kyrone K. Josiah

January 2021

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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

KK Josiah & CT Downs

Using the Southern African Bird Atlas Project (SABAP) as a tool to examine Spotted Thick-knee distributions across South Africa

Author contributions:

KKJ conceived paper with CTD. CTD sourced funding. KKJ collected and analysed data and wrote the paper. CTD contributed valuable comments to the manuscript.

PUBLICATION 2

KK Josiah & CT Downs

Presence of the Spotted Thick-knee across the urban landscape of Pietermaritzburg, South Africa, and the resulting human-wildlife interactions

Author contributions:

KKJ conceived paper with CTD. CTD sourced funding. KKJ collected and analysed data and wrote the paper. CTD contributed valuable comments to the manuscript.

PUBLICATION 3

KK Josiah & CT Downs

Facets of Spotted Thick-knee (*Burhinus capensis*) nesting ecology across an anthropogenic landscape

Author contributions:

KKJ conceived paper with CTD. CTD sourced funding. KKJ collected and analysed data and wrote the paper. CTD contributed valuable comments to the manuscript.

Signed: [redacted] ……………………………

Kyrone K. Josiah

January 2021

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I dedicate this thesis to my late grandfather *Jasper Matthew Josiah*, grandmother *Dolores Bridget Josiah*, father *Craig Nolan Josiah*, mother *Navi Josiah*, sister *Cleo Cade Josiah*, and daymother *Ntombizanele 'Gladys' Sukude*. I am immensely appreciative of the roles you have each played in my life. To my grandpa, you did not get to see me or any of your grandchildren make it through university for their first degree, but I hope you are happy up there knowing that I went even further just like you pushed me to. To my granny, thank you for doing more than the position required and making sure I was (am) always seen to, I will never forget the amazing person that you are. To my father, thank you for all the sacrifices you have made and for teaching me to stand up for what I believe. To my mother, thank you as well for all the sacrifices you have made and for being my shoulder to lean on. To my sister, thank you for bringing excitement into my life and doing your best to support me in all the ways you have. To Gladys, thank you for taking care of me and doing more than your job required, you have significantly contributed to my growth and development. I want to acknowledge the rest of my family for their roles because the person that I am now is the result of a group effort. To my aunties: *Deveshnee*; *Felicia*; *Lerusha*; *Odette*; *René*; *Rochelle*, and uncles: *Anesh*; *Feroz*; *Erwin*; *Byron*; *Sashen*; *Seelan*, thank you for the roles each of you have played my life, this thesis is also a result of your efforts. To my cousins, thank you for making life fun, I hope I set a good example for you all. To *my future self*, I hope that you look back at this thesis if you ever feel insignificant, lost, or under pressure. I have no doubt that when you read this thesis, you will be reminded of the challenges you faced during this time and understand that there is no obstacle or challenge that is too difficult for you to overcome.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

Introduction

1.1 Urbanisation and its impact

With increasing human populations globally, there has been elevated anthropogenic effects on the planet's environments and biodiversity (Hunter 2007; McCleery et al. 2012; Mahmoud and Gan 2018). Urbanisation has been identified as one of the most significant anthropogenic activities to impact the natural environment (McKinney 2002; Hunter 2007; McCleery et al. 2012; Mahmoud and Gan 2018). Urbanisation is defined as "the process of man altering natural landscapes for development" and is commonly used to describe the process of change, from natural areas to anthropogenic developed areas (McKinney 2006; Sih 2013; Sol et al. 2014). Different urban environments are created based on the function and needs of the human population within that area (McKinney 2006). This aforementioned process can be complicated as the different developments allow for a wide range of areas that are classified as urban. Within that range, there are areas that do not have strong pressures on species than those with various factors that increase pressures on a species' survival (Singh and Downs 2016; Widdows and Downs 2017; Downs et al. 2021). The most notable impact that urbanisation has, whether small scale or large scale, is the ability to destabilise ecosystem functioning (McCleery et al. 2012; Wang et al. 2019; Hasan et al. 2020).

Ecosystem functionality is pivotal to the survival of plant and animal species within them (McCleery et al. 2012; Light et al. 2013). Ecosystem services can be defined as "ecological processes that yield goods and services, either directly or indirectly" (Elmqvist et al. 2003; Light et al. 2013). Major ecosystem services that can be provided include water and air purification and the mitigation of droughts and floods. Biodiversity is also maintained through ecosystem services (Elmqvist et al. 2003; Light et al. 2013; Evers et al. 2018). Interruptions or loss of ecosystem services through urbanisation can have a profoundly negative effect on humankind and other species (Elmqvist et al. 2003; Evers et al. 2018; Filloy et al. 2019). For example, carbon dioxide (CO_2) emissions from deforestation and urban environments' development negatively affect the carbon cycle by producing more carbon than the Earth can absorb, consequently fuelling climate change (Mahmoud and Gan 2018). Urban water bodies that have been exposed to degradation because of urbanisation have compromised the ability of the land to deliver services (Light et al. 2013). The disruption of ecosystem functioning through anthropogenic activities has also led to drastic decreases in biodiversity in many parts of the world (Mahmoud and Gan 2018). For example, anthropogenic activities such as farming and infrastructural development have negatively impacted species biodiversity (Elmqvist et al. 2003; Adams et al. 2006).

Although urban environments are modified to the needs of the human population residing in them, it can be argued that they are diverse and are capable of accommodating natural functioning ecosystems, hence the growing use of the term ‘urban ecosystem’ (Wilby and Perry 2006; Davis et al. 2011; Wu 2014; Barot et al. 2019; Rivkin et al. 2019). Land-use differs greatly depending on the use and the activity on the land, which in turn, creates fragmented areas of different habitats resulting in a mosaic of natural and urban areas (Alberti et al. 2003; Adams et al. 2006; Wilby and Perry 2006; Davis et al. 2011; Wu 2014; Barot et al. 2019; Rivkin et al. 2019).

There has been an increase in the need to study urban areas and the systems within them, and this has led to the field known as ‘urban ecology’ (Wu 2014; Barot et al. 2019; Rivkin et al. 2019). There has been a sharp rise in the number of studies that incorporates anthropogenic activity and human-made environments as a factor of influence compared with those studies that strictly focused on natural ecology (Alberti et al. 2003; Wilby and Perry 2006; Benton-Short and Short 2008; Ramalho and Hobbs 2012; Barot et al. 2019; Rivkin et al. 2019). Urban ecology has developed considerably as a field of study globally, with an increased focus on how species persist in urban environments (Wu 2014; Barot et al. 2019; Callaghan et al. 2019; Rivkin et al. 2019).

1.2 Importance of studying urban areas and the species within them

There are many habitats where humans and animals interact and coexist, but none are as anthropogenically complex, as that of an urban area (Marzluff et al. 2008; Sol et al. 2013). These urban areas may seem uninhabitable by other species; nevertheless, fauna and flora species are found in these fragmented areas. Hence, it is important to understand these areas because they are now identified as transformed habitats for many species (Filloy et al. 2019; Fontúrbel et al. 2019). If these newly transformed habitats are mismanaged, it will negatively impact many urban-persisting species, and conservation efforts will need to be put in place (Hobbs et al. 2009; Filloy et al. 2019). Therefore, the sooner these transformed habitats are understood, the more informed decision-making will be, especially from a conservation perspective.

Conservation is of increasing importance because of the negative impacts' humans have on biodiversity. For example, urban biodiversity has been in the conservation limelight for many years, focusing on conservation efforts in urban areas like cities (Hobbs et al. 2009; Evers et al. 2018). Anthropogenically influenced environments can generally not be restored to their former state (Evers et al. 2018). Anthropogenic land transformation has become an inevitable part of the Earth's future, which raises the requirement for further studies on urban environments and the species within them (Evers et al. 2018). Understanding how anthropogenic activities change and influence the natural environment can better conservation practice in the future (Hobbs et al. 2009).

The need to understand these newly transformed habitats and the interactions of species of fauna and flora within them has become of increasing importance (Alberti et al. 2003; Adams et al. 2006; Wilby and Perry 2006; Davis et al. 2011; Wu 2014; Barot et al. 2019; Rivkin et al. 2019). Studies on urban ecology provide insight into how species have reacted and will react to increasing urbanisation which will aid in better decision-making with regards to actions that we previously perceived as benefits without consequences (White et al. 2005; Garden et al. 2010; Ramalho and Hobbs 2012; Wu 2014; Barot et al. 2019; Rivkin et al. 2019).

1.3 Response of species to urban areas and the process of urbanisation

Although many species of fauna and flora are adversely affected by urbanisation, some species have been shown to adjust to urbanisation changes (McKinney 2006; Shochat et al. 2010; Sol et al. 2013). Furthermore, some species persist or thrive in these modified environments, namely: urban adapters and urban exploiters. Urban adapters are those species that are new to or persist well in urban environments whilst taking advantage of similar or even identical resources found in their natural environments (Hunter 2007; Filloy et al. 2019; Fournier et al. 2020). Urban exploiters are often the focus of research in this field of study because species associated to this group not only survive in these fragmented environments; instead, they thrive in them by making use of 'urban' constructs and resources (Hunter 2007; Filloy et al. 2019; Fournier et al. 2020).

Species that persist in urban environments have to adapt at a 'rapid' rate because of the increase in risks and changes that they face; otherwise, they become threatened or locally extinct (Kark et al. 2007; Lowry et al. 2013; Sol et al. 2013; Filloy et al. 2019; Fournier et al. 2020). In addition to natural challenges such as predation and competition, other challenges are characteristic of urban areas, such as human disturbance (McKinney 2006; Filloy et al. 2019; Fournier et al. 2020). Most of the well-known urban exploiter species are generalists in that they have a wide tolerance range of environmental conditions, because of their ability to utilise other less preferred resources when those that are most preferred are inaccessible (Lowry et al. 2013; Callaghan et al. 2019; Filloy et al. 2019). Through various studies, it has become apparent that what is common and most certainly essential to successful urban adapted animal species, is that they display changes in some or all of the following aspects, namely: habitat use, ranges, movements, foraging and reproduction (Barot et al. 2019; Callaghan et al. 2019; Rivkin et al. 2019). The study of these different characteristics in individual species or communities allows for valuable ecological information to be attained such as the importance of mobility (Bradsworth et al. 2017; Barot et al. 2019; Rivkin et al. 2019).

Regarding terrestrial vertebrate species, mobility is key to survival in urban environments hence many reptiles and mammals that thrive in these environments are generally small in size (Bradsworth et al. 2017; Barot et al. 2019; Rivkin et al. 2019). Examples of urban terrestrial exploiters include racoons (*Procyon lotor*), tropical house geckos (*Hemidactylus mabouia*) and kit foxes (*Vulpes macrotis*) (Kark et al. 2007; Lowry et al. 2013). Examples of urban terrestrial exploiter species found in South Africa are the small-spotted genets (*Genetta genetta*) (Bateman and Fleming 2012) and the large-spotted genet (*Genetta tigrina*) (Widdows and Downs 2017).

Animals that fly, such as most bird and insect species, are assumed to be able to traverse urban environments relatively easily in comparison with terrestrial species, although some bird and insect species have also been negatively impacted by urbanisation, especially those that are known as habitat specialists (Marzluff 2001; Isaksson 2018; Guenat et al. 2019). There has been a recent trend in studying avian species because they have the greatest mobility to move in and out of these areas (Callaghan et al. 2019; Filloy et al. 2019; Rivkin et al. 2019). There is a paucity of research on specific species; thus information about their urban ecology is relatively limited. The literature that exists is partially biased since it is mostly composed of studies from Europe and the

Americas, which is problematic because major urbanisation developments and changes are currently occurring in Africa (Warren and Lepczyk 2012). However, in South Africa, there are some bird species that are well documented as urban exploiters such as Hadada Ibis (*Bostrychia hagedash*), Pied Crows (*Corvus albus*), Egyptian Geese (*Alopochen aegyptiaca*), Rock Doves (*Columba livia*) and several raptor species (Greenwood 2007; McPherson et al. 2015; Callaghan and Brooks 2016; Singh and Downs 2016).

Although there have been several general studies (morphology, physiology, behaviour) on urban terrestrial bird species, relatively few have investigated urban terrestrial bird species' ecology. The global number of identified species in an urban context has relatively few terrestrial bird species studied in this context. Most terrestrial species can fly whereas the rest cannot, and as a result, they are fully dependent on the land e.g., Ostrich (*Struthio camelus*). Even those terrestrial species that can fly are dependent on the land for some major part of their life cycle (feeding and/or breeding), which has led to their inclusion in the reproductive behavioural group of species that are identified as "ground-nesting birds" (Somveille et al. 2019). There is an increase in the importance of studying ground-nesting birds because of urban expansion, which results in the decline of natural vegetation and natural land, which are two environmental factors they are highly dependent on for survival (Callaghan et al. 2019; Somveille et al. 2019).

1.4 Ground-nesting birds in South Africa

Bird species belonging to the class Aves are the most commonly known fauna to occupy the Earth's atmosphere out of all animal classes. However, birds are not only found in the air as select species thrive in aquatic habitats which are known as semi-aquatic species, whilst some species have limited flight capability, or are not able to fly at all, which are known as terrestrial species

(Roots 2006; Brusatte et al. 2015; Rico-Guevara et al. 2019; Tobajas et al. 2020). The flightless group includes all species from the paraphyletic group 'ratites' (e.g., order: Struthioniformes) and some species within the orders: Anseriformes; Galliformes; Podicipediformes; Pelecaniformes; Sphenisciformes; Coraciiformes; Ciconiiformes; Gruiformes; Mesitornithiformes; Charadriiformes; Falconiformes; Psittaciformes; Columbiformes; Caprimulgiformes; Strigiformes; and Passeriformes (Roots 2006; Rico-Guevara et al. 2019; Tobajas et al. 2020). A common trait amongst all bird species is that they depend on land in some aspect of their life cycle such as breeding (i.e., nesting, development into adulthood etc.); and/or survival (i.e., diet resources, protection against predation etc.) (Alerstam and Högstedt 1982; Isaksson 2018; Tong 2020). It is apparent that the land is largely utilised for breeding and nesting by most species, but it is vital to the survival of all bird species (Alerstam and Högstedt 1982; Isaksson 2018; Tong 2020).

Although all bird species use the land or material from the land for their nesting habits, there are various ways in which birds' nest (Alerstam and Högstedt 1982; Gould and Gould 2012; Tarboton 2014; Tong 2020). There are certain species which do not have a nest structure and may lay eggs on the bare ground, but most species have actual nest structures constructed from various materials such as mud, plant matter, as well as their saliva (Gould and Gould 2012; Tarboton 2014; Tong 2020). Apart from the actual nest structure, another key element is the nesting habit which describes 'where' and sometimes 'how' the nest site is chosen and/or constructed (Gould and Gould 2012; Tarboton 2014; Tong 2020). These nesting habits are categorised as: no nests; floating; platform (including ledges and cliff edges); burrow; mound; brood parasitic; ground; foliage/vegetation supported and cavity (excavators' and those that use pre-existing cavities, including cliff faces) (Gould and Gould 2012; Tarboton 2014; Tong 2020). In many cases, the ground-nesting category incorporates other nesting habits because of interrelating features. Furthermore, it could also be because of the lack of clarification of what constitutes “ground-nesting” as this term still does not have a specific, defining criteria. It is not only their nesting habits but also a paucity of general ecological research carried out on “ground-nesting” that has led to this investigation, especially in an avifaunal rich region such as South Africa.

South Africa has over 720 bird species that are either resident, naturalised or annual breeding visitors with over 50 endemic species to the region (Taylor and Peacock 2018). Approximately 211 of those 720 species have been observed to have successfully bred by making use of ground-nesting habits.

Table 1.1 Summary table for the number of ground-nesting bird species in South Africa.

Number of solely ground-nesting species	157
Number of species that have ground-nesting and other nesting habits	54
Total	**211**

Table 1.1 above, summarises the numbers of catalogued ground-nesting species that have been verified to breed in South Africa (Supplementary information Table S1.1). The supplementary information was compiled from the various bird guides book and cross-referenced with the latest records from BirdLife International’s online database (Hockey et al. 2005; Tarboton 2014; BirdLife International 2021a, 2021b). The supplementary information includes species variations mainly because not all variations are found in the region and/or not all variations of a species may conform to the same nesting habit (Supplementary information Table S1.1) (Campbell and Lack 2013). For the purpose of this compilation regarding species that breed in South Africa

(Supplementary information Table S1.1), the following characteristics and/or conditions were taken into consideration for the species to be considered as 'ground-nesting':

- Depressions/scrape(s) (both by the bird species direct action or by other actions/events such as a depression created by a large animal footprint) in the ground where eggs are laid, or eggs laid on bare ground.
- Mounds, burrows, and cavities in low ground areas and embankments (not in trees or other vegetation) were considered ground-nesting forms.
- If there is an actual nest structure, the nest must comprise of unattached/dead material and must be placed directly on the ground or the mound, or in a burrow.
- If there is a platform, it must comprise of unattached/dead material directly in contact with the ground.
- Species with only foliage supported nests that were supported by live vegetation were not considered as ground-nesting.
- Brood parasitic nesting species were not considered, especially because no recorded brood parasite species have hosts that are strictly ground-nesting species.
- Species with nests solely on cliff faces/edges were not considered as ground-nesting.
- No inclusion of domestic bird species e.g., the Chicken (*Gallus gallus domesticus*).

Due to the occurrence of numerous ground-nesting species in South Africa (Table 1; Supplementary information Table S1.1), there is a need to further investigate this "group" and collect new information on these species' or contribute to the limited knowledge pool at present. It is especially important because human activities will potentially be a greater infringement on their natural habitats in the foreseeable future. Some of the ground-nesting species may have successfully survived, if not persisting, in urban areas but there is little evidence of this because of a lack of study. In South Africa, one such ground-nesting species that lacks urban ecological information is the Spotted Thick-knee (*Burhinus capensis*) especially in Pietermaritzburg (KwaZulu-Natal Province) where there are increased sightings in urban areas.

1.5 Spotted Thick-knee

The Spotted Thick-knee belongs to the order Charadriiformes in the Burhinidae family and is a native species to the continent of Africa, commonly occurring in central (mostly on the western side) to many parts of southern Africa (Hockey 2005; Hume et al. 2019; SABAP2 2021). There are four subspecies of Spotted Thick-knee namely: *B. c. maculosus* (Senegal to Eritrea and Somalia, and south to Uganda and Kenya); *B. c. dodsoni* (coastal Eritrea, Somalia and Arabia); *B. c. damarensis* (Angola, Namibia, Botswana and the northwestern parts of South Africa); and *B. c. capensis* (Kenya to South Africa and on the western side of the continent from Zambia to Angola) (Hume et al. 2019; SABAP2 2021).

The Spotted Thick-knee is sometimes known as a shorebird or wader species which are bird species that are characterised as such because of populations commonly being found along the coastal shorelines, or inland near mudflats (Hockey 2005; Hume et al. 2019). However, natural populations have been located in savanna, grassland and desert areas in many parts of Africa, particularly in South Africa (Hockey 2005; Hume et al. 2019; SABAP2 2021). They are a nocturnal species that are relatively sedentary during the day. They can fly but spend most of their time walking on the ground (Hockey 2005). They are mostly resident; however, there have been instances where populations that occur in high rainfall areas, have migrated to drier regions during summer rain periods (e.g., Zimbabwe) (Hockey 2005). This nomadic behaviour is a response to high rainfall periods and has been found in several other avian species by which they are labelled as ‘rain migrants’ (Sorensen et al. 2016).

The Spotted Thick-knee is medium in size compared with many other wading bird species, but relatively large compared with other thick-knee’s, with adults growing up to 46 cm in height and weighing between 360 - 620 g (Hockey 2005; Hume et al. 2019). They have a brown head with a short, black beak and noticeable yellow-coloured eyes (Fig. 1.1). They have brown and white plumage with the white or very light-brown colouration occurring on the underside of the bird, from the throat to the posterior of the bird and the brown colouration with black spots on the back, sides and wings of the bird (Hockey 2005; Hume et al. 2019). The wings are white on the underside with black-tipped feathers and a white patch at the end of the wings which is conspicuous when the wings are spread open or when the bird is in flight (Hockey 2005; Hume et al. 2019). Like most thick-knee species, the legs are peculiar in that they are comparatively long and yellow in colouration with enlarged tibiotarsal joints hence the name, although it is the “ankle” and not the “knee” join that is prominent (Hockey 2005; Hume et al. 2019).

Fig. 1.1 Spotted Thick-knee adult accompanied by two hatchlings (photo credit: Rob Guest).

The Spotted Thick-knee is a monogamous species, but if one partner dies, the living partner will find a suitable replacement (Hockey 2005; Hume et al. 2019). They are not a sexually dimorphic species except for their difference in sexual orientation, thus not portraying any other clearly defined difference from male and female individuals (Hockey 2005; Hume et al. 2019). They generally breed in spring or early summer but breed from August to April in South Africa and can lay up to three broods in a breeding season (Hockey 2005; Tarboton 2014). They are ground-nesting and lay eggs that are light brown-grey with brown speckles, in a bushy area or in shallow scrapes on the ground that they may fortify with grasses, feathers, and twigs (Hockey 2005; Tarboton 2014; Hume et al. 2019). The female lays 1 to 3 eggs with an incubation period of 24 to 30 days and both the male and female rear their offspring together (Hockey 2005; Tarboton 2014; Hume et al. 2019). Spotted Thick-knees are relatively aggressive in defending their nests and are territorial during the nesting period. They can generally be found in pairs or small family groups, but it is not extremely rare to find them in larger groups made up of eight or more individuals (including juveniles and adults) (Hockey 2005).

Spotted Thick-knees forage on the ground in a plover-like fashion. Their diet typically consists of grass seeds and invertebrates but is not restricted to the aforementioned as they have been observed to consume small mammals, lizards and even other bird species eggs (Hockey 2005; Hume et al. 2019). They communicate using several different calls that can be heard during the night, but during the day, they are relatively silent (Hockey 2005; Hume et al. 2019).

The Spotted Thick-knee is categorised as “Least Concern” on the IUCN Red List because it is known to have an extensive distribution range, and there is currently no indication that there is a decrease in population numbers (Fig. 1.2; BirdLife International 2016, 2021a, 2021b). Hence stable numbers and populations have been assumed to exist; however, the data were last updated in 2016 (BirdLife International 2016, 2021a). They have been sighted in various anthropogenically changed land-use areas, from agricultural lands to more developed residential suburbs, despite being a ground-nesting bird (Hume et al. 2019; BirdLife International 2021a; pers. obs.).

Fig. 1.2 Map showing the Spotted Thick-knee distribution range in Africa (area shaded in green indicates populations that are native residents) (Source: BirdLife International 2021a).

1.6 Problem statement

Human populations continue to increase globally, which has led to an increase in urban development (Mahmoud and Gan 2018). The increase in building density within already existing human settlements and the removal of natural landscape for further development and human benefit has more often than not, resulted in consequential outcomes for many fauna and flora. Species within the class Aves are not exceptions to this trend with many species becoming critically endangered.

For some bird species, extensive literature and studies have been conducted to understand their response to anthropogenic land-use change and developments such as urbanisation. In some instances, these species' responses are referred to when investigating an under-studied species because they may share similarities. This approach has been successful in some studies, to the point that species can be grouped regardless of taxonomic relatedness, and inference are made based on the group that the species belongs. However, some groups have a paucity of literature regarding their response to anthropogenic processes (i.e., urbanisation). One such group is that of ground-nesting birds, specifically those species that are specialists regarding their nesting habit. It can be argued that these species rarely occupy human-modified habitats in comparison with species with more versatile nesting habits, but it is only a matter of time before this trend changes. Should increasing infringement on their natural habitats lead to a decline in population numbers, intervention would be difficult without baseline data and literature on some species' response within this group. Terrestrial-dependent species are predicted to react negatively to urban development because they have specific or preferential traits to their natural habitats. It is imperative that studies be undertaken on their responses as there is already an increase in some of these species' observations in urban areas of South Africa.

Spotted Thick-knees have been observed in or close to urban areas over the past 30 years, with reports of residential gardens and school grounds being used for nesting (BirdLife International 2021a). However, their presence in urban areas has not been examined in detail until the current studies within this thesis. Spotted Thick-knee are:

- Ground-nesting with the simplest form of nest construction such as scrapes in the ground or eggs laid on bare ground.
- Unable to perch on tree branches and similar shaped objects because of their foot structure which is tridactyl meaning they have three front-facing toes but no back-facing toes.
- Rarely seen in the air but commonly sighted on the ground.

These traits and observations emphasise their terrestrial dependence. Due to their known association with anthropogenically-altered environments, they provide a suitable model candidate for study as an indicator species regarding their response to anthropogenic developments. This study provides novel information for the species in an urban context and could limit the need for conservation practice in the future should a ground-nesting species survival be threatened because of urban development.

1.7 Aims and objectives

This study aimed to evaluate aspects of the Spotted Thick-knee's urban ecology, particularly in Pietermaritzburg, KwaZulu-Natal, South Africa. The objectives of the study were to:

1. Examine past and present geospatial data to determine if there are changes in Spotted Thick-knee range, distribution and abundance across South Africa, whilst highlighting historical and current perspectives.

2. Assess human-wildlife interactions that result from the presence of Spotted Thick-knees across a fragmented and human-modified landscape which consists of varying anthropogenic developments.
3. Investigate differing land-use and anthropogenic activities as potential factors influencing nest-site selection, nesting attempts and nesting success for Spotted Thick-knees breeding across an urbanised landscape

1.8 Structure of the thesis

The main body of this thesis is organised as manuscripts prepared for publication in peer-reviewed journal articles. The first chapter (Chapter 1) is the introduction that provides the literature review of the concepts covered in this study and highlights the fact that there is currently a paucity of literature on the study species regarding such concepts. The next three chapters (Chapter 2, 3 and 4) are data chapters with each one covering a specific objective. Chapter 5 is the final concluding chapter that synthesizes the three data chapters. Each chapter is formatted according to the international peer-reviewed journal it is intended to be submitted. Because of this thesis format, a certain degree of repetition, especially in the methods section, was unavoidable. However, this is deemed to be of little concern as this format allows the reader to read each chapter separately without losing the overall context of the thesis. Chapter 2 examines the changes between historic and current range, distribution and abundance of Spotted Thick-knee across South Africa using the Southern African Bird Atlas Project (SABAP). Chapter 3 assesses Spotted Thick-knees' presence across the landscape of Pietermaritzburg, South Africa and the resulting human-wildlife interactions from such presence. Chapter 4 investigate facets of Spotted Thick-knee nesting ecology across an anthropogenic landscape by investigating breeding pairs and monitoring nest sites within Pietermaritzburg's urban mosaic, South Africa. The final chapter (Chapter 5) summarises the results and main findings from each chapter and provides future research recommendations.

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1.10 Supplementary information

Supplementary information Table S1.1 Ground-nesting birds that have been identified as species that breed in South Africa.

Common name[1]	**Scientific name[1] (with variations present in SA)**	**Nesting habit**	**Supporting nesting information (nest type, use of man-made structures etc.)**
Common Ostrich	*Struthio camelus*	Solely ground-nesting	Scrape in the ground.
Chukar Partridge	*Alectoris chukar* [2]	Solely ground-nesting	Scrape in the ground.
Coqui Francolin	*Peliperdix coqui*	Solely ground-nesting	Scrape in the ground.
Crested Francolin	*Dendroperdix sephaena sephaena*	Solely ground-nesting	Scrape in the ground.
Grey-winged Francolin	*Scleroptila africanus*	Solely ground-nesting	Scrape in the ground.
Red-winged Francolin	*Scleroptila levaillantii*	Solely ground-nesting	Scrape in the ground.
Shelly's Francolin	*Scleroptila shelleyi*	Solely ground-nesting	Scrape in the ground.
Orange River Francolin	*Scleroptila levaillantoides*	Solely ground-nesting	Scrape in the ground.
Hartlaub's Spurfowl	*Pternistis hartlaubi*	Solely ground-nesting	Scrape in the ground.
Red-billed Spurfowl	*Pternistis adspersus adspersus*	Solely ground-nesting	Scrape in the ground.
Cape Spurfowl	*Pternistis capensis*	Solely ground-nesting	Scrape in the ground, generally under a bush.
Natal Spurfowl	*Pternistis natalensis*	Solely ground-nesting	Scrape in the ground.
Red-necked Spurfowl	*Pternistis afer castaneiventer*	Solely ground-nesting	Scrape in the ground.
Swainson's Spurfowl	*Pternistis swainsonii*	Solely ground-nesting	Scrape in the ground.
Common Quail	*Coturnix coturnix coturnix*	Solely ground-nesting	Scrape in the ground.
Harlequin Quail	*Coturnix delegorguei*	Solely ground-nesting	Scrape in the ground.
Blue Quail	*Coturnix adansonii*	Solely ground-nesting	Padded bowl of dry grass stems on the ground.
Northern Bobwhite Quail	*Colinus virginianus* [2]	Solely ground-nesting	Nest on the ground (nest made of grass).
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Supplementary Table S1.1 - *Continued from previous page*			
Indian Peafowl (Common Peacock)	*Pavo cristatus* [2]	Solely ground-nesting	Scrape in the ground.
Crested Guineafowl	*Guttera edouardi*	Solely ground-nesting	Scrape in the ground.
Helmet Guineafowl	*Numida meleagris coronata* *N. m. galeata* [2]	Solely ground-nesting	Scrape in the ground.
Fulvous Duck	*Dendrocygna bicolor*	Other (over water (floating))	Scrape in the ground. Bowl of plant material (e.g., reeds) over water.
White-faced Duck	*Dendrocygna viduata*	Solely ground-nesting	Scrape in the ground.
Plumed whistling Duck	*Dendrocygna eytoni* [2]	Solely ground-nesting	Pile of dead grass and other plant material placed on the ground.
Egyptian Goose	*Alopochen aegyptiaca*	Other (platform)	Eggs placed on the ground amongst vegetation. Nests on shelves of buildings above ground.
South African Shelduck	*Tadorna cana*	Solely ground-nesting	Bowl of grass and down placed in end of hole in the ground (e.g., aardvark dug-up holes, porcupine holes).
Spur-winged Goose	*Plectropterus gambensis*	Other (cavity)	Scrape in the ground. Nests in large tree cavities above ground.
Comb Duck (Knob-billed duck)	*Sarkidiornis melanotos*	Other (cavity)	On the ground surrounded by tall grass. Above ground in tree cavities/holes.
African Pygmy-Goose	*Nettapus auritus*	Other (cavity; platform)	On termite mounds or among rocks on the ground. Nests above ground in tree cavities and on tree stumps.
Cape Teal	*Anas capensis*	Solely ground-nesting	Scrape in the ground.
African Black Duck	*Anas sparsa*	Other (cavity; platform)	On the ground in dense grass. Above ground on cliff ledges.
Mallard Duck	*Anas platyrhynchos* [2]	Other (cavity)	Bowl of grass and soft plant stems on the ground. Nests in man-made nest boxes.
Yellow-billed Duck	*Anas undulata*	Solely ground-nesting	Bowl of grass or other dead plant material on the ground.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Cape Shoveler	*Anas smithii*	Solely ground-nesting	Bowl of dry grass and down placed on the ground in a scrape.
Red-billed Teal	*Anas erythrorhyncha*	Solely ground-nesting	Bowl of dry grass and down placed on the ground in a scrape.
Hottentot Teal	*Anas hottentota*	Other (over water (floating))	On the ground. Nests in a bowl of reeds, down and grass over water.
Southern Pochard	*Netta erythrophthalma*	Other (over water (floating))	On the ground. Nests in a bowl of down and plant matter over the water.
Kurrichane Buttonquil	*Turnix sylvaticus*	Solely ground-nesting	Scrape in the ground.
Black-rumped Buttonquail	*Turnix nanus*	Solely ground-nesting	Scrape in the ground.
Hottentot Buttonquail	*Turnix hottentottus*	Solely ground-nesting	Scrape in the ground.
Ground Woodpecker	*Geocolaptes olivaceus*	Solely ground-nesting	Excavated into ground, wall of dongas or gravel pits.
Southern Ground-Hornbill	*Bucorvus leadbeateri*	Other (cavity)	Nest is placed on the ground (lined with plant material). Rarely nests in walls of embankments or dongas.
African Hoopoe	*Upupa africana*	Other (cavity)	Hole in the ground, occasionally a disused termataria. Man-made sites such as nest boxes or the wall cavities of buildings.
Half-collared Kingfisher	*Alcedo semitorquata semitorquata*	Solely ground-nesting	Excavated into the ground (eggs may be laid on a bed of fish bones and/or fish scales).
Malachite Kingfisher	*Alcedo cristata cristata* *A. c. cyanostigma*	Solely ground-nesting	Excavated into ground, wall of pits/dongas, aardvark holes, soil compacted onto roots of fallen trees.
African Pygmy-Kingfisher	*Ispidina picta*	Solely ground-nesting	Excavated into ground, wall of pits/dongas, aardvark holes.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Grey-headed Kingfisher	*Halcyon leucocephala*	Solely ground-nesting	Excavated into ground, wall of pit, aardvark holes. Nests in irrigation channels or other man-made excavations.
Brown-hooded Kingfisher	*Halcyon albiventris* *H. a. vociferans*	Solely ground-nesting	Excavated into ground, rarely in aardvark holes. Nests in irrigation channels or other man-made excavations.
Giant Kingfisher	*Megaceryle maxima*	Solely ground-nesting	Excavated into the ground. Nests in man-made sites such as road cuttings or sand quarries.
Pied Kingfisher	*Ceryle rudis*	Solely ground-nesting	Excavated into the ground. Nests in road cuttings.
White-fronted Bee-eater	*Merops bullockoides*	Solely ground-nesting	Excavated into the ground.
Little Bee-eater	*Merops pusillus meridionalis*	Solely ground-nesting	Excavated into ground, wall of pits, aardvark holes. Nests in road cuttings or man-made pits.
Swallow-tailed Bee-eater	*Merops hirundineus hirundineus* *M. h. furcatus*	Solely ground-nesting	Excavated into ground, aardvark holes. Nests in road embankments.
European Bee-eater	*Merops apiaster*	Solely ground-nesting	Excavated into ground, pits. Nests in road cuttings, man-made pits/trenches.
Southern Carmine Bee-eater	*Merops nubicoides*	Solely ground-nesting	Excavated into the ground.
Horus Swift	*Apus horus*	Solely ground-nesting	Excavated into the ground (saucer-shaped pan of feathers). Nests in road cuttings, mine-tailings.
African Grass-Owl	*Tyto capensis*	Solely ground-nesting	Eggs laid on the ground on a thin pad of grass-stems.
Cape Eagle-Owl	*Bubo capensis capensis*	Other (platform)	Scrape in the ground. Above ground on cliff edges.
Spotted Eagle-Owl	*Bubo africanus*	Other (cavity; foliage/vegetation support)	Eggs laid on the bare ground. Nests above ground in a tree cavity or builds bowl in crotch of tree.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Marsh Owl	*Asio capensis*	Other (over water (floating))	Saucer-shaped pad of green and dry grass-stems placed on thick grass on the ground or over water.
Fiery-necked Nightjar	*Caprimulgus pectoralis*	Solely ground-nesting	Eggs laid on the ground on a bed of leaf litter.
Swamp Nightjar	*Caprimulgus natalensis natalensis*	Solely ground-nesting	Eggs laid on the ground between or under grass-tufts.
Square-tailed Nightjar	*Caprimulgus fossii mossambicus*	Solely ground-nesting	Eggs laid on the bare ground.
Rufous-cheeked Nightjar	*Caprimulgus rufigena rufigena* *C. r. damarensis*	Solely ground-nesting	Eggs laid on the bare ground.
Freckled Nightjar	*Caprimulgus tristigma granosus* *C. t. lentiginosus*	Solely ground-nesting	Eggs laid on the bare ground (generally rocky surface).
Pennant-winged Nightjar	*Macrodipteryx vexillarius*	Solely ground-nesting	Eggs laid on the bare ground.
Denham's Bustard	*Neotis denhami stanleyi*	Solely ground-nesting	Eggs laid on the bare ground in open space.
Ludwig's Bustard	*Neotis ludwigii*	Solely ground-nesting	Scrape in the ground.
Kori Bustard	*Ardeotis kori*	Solely ground-nesting	Scrape in the ground.
Red-crested Korhaan	*Laphotis ruficrista*	Solely ground-nesting	Scrape in the ground.
Southern Black Korhaan	*Afrotis afra*	Solely ground-nesting	Eggs laid on the bare ground.
Northern Black Korhaan	*Afrotis afraoides afraoides*	Solely ground-nesting	Eggs laid on the bare ground (sometimes in scrapes).
Karoo Korhaan	*Eupodotis vigorsii vigorsii* *E. v. namaqua*	Solely ground-nesting	Scrape in the ground.
Blue Korhaan	*Eupodotis caerulescens*	Solely ground-nesting	Scrape in the ground.
White-bellied Korhaan	*Eupodotis senegalensis barrowii*	Solely ground-nesting	Eggs laid on the bare ground (sometimes in scrapes).
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Black-bellied Bustard	*Lissotis melanogaster*	Solely ground-nesting	Eggs laid in a scrape in the ground.
Grey Crowned Crane	*Balearica regulorum*	Other (over water (floating); foliage/vegetation support)	Nest of dead plant material placed on the ground. Nests on a pad of vegetation over water. Nests in tress above ground.
Blue Crane	*Anthropoides paradiseus*	Other (over water (floating); platform)	Eggs laid on the bare ground. Nests over water on a platform.
Buff-spotted Flufftail	*Sarothrura elegans*	Solely ground-nesting	Nest placed on the ground (made of dead leaves, moss, grass-stems, twigs, bark).
Red-chested Flufftail	*Sarothrura rufa*	Other (over water (floating))	Cup on the ground. Nests above water on a pad of floating vegetation.
Streaky-breasted Flufftail	*Sarothrura boehmi*	Solely ground-nesting	Nest placed on the ground (saucer made of grass-stems and blades).
Striped Flufftail	*Sarothrura affinis affinis*	Solely ground-nesting	Bowl placed on the ground (made of dry grass stems).
Namaqua Sandgrouse	*Pterocles Namaqua*	Solely ground-nesting	Scrape in the ground.
Yellow-throated Sandgrouse	*Pterocles gutturalis*	Solely ground-nesting	Scrape in the ground.
Double-banded Sandgrouse	*Pterocles bicinctus bicinctus P. b. multicolour*	Solely ground-nesting	Scrape in the ground.
Burchell's Sandgrouse	*Pterocles burchelli*	Solely ground-nesting	Scrape in the ground/soil.
African Snipe	*Gallinago nigripennis*	Other (over water (floating))	Saucer-shaped pad placed on the ground (made of dry grass). Nests on a reed bed over water.
Greater Painted-snipe	*Rostratula benghalensis*	Other (over marsh)	Saucer-shaped pad placed on the ground (saucer made of grass). Nests on dry mud without vegetation in marsh areas.
Water Thick-knee	*Burhinus vermiculatus*	Solely ground-nesting	Scrape in the ground.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Spotted Thick-knee	*Burhinus capensis capensis* *B. c. damarensis*	Solely ground-nesting	Scrape in the ground (occasionally on the bare ground without a scrape).
African Black Oystercatcher	*Haematopus moquini*	Solely ground-nesting	Scrape in the ground or on bare rocks on the ground.
Pied Avocet	*Recurvirostra avosetta*	Solely ground-nesting	Scrape in the ground, usually on a pad of dead grass or other plant material. May use indentations in the ground made by other factors such as an animal footprint.
Kittlitz's Plover	*Charadrius pecuarius*	Solely ground-nesting	Scrape in the ground.
Three-banded Plover	*Charadrius tricollaris*	Solely ground-nesting	Scrape in the ground.
Chestnut-banded Plover	*Charadrius pallidus*	Solely ground-nesting	Scrape in the ground.
White-fronted Plover	*Charadrius marginatus marginatus* *C. m. mechowi* *C. m. arenaceus*	Solely ground-nesting	Scrape in the ground, generally sand or gravel.
Long-toed Lapwing	*Vanellus crassirostris*	Other (over water (floating); foliage/vegetation support)	Nests on the ground close to water. Nests on vegetation above ground (very rarely). Nests on exposed islet surrounded by boggy ground. Nests on floating platform of vegetation.
Blacksmith Lapwing	*Vanellus armatus*	Solely ground-nesting	Scrape in the ground (lays eggs in ground indentations made by other factors such as an animal footprint).
White-crowned Lapwing	*Vanellus albiceps*	Solely ground-nesting	Scrape in the ground or sand.
African Wattled Lapwing	*Vanellus senegallus*	Solely ground-nesting	Scrape in the ground.
Senegal Lapwing	*Vanellus lugubris*	Solely ground-nesting	Scrape in the ground.
Black-winged Lapwing	*Vanellus melanopterus*	Solely ground-nesting	Scrape in the ground.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Crowned Lapwing	*Vanellus coronatus coronatus* *V. c. xerophilus*	Solely ground-nesting	Scrape in the ground.
Double-banded Courser	*Rhinoptilus africanus africanus* *R. a. granti*	Solely ground-nesting	Single egg laid on the bare ground (generally next to animal droppings or substrates that are the same colour as the egg).
Bronze-winged Courser	*Rhinoptilus chalcopterus*	Solely ground-nesting	Scrape in the ground (lays eggs in ground indentations made by other factors such as an animal footprint).
Burchell's Courser	*Cursorius rufus*	Solely ground-nesting	Eggs laid on the bare ground.
Temminck's Courser	*Cursorius temminckii ruvanensis* *C. t. aridus*	Solely ground-nesting	Eggs laid on the bare ground.
Collared Pratincole	*Glareola pratincola*	Solely ground-nesting	Eggs laid on the ground in a shallow depression (e.g., animal footprint).
Rock Pratincole	*Glareola nuchalis*	Solely ground-nesting	Egg laid on the bare ground in a depression, crack, small pothole or flat surface where sand or gravel has gathered.
Kelp Gull	*Larus dominicanus vetula* *L. d. judithae*	Solely ground-nesting	Bowl placed on the ground, built with whatever dead plant material is available.
Grey-headed Gull	*Chroicocephalus cirrocephalus*	Other (over water (floating); platform; foliage/vegetation support)	Bowl placed on the ground (built with twigs, grass and weed stems). Nests on large rocks. Nests over water on emergent vegetation.
Hartlaub's Gull	*Chroicocephalus hartlaubii*	Other (platform; foliage/vegetation support)	Bowl placed on the ground (built of dry grass, roots, twigs and other debris). Nests on low vegetation. Nests on man-made structures like harbour buildings and roofs.
Caspian Tern	*Hydroprogne caspia*	Solely ground-nesting	Scrape in the ground, generally sand or dry mud.
Swift Tern	*Thalasseus bergii*	Solely ground-nesting	Scrape in the ground.
Roseate Tern	*Sterna dougallii dougallii* *S. d. bangsi*	Solely ground-nesting	Scrape in the ground, generally sand.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Damara Tern	*Sternula balaenarum*	Solely ground-nesting	Single egg laid on the bare ground, sometimes in a scrape in the ground.
Black Harrier	*Circus maurus*	Other (foliage/vegetation support)	Cup placed on the ground (base of sticks, weed-stems, sedges, reeds or grass tussocks). Nests above ground on tall vegetation.
Cape Gannet	*Morus capensis*	Solely ground-nesting	On a mound of guano, twigs, feathers and other dead plant materials.
Bank Cormorant	*Phalacrocorax neglectus*	Other (platform)	Dying seaweed on the ground. Nests above ground on large, slanted rocks on a platform made of seaweed.
Cape Cormorant	*Phalacrocorax capensis*	Other (Platform)	Eggs laid on the ground on a pile of sticks, feathers, bones and beach debris. Nests on cliffs and inshore rocks. Nests on man-made structures such as concrete jetties, piers and buildings.
Goliath Heron	*Ardea goliath*	Other (over water; platform; foliage/vegetation support)	Saucer-shaped pan placed on the ground. Nests on a platform built with sticks and/or reed-stems. Nests above ground on flooded trees, bushes or reed beds. Nests on bushes growing out of cliff faces with a platform of sticks.
Lesser Flamingo	*Phoeniconaias minor*	Solely ground-nesting	Nests on conical turret/mound of mud built from the ground up.
Glossy Ibis	*Plegadis falcinellus*	Solely ground-nesting	Nest placed on the ground (made of compacted sticks, twigs, or reeds).
African Spoonbill	*Platalea alba*	Other (over water; platform; foliage/vegetation support)	On the ground on a pad of reed or sedge stems. Nests made of twigs in the trees above ground. Nests on reed beds or trees over water.
Great White Pelican	*Pelecanus onocrotalus*	Solely ground-nesting	Nests on the ground (on grass, sticks and other debris).
African Penguin	*Spheniscus demersus*	Solely ground-nesting	Burrow in, or bowl on the ground (made up of various loose materials).
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Leach's Storm-Petrel	*Oceanodroma leucorhoa*	Solely ground-nesting	Burrow in the ground.
Cape Rockjumper	*Chaetops frenatus*	Solely ground-nesting	Cup placed on the ground (mostly under a rock slab) made of stems of dry grass and forbs.
Drakensberg Rockjumper	*Chaetops aurantius*	Solely ground-nesting	Cup placed on the ground (under a shrub or small, projecting rock).
Grey Tit	*Parus afer afer* *P. a. arens*	Other (cavity)	Cupped pad of fine grass made in earth bank, walls of dongas. Nests in cavities in rock faces or tree stumps. Nests in drainpipes, crevices in bridges, old buildings and hollow fence posts (man-made sites).
Brown-throated Martin	*Riparia paludicola*	Solely ground-nesting	A tunnel with a nest cup at the end of the chamber (made of dry grass and feathers).
Banded Martin	*Riparia cincta cincta*	Solely ground-nesting	Saucer-shaped nest of dry grass at the end of tunnel excavated into a vertical sandbank (sometimes uses aardvark holes).
Grey-rumped Swallow	*Pseudohirundo griseopyga*	Solely ground-nesting	Nest pad of dry grass at the end of a chamber in the bottom of a tunnel (generally a rodent tunnel).
Blue Swallow	*Hirundo atrocaerulea*	Solely ground-nesting	Cup attached to a sloping or vertical wall in subterranean holes in the ground (such as aardvark holes). Nests in man-made sites such as prospecting pits and mine workings.
Pearl-breasted Swallow	*Hirundo dimidiate dimidiate* *H. d. marwitzi*	Other (platform)	Cup of mud attached to sloping wall of aardvark or porcupine hole. Nests on walls and just beneath overhangs and ceilings of buildings.
Red-breasted Swallow	*Cecropis semirufa*	Other (cavity; platform)	Closed bowl of mud pellets (lined with feathers, hair and grass) in cavities in the ground (such as holes dug by animals and the interior of broken termitaria). Nests on man-made structures such as road culverts, low bridges and on buildings.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Black Saw-wing	*Psalidoprogne holomelas*	Solely ground-nesting	Saucer-shaped nest pad of dry grass, rootlets, or moss placed in a tunnel excavated into earth bank, roofs of aardvark holes or an erosion gulley. Man- made sites such as road cuttings, drainage ditches and pits.
Victorin's Warbler	*Cryptillas victorini*	Other (foliage/vegetation support)	Open cup placed on the ground (made of dry grass, dead leaves and other plant material). Nests above ground on vegetation.
Knysna Warbler	*Bradypterus sylvaticus sylvaticus* *B. s. pondoensis*	Other (foliage/vegetation support)	Cup placed on the ground (made of dry grass, leaves and stems). Nests above ground in a cup placed on tall grass and shrubs.
Barratt's Warbler	*Bradypterus barratii barratii* *B. b. godfreyi* *B. b. cathkinensis*	Other (foliage/vegetation support)	Cup placed on the ground (made of dry plant stems, dry grass blades and leaves). Nests above ground in a cup placed on tall grass or shrubs.
Ayres' Cisticola (Wing-snapping Cisticola)	*Cisticola ayresii*	Solely ground-nesting	Nest is a spherical ball placed on the ground in-between grass tufts (made of dry grass and live grass blades).
Monotonous Lark	*Mirafra passerina*	Solely ground-nesting	A cup placed in the ground placed between or against grass tufts.
Melodious Lark	*Mirafra cheniana*	Solely ground-nesting	Cup placed in the ground between grass tufts.
Rufous-naped Lark	*Mirafra africana africana* *M. a. transvaalensis*	Solely ground-nesting	Cup placed on the ground (made of dry grass material).
Flappet Lark	*Mirafra rufocinnamomea pintoi* *M. r. smithersi*	Solely ground-nesting	Cup placed in a scrape in the ground between grass or forb tufts.
Cape Clapper Lark	*Mirafra apiata apiata* *M. a. marjoriae*	Solely ground-nesting	Cup placed on the ground between or against tufts.
Eastern Clapper Lark	*Mirafra fasciolata fasciolata*	Solely ground-nesting	Cup placed on the ground amongst grass tufts.
Rudd's Lark	*Heteromirafra ruddi*	Solely ground-nesting	Cup placed in a scrape in the ground between grass tufts.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Sabota Lark	*Calendulauda sabota sabota* *C. s. sabotoides* *C. s. suffusca* *C. s. bradfieldi* *C. s. herero*	Solely ground-nesting	Cup placed in a scrape in the ground against or between grass tufts or stones.
Fawn-coloured Lark	*Calendulauda africanoides africanoides* *C. a. harei* *C. a. sarwensis*	Solely ground-nesting	Cup placed on the ground between tufts.
Red Lark	*Calendulauda burra*	Solely ground-nesting	Cup placed on the ground at the base of a grass tuft or between two grass tufts.
Karoo Lark	*Calendulauda albescens albescens* *C. a. guttata* *C. a. codea* *C. a. karruensis*	Solely ground-nesting	Cup placed in a scrape in the ground set between or against one or more low shrubs or grass tufts.
Barlow's Lark	*Calendulauda barlowi cavei* *C. b. patae*	Solely ground-nesting	Domed structure placed on the ground/sand under cover. Structure is woven into the bushes under which they are placed.
Spike-heeled Lark	*Chersomanes albofasciata albofasciata* *C. a. garrula* *C. a. arenaria* *C. a. alticola* *C. a. macdonaldi*	Solely ground-nesting	Cup placed in a scrape in the ground.
Cape Long-billed Lark	*Certhilauda curvirostris curvivostris* *C. c. falcirostris*	Solely ground-nesting	Cup placed on the ground between grass tufts, shrubs and/or stones.
Agulhas Long-billed Lark	*Certhilauda brevirostris*	Solely ground-nesting	Cup placed on the ground between shrubs.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Eastern Long-billed Lark	*Certhilauda semitorquata semitorquata* *C. s. transvaalensis* *C. s. algida*	Solely ground-nesting	Cup placed on the ground against a rock, under a stone projecting out of the ground, against a tuft or shrub.
Karoo Long-billed Lark	*Certhilauda subcoronata subcoronata* *C. s. bradshawi* *C. s. gilli*	Solely ground-nesting	Cup placed in a scrape in the ground (made of twigs, lined with fluffy *Eriocephalus* seeds) at the base of a plant or stone.
Short-clawed Lark	*Certhilauda chuana*	Solely ground-nesting	Cup placed in a scrape in the ground against a low shrub, forb, grass tuft or thorn tree sapling.
Black-eared Sparrow-Lark	*Eremopterix australis*	Solely ground-nesting	Cup placed in a scrape in the ground (usually placed against a low shrub).
Chestnut-backed Sparrow-Lark	*Eremopterix leucotis smithi*	Solely ground-nesting	Cup placed in a scrape in the ground against a clod of earth, a stone, grass tuft or weed stem.
Grey-backed Sparrow-Lark	*Eremopterix verticalis verticalis* *E. v. damarensis*	Solely ground-nesting	Cup either placed in a scrape in the ground or raised on the ground on pebbles, soil clods or short twigs.
Red-capped Lark	*Calandrella cinereal cinerea*	Solely ground-nesting	Cup placed in the ground against a mound, stone or grass tuft.
Stark's Lark	*Spizocorys starki*	Solely ground-nesting	Cup placed on the ground, usually against a grass tuft.
Pink-bellied Lark	*Spizocorys conirostris conirostris* *S. c. barlowi*	Solely ground-nesting	Cup placed in a scrape in the ground, usually against a low tuft of *Stipagrostis* or other grass, or against a stone (placed on the most shaded side).
Botha's Lark	*Spizocorys fringillaris*	Solely ground-nesting	Cup placed in a scrape in the ground concealed by short grass tufts.
Sclater's Lark	*Spizocorys sclateri*	Solely ground-nesting	Cup placed in a scrape in the ground.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Large-billed Lark	*Galerida magnirostris magnirostris* *G. m. harei* *G. m. sedentaria*	Solely ground-nesting	Cup placed on the ground, inside thick grass. Lined with finer stems and rootlets and, in some cases, with plant down (*Eriocephalus*), wool or a few feathers.
Sentinel Rock Thrush	*Monticola explorator explorator* *M. e. tenebriformis*	Solely ground-nesting	Bowl with a central cup placed on the ground usually under a boulder or slab or rock.
Short-toed Rock Thrush	*Monticola brevipes brevipes* *M. b. pretoriae*	Solely ground-nesting	Cup placed on the ground, hidden under a slab of rock or beneath a thick grass tuft (some are built into the stems or roots of a tree but still placed on the ground).
White-starred Robin	*Pogonocichla stellata stellata* *P. s. transvaalensis*	Other (cavity)	Ball-shaped, consisting of a deep cup placed on the ground. Nests above ground in rotten tree trunks.
Cape Robin-Chat	*Cossypha caffra caffra* *C. c. namaquensis*	Other (cavity; over water (floating); platform; foliage/ vegetation support).	Cup placed on the ground on top of twigs, pieces of bark moss, grass and leaves. Nests placed in a variety of sites, most notably: a hollow stump, in tree trunks. Nests over water in flood debris. Nests above ground on a densely foliaged shrub. Nests on creeper-covered walls or hanging fern baskets (man-made).
White-throated Robin-Chat	*Cossypha humeralis*	Other (foliage/vegetation support)	Cup placed on the ground under a tree or bush canopy where there is a mass of dead leaf. Nests built inside rusted pots and tins (man-made).
White-browed Robin-Chat (Heuglin's Robin-Chat)	*Cossypha heuglini*	Other (cavity; foliage/vegetation support)	Open cup placed on the ground. Nests placed in a rot- hole or cleft in the tree trunk or on stumps. Nests on root mats on banks and creepers/vines.
Red-capped Robin Chat	*Cossypha natalensis natalensis*	Other (cavity; platform foliage/vegetation support).	Cup placed on the ground. Nests on a broken-off stump or in a rot-hole/crevice in a tree trunk. Nests on creepers and dense thickets.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Karoo Scrub-Robin	*Erythropygia coryphaeus coryphaeus* *E. c. abbotti* *E. c. cinerea*	Other (platform; foliage/ vegetation support)	Cup placed on the ground, concealed under a small shrub or fallen branch. Nests in a dense shrub (up to 1 meter above ground) or in a heap of flood debris.
African Stonechat	*Saxicola torquatus torquatus* *S. t. stonei* *S. t. oreobates* *S. t. clanceyi*	Solely ground-nesting	Cup placed on the ground hidden in vegetation cover from above, usually at the base of a leafy forb or dense grass tuft.
Mountain wheatear	*Oenanthe monticola monticola*	Other (cavity; platform)	Cup placed on the ground or in a flattened heap of coarse material, usually hidden under a rock on a hill- slope or in a deep recess between rocks. Nests at man-made sites are found on ledges under roof overhangs, drain water pipes, windowsills and wall cavities in buildings.
Capped Wheatear	*Oenanthe pileata pileata* *O. p. livingstonii* *O. p. neseri*	Other (cavity; platform).	Cup placed below the ground in a tunnel, mostly at the end of a rodent burrow. Nests under discarded railway sleepers or in the eaves of buildings.
Buff-streaked Chat	*Campicoloides bifasciata*	Solely ground-nesting	Cup placed on the ground against the down-slope side of a large rock or boulder.
Sickle-winged Chat	*Cercomela sinuata sinuata* *C. s. hypernephela* *C. s. ensifera*	Solely ground-nesting	Cup placed on the ground under a thick grass tussock or low shrub, less often under a rock or a clod of earth.
Karoo Chat	*Cercomela schlegelii pollux* *C. s. namaquensis*	Solely ground-nesting	Cup placed on the ground at the base of a low shrub or rock.
Tractrac Chat	*Cercomela tractrac tractrac* *C. t. nebulosa*	Solely ground-nesting	Cup placed on the ground under a low bush or rock. Base built with twigs and dry plant stems.
Continue to next page			

Supplementary Table S1.1 - *Continued from previous page*			
Familiar Chat	*Cercomela familiaris familiaris* *C. f. galtoni* *C. f. hellmayri* *C. f. actuosa*	Other (cavity; platform)	Cup placed on the ground or in a disused starling or bee-eater bank burrow. Man-made sites such as: holes in walls, under eaves of roofs, in disused machinery, in pipes and even inside buildings on ledges.
Ant-eating Chat	*Myrmecocichla formicivora formicivora* *M. f. minor* *M. f. orestes*	Solely ground-nesting	Bowl-shaped, placed in a tunnel excavated in an earth bank (commonly uses aardvark holes) made of dry grass and rootlets. Nests in man-made sites such as road cuttings.
Pied Starling	*Lamprotornis bicolor*	Solely ground-nesting	Bowl set in an excavated tunnel in earth banks.
Common Starling	*Sturnus vulgaris* [2]	Other (cavity; platform; foliage/vegetation support)	Cup placed in a burrow or excavated tunnel. Nests above ground in trees and rock faces. Man-made sites such as: roofs of buildings, pipes, holes in walls.
African Quailfinch	*Ortygospiza atricollis bradfieldi* *O. a. digressa*	Solely ground-nesting	Ball-shaped nest placed on the ground between grass tufts. Hidden under or against tufts of grass.
Common Waxbill	*Estrilda astrild astrild* *E. a. damarensis* *E. a. tenebridorsa*	Other (foliage/vegetation support)	Ball-shaped nest placed on the ground. Most nests have a false nest (or 'cock's nest') built on top of main structure. Nests above ground set into a grass tuft.
Pink-throated Twinspot	*Hypargos margaritatus*	Other (foliage/vegetation support)	Oval-shaped nest with a short tunnel- entrance, placed on the ground. Well hidden among litter and old grass.
Red-billed Firefinch	*Lagonosticta senegala*	Other (foliage/vegetation support).	Ball-shaped nest placed on the ground. Nests above ground on shrubs. Man-made sites such as: garden plants, flowerpots and wall creepers.
Jameson's Firefinch	*Lagonosticta rhodopareia jamesoni*	Other (foliage/vegetation support)	Placed on the ground. Nests above ground, beneath tree canopy. Flowerpots and hanging baskets.
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Supplementary Table S1.1 - *Continued from previous page*			
African Pied Wagtail	*Motacilla aguimp aguimp* *M. a. vidua*	Other (cavity; over water (floating); platform; foliage/vegetation support).	Open-cupped bowl placed on the ground. Nests over water on driftwood/flood debris/reed-clumps. Nests above ground in trees or bushes. Man-made sites such as: moored boats, cavities in walls and ledges in buildings, roofs and bridges.
Cape Wagtail	*Motacilla capensis capensis*	Other (cavity; platform; foliage/vegetation support)	Open-cupped bowl placed on the ground. Nests above ground on vegetation. Nests in man-made sites such as: ledges, cavities in buildings, bridges, hedges, shrubs, creepers and pot-plants.
Cape Longclaw	*Macronyx capensis capensis* *M. c. colletti*	Other (foliage/vegetation support)	Cup placed on the ground. Above ground-nesting in tall grass.
Rosy-throated Longclaw	*Macronyx ameliae ameliae*	Other (over marsh; foliage/vegetation support)	Cup placed into a hollow in the ground or on dense grass concealed by overhanging grass. Above ground-nesting in grass over marsh ground.
Yellow-breasted Pipit	*Anthus chloris*	Solely ground-nesting	Cup placed in a scrape in the ground or hollow between two or more grass tufts.
Striped Pipit	*Anthus lineiventris lineiventris* *A. l. stygium*	Other (foliage/vegetation support)	Cup placed on the ground. Nests above ground in tree canopy.
African Rock Pipit	*Anthus crenatus*	Solely ground-nesting	Cup placed on the ground, against/inside a grass tuft.
African Pipit	*Anthus cinnamomeus bocagii* *A. c. rufuloides*	Solely ground-nesting	Cup placed in a scrape or hollow in the ground. Generally concealed by overhanging vegetation.
Mountain Pipet	*Anthus hoeschi*	Solely ground-nesting	Cup placed in a scrape or hollow in the ground.
Plain-backed Pipit	*Anthus leucophrys leucophrys*	Solely ground-nesting	Cup placed in scrape or hollow in the ground.
Buffy Pipit	*Anthus vaalensis vaalensis*	Solely ground-nesting	Cup placed in a scrape or hollow in the ground between tufts of grass, or against a clod of earth or rocks.
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Supplementary Table S1.1 - *Continued from previous page*			
Long-billed Pipit	*Anthus similis nicholsoni* *A. s. petricolus* *A. s. primarius*	Solely ground-nesting	Cup placed in a scrape or hollow in the ground against a tuft of grass or the underside of a sloping rock.
Kimberley Pipit	*Anthus pseudosimilis*	Solely ground-nesting	Cup placed in a scrape in the ground or hollow in a tuft of grass.
Short-tailed Pipit	*Anthus brachyurus*	Solely ground-nesting	Cup placed on the ground. Usually screened above by overhanging vegetation.
Bushveld Pipit	*Anthus caffer caffer* *A. c. traylori*	Solely ground-nesting	Cup placed in a scrape in the ground.
Lark-like Bunting	*Emberiza impetuani impetuani* *E. i. sloggetti*	Solely ground-nesting	Cup placed on the ground, usually at the base of a rock.
Cinnamon-breasted Bunting	*Emberiza tahapisi tahapisi*	Solely ground-nesting	Cup placed in a scrape in the ground against the underside of a rock, tuft or clod of earth. Man-made sites such as old mine workings.
Cape Bunting	*Emberiza capensis capensis* *E. c. cinnamomea* *E. c. reidi* *E. c. limpopoensis* *E. c. basutoensis* *E. c. vinacea*	Other (foliage/vegetation support).	Cup placed on the ground. Nests above ground on shrubs and low vegetation.
Peregrine Falcon	*Falco peregrinus minor*	Other (platform)	Scrape in the ground. Nests on cliff edges above ground. Man-made sites such as bridges, roofs or sides of tall buildings.
End of table			

Footnote: [1] Taxonomic nomenclature based on the most recent 'BirdLife South Africa List of South African Birds' which was last updated in 2020 (BirdLife South Africa, 2020). [2] Species are categorized as invasive bird species in South Africa, according to the National Environmental Management: Biodiversity Act (NEMBA) (DEA, 2016).

CHAPTER 2

The Southern African Bird Atlas Project (SABAP) as a tool to examine Spotted Thick-knee distributions across South Africa

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Running header: Spotted Thick-knee distributions across South Africa

2.1 Abstract

Attempts to assess species responses to anthropogenic changes have rarely been conducted over a large, geographic area. There has been increased global awareness regarding the importance of biodiversity, and as a result, strategies relevant to the distributional monitoring of species have been implemented in select regions. The Southern African Bird Atlas Project (SABAP) is one such approach that utilises voluntarily collected records of species sightings, with most participants being members of the public. The atlas data from this long-term project has been invaluable in interpretation of changes in species ranges and distributions. Examination of historical and present data from SABAP was used to determine whether the Spotted Thick-knee (*Burhinus capensis*) has experienced distribution range and abundance changes across the region of South Africa. The study used data from the South African Bird Atlas Project 1 (SABAP1) which took place between 1987 to 1993, and the South African Bird Atlas Project 2 (SABAP2) which initiated in 2007 and currently ongoing as of 2021. Measures of distribution range and abundance were expressed in the changes of reporting rates for Quarter Degree Grid Cells (QDGC). Results suggest that the Spotted Thick-knee has experienced a change in distribution range and an overall decrease in distribution over the region of South Africa. The species has shown a distribution range expansion into areas previously considered unsuitable for inhabitancy, such as many parts of the Northern Cape Province. The study has substantiated the usability and importance of citizen science data and atlas survey methods, in providing valuable geospatial information and monitoring of species at a large-scale.

Keywords: abundance, citizen science, monitoring, range, SABAP1, SABAP2

2.2 Introduction

Human activity has been in the limelight recently because of the negative impacts' humans have had on the environment (McKinney 2002; McCleery et al. 2012; Mahmoud and Gan 2018). Anthropogenic activities such as deforestation and urbanisation have harmed fauna and flora species on a global scale. Many species have been locally or globally extinct because of human activities and negligence, and it is widely suggested that species extinctions will occur more frequently in the near future (McKinney 2002; McCleery et al. 2012; Mahmoud and Gan 2018). One of the major problems in gaining an insight into most species' state is the actual monitoring of their numbers and spatial information about individuals, groups or populations. Recently, there has been greater global awareness of the impact humans have had on biodiversity and the adverse effect of biodiversity loss on humans (McKinney 2002; McCleery et al. 2012; Mahmoud and Gan 2018). Through this realisation, in many countries, the initiative has been taken to implement strategies that deal with monitoring species populations and distributions to reduce biodiversity loss (McKinney 2002; McCleery et al. 2012; Mahmoud and Gan 2018).

Technology has developed considerably in the last two decades, resulting in a more efficient and reliable monitoring of species (Wall et al. 2014; Nicheporchuk et al. 2020). There was a time when access to information, especially reputable data from a specific study or the most efficient method to analyse data, was unobtainable or restricted. There was also a lack of awareness about such studies and investigator findings. Subsequently, many programmes have become open-access with open-source software, meaning that members of the public have access to these programmes, the data in them, contribute and use the tools to analyse the data (Wall et al. 2014; Nicheporchuk et al. 2020).

It is without a doubt that one the most beneficial features that have, in most cases, been freely available to the public is that of geographical information (Wall et al. 2014; Nicheporchuk et al. 2020). Geographical information consists of spatial and attributional data of an object, a landscape or living organism which can be interpreted through various geographic outputs such as satellite imagery and map/atlas outputs (Wall et al. 2014; Nicheporchuk et al. 2020). Geographical information has been key to use as a variable for biodiversity monitoring, especially for critically endangered species or those of high importance (flagship/key species and/or those species that are tourist attractions) (Wall et al. 2014; Nicheporchuk et al. 2020).

Although monitoring species is generally associated with wildlife tracking in the form of Global Positioning System (GPS) trackers, radio-telemetry or bio-loggers, they are very costly and, in most cases, certain conditions have to be met to use these methods (Thomas et al. 2012; Wall et al. 2014; Nicheporchuk et al. 2020). This has led to restrictions on studies in terms of what investigative methods can be undertaken during the data collection period. Although the information collected may be of high quality concerning some variables, it may come at the expense of study aims which draw attention to parts of the data that is insufficiently collected (Thomas et al. 2012; Wall et al. 2014; Nicheporchuk et al. 2020). The use of the incorrect methodological approaches along with time constraints and not having enough labour force or 'hands on deck' to assist with collecting or processing data have been common limiting factors for species monitoring studies, especially concerning their distributions over large geographical regions (Thomas et al. 2012; Wall et al. 2014; Nicheporchuk et al. 2020).

The aid of interested parties in identifying, collecting or contributing information to a study through an approach termed "citizen science" has been used, in numerous studies, to effectively deal with some of the constraints mentioned above (Connors et al. 2012). Citizen science is when a member of the public or any other interested party not originally associated with the study/project, contributes through data collection, data processing and/or the sharing of knowledge (such as indigenous knowledge) and essentially collaborates with those carrying out the study/project (Cohn 2008; Bonney et al. 2009; Dickinson et al. 2010; Connors et al. 2012; Rose et al. 2020). It has become an integral component of many fields of study with anthropogenic elements and will grow in importance, the more human populations increase, and the further their actions impact the planet.

Historically, the involvement of citizens in studies was restricted to a select few in that only those that had the means and resources to participate were allowed to (Cohn 2008; Bonney et al. 2009; Silvertown 2009). Widespread contributions in citizen science originally belonged in developed countries that had the infrastructure and citizens with the means to carry out their volunteer research (Cohn 2008; Bonney et al. 2009; Silvertown 2009). With the advent of more developed and accessible technologies, there has been greater involvement and more significant contributions from public members of developing countries as well, especially for projects associated with natural science fields such as ecology (Harrison et al. 2008; Dickinson et al. 2010; Lee et al. 2017; Harrison 2020). Citizen science does not always allow for contributions on all species, but for some animal species such as birds, this approach has been invaluable (Greenwood 2007; Silvertown 2009; Lee et al. 2017; Harebottle 2020). For example, the Christmas Bird Count (CPC) in the United States of America has taken place every year since 1900 because of the efforts of the National Audubon Society and several thousand volunteers which has sometimes resulted in the yearly recording of over 60 million birds during the Christmas period (Silvertown 2009). In a developing region such as southern Africa, one such effective project is the “Southern African Bird Atlas Project” whereby the public can contribute valuable information concerning the identifying and locational recording of bird species that have been sighted in the region (Harrison et al. 2008; Loftie-Eaton 2015; Lee et al. 2017; Harebottle 2020; Harrison 2020; Rose et al. 2020; SABAP2 2021a).

The Southern African Bird Atlas Project involves the distributional mapping of bird species that have been sighted and identified in Botswana, eSwatini, Lesotho, Mozambique, Namibia, South Africa, Zambia and Zimbabwe (SABAP2 2021a). The project was broken up into two parts, namely SABAP1 with recordings mainly taking place from 1987 to 1991 but records were collected until 1993 for some species including the Spotted Thick-knee (*Burhinus capensis*)); and SABAP2 with recordings from 2007 and currently ongoing as of 2020 (SABAP2 2021a). The project was implemented to allow for a more efficient manner in mapping the distribution and relative abundance of the many bird species found living, breeding or migrating to/from the southern African region (Harrison et al. 2008; Loftie-Eaton 2015; SABAP2 2021a). This is done by way of participants identifying and recording the location of the bird species they observe in a geographically sectioned area known as a 'pentad' within a set period. The information is then uploaded to the Southern African Bird Atlas Project database where it is freely accessible for those requiring distributional information for bird species to use, whether in research or to help inform the public and create awareness (SABAP2 2021a).

Over the years, the Southern African Bird Atlas Project (SABAP2) with over 2 million records collected yearly, has been identified as a valuable tool to provide information for aspects such as determining species conservation status (such as the red-list status of some species); identifying areas of importance to establish as key biodiversity areas for species; and to generate information that can assist in decision making regarding anthropogenic development in an area (e.g., environmental and ecological impact assessments) (Loftie-Eaton 2015; Harrison 2020; Rose et al. 2020; SABAP2 2021a). SAPAP is especially valuable when used for examining changes in range, distribution and abundance of common species because the sightings of such species are more verifiable as compared to rare species. There has been a perceived increase of Spotted Thick-knee numbers across South Africa, and due to their commonality in many parts of the country, it is not difficult to dispute this perceived trend. However, Spotted Thick-knee have specific requirements for its nesting ecology. Therefore, it is thought to be more at risk of changes to its habitat and natural surroundings. SABAP allows for empirical analyses of Spotted Thick-knee distributions from SABAP1 to SABAP2, which would allow for improved understanding of the state of the current Spotted Thick-knee populations over South Africa.

Our study aimed to assess the Spotted Thick-knee's historical and present distributions across South Africa. Our study's objectives were to use SAPAB and QGIS as tools to examine and analyse the recorded data to determine possible changes in range, distribution and abundance of Spotted Thick-knees across South Africa. We hypothesised significant changes in Spotted Thick-knee range and distribution and predicted an overall decrease in abundance from SABAP2 compared with historical data recorded in SAPAB1. We predicted that these changes are consequences of urbanisation and anthropogenic activity, leading to decreasing natural habitat for Spotted Thick-knees.

2.3 Methods

2.3.1 Study species

The Spotted Thick-knee belongs to the order Charadriiformes (shorebirds) in the Burhinidae family and is a native species to the continent of Africa (Hockey 2005; Hume et al. 2019; SABAP2 2021b). Two of the four subspecies are present in South Africa, namely: *B. c. damarensis* and *B.*

c. capensis (Hume et al. 2019; SABAP2 2021b). They have been found in a wide range of environments including grassland, savanna, desert and shore areas (Hockey 2005; Hume et al. 2019). In the range of environments that they are found in, their diet is mostly made up of invertebrates which they forage for on the ground, however small mammals and lizards have been observed to be consumed especially in urban areas (Hockey 2005; Hume et al. 2019). Although they are known as a resident species in their naturally occurring range, nomadic individuals and groups have been identified in urban areas and fringe areas of their natural habitats (Hockey 2005). They are a nocturnal species which has made it difficult to observe their movements at local scales. They are a ground-nesting species (uses a simple scrape in the ground as a nesting area) with flight capability; however, they spend little time in the air compared with the time on the ground (Hockey 2005). Spotted Thick-knees are monogamous, but if one partner dies, the surviving partner will find a suitable replacement (Hockey 2005; Hume et al. 2019).

The Spotted Thick-knee is categorised as "Least Concern" on the IUCN Red List, but there is a need for a status update as the data on their distributions and numbers were last updated in 2016 (BirdLife International 2016). Their distribution is assumed to be increasing because of the increase in their sightings and no evidence of environmental dependence, indicating that they are not strictly dependent on particular aspects of their natural environments such as a specific diet or definite breeding requirements/conditions. With the increasing urban expansion in South Africa, there is a need to examine distributions and populations for ground dependent bird species such as the Spotted Thick-knee.

2.3.2 Study area

South Africa has an area landmass of approximately 1 221 037 km^2 and the total landmass area of the study area is 1251 392 km^2 when taking into consideration the landlocked country of Lesotho (total landmass area= 30355 km^2) because of the study species possible movement between the countries borders (Hennig 2010). South Africa has eight terrestrial biomes namely: Grassland, Savanna, Succulent Karoo, Nama Karoo, Forest, Fynbos, Desert, Albany Thicket and the Indian Ocean Coastal Belt (Mucina and Rutherford 2006). The country is bordered by two oceans namely the Indian Ocean on the East Coast and the Atlantic Ocean on the West Coast (the two oceans meet at the most Southwestern part of the country) (Rae 1991). The combination of the two oceans, the climate and the topography of the land allows for an abundance of fauna and flora, including many endemic species, to thrive in the various environments. The country has an increasing human population which currently numbers 59804820 in estimates as of 18 January 2021 (Worldometers.info 2020). The growing human population has increased urbanisation rate from 61.7% in 2009 to 66.9% in 2019 (a rise of 5.2% over 10 years) (Plecher 2020). This has consequently led to more anthropogenic developments at the natural environment's cost.

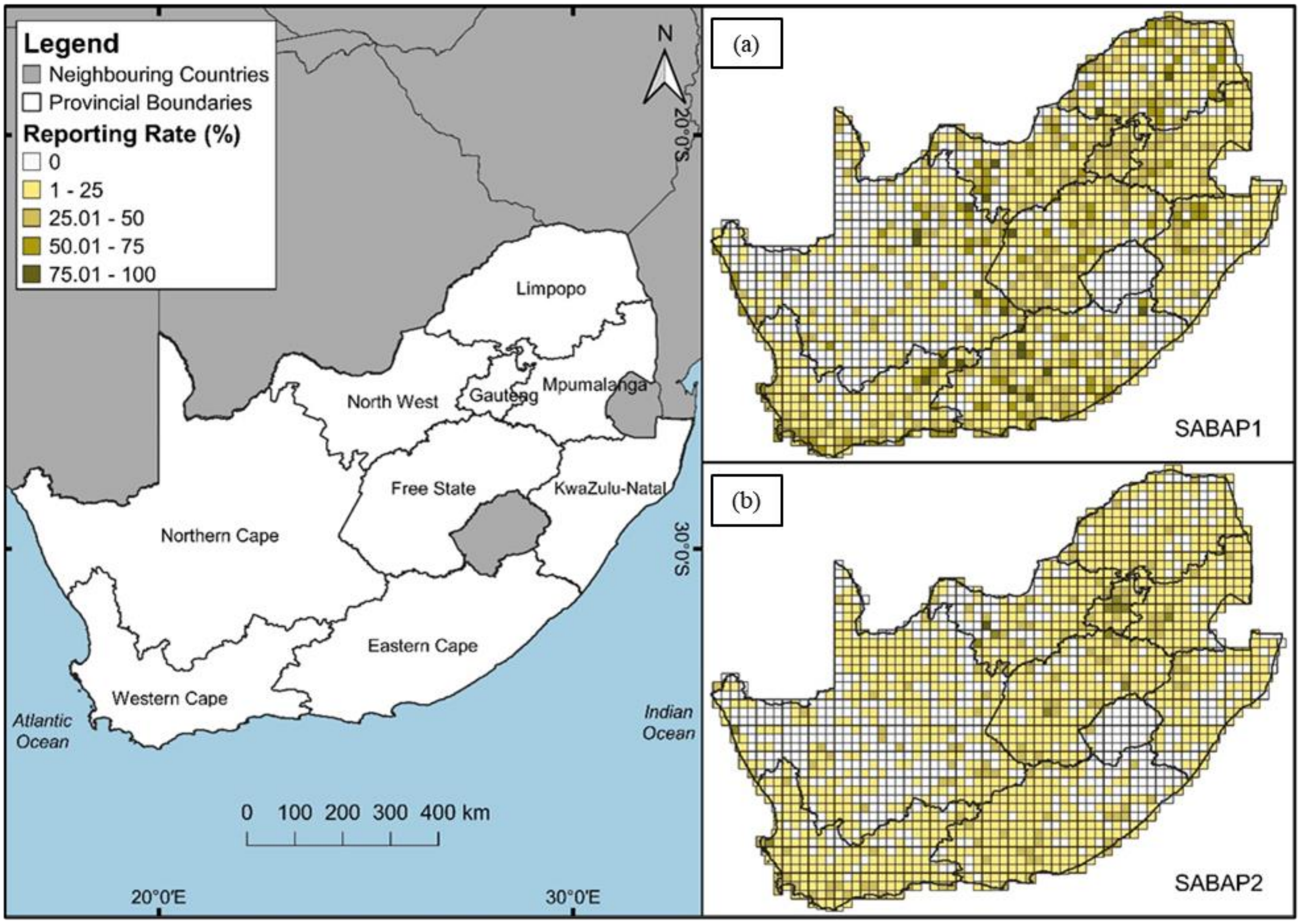

Figure 2.1: Provinces of South Africa. Reporting rate percentages for Spotted Thick-knees across South Africa and Lesotho from (a) SABAP1 data recorded between 1987–1993; and (b) SABAP2 data recorded between 2007–2021 (18 January 2021).

2.3.3 Data collection

We obtained distributional data for Spotted Thick-knee from the Southern African Bird Atlas Project 1 (SABAP1) and Southern African Bird Atlas Project 2 (SABAP2) for South Africa, with the inclusion of data collected in Lesotho (SABAP, 2021). Data for SABAP1 were collected between 1987 and 1993 in a quarter degree grid cell (QDGC) resolution measured by a grid of 15 min of latitude by 15 min of longitude (SABAP, 2021a). Data for SABAP2 was first collected in

2007 and is ongoing as of 2021. However, because of the study completing in January 2021, only data collected until 18 January 2021 were used in our analyses.

SABAP2 data were originally collected in the pentad format with a resolution grid of 5 min latitude by 5 min longitude. However, as of 2020, the data were also converted to QDGC format for the convenience of analyses between the two. We downloaded data as a 'Comma-separated Values' (CSV) file labelled as 'SABAP1 vs SABAP2 reporting rates' in the 'Data access' tab for Spotted Thick-knee (species number = 275), which we accessed through http://sabap2.birdmap.africa/species/275. Data were made up of reporting rates, which is the number of checklists with species report cards returned by observers, divided by the total report cards placed in a QDGC. All data are freely available for viewing or download on the SABAP2 website, in the form of Microsoft Excel© spreadsheets or summarised Portable Document Format (PDF) files.

2.3.4 Data analyses

We only used QDGC format data in our analyses which allowed for evaluation of range-changes and perceived abundance in Spotted Thick-knee populations within South Africa. Data in the pentad format would have allowed for more in-depth distribution analyses, but because SABAP1 data were not recorded with such a method, we felt that any attempt to convert SABAP1 data close to pentad format or carry out analyses using the information in both QDGC and pentad format (SABAP1) would jeopardise the integrity of the results. We examined data further by investigating provincial changes in Spotted Thick-knee distribution and relative abundance. A 1:50000 Topographic map with Quarter Degree Grid Cells labelled, was used to verify each cell and the province each cell was contained within. We vetted all cells through this process as we found that some cells had not been grouped by province or had been erroneously grouped in the original SAPAB1 data. Unallocated cells that were on the border of two or more provinces or a province and neighbouring country were allocated to the province that took up most of that cell using a geometry-shaded region approach (Supplementary information Figure S2.1). The allocation of cells, and the data within them, to only one province, prevented duplication of data which could have erroneously influenced the study results and the conclusions drawn from such results.

To display the change in the relative abundance of Spotted Thick-knees in South Africa, we used the method first described by Underhill and Bradfield (2013) with further adjustments by Underhill and Brooks (2016). For a more statistically sound approach, only cells with four or more (> 4) checklists for both SABAP periods were analysed to increase the accuracy of reporting rates (at a 95% confidence interval) and to account for small sampling variability that resulted from limited surveying of some areas (Underhill and Brooks, 2016). The relative change in abundance from SABAP 1 to SABAP2 was calculated by a '*C*' value which indicated an increase of relative change in abundance when $C < 1$, decrease in relative abundance when $C > 1$, and no change in abundance if $C = 1$ (Underhill and Brooks 2016). The following equation was used to calculate *C* values:

$$\boldsymbol{C} = \log(1 - \mathbf{RR2}) / \log(1 - \mathbf{RR1})$$

Where:

C is the measure of relative change in abundance

RR1 is the reporting rate from SABAP1 records

RR2 is the reporting rate from SABAP2 records

We compared the reporting rates (RR) for each QDGC (15' by 15') and geospatially identified each on a 1:50000 map layer, using QGIS software version 3.10.11. The number of cells with valid reporting rates (RR) between SABAP1 and SABAP2, for South Africa and then by each province, were analysed using Chi-square tests in IBM SPSS© Statistics version 27 (SPSS Inc., Chicago, USA) at an alpha level of 0.05 ($\alpha = 0.05$). Cells were separated by QDGC reporting rates and categorized as 'No Change' or 'Change'. 'No Change' when a cell showed a stable value. 'Change' when a cell showed an increase or decrease in reporting rate, a new record for that cell or an absence of sighting the species in SABAP 2 records for that cell. Cells which were either invalid (checklists < 4) or unsurveyed, were omitted from Chi-square analyses. However, we expressed the percentage of total cells that indicated these outcomes at both the national (i.e., South Africa) and provincial levels (i.e., Eastern Cape, Free State etc.).

2.4 Results

2.4.1 South Africa

South Africa comprises 1929 QDGC (15 by 15), excluding Lesotho and 1981 (15 by 15) QDGC including Lesotho. Regarding only South Africa (n = 1929), 2.1% (n = 41) of cells were unsurveyed, 11.3% (n = 217) of cells never recorded the species in either SABAP1 or SABAP2 surveys, and 7.4% (n = 142) were invalid for the study because the cells contained less than four checklists for either SABAP1 or SABAP2 survey periods (Supplementary information Table S2.1). For those cells that had recordings of the species, 0.3% (n = 6) showed no change or a stable C-value ($C = 1$), 16.2% (n = 312) showed an increase in C-value ($C > 1$) reflecting an increase in abundance in those areas, 36.0% (n = 694) showed a decrease in C-values ($C < 1$) reflecting a decrease in abundance in those areas, 13.3% (n = 257) where the species was absent in areas for

SABAP2 where it was recorded in SABAP1 surveys, 13.5% (n = 260) showed new areas where the species was not recorded in SABAP1 surveys (Figure 2.2).

At the time of data download and study completion (17 January 2021), there was a significant difference in the number of cells which showed an increase or new record (n = 572) from SABAP1 to SABAP2 compared with cells that showed a decrease (n = 951) or species absence from SABAP1 to SABAP2 (χ^2 = 188.63; df = 1; $p < 0.001$), indicating an overall decrease in Spotted Thick-knee abundance across South Africa (Table 2.1; Figure 2.2).

2.4.2 Provinces of South Africa

Generally, the provinces in South Africa showed significant differences in the number of cells with Spotted Thick-knees between the SABAP1 or SABAP2 survey periods. The Eastern Cape Province (n = 255) had a significant difference between the number of cells reflecting an increase (n = 78) and cells reflecting a decrease in Spotted Thick-knees (n = 135) (χ^2 = 30.51; df = 1; $p <$ 0.001; Table 2.1). The Free State Province (n = 226) had a significant difference between the number of cells reflecting an increase (n = 87) and cells reflecting a decrease (n = 131) (χ^2 = 17.76; df = 1; $p < 0.001$; Table 2.1). Gauteng Province (n = 38) had a difference between the number of cells reflecting an increase (n = 16) and cells reflecting a decrease (n = 22), but the difference was not statistically significant (χ^2 = 1.89; df = 1; p = 0.17; Table 2.1). KwaZulu-Natal Province (n = 153) had a significant difference between the number of cells reflecting an increase (n = 20) and cells reflecting a decrease (n = 105) (χ^2 = 115.6; df = 1; $p < 0.001$; Table 2.1). Limpopo Province (n = 179) had a significant difference between the number of cells reflecting an increase (n = 50) and cells reflecting a decrease (n = 98) (χ^2 = 31.14; df = 1; $p < 0.001$; Table 2.1). Mpumalanga Province (n = 117) had a significant difference between the number of cells reflecting an increase

(n = 40) and cells reflecting a decrease (n = 74) ($\chi^2 = 20.28$; df = 1; $p < 0.001$; Table 2.1). The Northern Cape (n = 587) had a difference between the number of cells reflecting an increase (n = 170) and cells reflecting a decrease (n = 174), but the difference was not statistically significant ($\chi^2 = 0.09$; df = 1; $p = 0.76$; Table 2.1). North West Province (n = 221) had a significant difference between the number of cells reflecting an increase (n = 39) and cells reflecting a decrease (n = 86) ($\chi^2 = 35.34$; df = 1; $p < 0.001$; Table 2.1). Western Cape Province (n = 221) had a significant difference between the number of cells reflecting an increase (n = 72) and cells reflecting a decrease (n = 126) ($\chi^2 = 29.45$; df = 1; $p < 0.001$; Table 2.1). Significant changes in Spotted Thick-knee abundance, by measure of change in reporting rates from SABAP1 to SABAP2, were identified with an overall decrease in the provinces of the Eastern Cape, the Free State, KwaZulu-Natal, Limpopo, Mpumalanga, North West and the Western Cape (Table 2.1).

Table 2.1: Summary of reporting rate changes in quarter degree grid cells (QDGC) for South Africa at the national and provincial levels for SABAP 1 and 2 for Spotted Thick-knees in the present study. The number of cells with no change or change expressed as a percentage of the number of QDGC, which are the total number of cells for each category.

Category	Number of QDGC	No Change	Change		Other*	No Change vs Change
	n	Stable	Increase	Decrease		*p*-value
National Level						
South Africa	1929	0.3%	29.6%	49.3%	20.7%	$p < 0.001$
Provincial level						
Eastern Cape	255	0.0%	30.6%	52.9%	16.5%	$p < 0.001$
Free State	226	0.4%	38.5%	58.0%	3.1%	$p < 0.001$
Gauteng	38	0.0%	42.1%	57.8%	0.0%	$p = 0.17$
KwaZulu-Natal	153	0.0%	13.1%	68.6%	18.3%	$p < 0.001$
Limpopo	179	0.6%	27.9%	54.8%	16.8%	$p < 0.001$
Mpumalanga	117	0.0%	34.2%	63.3%	2.6%	$p < 0.001$
Northern Cape	587	0.7%	29.0%	29.6%	40.7%	$p = 0.76$
North West	153	0.0%	25.5%	56.2%	18.3%	$p < 0.001$
Western Cape	221	0.0%	32.6%	57.0%	10.4%	$p < 0.001$

Footnote: '*' Combined category of QDGCs with invalid data (checklists < 4), unsurveyed cells, and surveyed cells with no records of Spotted Thick-knee sightings in both SAPAB1 and SABAP2 (at time of data download, 18 January 2021).

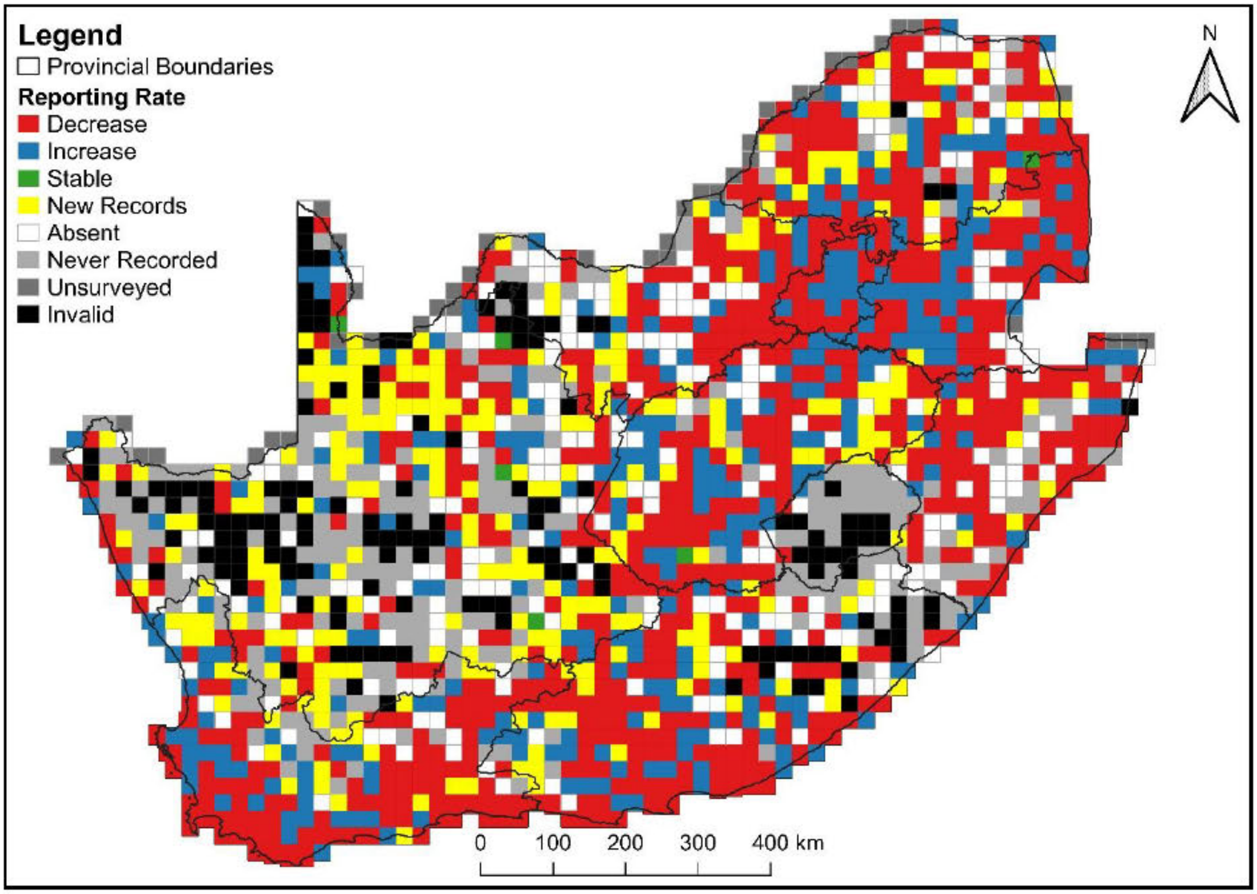

Figure 2.2: Change in Spotted Thick-knees' reporting rates between Southern African Bird Atlas Project 1 (SABAP1) and 2 (SABAP2), from South Africa and Lesotho quarter degree grid cells (QDGCs; $N = 1981$). Changes, or lack thereof, in reporting rates from SABAP1 to SABAP2 are expressed for each QDGC whereby red-cells represent a 'Decrease' ($C < 1$); blue-cells represent an 'Increase' ($C > 1$); green-cells represent 'Stable' ($C = 1$) or no change in reporting rates; yellow-cells represent a 'New Record' from SABAP2 not recorded in SAPAB1; white-cells represent 'Absent' areas that had sighting reports of the species in SABAP1 but no sighting reports from SABAP2 surveys; light-grey-cells represent 'Never Recorded' areas which indicate that there was no reported sighting of the species during surveys from both SABAP1 and SABAP2; dark-grey-cells represent 'Unsurveyed' areas that were not surveyed for SABAP1 and not yet surveyed for SABAP2 at the time of data download (18 January 2021); and black-cells represent 'Invalid' cells with a total number of reporting checklists < 4 in both SABAP1 and SABAP2.

2.5 Discussion

The study findings suggest that Spotted Thick-knee range distribution has changed in the past 30 years or so. There was an overall increase in the number of QDGC or areas where the species was not recorded in the previous project between 1987–1993. The Free State Province, Limpopo Province, Northern Cape Province and Western Cape Province all showed this trend. All other provinces had more areas showing an absence of the species, except the Gauteng Province which had no new records and no records showing an absence of the species. The increase in the number of areas with new sightings indicates possible colonisation of these areas, whilst the increase in the number of areas with the species currently absent indicates species shift or removal from these areas. It is unlikely that trends for all areas could be because of chance or insufficient observations. A similar approach was used by Hofmeyr et al. (2014) in their study of the Secretarybird (*Sagittarius serpentarius*) to show distribution and population trends. This approach is considered to be the most appropriate method to analyse single-species distribution data after examination of its applicability (Underhill and Brooks 2016).

Spotted Thick-knees have appeared in areas where it was previously unsuitable for their occurrence. According to Maclean (1993), many parts of the Northern Cape Province were previously considered to be too arid for Spotted Thick-knees, and yet this province has experience newly recorded sightings in 19.8% of the provinces allocated QDGC. This is a substantial change when one considers that 20.1% of cells for the province are either invalid or unsurveyed at the completion of the study. Their recent occurrence in these areas could be because of the transformation of the arid landscape for developments that provide more suitable conditions for them compared with the dry, barren areas that existed before urban development.

There was an apparent absence and avoidance of the species in Lesotho and the border area of the Eastern Cape Province and KwaZulu-Natal Province which was previously known as the Transkei region. The avoidance of these areas was apparent in historical records as well. It was suggested that Spotted Thick-knee were not sighted or commonly sighted in these areas because a large number of livestock species such as the domestic pig (*Sus scrofa domesticus*) move around freely and pose a threat because they eat the eggs that are laid on the ground (Maclean 1993). However, it might be reduced sighting efforts in these areas, as shown in other avian studies (Downs et al. 2014).

Spotted Thick-knees have decreased in abundance across South Africa and all its provinces. This trend is indicated by the number of QDGC or areas whereby there was a decrease in the reporting of the species from historical records to current records. It is no coincidence that this took place over all regions because, in the last 20 years, South Africa has experienced an increase in urban expansion and anthropogenic development across the region in all provinces (Plecher 2020).

The study findings regarding Spotted Thick-knee distribution ranges and abundance further emphasise that there is currently a decrease in their range distribution. Although the reporting rates for both projects were relatively low for this relatively common species, they are inconspicuous or hard to detect when in their natural environments because of their plumage providing camouflage. They become conspicuous when in an environment that does not suit their plumage. This could also be why there are perceived to have an increase in numbers and increased presence in urban areas. They could be noticed more because urban developments have reduced suitable habitat and led to closer contact between Spotted Thick-knee and humans.

In conclusion, the IUCN Red List species report for 2016 categorised the Spotted Thick-knee as "Least Concern" because of their extensive distribution, with stable numbers of populations assumed as there was no indication of population decrease throughout the species native range (BirdLife, 2016). Although, in the years since 2016, human populations and anthropogenic processes such as urbanisation have increased. South Africa is one such region with this increase in development but has also seen an increased presence of Spotted Thick-knees across urbanised landscapes. However, based on the changes between historical and current records, the present study has highlighted a trend of an overall decrease in species abundance for the region. The Spotted Thick-knee may have been categorised as "Least Concern" in 2016 but designation to this category should be re-evaluated, especially since the large-scale change in distribution range and abundance in South Africa, a region of Spotted Thick-knee native range.

2.6 Acknowledgements

We are grateful to numerous members of the public who kindly volunteer for SABAP year after year and to the founders of SABAP1 and SABAP2. We thank the National Research Foundation (ZA) and the University of KwaZulu-Natal (ZA) for funding.

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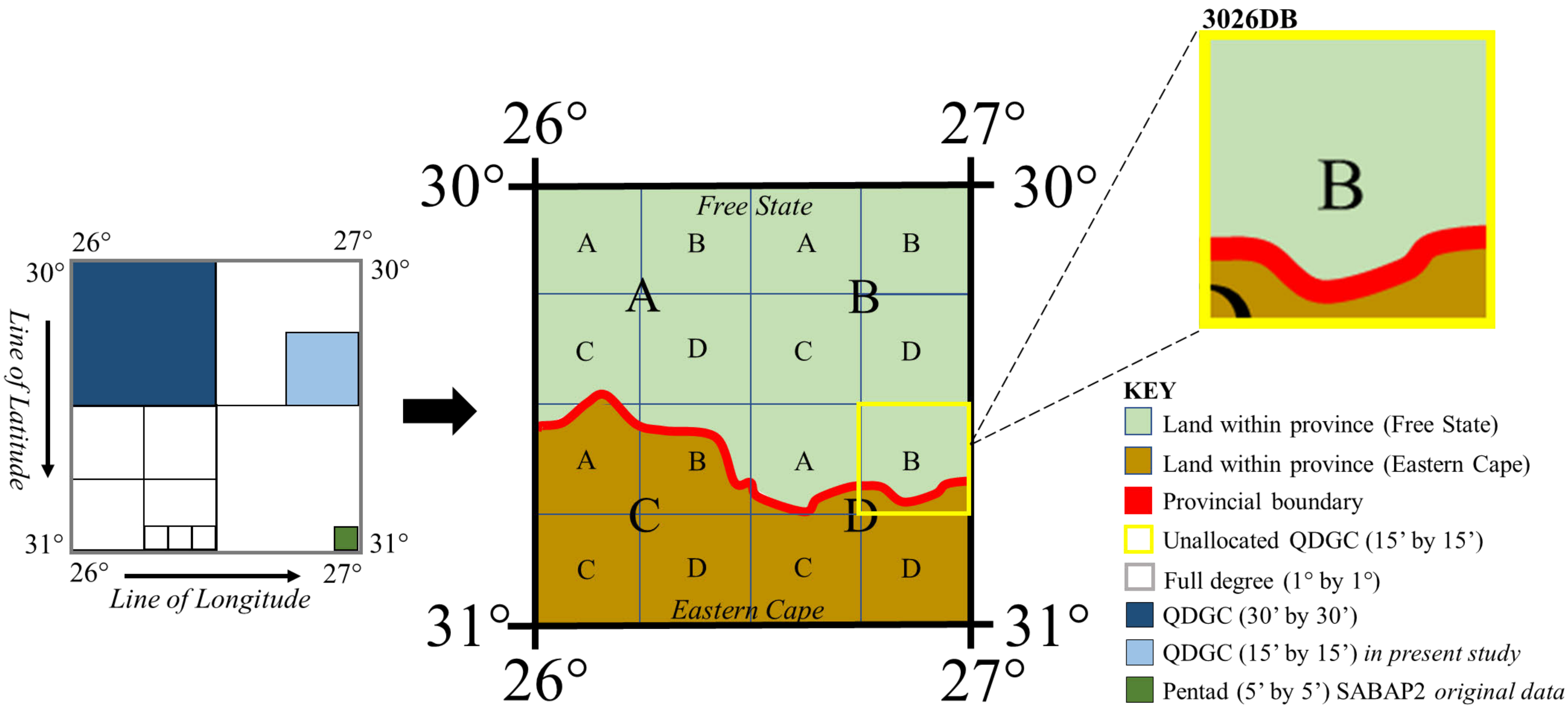
2.8 Supplementary information

Supplementary information Table S2.1: Total number of quarter degree grid cells (QDGC) for South Africa, Lesotho and the provinces of South Africa. The total number of cells were separated accordingly. Cells showed an increase ($C > 1$ or new record), decrease ($C < 1$ or absent record), no change or stable ($C = 1$). Some cells were invalid (checklists < 4) for purposes of the study, and the rest were either unsurveyed or had no record of Spotted Thick-knee sightings in both SABAP1 and SABAP2.

Area	**Number of QDGC**	**Increase**		**Stable**	**Decrease**		**Other**		
		***C* > 1**	**New record**	**No change (*C* = 1)**	***C* < 1**	**Absent**	**No record**	**Invalid**	**Unsurveyed**
National level									
Lesotho	52	2	1	0	2	2	30	15	0
South Africa	1929	312	260	6	694	257	217	142	41
Provincial level									
Eastern Cape	255	48	30	0	101	34	19	23	0
Free State	226	58	29	1	104	27	6	1	0
Gauteng	38	16	0	0	22	0	0	0	0
KwaZulu-Natal	153	12	8	0	74	31	23	2	3
Limpopo	179	22	28	1	73	25	13	4	13
Mpumalanga	117	36	4	0	61	13	1	1	1
Northern Cape	587	54	116	4	97	77	121	102	16
North West	153	19	20	0	52	34	12	8	8
Western Cape	221	47	25	0	110	16	22	1	0



Supplementary information Figure S2.1: Schematic diagram showing quarter degree grid cell (QDGC). Study allocation if a QDGC (15' by 15') was unallocated in raw data from Southern African Bird Atlas Project (SABAP). For example, the QDGC labelled '3026DB' was unallocated (yellow outline) and has the Free State and Eastern Cape Province within the cell area, separated by a provincial boundary (red line) within the cell. For the purpose of this study, QDGC '3026DB' is allocated to the Free State (shaded green) because more of the area within the cell is part of the Free State Province compared with the area that is part of the Eastern Cape Province (shaded brown).

CHAPTER 3

Presence of the Spotted Thick-knee across the urban landscape of Pietermaritzburg, South Africa, and the resulting human-wildlife interactions

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Running header: Presence of Spotted Thick-knees across an urban landscape

3.1 Abstract

Urbanisation has led to increased infringement on numerous bird species' natural habitat, which has more often than not, resulted in the loss of certain bird species in a localised area. In attempts to persist, some species are faced with increased intensity of natural pressures or encounter novel pressures. Depending on the species, they may experience human-wildlife interactions that benefit their survival or human-wildlife conflicts that put their survival at risk. The Spotted Thick-knee (*Burhinus capensis*) is one such species with a suggested increased presence in urbanised areas of South Africa. Our study's objective was to assess human-wildlife interactions that result from the presence of Spotted Thick-knees across the fragmented and human-modified landscape of Pietermaritzburg KwaZulu-Natal. We conducted presence-only surveys at 52 locations between July 2019 and December 2020. These locations were discovered through active surveying and public participation. Newspaper articles were distributed in June 2019, with requests for information regarding Spotted Thick-knee sightings. Furthermore, questionnaires were sent to respondents to collect qualitative information regarding their perception of the species in Pietermaritzburg. Results from the Spotted Thick-knee monthly-presence study suggest that their occurrence at known locations was not random with Spotted Thick-knee present at 30 out of 52 sites for more than 75% of the number of months in the study period; and the movements of individuals and/or pairs could be seasonally influenced as there were less sites with Spotted Thick-knee present during known non-breeding months compared to breeding months. Questionnaire feedback highlighted the species response, or lack thereof, to novel pressures associated with persistence in human-modified habitats.

Keywords Spotted Thick-knee • Urbanisation • Questionnaire • Human-wildlife conflict • Resident population • Novel pressures

3.2 Introduction

The human global population numbers have increased significantly in the past 50 years, necessitating greater development and expansion of human settlements (da Silva and Gouveia 2020). Due to innovation and technological advances, it has become much more efficient to build infrastructure resulting in quicker urban growth of the development area (Goi 2017; da Silva and Gouveia 2020). Most large-scale developments have taken place in urban areas, which generates population growth in the urban area. For example, a developing city may attract humans from the surrounding rural or less developed for better living opportunities (rural-urban migration), which could create overcapacity if the city does not keep expanding (Tacolu et al. 2015; da Silva and Gouveia 2020).

Urbanisation is spreading globally at an alarming rate and cities typically require vast amounts of land and resources which comes at the expense of the natural environment and the fauna and flora that were the original inhabitants of the area (Sol et al. 2014; Ibáñez-Álamo et al. 2017; da Silva and Gouveia 2020). Numerous studies have shown that the processes of anthropogenic land-use change and land-cover change are some of the greatest threats to biodiversity (Cohen 2006; Chiron et al. 2008; Aronson et al. 2014; Seress and Liker 2015; Sirami et al. 2016; Ibáñez-Álamo et al. 2017; Litteral and Shochat 2017; Hersperger et al. 2018; Albert 2020). These processes are not solely linked with urbanisation and built-up areas but are outcomes of any anthropogenic development or activity that has to do with a change in the landscape (Chiron et al. 2008; Hersperger et al. 2018). By the continuous destruction of the natural environment, ecosystems have collapsed, and numerous fauna and flora species have become extinct, which will create further global change that will negatively impact our survival (Chiron et al. 2008; Hersperger et al. 2018). However, the continuously developing anthropogenic environments (e.g., cities) offer valuable urban ecological study opportunities, especially because of the different anthropogenic land-uses and land-cover changes that take place and the resulting impact on the natural environments in a localised area (McCleery et al. 2012; Litteral and Shochat 2017). There are some instances whereby urban areas allow for ecosystem functioning although, it is not as complex compared with a natural ecosystem (Alberti 2005; Kowarik 2011; McCleery et al. 2012; Fournier et al. 2020). Some of these altered landscapes generally have a mix of anthropogenic and natural elements creating an urban mosaic-like environment that offers opportunities for persistence and survival to certain species (McCleery et al. 2012; Fournier et al. 2020; Downs et al. 2021). Some city landscapes have green spaces between built-up areas that can act as ecological corridors and gardens within residential suburbs can provide suitable habitat or facilitate natural predators' access (McCleery et al. 2012; Widdows and Downs 2017).

For animal species that persist with increased urbanisation, they generally show behavioural plasticity to persist and survive (Peterson et al. 2007; Norton et al. 2016; Bradsworth et al. 2017; Barot et al. 2019; Rivkin et al. 2019; Downs et al. 2021). Evidence suggests that mobility, behavioural plasticity and body size are key aspects that influence a species fitness in an urban area (Peterson et al. 2007; Lowry et al. 2013; Norton et al. 2016; Bradsworth et al. 2017; Barot et al. 2019; Rivkin et al. 2019; Fournier et al. 2020; Downs et al. 2021). Species that are more plastic in terms of their diet and habitat selection, typically are more tolerant to changes within a wider range of environmental and climatic conditions. They have greater chances of survival than species that are less tolerant and more specific in their diet and habitat (Peterson et al. 2007; Lowry et al. 2013; Norton et al. 2016; Bradsworth et al. 2017; Barot et al. 2019; Rivkin et al. 2019; Fournier et al. 2020; Downs et al. 2021). Larger animals such as various mammal species are more vulnerable because of their greater resource and habitat requirements than animals much smaller in size (Lowrey et al. 2013; Norton et al. 2016; Widdows and Downs 2017; Fournier et al. 2020; Downs et al. 2021). It is because of these differences mentioned above that for most animal communities present in urban areas comprise of either: small to medium reptile species; small mammal species (rarely medium-sized species), insect species; and bird species. These species have to not only deal with their natural pressures such as predation or competition for resources but also conditions that escalate their natural pressures (e.g., decrease in suitable habitat or preferential resources resulting in increased competition) or newfound anthropogenic pressures such as harmful environments with urban pollutants or human-wildlife conflict (Bonnington et al. 2015; Soulsbury and White 2015; Goddard et al. 2017; Kekkonen 2017; Fournier et al. 2020; Downs et al. 2021)

It has been of increasing importance that for some urban-dwelling species, studies should consider the public observations and perceptions by the human inhabitants and any information regarding close interactions or conflict with the study species (Soulsbury and White 2015; Goddard et al. 2017; Downs et al. 2021). This approach is important, especially for bird species in urban areas because they could be possible vectors of diseases such as Avian Influenza (bird flu) and/or carriers of parasites such as the pigeon tick (*Argas reflexus*), making them health risks to the unaware public who may interact too closely with the species (Haag-Wackernagel 2005; Soulsbury and White 2015; Goddard et al. 2017).

Information on human-wildlife interactions in urban areas is necessary for the conservation of bird species, especially those with greater terrestrial dependence for their survival, such as ground-nesting species and flightless species belonging to the paraphyletic group 'ratites' (e.g., order: Struthioniformes) (Roots 2006; Rico-Guevara et al. 2019; Tobajas et al. 2020). These species are more vulnerable in urban areas because they are more dependent on the land for significant life cycle stages (e.g., breeding, nesting etc.). Recently in some countries, there has been an increase in sightings of some ground-nesting species in urban areas, but there is a lack of knowledge in the existing literature of such species in an urban ecological context. In South Africa, the Spotted Thick-knee (*Burhinus capensis*) is one such species that has shown an increased presence in urban areas although there has been no investigation of why this is so (SABAP2 2021; Josiah and Downs unpublished data).

Our study aimed to investigate Spotted Thick-knees' presence in Pietermaritzburg, South Africa, and assess human-wildlife interactions resulting from their presence. We collected information on human-wildlife interactions and public perceptions of Spotted Thick-knees from the city's human inhabitants. With increasing urbanisation and infringement on their natural habitats, it is important to investigate ecological factors such as their occurrence in urban areas and their response to newfound risks that stem from persisting in an anthropogenic environment.

3.3 Methods

3.3.1 Study species

The Spotted Thick-knee (order: Charadriiformes) belonging to the Burhinidae family is a nocturnal bird species native to Africa. Of the two subspecies that are found in South Africa, *Burhinus c. capensis* is the only one found in the KwaZulu-Natal Province (Hume et al. 2019; SABAP2 2021). The species is categorised as "Least Concern" on the IUCN red list from 2016, but there needs to be an update to determine the current status of the species in terms of population numbers (BirdLife International 2016, 2021). Although it is classified as a shorebird, which are species with distributions generally close to coastlines and aquatic environments, viable populations are located much further inland as well even to the extent of occurring in relatively dry environments like savanna and desert biomes (Hockey 2005; Hume et al. 2019; SABAP2 2021). They are commonly observed whilst on the ground although they can fly well and are considered mostly a resident species, but nomadic groups from resident populations have been identified (Hockey 2005). In South Africa, this ground-nesting species has a known breeding period from August to April the following year (Hockey 2005; Tarboton

2014; Hume et al. 2019). The species diet mostly consists of invertebrates, but they also consume small mammals and/or reptiles (Hockey 2005; Hume et al. 2019). In recent times, this species has been observed in a range of anthropogenic land-use areas from rural farming lands to more anthropogenically influenced environments, such as highly developed residential suburbs and even areas where there is limited vegetation and greenery (BirdLife International 2016, 2020; Hume et al. 2019; pers. obs.).

3.3.2 Study area

Our study was conducted in KwaZulu-Natal Province, South Africa. The focus area was the city of Pietermaritzburg and surroundings (within 15 km of the city perimeter) because of pilot observations indicating that the study species was present in neighbouring villages such as Ashburton. The geographic coordinates for Pietermaritzburg are: 29°37’04” S, 30°23’57” E and the city is located in the Msunduzi Local Municipality within the uMgungundlovu District Municipality. Pietermaritzburg is the capital city as well as the second-largest city in the KwaZulu-Natal Province, both in terms of geographic size (area = 126.2 km^2) and human population (~531,990 inhabitants as of 18 January 2021) (United Nations 2021).

Regarding the natural landscape of the city, there are small areas or patches of thicket in a few locations, but the landscape is largely made up of the Savanna biome with some areas situated in a Grassland biome region (Mucina and Rutherford 2006; Jewitt 2018). Topographically, the city is situated in the Msunduzi River valley at the bottom of an escarpment (Bordy et al. 2017). The region generally experiences warm-to-hot summer temperatures with frequent rainfall and dry winters with high diurnal temperature variation (Nel 2009; Thabethe and Downs 2018). The vegetation composition, topography and subtropical climate zone are the major factors that contribute to the area's suitability as a habitat for several wildlife species, particularly bird species (Thabethe and Downs 2018).

The city's zoning is a mix of old and new developments that have created a unique mosaic of housing, industrial and business infrastructure, rural and green spaces. Housing ranges from informal settlements to residential suburbs consisting of properties with no gardens and no vegetation; properties with small gardens and limited vegetation; and properties in high-income suburbs with large garden spaces and various vegetation types. Industrial and business zones are generally vegetation-absent areas, although some places may have small gardens or a few trees present. However, Pietermaritzburg has several natural and maintained green spaces including areas of relatively large patches of natural vegetation and greenery, parks and gardens (e.g., the Hesketh Conservancy area). Some of these areas form potential natural or human-made greenbelts and/or ecological corridors for those species still present in and around the city. Pietermaritzburg's continuous urban developments and growth have allowed the public to identify the Spotted Thick-knees more easily within the fragmented landscape (pers. obs.).

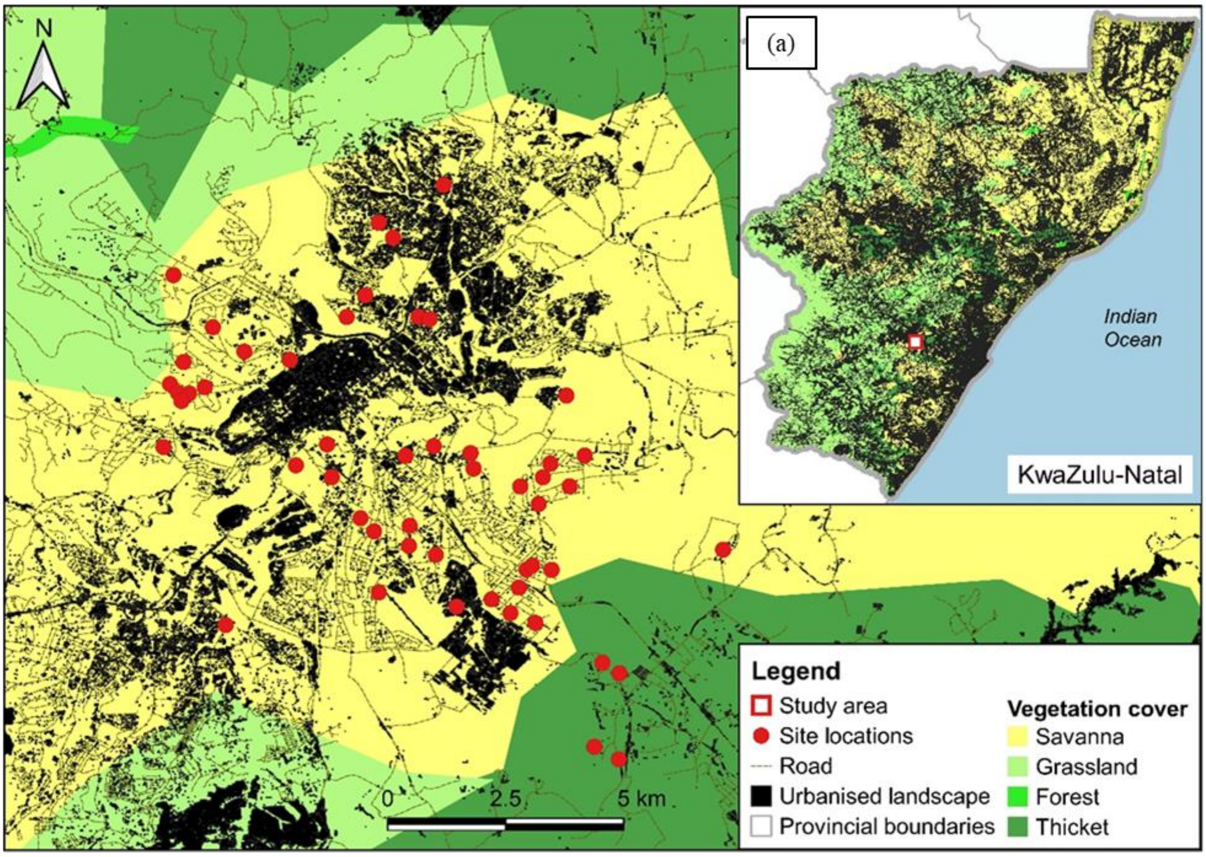

Fig. 3.1 Spotted Thick-knee site locations (*n* = 52) included in the present study, across the urbanised landscape of Pietermaritzburg and (a) the study area in KwaZulu-Natal Province, South Africa.

3.3.3 Data collection- Presence across the landscape

We identified Spotted Thick-knee locations in Pietermaritzburg using two methods of approach during 2019 and 2020. Our first approach consisted of pilot observations carried out between 1 April 2019 and 30 June 2019 in public spaces and other accessible spaces across the city landscape at areas where the study species could have potentially been found or was sighted before the study commenced. The potential locations, environments and conditions for the presence of individuals/groups/populations of the study species were based on current knowledge in existing literature and before-study observations of already identified locations of individuals/groups of the study species. The potential locations were first identified using

Google Earth (Version 7.3.2) followed by actively surveying those identified areas to ground truth them and visited any other areas of possible Spotted Thick-knee occurrence whilst carrying out field surveys. We conducted these surveys during the day between 08h00 and 17h00 when Spotted Thick-knees were least active in terms of movement. We did this until all publicly accessible areas of Pietermaritzburg were surveyed. The geographic locations of identified Spotted Thick-knees were recorded using a Global Positioning System (GPS) and tabulated in a Microsoft Excel Spreadsheet. From this approach, 26 site locations were found by the start of the study field sampling on 18 July 2019.

Our second approach utilised citizen science through public participation in the form of a newspaper article request for any geographic locations and/or information on Spotted Thick-knees' sightings by the public (Supplementary Material S3.1). The article was distributed to the public in the first week of June 2019, in newspapers delivered throughout Pietermaritzburg and surrounding areas, often for free. There was a total of 178 respondents to the article, but three respondents gave sighting information for locations outside the study area and therefore excluded from data collection and data analyses. Some participants gave multiple locations for Spotted Thick-knee sightings and there were a few data points that were duplicated, in terms of the general area where the Spotted Thick-knee were sighted. Through this approach, we identified 61 geographic locations of potential Spotted Thick-knee presence in the study area, but after ground-truthing locations and vetting reports of sightings from respondents, we excluded 20 geographic locations from further data collection and analyses. We excluded these locations in the study because they were locations where Spotted Thick-knees had not been seen for more than 10 years; urban development had taken place at a large scale, and there was no natural landscape within 75 m radius of the site GPS location; private properties that denied access when asked for permission; and sites with a false report resulting from the respondent incorrectly identifying the bird species they sighted as a Spotted Thick-knee or the eggs of other ground-nesting species (e.g., Crowned Lapwing (*Vanellus coronatus*)) as Spotted Thick-knee eggs.

We combined the 26 locations obtained using the first approach with 41 locations from the second approach giving a total of 52 locations because some sites were found through both approaches resulting in duplications. We visited 47 sites from July 2019 to December 2020; while 1 site was visited from September 2019 to December 2020; 2 sites were visited from October 2019 to December 2020; 1 site from November 2019 to December 2020; and 1 site from January 2020 to December 2020. These five sites were not visited from the start because respondents contacted the study investigator after the commencement of field data collection. No field data collection took place during the months of March 2020, April 2020 and May 2020 because of South Africa's National Lockdown Regulations in response to the COVID-19 global pandemic.

We visited sites at least once month, but if the study species was not present during the first monthly visit, the site was revisited for a maximum of four further visits on temporally randomised days to get a recording for that specific month. If at least one Spotted Thick-knee was observed during a visit, the site location was recorded as 'present' for that month and recorded as 'not present' if there was no observed presence of the study species after five monthly visits. The duration spent at each site was a maximum of 15 min. If the study species was not found at the site at the end of the 15 min., it was recorded as 'not present' for that respective visit. The study species had mobility and was not expected to be at the exact same place as the original sighting. Therefore, a maximum radius distance of 75 m from the original GPS location (as the centre reference point) where the species was first observed, was used to determine whether the study species was still present in that relative location. 100 m was the maximum distance the observer could clearly see and accurately identify the study species. However, in some cases, it was impossible to clearly see the surroundings at 100 m for a full

360° view because of obstruction of sight by obstacles such as buildings, walls and trees etc. It was unavoidable that for some sites on private properties, access was limited to an area less than 75 m radius from the original GPS location. Sites within the same suburb or in relatively close distance were visited on the same day to reduce the possibility that the same individuals were seen at different locations within the assumed movement range of the study species.

3.3.5 Public perceptions of the Spotted Thick-knee

A questionnaire (Supplementary Material S3.2) was distributed to members of the public or institutions that responded to the newspaper articles and requested geographic information on the study species. Ethical permission for the use of questionnaires for respondents was approved by the University of KwaZulu-Natal Humanities and Social Sciences Research Ethics Committee (Protocol number HSSREC/00000865/2019) following the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration as revised in 2013. Of the 175 valid responders to the newspaper article, 144 completed and returned the questionnaire. The responses from the questionnaires were tabulated in Microsoft© Excel.

3.3.6 Data analyses

We analysed all data using IBM SPSS© Statistics version 27 (SPSS Inc., Chicago, USA). Non-parametric tests, in conjunction with descriptive statistics, were used because of the exploratory nature of the study and the sampling of count data.

We used a Wald–Wolfowitz Runs test, with the corresponding exact value, to determine whether sightings at all visited locations over the study period were random or not. The binary cataloguing of the data with Spotted Thick-knee ‘present = 1; absent/not present = 0’ was suitable for such analyses. A user-defined value of ‘0.5’ was set for the test because the use of the median, mean or maximum values would not be statistically appropriate for binary formatted data. This also allowed for the inclusion of locations that were reported in 2019 after the first month of field visits because the test results would not be compromised by locations where data were not collected over the full period of study. Chi-square tests were used to compare the number of sites with presence/no presence, for the same months but in different years to determine whether there were significant yearly changes.

We recorded the number of reports for each response as a percentage of all valid reports. Not all responses to questions were analysed because we felt that some questions were extraneous to this study. However, the investigator's responses to these questions or lack thereof were examined as they may have been related to responses of questions that were of interest. Descriptive statistics were reported for novel trends or already-known aspects which could be supplemented by existing literature. We highlighted the reporting of injuries or deaths of Spotted Thick-knee separately from other responses because most of them were recorded under "additional comments" or reported separately through email or phone calls. These reports were labelled as 'incidence(s)' and collected from both respondents that completed questionnaires and those that did not. Some participants reported more than one incidence and/or incidences with different causes of injury or death to Spotted Thick-knees. A total of 216 incidences were reported, which were separated according to the cause of incidence. An incidence was grouped according to the known specific cause (domestic dog (*Canis lupus familiaris*), domestic cat (*Felis catus*), motor vehicle, pool drowning); general category of cause (wild animal); and unknown cause (including reports where the cause of injury or death was 'speculated').

3.4 Results

3.4.1 Presence across the landscape

Although the sampling method for site visits was randomised, the presence of Spotted Thick-knee at locations throughout the months included in the study was not random (Wald–Wolfowitz Runs test $z = -2.454$; $p = 0.016$). Of the sites, 7.9% ($n = 4$) had at least one Spotted Thick-knee present during all months of visit, 51.9% ($n = 27$) had the study species present during 75% to 100% of total months visited, 34.6% ($n = 18$) had the study species present during 50% to 74.9% of the total months visited and 5.8% of sites ($n = 3$) had the study species present during less than 50% of total months visited (Fig. 3.2).

November 2019 had 92.0% of sites ($n = 46$) with the study species present, which was the highest for all months within the study period that had data collected. July 2019 had 55.3% of sites ($n = 26$) with the study species present, which was the lowest for all months within the study period that had data collected (Fig. 3.3).

There was a significant difference in the number of sites with the presence of the study species in November 2019 ($n = 46$) which was greater than the number of sites with a presence in November 2020 ($n = 38$) ($\chi^2 = 6.28$; df = 1; $p < 0.012$). There was a significant difference between December 2019 ($n = 45$) which had a greater number of sites with the study species present compared with sites indicating presence in December 2020 ($n = 34$) ($\chi^2 = 7.53$; df = 1; $p < 0.05$). There were no other significant differences between the same months in different years.

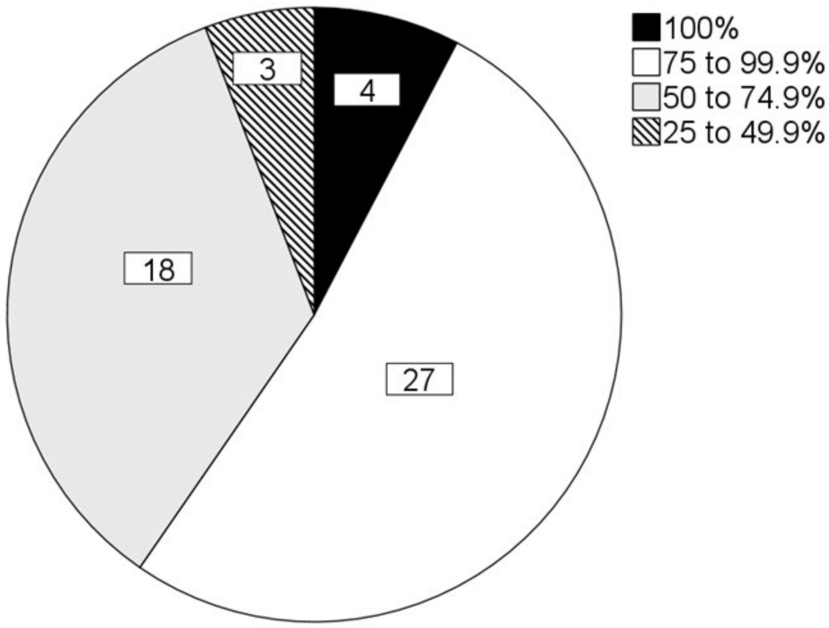

Fig. 3.2 Total number (*n* = 52) of Spotted Thick-knee site locations grouped according to the percentage of months for each site where the study species was present. (The percentage was calculated by dividing the number of months that a site was visited by the number of months with presence recorded for that site and then multiplying the value by 100).

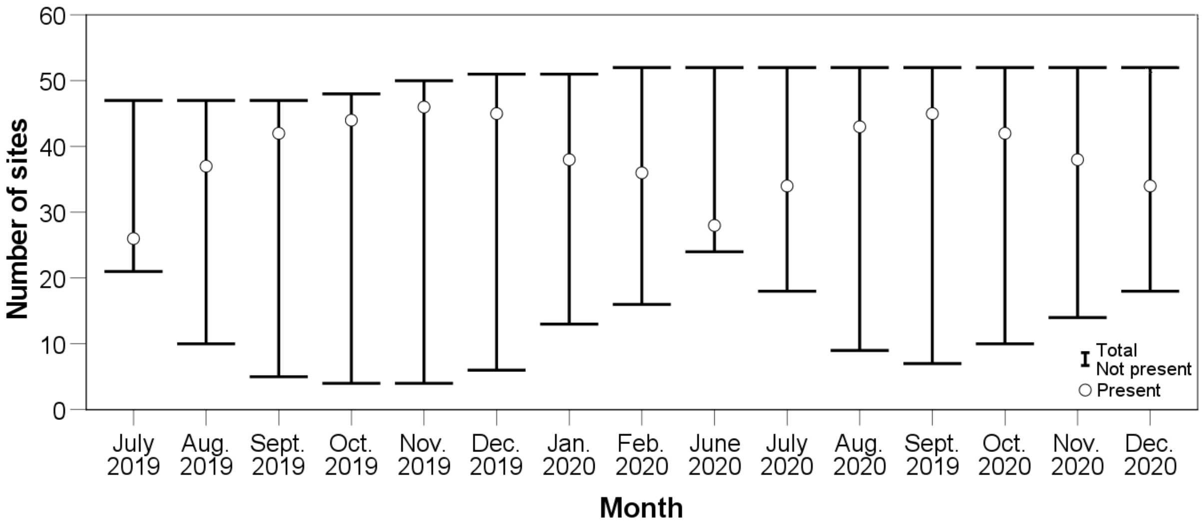

Fig. 3.3 Number of sites with Spotted Thick-knees 'present' or 'not present' in the present study, relative to all site locations visited for each month. (The top-whisker indicates the total number of sites visited for each month; bottom-whisker indicates sites with study species not present, and the white dot (○) in the bar indicates sites with study species present).

3.4.2 Public perceptions of the Spotted Thick-knee

Most public participants (n = 118; 81.9%) had detected or observed Spotted Thick-knees in the afternoon (12h01–18h00). Spotted Thick-knees were most commonly seen in pairs (n = 107; 74.3%; Table 3.1). Spotted Thick-knees were most commonly observed standing or sitting still on the ground (n = 125; 86.8%; Table 3.1). Regarding conflict, public participants had mostly observed Spotted Thick-knee being threatened and preyed on (n = 76; 52.8%; Table 3.1).

A total of 216 incidences were reported regarding causes of injury or death to Spotted Thick-knees with 27.8% of reports domestic dogs (n = 60); 19.0% of pool drownings (n = 41); 17.6% of unknown causes (n = 38); 13.4% of wild animals (n = 29); 12.5% of domestic cats (n = 27); and 9.7% of motor vehicles (n = 21) (Fig. 3.4).

Table 3 Number of valid responses for each question from the total number of questionnaires (n = 144) completed and returned by public participants in the present study. Frequency of responses is expressed as percentages.

Category	Number of valid responses	Frequency of responses as a percentage (%)
Detection		
Morning (06h01 – 12h00)	85	59. 3
Afternoon (12h01 – 18h00)	118	81.9
Evening (18h01 – 24h00)	36	25.0
Night-time (24h01 – 06h00)	20	13.9
Number of specimens (all-at-once)		
1 (Alone)	60	41.7
2 (Pair)	107	74.3
3-5	40	27.8
6-10	9	6.3
11 or more	2	1.4
Activity		
Feeding	29	20.1
Staying still	125	86.8

Nesting	65	45.1
Other: walking/running	97	67.4
Conflict		
Attack	26	18.1
Preyed on	76	52.8

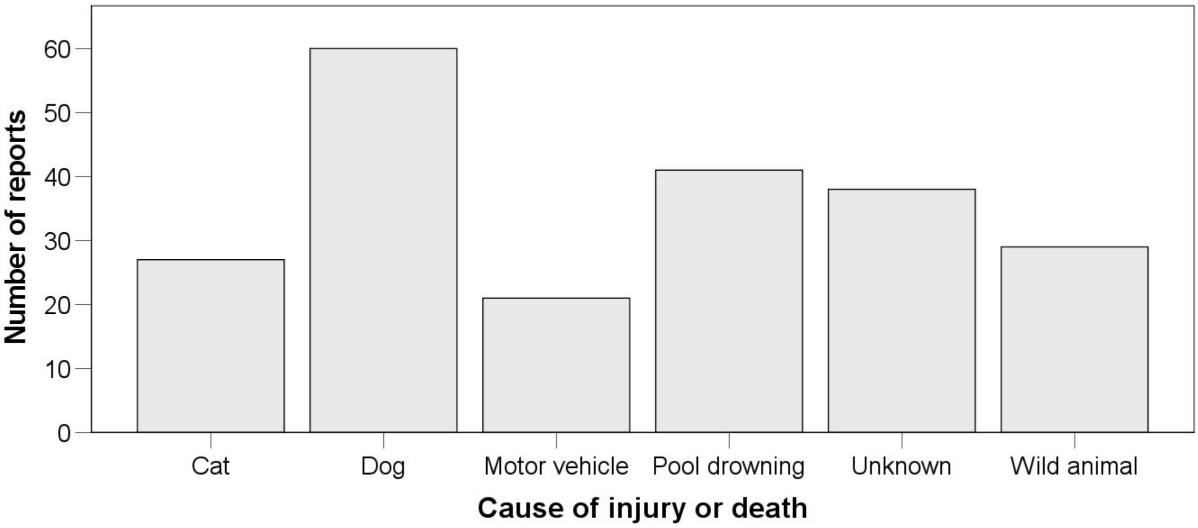

Fig. 3.4 Number of reports for causes of injury or death to Spotted Thick-knees in the present study, as observed by public participants that completed questionnaires or reported incidents through other communication.

3.5 Discussion

Findings from presence-only analyses revealed that Spotted Thick-knee occurrence at study sites was not random and that most Spotted Thick-knees were present at those sites for at least 75% of months visited. The individuals or family groups within this study likely belonged to a resident population. Their limited movement is supported by existing literature for populations within this part of South Africa, where it has been suggested that they are mostly sedentary with a few individuals in a population that may be nomadic, and that they rarely move around during the breeding season (Maclean 1993; Hockey 2005).

Our study was constrained by insufficient data collected during the non-breeding season, which coincided with South Africa's National Lockdown Regulations in response to the COVID-19 global pandemic. However, the four months with the lowest number of the species present at sites was July 2019, February 2020, June 2020, July 2020. It is no coincidence that June falls within the non-breeding season; July falls within the beginning of the breeding season, and February falls within the later period of the breeding season. These periods are suggested to have greater movement of Spotted Thick-knees compared with months within the middle or 'peak' of the breeding season that takes place sometime between September and December within the same year (Tarboton, 2014). Most sites surveyed had Spotted Thick-knees present for at least 75% of the number of months that each site was visited. This further supports the knowledge that they are a mostly sedentary species and their residential behaviour within Pietermaritzburg and surroundings.

In some instances, the movement of individuals was observed in residential areas whereby they were found in a private property in the initial month and the neighbouring private property in the following month (pers. obs.). This was not unexpected as the species is mobile and capable of flight, but no event took place where the individual or group was originally in a residential garden and then observed to be in an open area within the site area. Although the detection of Spotted Thick-knee in these locations was more difficult, this trend suggests that residential gardens' occupancy offers resources or some form of benefit to these individuals or groups. This trend was corroborated by Josiah and Downs (unpublished data; Chapter 4) in their study of Spotted Thick-knee nesting across an urban landscape, which showed that residential areas, specifically gardens, were preferred by breeding pairs and had a higher rate of successful nesting attempts compared with other land-use areas. Although Spotted Thick-knees are nocturnal, no inference could be made on their movements during this period because direct observations were only carried out during the day. However, it is not likely for movement of this species to be at a significantly greater distance at night only to return shortly during the day, because this would be of high energy cost and their sedentariness requires them to occupy areas relatively close to resources and nest sites (Brown and Downs 2003, 2004).

We made no observations of more than five Spotted Thick-knees at any one site during a single visit. This is relatively common when breeding pairs separate from large flocks of up to 50 individuals as the breeding season approaches (Maclean 1993; Hockey 2005). Although observations were only carried out for one month in a non-breeding season, even then, there were no instances of more than five members in a group. Hatchlings and immature or sub-adult individuals were observed during the course of the study (pers. obs.). However, not all sites had a pair of Spotted Thick-knee present, nor was there evidence of breeding and nesting behaviour at all sites where there were two Spotted Thick-knee for more than one month. At some sites, hatchlings and/or immature adults had not been detected or a smaller number of them had been detected at each site during further visits, although site visits were within a time period where it was known that they would still be with the breeding pair. This trend suggested a loss of life for these individuals which is not uncommon for precocial species as they are considered to experience the most risk to their survival within the first few months or first year of hatching (Brown and Downs 2003, 2004).

Regarding human perceptions, Spotted Thick-knees were most commonly seen or heard during the afternoon, followed by the morning period. Although they are more easily detected during the daytime, most participants observed them sitting or standing still, which was indicative of their inactivity and limited long-distance movements during the day. There was little mention of Spotted Thick-knees flying. This may be because when they do fly, it is at a height too great for them to be noticed easily, but it also emphasises their known behaviour of spending more time on land. They were most commonly observed in pairs and sometimes alone. They were rarely observed in family groups. This could be because the young are cryptic and generally hidden within taller grass or bush-area to prevent detection. Only two respondents observed them in groups of more than six members with the largest group having 12 members. These numbers are still much lower than reported in existing literature, with flocks as large as 50 members in non-breeding seasons (Maclean 1993).

Feeding by Spotted Thick-knees was observed, but the actual object consumed was rarely identified by respondents. Their feeding action was commonly described as the individual moving ‘forward, pausing, pecking at the ground’ and then repeating the process. For instances where it was difficult to tell what was consumed because of the object being incredibly small-sized, possibilities include small invertebrates and grass seeds (Hockey 2005; Hume et al. 2019). Supplementary feeding attempts of Spotted Thick-knee were reported although relatively rarely. Items offered and consumed included: cheese; rice; and shredded pieces of roast chicken (*Gallus gallus domesticus)* (pers. comm.). This type of supplementary feeding was found to be common for African woolly-necked storks (*Ciconia microscelis*) in suburban areas of KwaZulu-Natal (Thabethe and Downs 2018). It was also reported by some respondents that bowls of water were placed for them on extremely ‘hot’ days or they used to ‘bath’ and drink from the pool, water fountains or garden ponds*)* (pers. comm.). One respondent used to set up a water sprinkler which they would drink or ‘bath’ from*)* (pers. comm.). Over time this led to the Spotted Thick-knee pair or family group waiting by the sprinkler on hot days (pers. comm.). Visual footage of this novel behaviour can be downloaded from or viewed at:

https://drive.google.com/file/d/1GXQ4js0veiKmrd0PBZvTEHCq3V6xovs8/view?usp=sharing.

Feedback through both the interactions and additional comments sections of the questionnaire highlighted some of the conflicts and threats faced by Spotted Thick-knee persisting in urban areas. Spotted Thick-knees were reported to be aggressive, especially during the breeding season around nest sites, and were observed to spread their wings wide and screech loudly whilst moving towards the perceived threat or in a direction that would take the perceived threats attention away from the nest as previously documented (Hockey 2005; Tarboton 2014; Hume et al. 2019). There was no mention of another common defensive behaviour of theirs whereby the adult(s) act as if they are injured or have a broken wing to attract the danger away from their nest sites or hatchlings. The most commonly observed threat to Spotted Thick-knees were domestic pets, specifically domestic dogs. Domestic cats were less observed as threats in reports of conflict, but this could be attributed to them being crepuscular and sometimes showing peak activity at night-time (Long et al. 2020). It is possible that many interaction events between Spotted Thick-knees and cats were not observed. This is supported by an additional comment from a respondent with the following statement: “In the morning I found the dead bird with scratches on the body, it looked like a cat attacked it as I heard its distress call followed by a cat screeching” (pers. obs.). At a global scale, domestic cats and dogs have both been frequently mentioned as predation threats faced by wildlife occurring in human-modified habitats, especially birds (Long et al. 2020; Luna et al. 2021).

Pool drownings were reported for Spotted Thick-knees with most drowning incidents being that of hatchlings and juveniles (pers. comm.). Spotted Thick-knee adults and hatchlings were reported as casualties of road-kill incidents. Unknown injuries included hatchlings, sub-adults, and adults found dead or injured, but the cause was not mentioned from the public response. Relatively few instances of wild animal interactions were observed with vervet monkeys (*Chlorocebus pygerythrus*) being the most common species reported. Still, it was noted that in a few cases around the same neighbourhood, incomplete Spotted Thick-knee carcasses had been found. It was known that the area was inhabited by a breeding pair of Spotted Eagle-Owl (*Bubo africanus*) (pers. comm.).

Urban persistence has allowed some species to limit predation from their natural predators because these areas may be inaccessible to such predators which are generally much larger in size, making it difficult to inhabit urban areas (Manton et al. 2019). However, studies have shown an increased urban presence for some raptor species in South Africa, such as the Verreaux's Eagle (*Aquila verreauxii*) (Symes and Kruger 2012); Peregrine Falcon (*Falco peregrinus*) (Altwegg et al. 2014); Black Sparrowhawk (*Accipiter Melanoleucus*) (Rose et al. 2017); and Crowned Eagle (*Stephanoaetus coronatus*) (McPherson et al. 2019; Downs et al. 2021). The raptor species within the study area included natural predators of the Spotted Thick-knee such as the Verreaux's Eagle and Spotted Eagle-Owl, although their abundance and specific habitats are not fully known. Their presence suggests that some of the Spotted Thick-knee population in the study area are at risk from predation by unnatural and natural predators.

Many respondents highlighted the enjoyment Spotted Thick-knees gave them and how they appreciate and value the birds, especially in their gardens (pers. comm.). Bird species in gardens or green spaces in urban areas have been frequently mentioned as providers of calmness and joy to the humans that witness them. This has recently been quantified in the study by Methorst et al. (2020), where the study investigators related avian species richness to daily: productivity; happiness; and satisfaction, in participants of the study, which was conducted in Europe. Their findings highlighted the immaterial value of species to human wellbeing, and it is suggested that the findings will be more prominent in regions with greater avifaunal diversity, such as South Africa.

However, this association appreciation is not the same for everyone. A few respondents mentioned that the bird is a food resource in some areas, although it is not consumed as frequently as before (pers. comm.). This is no surprise as Spotted Thick-knee were previously considered game bird as documented by Maclean (1993), but their designation within this category has recently been removed (Hockey 2005; Hume et al. 2019). Three respondents expressed frustration towards them because of their loud calls in the night or early morning hours before sunrise. A few respondents showed distaste or know other members of the public who dislike the species to the point that they have shot and killed the individuals they have found in their gardens (pers. comm.). Others expressed caution towards the species and try to chase them away from their properties with mention of the species being ‘bad luck’. This has been documented in the Zulu traditional culture whereby Spotted Thick-knee are called ‘umbangaqhwa’ which means ‘causer of frost’ and their appearance at a location is associated with trouble (Msimang 1975). South Africa is a diverse country with inhabitants of various cultures and traditions. Therefore, it is important to gain insight into these social factors because they could prevent the species from occupying potentially suitable habitat.

3.5.1 Conclusion

From this study of the Spotted Thick-knee population across Pietermaritzburg's urbanised landscape and surrounding areas, it was evident that the studied individuals/groups were a part of a resident population and their presence at select areas was not random. Spotted Thick-knee showed frequent inhabitancy of human-modified habitats such as gardens. All factors that could lead to conclusive reasoning for this trend could not be investigated within this study timeframe. However, feedback from citizen science data has provided some possible explanations. Select areas provide suitable habitat for nesting as well as access to resources both natural and unnatural (i.e., supplementary feeding). These areas may also provide safety from natural predators. However, the risks to Spotted Thick-knee survival in the gardens of urban-dwellings were apparent, especially regarding novel pressures such as domestic pets.

3.6 Acknowledgements

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3.8 Supplementary information

Supplementary Material S3.1: Newspaper article request for information on Spotted Thick-knee

Wanted: Information on the Spotted Thick-knee

We are requesting feedback on any possible observations of the Spotted Thick-knee (*Burhinus capensis*) (previously called "dikkop"), particularly where they were observed, as part of a MSc research project in the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg campus. Kyrone Josiah is investigating the prevalence of the Spotted Thick-knee in urban areas and their distribution across the urban mosaic landscape of Pietermaritzburg.

The Spotted Thick-knee is an African bird species with a large distribution range in South Africa. Males and females look similar in physical body characteristics and colouration. Except for their smaller size, juveniles look similar to the adults. The Spotted Thick-knee is omnivorous and feeds on grass seeds, small invertebrates (mainly termites and beetles) and even small reptiles but rarely small mammals. They are a ground-nesting species with a variety of nest types from simple shallow scrapes in the ground to nests decorated with various materials such as twigs and even animal faeces. They are monogamous laying two to four eggs at a time and producing one to three broods per season.

They occur in a range of environments from seashores to drier habitats like Savannas and grasslands. In urban areas, they are typically, but not solely, found in open areas with short grass. They are a nocturnal species that is rarely active during the day, but if spotted in the mornings and/or afternoons the day, they may be seen standing or sitting still.

If you know of any Spotted Thick-knee in your area, or if you have these birds in your garden, at your work, or school etc., we would really appreciate it if you could let us know. Geographical locations (GPS points) of individuals or groups would be of great value for our study.

Please contact Kyrone Josiah (email: 214560913@stu.ukzn.ac.za) or Prof. Colleen Downs (supervisor): Downs@ukzn.ac.za or contact 033 260 5127 (w) at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg campus, Scottsville.

Image 1: Adult Spotted Thick-knee

Image 2: Eggs laid on the ground (Picture taken from Roberts Nests & Eggs of southern African birds, Photo by Hugh Chittenden)

Supplementary Material S3.2: Questionnaire on Spotted Thick-knee in urban areas

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

Spotted Thick-knee in urban areas

We are currently investigating the presence of Spotted Thick-knee (*Burhinus capensis*) in urban areas. The main aim of this survey is to determine locations where Spotted Thick-knee are present as well as the possible factors that allow for their occurrence in urban areas. This survey is for information purposes only and we would be most grateful for your input about your observations. Please try to answer all questions to the best of your knowledge and be as accurate as possible, providing reasonably estimated answers when you are uncertain. If you have any queries about the information sheet or Spotted Thick-knee, please call Kyrone Josiah at 084 618 5848; or email 214560913@stu.ukzn.ac.za or Downs@ukzn.ac.za.

This research forms part of a study on Spotted Thick-knee in urban areas which is currently been undertaken in the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg campus by Kyrone Josiah (Masters candidate) under the supervision of Prof CT Downs.

NB: You are not obliged to complete this information sheet but your input will be highly appreciated.

Questions

1. Do you engage in bird watching activities? YES/NO
2. In which suburb/area do you live in? …………………………………………………………………….
3. Do you see Spotted Thick-knee around your area? YES/NO
4. When did you first notice Spotted Thick-knee in your area?..
5. Do they come to your home/ garden? YES/NO
6. Where else do you see them? ……………………………………………………………………………………
7. What time periods of the day do you see (or hear) Spotted Thick-knee's (possible to select more than one answer)?

Morning (06h01 – 12h00) YES/NO
Afternoon (12h01 – 18h00) YES/NO
Evening (18h01 – 24h00) YES/NO
Night time (24h01 – 06h00) YES/NO

8. What activities are they doing when you see them (possible to select more than one answer)?
   Feeding/Staying still /Nesting/Other (Specify): ……………………………………………………….
9. If feeding, what do you see them feeding on (possible to select more than one answer)?
   Seeds/Insects/Small mammals/Other? (Specify): …………………………………………………
10. Are the Spotted Thick-knee's present all year? YES/NO
    If no, when are the Spotted Thick-knee's not present in your area?.............................
11. Have you ever seen Spotted Thick-knee's interacting with other animals (attacks, being preyed on etc.)? YES/NO
    If yes: Which animals? …………………………………………………………………………………….

12. Have you seen them alone, in pairs, small family groups or large flocks (possible to select more than one answer)?
    Alone YES/NO
    Pair YES/NO
    3-5 YES/NO
    6-10 YES/NO
    11 or more YES/NO
    Specify number if possible (estimate): …………………………………………………………………..
13. Do you know of any nesting sites? YES/NO
    If yes, where about?..
14. Do you recall when you first started seeing them in urban areas (years)?...

Any further comments:
……
……
……
……

CONTACT DETAILS (optional)

If you would like to further assist in this study, please provide your contact details.

Name: …………………………………………………………………………

Address: …………………………………………………………………

Telephone: ……………………………………………………………….

E-mail address: ………………………………………………………

Thank you for your time answering this information sheet.

Contact:
Prof. C.T. Downs or Kyrone Josiah
Email: Downs@ukzn.ac.za or 214560913@stu.ukzn.ac.za
Telephone: (033) 260 5127/ 04 or Cell: 084 618 5848 with any questions or comments.

CHAPTER 4

Facets of Spotted Thick-knee (*Burhinus capensis*) nesting ecology across an anthropogenic landscape

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Formatted for **Landscape Ecology**

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Running header: Breeding of Spotted Thick-knees across an urban landscape

4.1 Abstract

Context Spotted Thick-knee have terrestrial-dependent nesting habits, and are predicted to be most at threat when their natural habitats are removed or altered through urbanisation.

Objectives Our study was undertaken to collect novel information on Spotted thick-knee presence across an urbanised landscape, by investigating facets of nesting ecology for a population within and around the city of Pietermaritzburg, South Africa.

Methods Spotted Thick-knee nesting and nest site data were collected between July 2019 and December 2020. Direct observations were carried out at 33 nest sites, and remote monitoring by use of camera-traps was carried out at a subsample of eight nest sites.

Results Spotted Thick-knee breeding pairs had preferences in select habitat and nest-site characteristics such as: greater use of shrub-like species for nest site placement; more grass cover; shorter grass; and flatter slopes at nest sites, compared to random sites. Successful nesting outcomes were significantly greater than failed nesting outcomes. Incubation activity was significantly longer during the day, and incubation activity had a significant adverse relationship with disturbance in human-modified habitats.

Conclusions Land-use and human activity influence nest-site selection and survival of nests. Spotted Thick-knee preferred both residential gardens and recreational areas as nest-sites in the urban mosaic, although nests were more successful in residential gardens. They preferred the use of shrub-like vegetation as nest-cover structures, possibly because of added protection from extreme weather or for less visual detection. Risks associated with nesting in human-modified habitats included increased threats from domestic animals and incubation activity costs because of disturbance around nest sites.

Keywords Spotted Thick-knee • Ground-nesting • Land-use • Anthropogenic activity • Camera trap

4.2 Introduction

The process of urbanisation is rapidly increasing globally and consequently, so has the rate at which species are becoming extinct at a regional or global scale (Lowry et al. 2012; Faeth et al. 2005; Kopij 2017). Despite increased anthropogenic activity and the correlating trend of species extinction, some wildlife species continue to occur in these anthropogenic environments (Dawson and Mannan 1994; Boal and Mannan 1998; Peterson et al. 2007; Lowry et al. 2012; Norton et al. 2016; Tripathi 2016; Kopij 2017; Smith et al. 2017; Chaudhury and Koli 2018; Downs et al. 2021). A wide variety of species from the class Aves are commonly sighted in urban areas, which could be attributed to the fact that many of these species are comparatively small in size and have greater mobility (i.e., flight) than most wildlife (Callaghan et al. 2019; Bressler et al. 2020). These traits allow for some bird species to not only move through urban areas with less risk, but it also allows for some species to occupy and utilise these unnatural environments for their survival (Bressler et al. 2020).

A commonality amongst all bird species is that they depend on the land in some aspect of their life cycle and because some urban areas compose of natural and anthropogenic elements across a fragmented landscape, they provide suitable conditions for inhabitation by select species (Alerstam and Högstedt 1982; Brusatte et a. 2015; Isaksson 2018; Rico-Guevara et al. 2019; Tobajas et al. 2020; Tong 2020). However, for most species, habitation within an urbanised environment is heavily dependent on the access to basic survival needs as well as the ability of the species to adapt (Marzluff 2001; Moller 2009; Galbraith et al. 2014; Cereghetti 2017; Jagiello et al. 2018). Studies indicate that a behavioural shift or novel behavioural change of some sort is prevalent in individuals/groups/populations of species that successfully persist in urban environments (Ditchkoff et al. 2006; Robb et al. 2008; Gillanders et al. 2017). Nesting behaviour is one such characteristic that determines a species ability to persist in urban areas, especially for those that are more terrestrial-dependent than others. Existing literature suggests that flightless species (i.e., ratites) and ground-nesting species are more dependent because they either spend their entire life on land and/or utilise the ground for an essential stage in their life cycle (Alerstam and Högstedt 1982; Isaksson 2018; Tong 2020). It is because of this dependence that the removal of suitable nesting habitat and nesting material (if used), in a localised area, is detrimental to the survival of the species within that area, especially considering that most bird species are specific when selecting their potential nest sites (Hartman et al. 2016; Winiarski et al. 2017; Zhang et al. 2017).

Anthropogenic activities can greatly impact the nesting success of numerous bird species, especially those in urban areas with a wider range of disturbance factors (Gill 2007). There are costs and benefits for those terrestrial nesting avian species that attempt to inhabit human-modified landscapes, but rarely the latter, as they have to deal with novel pressures or an increase in the intensity of natural pressures (Bressler et al. 2020). For instance, the unfamiliar human-modified habitat may decrease or increase competition for limited resources; restrict or increase access of natural predators (Patterson et al. 2016; Bressler et al. 2020; Luna et al. 2021). Some species have experienced predation by novel, 'unnatural' predators such as carnivorous species which have been domesticated (e.g., domestic dogs' (*Canis lupus familiaris*) and domestic cats (*Felis catus*)) (Patterson et al. 2016; Bressler et al. 2020; Luna et al. 2021; Josiah and Downs unpublished data; Chapter 3). Despite this fact, individuals or groups of terrestrial nesting avian species may still attempt to inhabit these anthropogenic environments, which sometimes offer opportunities for increased survival considering the rapid decline in suitable, natural habitat (Brown and Downs 2003, 2004). However, some ground-nesting avian species manage to survive and have shown an assumed increase in population-growth because of increased presence in urban areas, although this trend is recent and understudied.

The gaps in knowledge and deficiency of baseline data for avian terrestrial nesting species result from most studies being carried out in well-developed regions such as Europe where there is already limited biodiversity compared with previously less urban dense continents such as Africa (Chapter 1). Ground-nesting birds are terrestrial-dependent regarding their nesting habit, and therefore, are predicted to be most at threat when their natural habitats are removed or are altered for human benefit. Due to a large number of ground-nesting species occurring in South Africa, there is a need to further investigate this group to contribute to the limited knowledge pool (Chapter 1). In fact, it is possible that some ground-nesting species thrive in urban areas, but because of insufficient study, there is currently no conclusive evidence of this trend (Chapter 1; pers. obs.). The Spotted Thick-knee (*Burhinus capensis*) is one such ground-nesting species that has shown increased presence in urban areas of South Africa (Josiah and Downs unpublished data: Chapter 2).

Our study was undertaken to collect novel information on the presence of Spotted thick-knee across an urbanised landscape with varying land-use, by investigating facets of their nesting ecology and breeding habits of a population within and around the city of Pietermaritzburg, South Africa. The focus was placed on assessing their nest clutch size; nest outcomes of success or failure; nest-site selection and survival; incubation activity; and the predicted anthropogenic factors that could influence their breeding within an urban-ecological context. We predicted that, despite an increase in observed urban-presence, the various land-use and human activities were negatively impacting Spotted thick-knee breeding success or rather, some land-use and human activities may be more detrimental than others.

4.3 Methods

4.3.1 Study area and study sites

We conducted our study in the city of Pietermaritzburg (29°37'04" *S*, 30°23'57" *E*), South Africa (Fig. 4.1). Due to the widespread distribution of the study species, data were collected from surrounding areas within 5 km (peri-urban) of the city perimeter as well. The city's natural landscape mostly consists of vegetation characteristic of grassland landscapes with a few areas of vegetation characteristic of savanna landscapes and thicket patches (Mucina and Rutherford 2006; Jewitt 2018). The region experiences warm-to-hot summer temperatures with frequent rainfall and dry winters with high diurnal temperature variation (Nel 2009; Thabethe and Downs 2018). The city landscape is a unique mosaic of built-up areas, natural vegetation and managed green spaces (e.g., gardens and school sports fields).

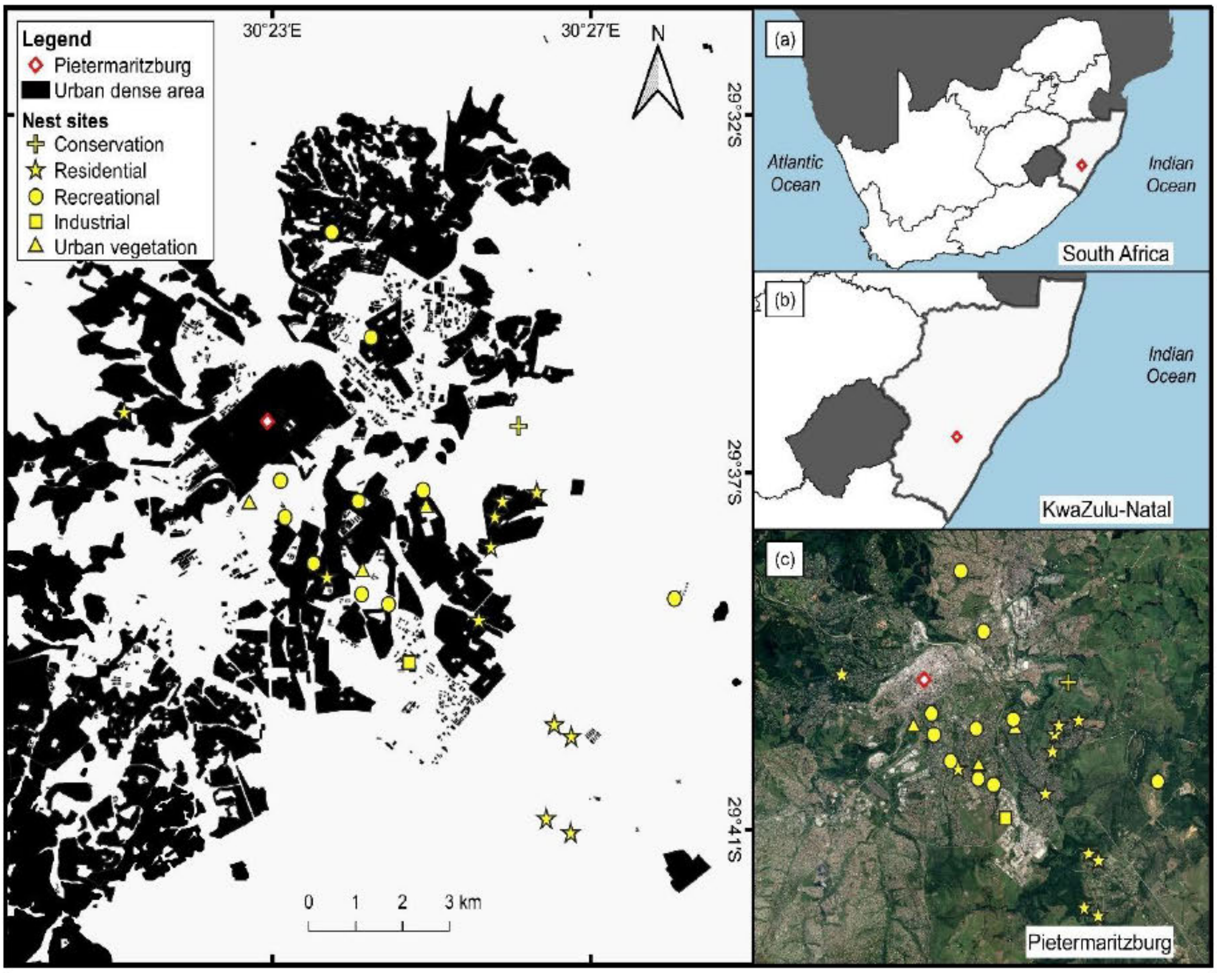

Fig. 4.1 Spotted Thick-knee nest site locations and the land-use classification for each nest around Pietermaritzburg, South Africa during the present study. The study area location in (a)

South Africa; (b) KwaZulu-Natal Province; and (c) satellite imagery overlay for improved interpretation of urban dense areas (Google Earth v7.3 2020).

4.3.2 Data collection

We collected Spotted Thick-knee nesting data between July 2019 and December 2020 in the study area of Pietermaritzburg, KwaZulu-Natal (Fig. 4.1). Locating of nest sites was accomplished by monitoring locations of Spotted Thick-knee occurrence within the study area. In addition, we collated information for Spotted Thick-knee nest site locations through feedback from public outreach and active surveying from a corollary study which investigated Spotted Thick-knee presence across the urban landscape of Pietermaritzburg (Josiah and Downs unpublished data; Chapter 3). We then geolocated each nest site location found using a Geographical Positioning System (GPS; Garmin eTrex 10, USA) (Fig. 4.1).

Spotted Thick-knee nest sites were visited at 4-day intervals from the day that the investigator located the nest through observations of nesting behaviour by breeding adults making scrapes in the ground, an incubating adult, or eggs laid. An interval of 4 days allowed for the same number of visits at all sites and was the most suitable option for logistic reasons. Each nest was visited until a nesting attempt outcome of success or failure was conclusive or until 30 days had passed since the first visit. For Spotted Thick-knees, 30 days is the recognised maximum incubation period for eggs to successfully hatch from a full clutch (Hockey 2005; Tarboton 2014; Hume et al. 2019). Therefore, an observational period of 30 days was used because eggs not hatched after 30 days were considered hatch failures. On the first visit, the incubating adult showed no reaction that disrupted incubation from at least 20 m away; thus, this distance was set to minimise investigator disturbance. However, some occasions required the investigator to approach the nest more closely to collect data for specific components in the study.

Binoculars (Nikon ACULON A211, 8 x 42 magnification, multi-coated optics) were occasionally used for increased accuracy when collecting information. Pertinent information collected at Spotted Thick-knee nest sites included: initial date of observation of nesting attempt and subsequent observer visits until the end of nesting attempts; the number of nesting attempts by breeding pair, nesting attempt outcome (success or failure) and recording of evidence for contributing factors of failure where possible (e.g., disturbance, abandonment, predation, egg displacement or failure to hatch). According to the standard for land cover mapping framework for South Africa, land-use classification was identified at each nesting site as either: residential; recreational; industrial; conservational; or urban vegetation (DRDLR 2019). Land-use was considered because our study was carried out across the urban landscape where the environmental surroundings and anthropogenic activities can differ according to land-use.

Between July 2020 and December 2020, we revisited all Spotted Thick-knee nest sites to determine whether they were re-used in subsequent breeding seasons. No ring banding of Spotted Thick-knees was conducted during our study, thus identifying cases of further nesting attempts by the original breeding pair was only included for pairs that used or were in proximity of the initial nesting site attempt. There was no evidence of interaction between the breeding pairs and other Spotted Thick-knee adult individuals. This knowledge about the study species and lack of interaction events were considered appropriate to reasonably determine whether it was the same breeding pair or not. The following sections include further information on data collected for each component of nesting investigated in our study.

4.3.3 Clutch size and nest outcome

We recorded a Spotted Thick-knee nest's clutch size, which we defined as the total number of eggs for each nesting attempt. There was a lack of published information regarding the time between laying eggs at the commencement of our study; therefore, clutch size was recorded on the second investigator visit because past observations of egg-laying intervals were no more than one day. We recorded the outcome of each nesting attempt as either ‘successful’ or ‘failed’. According to the general-use explanation for precocial species, we defined these outcomes whereby a nesting attempt was considered to have succeeded when at least one egg ($\geq$ 1) successfully hatched from the clutch (Lepage 1998). This was confirmed when at least one hatchling was present at the end of the incubation period or during an observer visit before the full 30 days. Nest sites were visited routinely after the maximum incubation period of 30 days until an outcome could be determined. Nests were considered to have failed if: all eggs for a nesting attempt did not hatch; some or all eggs were absent but no evidence of at least one hatchling with breeding pair or adult; evidence of predation, egg damage or parental abandonment of the nest with eggs still present. We could determine these outcomes from closer inspection of nest areas with knowledge that Spotted Thick-knee breeding pairs, or family groups remain close to nest sites post-incubation.

4.3.4 Nest-site selection

We collected habitat data for each Spotted Thick-knee nest site to determine whether certain habitat characteristics were preferred by breeding pairs when selecting locations for their nests. Measures of fine-scale microhabitat characteristics were recorded within a 10 m radius sample site with the nest as the central point. The circular plot was further divided into four equal sections (sections A to D) that intersected at the nest as the central point (Supplementary Fig. S4.1). We averaged the data from each of the four sections to represent the sample site, and which was known as a ‘nest-plot’ in the study. We recorded information on the following nest-plot characteristics: land cover, vegetation height, slope, altitude and nest-cover structure.

For each Spotted Thick-knee nest site, we recorded percentage estimates of land cover composition for bare ground surface cover, man-made (i.e., concrete), grass and vegetation (inclusive of leaf litter). Vegetation structures, other than species of grasses, were expressed as proportions of the vegetation cover within the nest-plot according to categories of the structure's max height level in metres, whereby they either belonged to height level 1 (0.15 m < height < 2 m), level 2 (2 m ≤ height ≤ 5 m), or level 3 (height > 5 m) (Supplementary Fig. S4.1). Height level 1 had a minimum value 0.15 m because structures below that level were not found at any site, but this could have been because of obstruction from tall grass height in some nest-plots. Grass height in metres (m) was estimated and recorded separately from vegetation data.

We found Spotted Thick-knee nest sites either had an absence of a nest-cover structure, or a shrub-like species or a tree species as a nest-cover structure. Nest-cover structure height was measured using a sectional pole and recorded the same way for all nest-cover structures. However, the method for width of shrub-like structures differed from that of nest-cover structures which were trees, although both measurements were taken using a measuring tape. Width for shrub-like structures was measured from the side of the structure that had the nest under it. Tree widths were measured by the commonly used dendrometric measurement of 'diameter at breast height' (DBH), which was always from 1.65 m above ground because the same investigator carried out all measurements. Patterns of nest construction were not investigated in this study because all nests were made from scrapes in the ground, and only one nest was lined with material such as dry leaves (pers. obs.). We used a GPS to record the nest-plot altitude or height above sea level in metres (m. a.s.l), with the nest as the reference point. Slope degree (°) of the nest-plot was measured using an optical clinometer (Brunton Lensatic, F-OMNISLOPE) for the most discernible slope of a 5 m line length with the nest at the midpoint (i.e., 2.5 m) (Supplementary information Fig. S4.1). Slope angle/gradient was considered at a fine-scale level (< 5 m) of topography as it has been suggested to be influential in nest-site selection, but other factors may overshadow its importance if slope is measured at a larger scale beyond this range (Korne et al. 2020).

Estimates of surface land cover percentages, average grass height and measurements specific to the nest-cover structure were taken on the first observation day of the Spotted Thick-knee nest site. They were considered as important factors in nest-site selection and measuring them at a later time in the nesting period could have altered results in the study. For example, short grass height may have been a factor of preferential site selection for a nesting attempt, therefore, measuring the grass height at a later stage where it could have grown, would have biased findings of the study. Site measurements of variables such as vegetation heights, altitude and slope were taken once a nesting attempt had concluded, or the nest site was deemed inactive because the breeding pair was not observed and there were no eggs in the nest. These variables either had: no support in existing literature as important factors of selection for ground-nesting species; the investigator assumed them to have a slight change in a measure during the nesting period which would not impact study findings; they would have taken too long of a time to measure during the early incubation period, therefore, increasing investigator disturbance and risk of failure on the nesting attempt.

We selected 26 random site locations to examine the differences between actual nest sites and potential nest sites available for breeding pairs. The coordinates for these random sites were computer-generated projected into Google Earth version 7.3. Random sites that were inaccessible were replaced with locations that had suitable accessibility to allow for appropriate data collection of ‘hypothetical’ nest-plots. Permission was granted by homeowners where a site was within their property. Identical approaches to data collection were undertaken at both actual and random nest sites. These sites were visited, and the closest vegetation structure (tree or shrub-like) within a 2 m distance from the initial random location was selected as one of the

26 random site locations. If there was no vegetation structure within 2 m, then that site was considered as one with no nest-cover structure.

4.3.5 Nest survival

We interpreted the nest survival of Spotted Thick-knees through daily nest survival which is the probability of the nest under examination to survive whilst known variables of influence are in effect or considered. Daily nest survival for all nests (N = 33) irrespective of which nesting attempt they belonged to, was analysed using Nest Survival Analysis in program MARK (White and Burnham 1999). Many nesting studies still utilise the Mayfield method or Apparent Estimator method, but these approaches consider nesting survival to be constant across all samples, which severely bias survival results and does not allow for biological inferences (Dinsmore et al. 2002; Jehle et al. 2004). MARK allowed for estimates of daily nest survival as constant survival but also allowed for survival to be influenced by various factors labelled as 'predictor variables' in this study. Nest survival models in MARK utilise a maximum likelihood estimation on a binary response variable. Except for one, variables were included in analyses based on *a priori* knowledge (Supplementary information Table S4.1). The variable 'observer effect' was included because a growing number of studies suggest that investigators effect nest survival through increased disturbance at nest sites, especially for Charadriiformes (Götmark 1992; Zhao et al. 2020).

We recorded Spotted Thick-knee nest date in the breeding season as the date of nest initiation for the first nest found in the study (i.e., 18 July 2019) labelled as day '0' and all subsequent nests as the number of days since the first nest. For example, a nest found on the first day of a nesting attempt by a breeding pair on 28 July 2019 would be labelled as a nest that started on 'day 10' of the nesting season. Nest age was recorded in days and estimated from the age of the nest on the first visit by the investigator. Although some Spotted Thick-knee nest sites were not visited immediately when the nesting attempt began, the nest initiation date was known by a public participant, such as a residential property owner, who informed the investigator about the nest. Readings for maximum daily precipitation (mm) along with the maximum and minimum daily ambient temperature (°*C*), were taken from Pietermaritzburg airport (29°38'29" *S*, 30°23'32" *E*) (SAWS 2020).

4.3.6 Incubation activity

Spotted Thick-knees are considered nocturnal and fairly sedentary during the day (Hockey 2005; Hume et al. 2019). This allowed for effective observation and monitoring of the species during the day. However, direct observations are time-consuming and, in most cases, not feasible. Therefore, we used a remote method for monitoring the species for successive 24-h periods for the breeding period. Camera-traps were appropriate for use as they allowed for continuous monitoring over the nesting period and reduced the potentially harmful effect of frequent observer visitation on nest sites. Camera-traps (Strike Force Pro X, model: BTC-5HDPX, Browning Arms Company, USA) and were programmed with the following photograph quality settings: 'Ultra' (20 megapixel (MP)); 'Motion detect'; 'Single shot'; '30-second delay'; and 'Infrared flash' which was suggested by Ehlers Smith et al. (2018) to be the most appropriate flash setting for nocturnal species. Each camera-trap had a date, time and ambient temperature stamp for all images captured. The secure digital memory card (64 GB) and six AA-batteries required for the camera-trap to function, were replaced every second visit by the study investigator.

We set up camera-traps for the first nesting attempts at nine Spotted Thick-knee nest sites. We used one camera unit per site except for a single site that required two camera-trap to meet the appropriate monitoring conditions for data to be included in analyses. We identified sites for camera-traps in the field before the commencement of egg-laying. This was through observation of nesting activity of breeding pairs such as scrape actions in the ground for nest building, or proximity to locations where Spotted Thick-knees had nested before and were showing signs of nesting again (public participation from corollary study). Twelve study sites met the required conditions to be included for this component, but three private property owners denied permission to install camera-traps on their property. We positioned camera-traps between 3 to 5 m away from the nest, and they were elevated 0.5 to 1 m above the ground and angled to face the nest site. The site with two camera-traps had the auxiliary camera-trap approximately 0.5 m away from the nest. These distances and heights were trial-tested before the commencement of the study and were recognised as optimal for accurate interpretation of Spotted Thick-knee nesting behaviour along with sufficient view of surroundings, which allowed for easier identification of disturbances or threats (e.g. predation) to the nest site and/or incubating adult.

Anthropogenic activities were recorded by the camera-traps that included humans, motor vehicles, domestic animals or wildlife, within the camera-trap field of view (the entirety of visual objects within the image). These interaction events occurred independently or in combination with each other to some extent. However, the incubating adult did not always react to these events in a manner that disrupted incubation. Therefore, interaction events were only considered as ‘known disturbance’ events when: incubation was disrupted during or immediately before an interaction event took place that was in the camera-trap field of view, or when incubation was disrupted and either or both the incubating adult and non-incubating partner displayed defensive behaviour towards a possible perceived threat not within the camera-trap field of view. We collated and described such events.

Each camera-trap was activated for 24-h periods known as a ‘camera-day’ where one camera-day was considered the period between 12:00 to 23:59. We examined the images collected for each observed Spotted Thick-knee nest site and removed ‘error’ images that resulted from a false capture (e.g., movements of tall grass in the camera-traps field of view). Each image was labelled as a 'camera event'. Camera events were examined, and pertinent data were collected regarding incubation events, disturbance events and their respective durations in min. for each hour in a camera-day. The data were collected from the date of the first egg laid or incubation initiation to the maximum known incubation period of 30 days for a nesting attempt (Tarboton 2014). Camera-traps were not retrieved immediately after nest outcome was decided because it was felt that such activity could deter the breeding pair from re-nesting at the same site shortly after the first attempt failed.

4.3.7 Nest site re-use

Not all sites from the 2019–2020 breeding season were used on first nesting attempt by a breeding pair. Therefore, all 33 sites irrespective of when the breeding pair attempted to nest in 2019–2020, were each visited once every two weeks until there was evidence of nest site re-use for the 2020–2021 breeding season. A nest site was considered to be re-used if there were eggs present or an incubating adult within the original nest-plot from the previous season. Due to the Covid-19 Pandemic and lockdown regulations in South Africa, some public participants were cautious of frequent visits to their properties by the study investigator. Logistics for fieldwork during 2020-2021 was severely impacted by the pandemic. This constrained the study and prevented replication of methodology from the first breeding season, hence the use of this approach. There was no strict scientific analysis carried out on data collected for this section because it was felt that the lack of strict scientific methodology made it difficult to compare this data with the previous breeding season data. However, descriptive statistics were used to support the findings of other aspects of nesting further.

4.3.8 Data analyses

All components, except for one, were analysed using IBM SPSS© Statistics version 27 (SPSS Inc., Chicago, USA). The nest survival component was analysed using program MARK (White and Burnham 1999). We used a significance level of $\alpha < 0.05$ at a 95% confidence interval (CI) for differences or associations to be considered significant. Results are presented as mean ± standard deviation (SD) unless specified otherwise.

We categorised Spotted Thick-knee nesting attempts by whether the nesting attempt was the first or second attempt, the month of initiation for the nesting attempt and the land-use classification of the site on which a nesting attempt was located. Due to values < 5 in our samples, we compared clutch sizes between nesting attempts using the Fisher's Exact test. For the testing of differences in clutch sizes according to months or land-use classification, we used the Fisher–Freeman–Halton Exact test as an alternative method to the Fisher's Exact test because it allowed for the comparison of contingency tables larger than two rows and two columns. We used a Chi-square test to examine differences in nest outcome for all nesting attempts as the assumptions of the test were met. We used the Fisher's Exact test for nest outcome differences according to first and secondary nesting attempts and the alternative Fisher–Freeman–Halton Exact test for differences according to initiation months and land-use classification.

The 26 Spotted Thick-knee nests that were identified as first nesting attempts were used for this analysis. We compared the use of nest-cover structure types between actual nest sites using a Chi-square test. Regarding nest sites and random sites, the Shapiro–Wilks test was used to test for normality in data followed by the log transformation of data that did not meet assumptions of normality. If data did not meet parametric test assumptions post-transformation, a non-parametric test was used. A Levene's test was used for testing homogeneity of variance, and equal variances were assumed unless stated otherwise for a specific analysis. We compared habitat characteristics of random sites and nest sites using Independent samples *t*-tests or the alternative non-parametric test, which was the Mann–Whitney *U*-test. The Mann–Whitney *U*-test *p*-value for significance was presented using the 2-tailed exact value.

In the Spotted Thick-knee nest survival analyses, we used an information-theoretic approach and evaluated support for models using Aikakes Information Criterion for small sample sizes (AICc), with the inclusion of model Akaike weight (*wi*) as a measure of the model likelihood. Models were processed in hierarchical stages with the constant survival (NULL) and competitive models (ΔAICc < 2.00 units) carried over to the next stage. The staged process was carried out to avoid spurious results from models. It was also carried out because the study area was relatively small and certain predictor variables, such as temperature and precipitation, would have a widespread and similar effect on all nest sites. The earlier inclusion of these predictor variables would only result in unnecessary model generating and a greater number of parameters for some models. We set nest survival as a binary response variable where nest outcome was coded with dummy variables of ‘successful = 0, failed = 1’. We used a logit link function in our analysis and did not standardise the real values of variables because it would generate irrational outputs in our models. Also, MARK would send an error message if using the unstandardised values of variables was problematic in any stage of the processing.

Base models were derived from the temporal analysis in stage 1 where constant survival was modelled against nest survival influenced by time, date in the nesting season, nest age, or a combination of predictor variables (stage 1 in Supplementary Table S4.2). The only categorial discrete nest-plot variable was nest-cover structure whereby: nests with a shrub-like structure were represented by ‘1 0’; nests with a tree structure were represented by ‘0 1’; and nests without a nest-cover structure represented by ‘0 0’. All other nest-plot variables were expressed using the real values. Nest-plot variables were assessed for correlation using Pearson correlation coefficients and variables with $r < 0.7$ were considered highly correlated. Highly correlated variables were not included in the same model. Stage 2 consisted of adding nest-plot predictor variables to base models and the resulting models with ΔAICc < 2.00 units were carried over to the next and final stage. We examined the most parameterised model in stage 2 for overdispersion by examining the *c*-value generated for nest survival analysis in MARK. Overdispersion in data exists when $c < 1$ but generally only has severe consequences in analyses where $c < 2$ and the model structure could be unstable and poor fit not accounted for.

Stage 3 combined competitive models from stage 2 with additive effects of daily temperature (°*C*), daily max precipitation (mm) and observer effect. Observer effect was included as a binary response where '1 = visit' and '0 = no visit' for each nest site on the days the investigator visited the site and the other days whilst the nest was active during the breeding season. We did not examine overdispersion in stage 3 because if there was an increase in the *c*-value, it would be because of the model fit and structure from additive effects. The lack of model fit can be attributed to the addition of extra parameters when including the linear and quadratic functions of a variable. The best-supported model from stage 3 was examined in terms of the logit link regression equation and beta values of the coefficients. Models with the lowest AICc values were considered to have the most support relative to all other models included in that specific analysis, but for stage 3, there were close competing models indicating model selection uncertainty. To account for model selection uncertainty in our analysis, we carried out a relative importance weighting of all predictor variables in the stage 3 candidate set (competitive models ΔAICc < 2.00 units). This allowed for better interpretation of each predictor variables importance relative to all other predictor variables from the candidate set.

One of the nine Spotted Thick-knee sites was omitted from analyses on account of insufficient data because the camera trap was tampered with shortly after installation. The nest was found with eggs crushed on the second visit day. Therefore, analyses were conducted for eight nest sites monitored by camera-traps. The time that incubation took place for each hour was quantified by the duration of incubation events and omission of time durations from camera events where there was no sign of an incubating adult. This allowed for a sum of minutes for incubation per hour for each site. Each hour was labelled on the hour with duration lengths of 59 min and 59 s. We rounded off the camera events to the nearest min. Data were categorised as ‘incubation time per hour (min. h^{-1}) over one camera-day’ (24-h period); ‘day’ period (12 h; 6:00 to 17:59); and ‘night’ period (12 h; 18:00 to 5:59). The same categories were used for disturbance events, and we considered the duration of each disturbance event the time from when the incubating adult left the nest until an adult returned and started incubating again. Disturbance event durations that went across hour periods had the disturbance event assigned for each hour during the disturbance period, and the min. of disturbance were allocated to each hour where they occurred.

Pre-analyses, we transformed data using the Date and Time function in SPSS to be expressed out of ‘60’ and not ‘100’ because our unit of measurement was in minutes. We used a paired samples *t*-test to examine whether there was a significant difference between incubation time during the day period compared with the night period. We did not compare disturbance durations because of uneven samples of events in the day and night periods, limiting the assumptions needed to use a paired samples *t*-test. We also felt that incorporating events where we could not fully discern the cause would not be scientifically appropriate. However, we compared the number of disturbance events by occurrence in categories of day and night and then by the disturbance event's identified cause, both using Chi-square tests. We used a linear regression analysis to evaluate the effect of disturbance on incubation, setting the incubation duration in minutes per hour (min. h^{-1}) as the response variable and disturbance durations in minutes per hour (min. h^{-1}) as the explanatory variable.

4.4 Results

We collected Spotted Thick-knee nesting data between 18 July 2019 to 17 January 2020 for all sections except 'nest-site re-use". Although we continued to observe sites until 25 February 2020 as this date was still within the breeding season, we found no further nesting attempts for the breeding season that began in 2019. We geolocated 26 breeding pair first-attempt nest-site locations and 7 secondary-attempt nest site locations. We revisited nest-site locations between July 2020 to December 2020 for the 'nest-site re-use' section.

4.4.1 Clutch size and nest outcome

Spotted Thick-knee mean clutch size was 1.9 ± 0.50 eggs for all nests ($N = 33$) with 15% of clutches consisting of 1 egg ($n = 5$), 76% of 2 eggs ($n = 25$) and 9% of 3 eggs ($n = 3$) respectively. There were no significant differences in clutch size between nesting attempts one (2.0 ± 0.49 eggs; $n = 26$) and two (1.7 ± 0.49 eggs; $n = 7$) (Fisher's Exact test $p = 0.606$; Table 4.1). Clutch size was highest for nests initiated in the month of September (2.1 ± 0.35 eggs; $n = 8$) and lowest in the month of October (1.7 ± 0.44 eggs; $n = 9$) but differences between months were not significantly different (Fisher–Freeman–Halton Exact test $p = 0.130$; Table 4.1). Clutch size was highest for nests on land-use designated as residential (2.1 ± 0.49 eggs; $n = 13$) and lowest for those situated on recreational land (1.8 ± 0.62 eggs; $n = 12$) but there were no significant differences between land-use classes on clutch size (Fisher–Freeman–Halton Exact test $p = 0.656$; Table 4.1).

There was a significant difference in Spotted Thick-knee nest outcome between all nesting attempts with more successful nests ($n = 21$) than failed nests ($n = 12$) for ($\chi^2 = 4.9$; df $= 1$; $p = 0.027$; $N = 33$; Table 4.1). Nesting attempt one ($n = 26$) had a successful nest outcome for 57.7% of nests whereas nesting attempt two ($n = 7$) had 85.7% of nests with a successful outcome. However, this difference was not statistically significant (Fisher's Exact test $p =$

0.171; Table 4.1). There was no significant difference regarding nest outcome for all nest-initiation months (Fisher–Freeman–Halton Exact test p = 0.565; Table 4.1; Fig. 4.2). Nests on residential properties (n = 13) had the highest success rate of 84.6% whereas nests on recreational land (n = 12) had the lowest success rate of 41.7%, but there was no significant difference in nest outcomes between land-use classes of nest sites (Fisher–Freeman–Halton Exact test p = 0.153; Table 4.1; Fig. 4.2).

We recorded seven breeding pairs of Spotted Thick-knee that carried out secondary nesting attempts. We found no evidence of secondary nesting attempts for the other 19 breeding pairs, and no evidence of third nesting attempts taking place for all breeding pairs included the study.

Table 4.1 Spotted Thick-knee clutch size and nest outcome for all nests and those categorised by nesting attempt, month and land-use in the present study.

Category	**Nest**	**Clutch size**				**Nest outcome**	
	n	Mean	Min	Median	Max	Success	Failed
Attempt							
All	33	1.94	1	2	3	21	12
Attempt 1	26	2	1	2	3	15	11
Attempt 2	7	1.71	1	2	2	6	1
Month							
July	1	n/a	3	3	3	1	0
August	10	1.9	1	2	3	7	3
September	8	2.13	2	2	3	6	0
October	9	1.78	1	2	2	4	5
November	4	2	2	2	2	3	1
December	1	n/a	1	1	1	0	1
Land-use							
Residential	13	2.08	1	2	3	11	2
Recreational	12	1.75	1	2	3	5	7
Industrial	2	2	2	2	2	1	1
Conservation	1	n/a	2	2	2	1	0
Urban vegetation	5	2	2	2	2	3	2

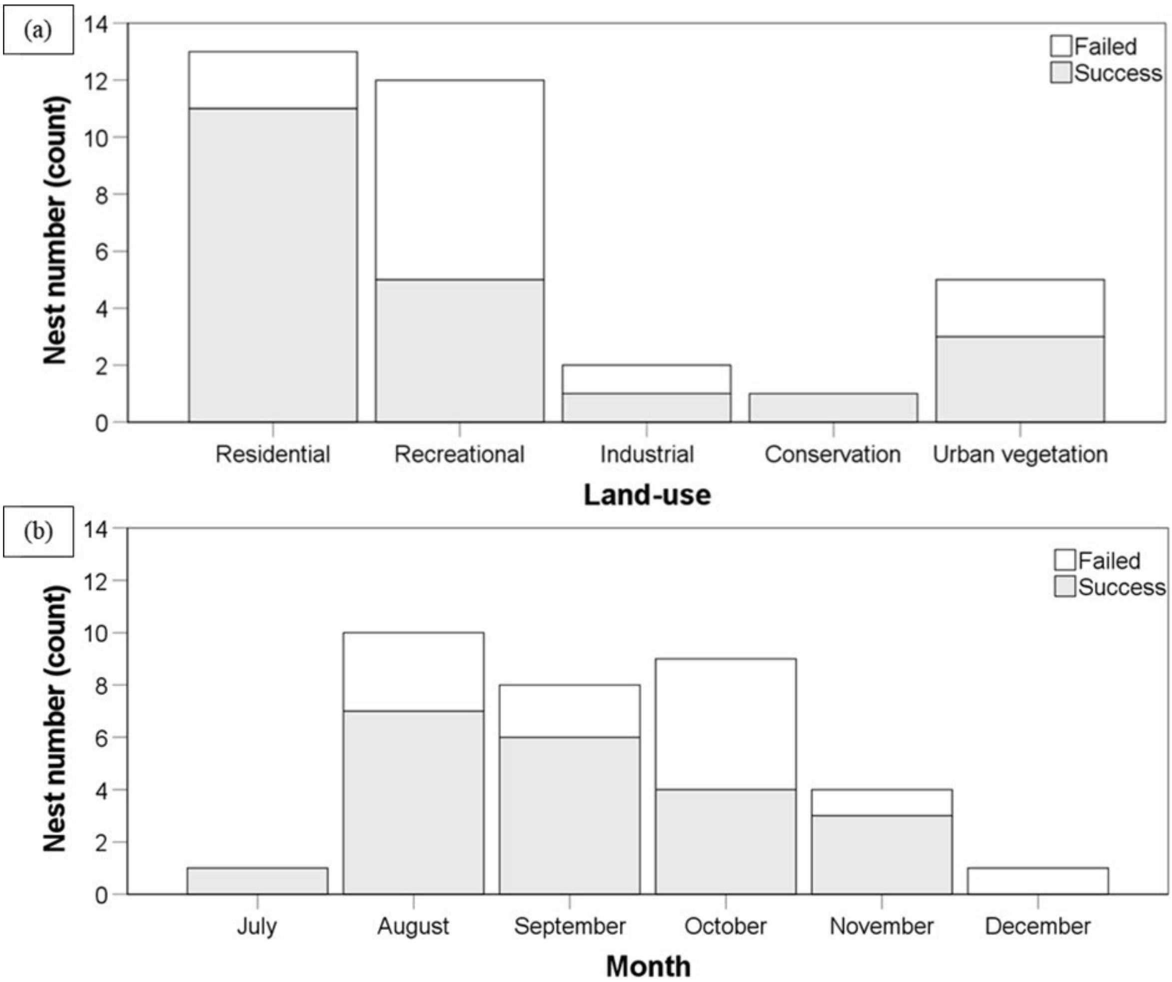

Fig. 4.2 Spotted Thick-knee number of nests and nest outcomes according to (a) land-use classification; and (b) month of initiation for nest attempt during the 2019-2020 breeding season.

4.4.2 Nest-site selection

A subsample of Spotted Thick-knee nests (n = 26) was used in these analyses. The nests were located on residential (n = 11), recreational (n = 10), urban vegetation (n = 3), conservation (n = 1), and industrial (n = 1) land. There was significantly greater use of shrub-like species for nest site placement (n = 20) compared with nests with tree species (n = 2) and nests with no cover structure (n = 4) (χ^2 = 33.692; df = 2; p < 0.001; n = 26).

For habitat variable percentage comparisons between Spotted Thick-knee nest sites (*n* = 26) and random sites (*n* = 26), mean percentage of grass cover at nest sites 75.7 ± 12.37% (*n* = 26) was significantly greater than the mean for random sites 44.0 ± 30.42% (*n* = 26) (t = 4.923; df = 50; $p < 0.001$; Table 4.2). Although percentage of surface vegetation cover was not significantly different between nest sites and random sites, nest site percentage of vegetation cover at height level 1 which was 76.7 ± 17.97% was significantly greater than at random sites with a percentage at height level 1 with a mean of 58.3 ± 30.13% (Mann–Whitney U = 205; z = 2.436 ; p = 0.014; Table 4.2).There was also a significant difference for percentage of vegetation at height level 2 with nest sites having a mean percentage of 15.4 ± 8.39% which was less than random sites with mean percentage of vegetation at height level 2 at 29.7 ± 24.86% (t = 2.778; df = 30.63; p = 0.009; no equal variance assumed; Table 4.2).

Regarding comparisons of habitat variables for Spotted Thick-knee, mean slope degree at nest sites was 12.5 ± 2.64˚(*n* = 26), which was significantly lower than at random sites 18.9 ± 10.8˚(*n* = 26) (t = 2.946; df = 27.982; p = 0.006; no equal variance assumed; Table 4.2; Fig. 4.3). Grass height at nest sites was a mean of 0.09 ± 0.04 m (*n* = 26) which was significantly shorter than at random sites with a mean of 0.16 ± 0.10 m (*n* = 26) (t = 2.636; df = 31.661; p = 0.013; no equal variance assumed; Table 4.2). For all other nest-plot variable comparisons not mentioned above, differences were not statistically significant between nest sites and random sites.

Table 4.2 Spotted Thick-knee habitat variables comparisons between nest sites and random sites in the present study.

Habitat variables	Nest sites	Random sites	Test significance
	Mean ± SD	Mean ± SD	*p*-value
Nest-plot			
Grass height (m)	0.09 ± 0.04	0.16 ± 0.10	0.013

Ground surface cover (%):			
Bare ground	9.1 ± 5.97	16.9 ± 18.37	0.184*****
Man-made	4.2 ± 8.05	22.0 ± 28.75	0.104*****
Grass	75.7 ± 12.38	43.9 ± 30.42	< 0.001
Vegetation	11.1 ± 7.87	17.1 ± 22.29	0.206*****
Vegetation at height level (%):			
Level 1 (0.15 m < height < 2 m)	76.7 ± 17.97	58.3 ± 30.13	0.014*****
Level 2 (2 m ≤ height ≤ 5 m)	15.4 ± 8.39	29.7 ± 24.86	0.009
Level 3 (height > 5 m)	4.0 ± 3.81	4.3 ± 6.59	0.317*****
Nest			
Altitude (m. a.s.l)	681.1 ± 44.9	679.2 ± 44.59	0.882
Slope°	12.5 ± 2.65	18.9 ± 10.8	0.006
Nest-cover structure			
Height at:			
Level 1 (0.15 m < height < 2 m)	1.4 ± 0.28	1.5 ± 0.29	0.73
Level 2 (2 m ≤ height ≤ 5 m)	2.8 ± 0.71	3.0 ± 0.69	0.72
Shrub width (m)	1.19 ± 0.27	1.25 ± 0.66	0.76
Tree DBH (m)	0.44 ± 0.06	0.56 ± 0.11	0.218*****

Footnote: **(*)** Indicates *p*-values from Mann–Whitney *U*-test using the exact significance (2-tailed).

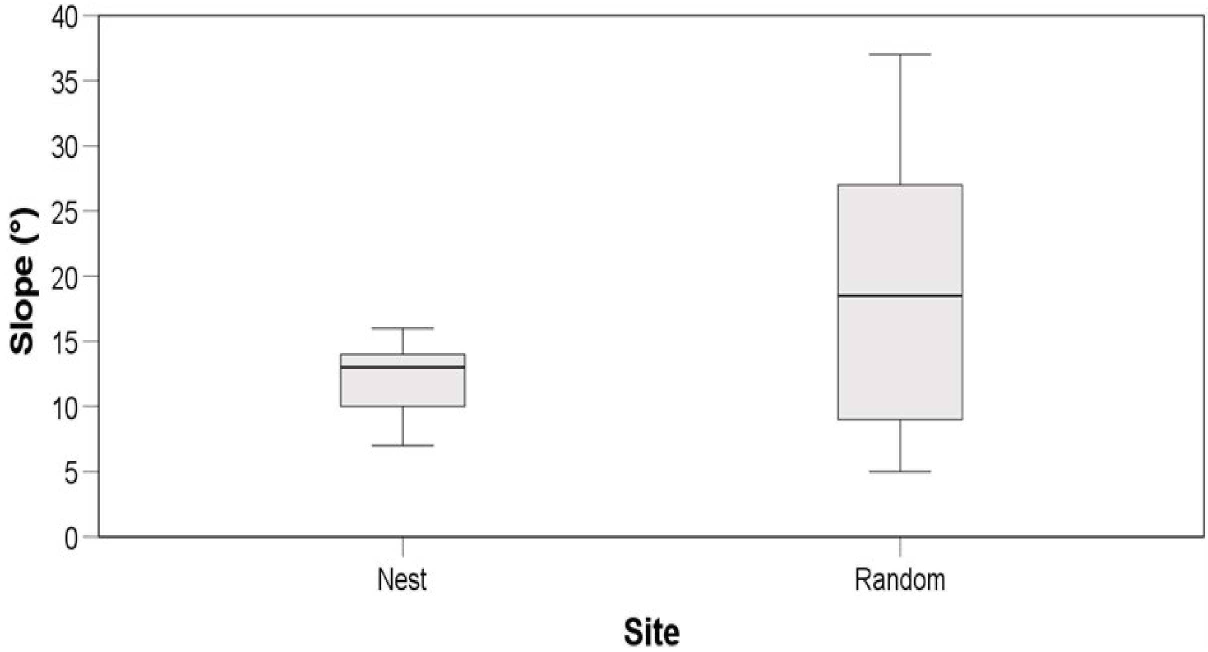

Fig. 4.3 Slope degree (°) for nest sites (n = 26) and random sites (n = 26) of Spotted Thick-knee nest-plots in the present study. Bold lines in the box represent the median; boxes represent the quartile deviation, and the whiskers represent the range of values.

4.4.3 Nest survival

Spotted Thick-knee nest-plot characteristics improved on the base models: time-influenced survival with nest date in season, and time-influenced survival with nesting season and nest age (no interaction). Six models were considered to have substantial support (ΔAICc < 2.00) relative to other models tested and were chosen as the subset of models to be analysed with weather variables and observer effect. The best-supported model included time-influenced survival, nesting season and nest age (no interaction), along with proportion of bare ground cover and shrub-like nest-structure as influential predictors (AICc = 79.05; *wi* = 0.15; -2log = 68.97; number parameters = 5). The best-supported model differed by more than 6 AICc units from the constant survival (null) model (Supplementary Table S4.2).

Regarding the subset models (six candidate models and null model), inclusion of weather variables and observer effect reduced the AICc weight for the best-supported and second best-supported habitat models (Table 4.3). However, the third best-supported model had a model likelihood of 0.95 and included the linear and quadratic function of daily Min- and Max- Temperature (AICc = 79.16; ΔAICc = 0.11; *wi* = 0.09; -2log = 67.02; number parameters = 9), and there was greater spread of AICc weight (*wi*) amongst all models and improvement in lower supported models resulting in 10 models (ΔAICc < 2.00 units), to be considered to have relatively substantial support (Table 4.3).

The best-supported model had an intercept of β = 4.34 and indicated a negative influence of: nest date in season (NestDate = -0.009); bare ground (PropBare = -11.56); and nest age in season (NestAge = -0.064), on daily nest survival (Table 4.4). Although, there was support for daily nest survival with positive influence by the use of a shrub-like nest-cover structure (strSHRUB = 1.58; Table 4.4). This combination of predictor variables best approximated the conditions of influence on daily nest survival compared with other models. For example, the best-supported models' regression equation showed that for nests using a shrub-like nest-cover structure and a set proportion of 0.05 (5%) bare ground on nest-plot, the probability of daily nest survival of different aged nests on 'day 25' in the nesting season: aged 1 was 0.98; aged 15 was 0.98; and aged 25 was 0.96 (Fig. 4.4). They differed from nests on 'day 105' which was later in the nesting season whereby: age 1 was 0.90; aged 15 was 0.89; aged 25 was 0.87 (Fig. 4.4). However, the influence of other models was not disregarded, especially considering the low AICc weight (*wi* = 0.09) for the best-supported model and model 2 (AICc = 79.14; ΔAICc = 0.09; *wi* = 0.09) and model 3 (AICc = 79.16; ΔAICc = 0.11; *wi* = 0.09) were well supported with model likelihoods of 0.95 (Table 4.3).

Through parameter weighting of the ten competitive models (ΔAICc < 2.00), it was found the date in nesting season (weight = 0.602) and shrub-like nest-structure (weight = 0.602) had the most weight as predictor variables compared with all other predictor variables from the 10 supported models (Table 4.5). Although observer effect (β = 2.91; SE = 1.87; 95% CI = -

2.50 – 3.11 (lower – upper) was included in a competitive model, the confidence interval crossed zero thus the effect estimation was considered weak (Table 4.5).

Table 4.3 Most supported models (ΔAICc < 2.00 units) from the stage 3 analysis of combined predictor variables for Spotted Thick-knee nest survival in the present study.

#	Model	AICc	ΔAICc	AICc Weights	Model Likelihood	Number of Parameters	-2log
1	**{St + NestDate + PropBare + strSHRUB + NestAge}**	79.05	0.00	0.09	1.00	5	68.96
2	**{St + NestDate + PropBare + Slope + strSHRUB + NestAge}**	79.14	0.09	0.09	0.95	6	67.02
3	**{St + NestDate + PropBare + strSHRUB + NestAge + (MinTemp*2 + MaxTemp*2)}**	79.16	0.11	0.09	0.95	9	65.00
4	**{St + NestDate + PropBare + strSHRUB}**	79.68	0.63	0.07	0.73	4	71.62
5	**{St + NestDate + PropBare + Slope + strSHRUB + NestAge + (MinTemp*2 + MaxTemp*2)}**	80.01	0.96	0.06	0.62	10	63.81
6	**{St + NestDate + PropBare + Slope + strSHRUB}**	80.04	0.99	0.06	0.61	5	69.96
7	**{St + NestDate + PropBare + strSHRUB + (MinTemp*2 + MaxTemp*2)}**	80.58	1.53	0.04	0.47	8	68.46
8	**{St + Nest Date + PropVeg + strSHRUB}**	80.90	1.85	0.04	0.40	4	72.84
9	**{St + NestDate + PropVeg + strSHRUB + NestAge}**	80.99	1.94	0.04	0.38	5	70.90
10	**{St + NestDate + PropBare + strSHRUB + NestAge + ObsEfct}**	81.03	1.98	0.03	0.37	6	68.91

Table 4.4 Coefficient estimates for predictor variables included in the most supported model from stage 3 for Spotted Thick-knee survival. Results presented by the beta estimate, standard error (SE), and 95% Confidence Intervals (CI).

Variable	**β-estimate**	**SE**	**95% CI (lower)**	**95% CI (upper)**
Intercept	4.34	1.04	1.9	6.22
NestDate	-0.009	0.007	-0.0245	0.0045
PropBare	-11.56	3.81	-20.18	-5.94
strSHRUB	1.58	0.67	0.277	2.884
NestAge	-0.064	0.041	-0.144	0.015

Table 4.5 Relative importance of predictor variables included in the ten most supported models (ΔAICc < 2.00 units) from stage 3 of Spotted Thick-knee survival analyses in the present study.

Predictor variable	**Code**	**Number of inclusions**	**Total weight**	**Relative importance rank**
Nest date in season	NestDate	10	0.60	1
Nest-cover structure (shrub)	strSHRUB	10	0.60	1
Bare ground surface cover	PropBare	8	0.53	2
Age of nest	NestAge	6	0.40	3
Slope (°)	Slope	3	0.20	4
Daily temperature (quadratic)	Min*2 + Max Temp*2	3	0.19	5
Daily temperature (linear)	Min + Max Temp	3	0.19	5
Vegetation surface cover	PropVeg	2	0.07	6
Observer effect	ObsEfct	1	0.04	7

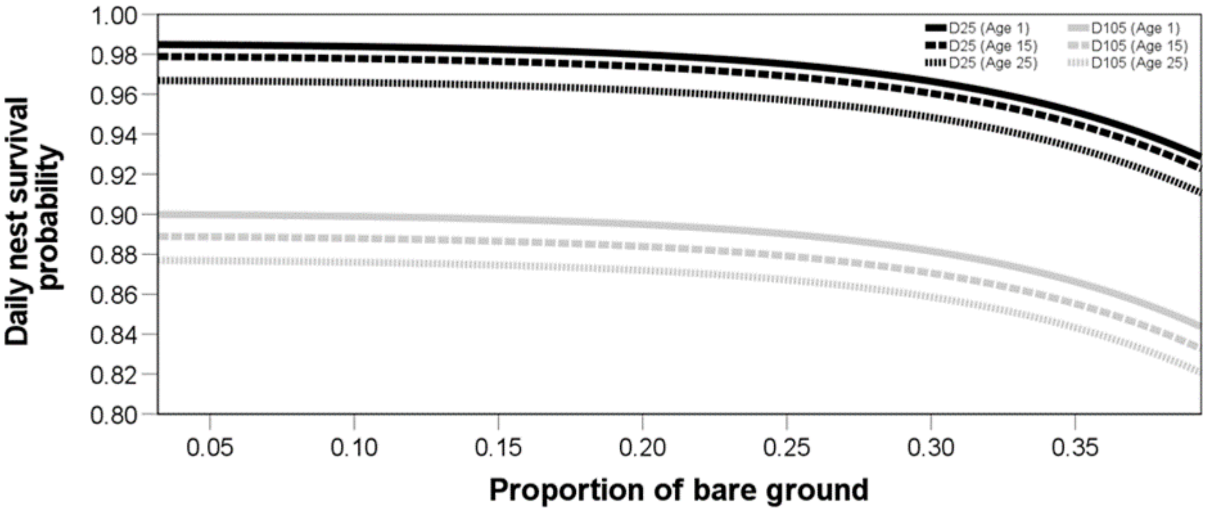

Fig. 4.4 Spotted Thick-knee probability of daily nest survival, from the best supported model, for nests aged 1, 15, and 25 early in the nesting season on day 25 ('D25' in figure) compared with nests of the same ages but initiated later in the nest season on day 105 ('D105' in figure) in the present study. Most nests had a shrub-like nest-cover structure and were influenced by an increase in the proportion of bare ground covering the surface of the nest-plot.

4.4.4 Incubation activity

A total of (N = 5400) camera-trap events were recorded from eight Spotted Thick-knee nesting sites regarding incubation activities. Incubation time was significantly longer during the day with mean 49.1 ± 6.5 min. h^{-1} compared with the night, which had a mean of 46.4 ± 4.35 min. h^{-1}, across a full 24-h camera-day ($t_{(2699)} = 40.31$; $p < 0.001$; Fig. 4.5). However, the '17:00 to 17:59' period, which was considered day-period, and had the shortest mean incubation time of 42.3 ± 9.16 min. (Fig. 4.5).

Breeding pairs were territorial and especially aggressive when defending nest sites. One or both adults stood upright, spreading their wings and calling out in loud shrieks whilst moving towards the perceived threat. There were 331 recorded camera-trap events of known disturbances with a total duration of 3 673 min. and mean duration for each event at 11.1 ± 5.31 min. There were significantly more known disturbance events during the day (n = 288) than during the night (n = 43) (χ^2 = 362.69; df = 1; p < 0.001). There was a significant difference in the identified causes of disturbance events (n = 331) whereby: 32.6% (n = 108) of events were because of domestic pets; 22.7% (n = 75) of events were because of humans; 8.8% (n = 29) events were because of wild animals; 12.1% (n = 40) events were because of motor vehicles; and 23.9% (n = 79) events had unknown causes for a defensive reaction from the incubating individual or breeding pair (χ^2 = 76.64; df = 4; p < 0.001; Fig. 4.7).

The regression analyses revealed that disturbance had a slope coefficient of -1.12 and significantly explained at least 33% of the variation in incubation activity; therefore, an increase in disturbance caused a decrease in incubation time (F (1, 5400) = 2764.44; R^2 = 0.338; p < 0.001; Fig. 4.6). The '17:00 to 17:59' period had the longest mean disturbance duration (13.3 ± 6.4 min.; n = 96), and it was no coincidence that this period also had the shortest mean incubation time.

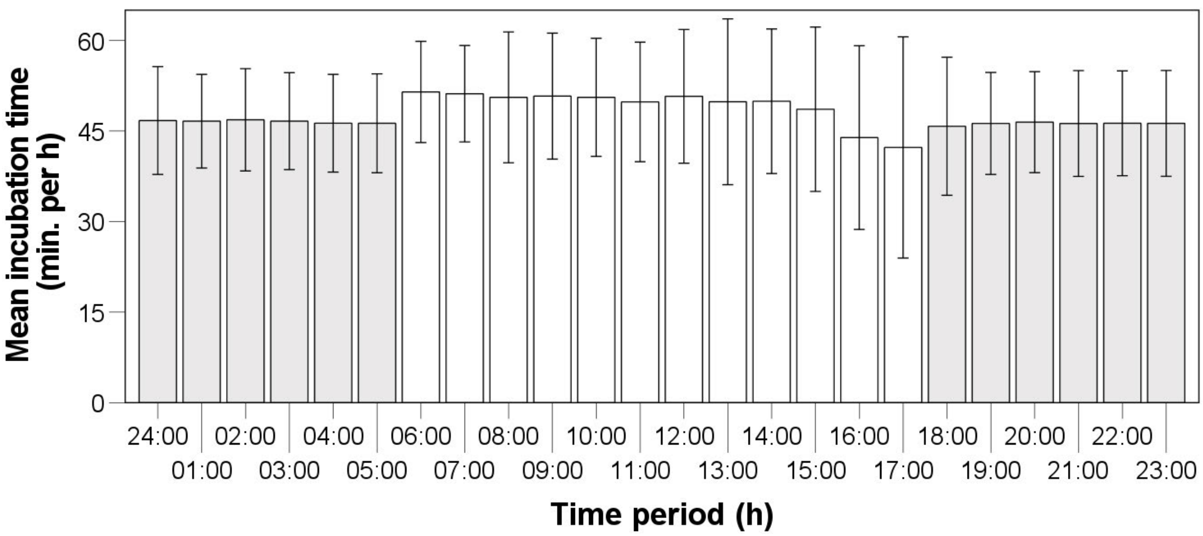

Fig. 4.5 Spotted Thick-knee mean incubation time per hour for each hour in a camera-trap day in the present study. Shaded bars indicate hours that were within the night period whilst bars with no shading indicate hours within the day period for our study. Hour (h) labels indicate the time of start and included the duration of 59 min. 59 s. for that hour. Error bars represent mean ± 2 SD (standard deviation).

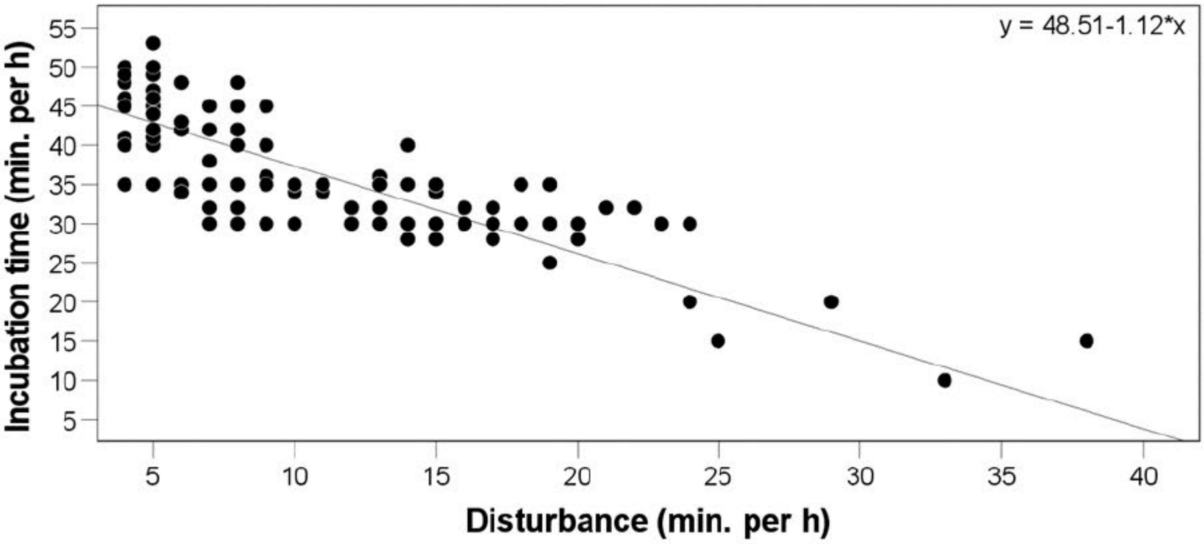

Fig. 4.6 Effect of increasing disturbance durations in minutes per hour (min. per h), on Spotted Thick-knee incubation time in the present study.

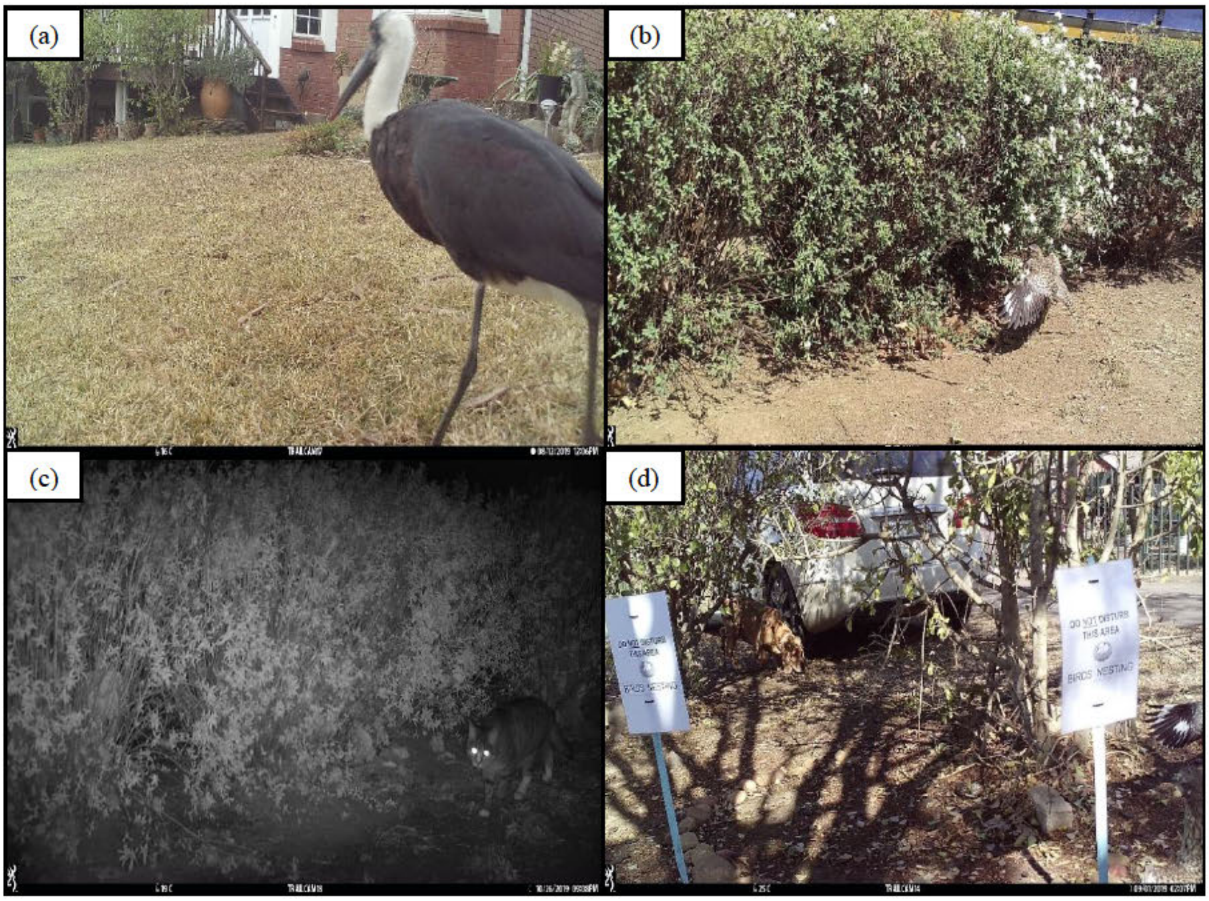

Fig. 4.7 Examples of camera-trap events identified as known disturbances, where Spotted Thick-knee incubation was taking place just before the disturbance where (a) shows the

incubating adult which moved away from the nest shortly before the appearance of a Woolly-necked Stork (*Ciconia microscelis*); (b) an adult displaying defensive behaviour at an unidentified object that was perceived as a threat; (c) incubating adult moved away from nest shortly before the appearance of a domestic animal identified as a domestic cat (*Felis catus*); and (d) a breeding pair (bottom right corner) displaying defensive behaviour towards a domestic dog (*Canis lupus*) after initial disruption of incubation by the parking of the motor vehicle.

Human interventions also caused disturbance to urban nesting Spotted Thick-knees in our study. One such case was a site where the human residents within a residential complex tried to move a Spotted Thick-knee nest because they thought the eggs were in danger. During this process of moving the eggs and building a ‘fence’ around the nest site, there was no incubation carried out on the eggs for 3 h. The eggs at this site did not hatch, likely because of insufficient incubation. The humans took ‘ownership’ of wild animals and assumed that any intervention was a positive one.

4.4.5 Nest site re-use

We found that 75.8% (n = 25) of Spotted Thick-knee nest sites from the 2019–2020 breeding season (N = 33) were re-used in the 2020–2021 breeding season. 80% (n = 20) of the 25 re-used nest sites had a successful nesting attempt in the previous breeding season which took place between 2019–2020.

4.5 Discussion

The present study is the first in South Africa to investigate the nesting ecology of a terrestrial dependent species in an urban context other than the ecophysiological studies of Brown and Downs (2003, 2004). There were no substantial differences in Spotted Thick-knee clutch sizes for nests compared for month of initiation, land-use, and nesting attempt. However, Spotted Thick-knee clutches from nesting attempts initiated in September 2019 had the most eggs per nest. The August–September period was historically recorded as the peak egg-laying months for the population within this geographic area (Tarboton 2014). The number of Spotted Thick-knee nesting attempts that were successful was substantially greater than those that failed, suggesting that some areas within human-modified urban mosaics provide suitable nesting opportunities and allow the species survival for future generations. Land-use appeared not to influence nest outcomes in our study, but there was an apparent preference for the use of residential areas such as gardens or recreational grounds with nesting in residential gardens leading to the highest number of successful nest outcomes. No two sites had identical environments as even areas of the same land-use can differ greatly according to human activities (pers. obs.). Other studies have shown strong support for the growing trend of avifaunal species successfully thriving in urban areas because of their occupancy in residential gardens (Cannon et al. 2005; Bressler et al. 2020).

Relatively few Spotted Thick-knee secondary nesting attempts occurred, and there was no evidence of breeding pairs nesting a third time, although capable of doing so (Hockey 2005). It has been suggested that they do attempt to nest again if the previous attempt failed, which was evident in the present study but there was also one case where a breeding pair nested a second time after successful hatching of the complete clutch from the first attempt. The property owner mentioned the fact that the pair had been nesting in the garden every year for the past eight years (pers. comm.). Although the property owner assumed it was the same breeding pair every year, the life span of Spotted Thick-knees is around 15 years (Hockey 2005) which makes this trend plausible. Even if not the same pair breeding every year, the successive use of nesting sites is indicative of areas determined to be suitable, especially since many bird species are strict in their selection of nesting sites (Latif et al. 2012). Our findings of Spotted Thick-knee nest-site selection section supported this. There was greater use of shrub-like species as nest-cover structures. The aerial cover provided by short wide vegetation prevents heavy rain from hitting the nest or making the ground around the nest damp, which would otherwise be harmful to the eggs during the incubation period (Rauter et al. 2002; Latif et al. 2012). The use of these vegetation structures could also prevent or deter raptors from preying on the nests and make the nest-site harder to detect by other animals perceived as threats (Rauter et al. 2002; Eggers et al. 2008; Latif et al. 2012). However, not all predators use visual cues when searching for prey. For example, domestic cats and dogs both use olfactory cues in combination with visual cues, which makes these animals such great threats to urban-dwelling Spotted Thick-knees, as they result in injury or death to the birds (Josiah and Downs unpublished data: Chapter 3).

Breeding Spotted Thick-knee pairs showed preferences for certain nest-site characteristics. They preferred nesting in areas with lots of short-grass cover for the surface. Although the amount of vegetation cover was indicated as preferential, they selected areas that were composed of relatively short vegetation structures between 2 m and 5 m in height. Existing literature supports these trends with reasoning that Spotted Thick-knee prefer shorter grass and a more open area around the nest site to have a wider field of view and detect approaching threats more timeously (Hockey 2005; Tarboton 2014; Hume et al. 2019). Slope angle has been shown to be an influential factor for ground-nesting birds (Hayward and Escano 1989; Whittingham et al. 2002; Korne et al. 2020). Slopes at nest sites were also relatively flat, allowing for a greater field of view to detect danger; more balanced positioning for the incubation parent; and stable positioning of eggs because uncontrolled movement or displacement can damage eggs (Whittingham et al. 2002; Korne et al. 2020).

Nest survival was expressed as a daily nest survival probability in our study. Study findings showed further support for Spotted Thick-knees using shrub-like vegetation structures as nest-cover as they improved the nests' chances of survival from incubation to successful completion of a nesting attempt. Other influential factors included nest age and nest date in the season, which adversely affected nest survival. Older nests are suggested to be more at risk of failure because the nest site and breeding pair have been in that specific area for a longer period, allowing for more instances where cues are given to predators about the nest location (Moller 1988; Bötsch et al. 2017). Nesting periods are when the breeding pair are most vulnerable; nests initiated later in the breeding season are suggested to be more at risk because there are less nests and incubating adults for predators to prey on, which means that the active nests may have more chance of predation occurring because (Garvey et al. 2013; Reynolds et al. 2019). This could also be a constraint to the survival and development of hatchlings if there are multiple family groups competing for limited resources (Garvey et al. 2013; Reynolds et al. 2019). This could also influence incubation activity even though both parents do this act, it may still require significant energy costs, and if resources are limited, it can reduce nest survival (Garvey et al. 2013; Reynolds et al. 2019). The amount of bare ground cover at nest sites influenced daily survival. Bare ground is important to Spotted Thick-knee as they lay their eggs on it or make scrapes and then lay eggs (Hockey 2005; Tarboton 2014; Hume et al. 2019). However, too much bare ground cover conversely means a decrease in grass and vegetation cover, which has always been a requirement in their natural habitats. There was little to no support for other *a priori* variables and their influence on Spotted Thick-knee nest survival. However, citing similar studies that highlight these variables' effect can be found in the supplementary information (Supplementary information Table S4.1).

Incubation activity in urban areas was highest during the daytime, which is expected because the Spotted Thick-knee is nocturnal and more active at night (Hockey 2005; Tarboton 2014; Hume et al. 2019). In addition, ambient temperatures require that the nests are incubated (Downs and Brown 2003, 2004). Both adults of the breeding pair alternate the role of incubation, which is widely considered to contribute greatly to the success of a nesting attempt (Boersma 1982; Gaines and Ryan 1988). The alternating of roles allows each adult to feed and replenish the lost energy whilst incubating, which, in turn, allows the incubation process to be more efficient (Boersma 1982; Gaines and Ryan 1988). However, when incubation is disrupted for long periods or short but frequent periods, it can result in eggs failing to hatch or lead to complications in the growth and development of hatchlings (Boersma 1982; Gaines and Ryan 1988). Our study findings revealed that incubation activities were adversely affected by anthropogenic activities close to the nest site. More often than not, incubation was disrupted by disturbances that were anthropogenically induced. Domestic cats and dogs were identified as sources of a disturbance along with motor vehicles which were driven in close proximity to nests. Findings in studies by McGowan and Simons (2006), and Chatwin et al. (2013) both verify and highlight the negative impact motor vehicles have on incubation activity. Human intervention also contributed to disturbances of incubation in our study. Despite the risks of nesting in these areas, most nest sites were re-used in the subsequent breeding season between 2020–2021. This finding suggests that they display breeding-site fidelity, which is not uncommon for species that are sedentary (Sheridan et al. 2020). The aspects mentioned above need to be considered when studying a species in an urban context, especially when the species can provide valuable information for similar species that may be showing increased presence across urban landscapes.

4.6 Acknowledgements

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4.8 Supplementary information

Supplementary information Table S4.1 Predictor variables used within the current study. Includes: description of each predictor variable; function of the variable; reason for inclusion in the present study; and a relevant studies that support or highlight the predictor variables associated with nest survival.

Predictor Variables (unit of measure)	Code (function)	Description	Reason for selection	Relevant studies
Temporal				
Survival over time	St	Time-influenced survival	This applies to all living organisms and cannot be excluded from any investigation relating to the survival of fauna and flora.	Not applicable
Nest date	NestDate (linear) NestDate*2 (quadtratic)	Date nest was found on first visit in relation to the first nest date (i.e., date of first nest found in study).	Some studies have shown that nest initiation date in the breeding season whether: early; in the middle of; or late in the season, have correlated with the nest survival of some species. However, there have been findings of positive and negative linear trends as well as quadratic trend between nest date in season as nest age. This variable has more influence when other factors such as habitat and resource availability are considered.	Wilson et al. (2007); Grant and Shaffer (2012); Webb et al. (2012); Zhao et al. (2020)
Nest age	NestAge (linear) NestAge*2 (quadtratic)	Nest age in season on first observer visit in relation to nest date	Nest age is considered to have an influence on nest survival for some species. Similar to nest initiation date in breeding season, the effects of this variable are evident in combination with other factors. For select species, sometimes an older nest will have increased risk because there is more activity when approaching egg-laying dates, and this can make the nest site more detectable by predators.	Wilson et al. (2007); Grant and Shaffer (2012); Klett and Johnson (1982); Zhao et al. (2020)

Temperature (°C)	(MinTemp + Max Temp) (linear) (MinTemp + MaxTemp*2) (quadratic)	Minimum and maximum daily temperature for each day in study period (paired variables)	Ambient temperature influences nest survival, incubation activity and productivity. Temperature changes are suggested to be more consequential for ground-nesting species, because of their nesting habit, they are more prone to temperature changes just below or at ground surface level. Extreme temperatures can impact the fitness of the incubating adult which in turn can reduce its effectiveness when incubating eggs.	Webb et al. (2012); Mougeot et al. (2014); Carroll et al. (2015); Tanner et al. (2017); Carroll et al. (2020)
Precipitation (mm)	MaxPrec (linear)	Maximum daily precipitation in millimetres for each day in study	Weather conditions such as rainfall can cause harm to the adult or the eggs in the nest. Intense precipitation can disrupt incubation activity. For some ground-nesting species, dampness of the soil and surface area around the nest can lower egg temperatures and extend incubation periods which is an energy cost to the adult.	Webb et al. (2012); Tanner et al. (2017); Yarnall et al. (2020)
Habitat (nest-plot)				
Surface cover (proportions)	PropBare PropMan PropGrass PropVeg	Bare ground Man-made Grass Vegetation	The varying proportions of different types of surface groundcover has an influence on nest survival, especially in an urban-transformed habitat where they can change in a magnitude over a short period. The influence of each type varies depending on the species, but it is suggested that increased bare ground cover and man-made cover, have decreased the nest survival of many ground-nesting species.	Taylor et al. (1999); Guerrero et al. (2012); Webb et al. (2012); Carroll et al. (2015); Lautenbach et al. (2019)
Nest-cover structure	strSHRUB strTREE	Shrub Tree Nests with no cover-structure did not have a parameter code	For species that nest with or without nest-cover structures, nests with cover structures have shown comparatively higher nest survival probabilities, as compared to nests that do not have cover structures. These structures provide protection against weather events and in some instances,	DeLong et al. (1995); Fogarty et al. (2017)

			they reduce incubating adult and nest detection by predators or perceived threats. However, not all structures provide these benefits to nest survival as it also depends on the phytomorphology of the specific vegetation structure.	
Slope (°)	Slope (linear)	Steepest slope angle of nest patch (5-meter length with nest in the centre)	The slope angle at nest sites has been suggested to be preferential by ground-nesting species. The relatively flat gradient of an area allows: for a wider field of view thus the incubating adult is able to react more quickly to approaching predators or perceived threats; and more stable incubation form and positioning of eggs which reduces risk of egg-displacement and damage. Expressed as a linear function because there is no evidence of preferential nest-site selection at both extremes of the range in nest-site slope angle/gradient (i.e., flat or very steep).	Hayward and Escano (1989); Whittingham et al. (2002); Korne et al. (2020)
Other				
Observer effect	ObsEfct	Day of visit to site for each visit	The effect of investigator disturbance at nest sites has been sufficiently documented. There is evidence showing that visiting of nest sites has directly led to: disruptions in incubation activity; instances of nest desertion; and increased predation by both terrestrial predators (e.g., carnivorous mammals) and avian predators (e.g., raptors).	Götmark (1992); Bötsch et al. (2017); Zhao et al. (2020)
Constant survival	S.	Null model	Often used in nest survival studies that use the Mayfield method or Apparent Estimator method. However, the findings from such approaches have little biological relevance. Included in analyses to compare the hypothetical situations that could result from examining predictor variables separately.	Dinsmore et al. (2002); Jehle et al. (2004)

Supplementary Table S4.2 Model outputs of daily nest survival for all model stages in nest survival analyses using program MARK. Models in bold were carried over to the next stage in analyses for stage 1 and 2. Models in bold from stage 3 were considered competitive (ΔAICc < 2.00 units).

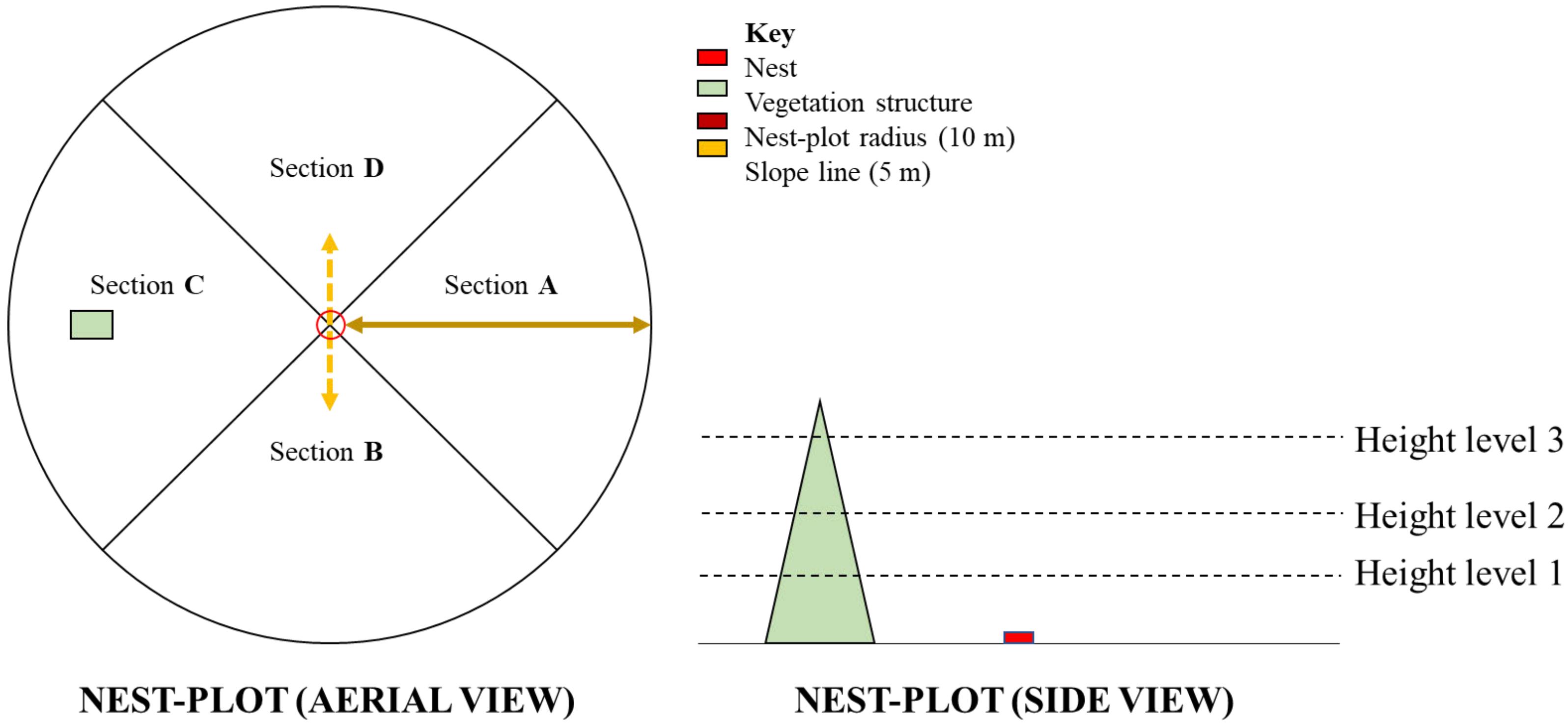
Code	**Model**	**AICc**	**ΔAICc**	**AICc Weights**	**Model Likelihood**	**Number of Parameters**	**-2log**
Stage 1: base models							
Base1	**{St + NestDate + NestAge}**	**85.00**	**0.00**	**0.14**	**1.00**	**3**	**80.98**
Base2	**{St + NestDate}**	**85.16**	**0.16**	**0.13**	**0.96**	**2**	**81.77**
Base3	{S.}	85.42	0.42	0.12	0.81	1	83.42
Base4	{St + NestAge}	85.59	0.59	0.11	0.75	2	81.57
Base5	{St + (NestDate + NestAge)} (interaction)	85.82	0.82	0.10	0.66	3	81.81
Base6	{St + NestDate + NestAge*2}	86.34	1.34	0.07	0.51	4	80.30
Base7	{St + NestDate*2 + NestAge}	86.35	1.34	0.07	0.51	4	80.31
Base8	{St + NestAge*2}	86.43	1.43	0.07	0.49	3	82.42
Base9	{St + NestAge + NestAge*2}	86.65	1.65	0.06	0.44	4	80.61
Base10	{St + (NestDate*2 + NestAge*2)} (interaction)	86.86	1.86	0.06	0.39	5	82.84
Base11	{St + NestDate + NestDate*2}	86.98	1.98	0.05	0.37	4	80.95
Stage 2: habitat (nest-plot characteristics)		**AICc**	**ΔAICc**	**AICc Weights**	**Model Likelihood**	**Number of Parameters**	**-2log**
H1	**{St + NestDate + PropBare + strSHRUB + NestAge}**	**79.05**	**0.00**	**0.15**	**1.00**	**5**	**68.96**
H2	**{St + NestDate + PropBare + Slope + strSHRUB + NestAge}**	**79.14**	**0.09**	**0.14**	**0.95**	**6**	**67.02**
H3	**{St + NestDate + PropBare + strSHRUB}**	**79.68**	**0.63**	**0.11**	**0.73**	**4**	**71.62**
H4	**{St + NestDate + PropBare + Slope + strSHRUB}**	**80.04**	**0.99**	**0.09**	**0.61**	**5**	**69.96**

H5	**{St + NestDate + PropVeg + strSHRUB}**	**80.90**	**1.85**	**0.06**	**0.40**	**4**	**72.84**
H6	**{St + NestDate + PropVeg + strSHRUB + NestAge}**	**80.99**	**1.94**	**0.05**	**0.38**	**5**	**70.90**
H7	{St + NestDate + PropBare}	81.98	2.93	0.03	0.23	3	75.95
H8	{St + NestDate + PropBare + strTREE + NestAge}	82.21	3.16	0.03	0.21	5	72.13
H9	{St + NestDate + PropBare + NestAge}	82.33	3.28	0.03	0.19	4	74.27
H10	{St + NestDate + PropBare + strTREE}	82.44	3.39	0.03	0.18	4	74.38
H11	{St + NestDate + PropVeg}	82.45	3.40	0.03	0.18	3	76.41
H12	{St + NestDate + PropMan + strSHRUB}	82.59	3.55	0.02	0.17	4	74.54
H13	{St + NestDate + PropVeg + Slope + strSHRUB}	82.80	3.75	0.02	0.15	5	72.72
H14	{St + NestDate + PropBare + Slope}	83.10	4.05	0.02	0.13	4	75.04
H15	{St + NestDate + PropVeg + NestAge}	83.14	4.09	0.02	0.13	4	75.09
H16	{St + NestDate + PropMan + Slope + strSHRUB}	83.20	4.15	0.02	0.13	5	73.12
H17	{St + NestDate + PropMan + strSHRUB + NestAge}	83.73	4.68	0.01	0.10	5	73.64
H18	{St + NestDate + PropBare + Slope + strTREE + NestAge}	83.99	4.94	0.01	0.08	6	71.87
H19	{St + NestDate + PropVeg + strTREE}	84.00	4.95	0.01	0.08	4	75.94
H20	{St + NestDate + PropBare + Slope + strTREE}	84.12	5.07	0.01	0.08	5	74.03
H21	{St + NestDate + PropVeg + Slope}	84.14	5.09	0.01	0.08	4	76.08
H22	{St + NestDate + PropVeg + strTREE + NestAge}	84.52	5.47	0.01	0.06	5	74.43
H23	{St + NestDate + PropVeg + Slope + NestAge}	84.85	5.80	0.01	0.06	5	74.76
H24	{St + NestDate + PropGrass + Slope + strSHRUB}	84.89	5.84	0.01	0.05	5	74.80
H25	{St + NestDate + NestAge}	85.00	5.95	0.01	0.05	3	80.98
H26	{St + NestDate}	85.16	6.11	0.01	0.04	2	77.22

H27	{S.}	85.42	6.37	0.01	0.04	1	83.42
H28	{St + NestDate + PropMan}	85.46	6.42	0.01	0.04	3	79.43
H29	{St + NestDate + PropMan + strTREE}	85.54	6.49	0.01	0.04	4	77.48
H30	{St + NestDate + PropVeg + Slope + strTREE}	85.90	6.85	0.00	0.03	5	75.81
H31	{St + NestDate + PropGrass + Slope + strSHRUB + NestAge}	86.26	7.21	0.00	0.03	6	74.14
H32	{St + NestDate + PropGrass + strSHRUB}	86.34	7.29	0.00	0.03	4	80.30
H33	{St + NestDate + PropGrass + strSHRUB + NestAge}	86.41	7.36	0.00	0.03	5	76.33
H34	{St + NestDate + PropVeg + Slope + strTREE + NestAge}	86.46	7.41	0.00	0.02	6	74.34
H35	{St + NestDate + PropGrass}	86.56	7.51	0.00	0.02	3	80.52
H36	{St + NestDate + PropGrass + strTREE}	86.56	7.51	0.00	0.02	4	78.50
H37	{St + NestDate + PropMan + strTREE + NestAge}	86.63	7.58	0.00	0.02	5	76.55
H38	{St + NestDate + PropMan + NestAge}	86.75	7.70	0.00	0.02	4	78.70
H39	{St + NestDate + PropMan + Slope}	86.93	7.88	0.00	0.02	4	78.87
H40	{St + NestDate + PropMan + Slope + strTREE}	87.45	8.40	0.00	0.01	5	77.37
H41	{St + NestDate + PropGrass + strTREE + NestAge}	87.71	8.66	0.00	0.01	5	77.62
H42	{St + NestDate + PropGrass + Slope}	87.72	8.67	0.00	0.01	4	79.67
H43	{St + NestDate + PropGrass + NestAge}	87.90	8.85	0.00	0.01	4	79.84
H44	{St + NestDate + PropGrass + Slope + strTREE}	88.27	9.22	0.00	0.01	5	78.19
H45	{St + NestDate + PropMan + Slope + NestAge}	88.33	9.28	0.00	0.01	5	78.24
H46	{St + NestDate + PropGrass + Slope + NestAge}	89.20	10.15	0.00	0.01	5	79.11

Stage 3: combined models (habitat, weather and observer effect)		AICc	ΔAICc	AICc Weights	Model Likelihood	Number of Parameters	-2log
1	**{St + NestDate + PropBare + strSHRUB + NestAge}**	**79.05**	**0.00**	**0.09**	**1.00**	**5**	**68.96**
2	**{St + NestDate + PropBare + Slope + strSHRUB + NestAge}**	**79.14**	**0.09**	**0.09**	**0.95**	**6**	**67.02**
3	**{St + NestDate + PropBare + strSHRUB + NestAge + (MinTemp*2 + MaxTemp*2)}**	**79.16**	**0.11**	**0.09**	**0.95**	**9**	**65.00**
4	**{St + NestDate + PropBare + strSHRUB}**	**79.68**	**0.63**	**0.07**	**0.73**	**4**	**71.62**
5	**{St + NestDate + PropBare + Slope + strSHRUB + NestAge + (MinTemp*2 + MaxTemp*2)}**	**80.01**	**0.96**	**0.06**	**0.62**	**10**	**63.81**
6	**{St + NestDate + PropBare + Slope + strSHRUB}**	**80.04**	**0.99**	**0.06**	**0.61**	**5**	**69.96**
7	**{St + NestDate + PropBare + strSHRUB + (MinTemp*2 + MaxTemp*2)}**	**80.58**	**1.53**	**0.04**	**0.47**	**8**	**68.46**
8	**{St + NestDate + PropVeg + strSHRUB}**	**80.90**	**1.85**	**0.04**	**0.40**	**4**	**72.84**
9	**{St + NestDate + PropVeg + strSHRUB + NestAge}**	**80.99**	**1.94**	**0.04**	**0.38**	**5**	**70.90**
10	**{St + NestDate + PropBare + strSHRUB + NestAge + ObsEfct}**	**81.03**	**1.98**	**0.03**	**0.37**	**6**	**68.91**
11	{St + NestDate + PropBare + strSHRUB + NestAge + MaxPrec}	81.07	2.02	0.03	0.36	6	68.95
12	{St + NestDate + PropBare + Slope + strSHRUB + NestAge + ObsEfct}	81.14	2.09	0.03	0.35	7	66.98
13	{St + NestDate + PropBare + Slope + strSHRUB + NestAge + MaxPrec}	81.17	2.12	0.03	0.35	7	67.01
14	{St + NestDate + PropBare + strSHRUB + NestAge + (MinTemp + MaxTemp)}	81.24	2.19	0.03	0.33	7	67.08
15	{St + NestDate + PropBare + strSHRUB + ObsEfct}	81.61	2.56	0.03	0.28	5	71.52

16	{St + NestDate + PropBare + strSHRUB + MaxPrec}	81.67	2.62	0.03	0.27	5	71.58
17	{St + NestDate + PropBare + Slope + strSHRUB + ObsEfct}	81.98	2.93	0.02	0.23	6	69.86
18	{St + NestDate + PropBare + Slope + strSHRUB + MaxPrec}	82.08	3.03	0.02	0.22	6	69.96
19	{St + NestDate + PropBare + strSHRUB + (MinTemp + MaxTemp)}	82.19	3.14	0.02	0.21	6	70.07
20	{St + NestDate + PropBare + Slope + strSHRUB + NestAge + (MinTemp + MaxTemp)}	82.20	3.15	0.02	0.21	8	65.99
21	{St + NestDate + PropVeg + strSHRUB + NestAge + (MinTemp*2 + MaxTemp*2)}	82.26	3.21	0.02	0.20	9	68.09
22	{St + NestDate + PropVeg + strSHRUB + (MinTemp*2 + MaxTemp*2)}	82.66	3.61	0.02	0.16	8	70.54
23	{St + NestDate + PropVeg + strSHRUB + ObsEfct}	82.85	3.80	0.01	0.15	5	72.76
24	{St + NestDate + PropBare + Slope + strSHRUB + (MaxTemp + MinTemp)}	82.86	3.81	0.01	0.15	7	68.70
25	{St + NestDate + PropVeg + strSHRUB + MaxPrec}	82.92	3.87	0.01	0.14	5	72.83
26	{St + NestDate + PropBare + Slope + strSHRUB + (MaxTemp*2 + MinTemp*2)}	82.96	3.91	0.01	0.14	9	68.80
27	{St + NestDate + PropVeg + strSHRUB + NestAge + ObsEfct}	82.97	3.92	0.01	0.14	6	70.85
28	{St + NestDate + PropVeg + strSHRUB + NestAge + MaxPrec}	83.01	3.96	0.01	0.14	6	70.89
29	{St + NestDate + PropVeg + strSHRUB + NestAge + (MinTemp + MaxTemp)}	83.65	4.60	0.01	0.10	7	69.49
30	{St + NestDate + PropVeg + strSHRUB + (MinTemp + MaxTemp)}	83.78	4.73	0.01	0.09	6	71.66
31	{S.}	85.42	6.37	0.00	0.04	1	83.42



Supplementary information Fig. S4.1 Schematic diagram showing how data were collected from each nest-plot which had a radius of 10 m with the nest at the centre. From the aerial view, all nest-plots were sectioned (Section **A** to **B**) and the estimates of surface cover, grass height and vegetation structure proportions at height levels 1 to 3, for each section were combined and averaged to represent the nest-plot values for that specific characteristic. The slope line 5 m in length had the nest at the midpoint distance. From the side view, the height class level 1 (0.15 m < height < 2 m), level 2 (2 m ≤ height ≤ 5 m), level 3 (height > 5 m), that vegetation structures were within. For example, the appropriate measurements for the vegetation structure within the diagram would be recorded, and the structure would be noted as class height level 3 (height > 5 m) because the maximum height is above the line where height level 3 starts.

CHAPTER 5

Conclusions and recommendations

5.1 Introduction

With the increase in urbanisation and the negative impact it has had on biodiversity globally, there has been a recent trend in studying species responses to the unnatural changes in their habitats (Alberti 2003). These studies have become so extensive that they have formed a recent field in science, known as 'urban ecology'. Urban ecology has developed considerably as a field of study, with increased focus on how species persist in urban environments, especially for avian species (Adams et al. 2006; Ibáñez-Álamo et al. 2017; Reynolds et al. 2019; Luna et al. 2020; Purger et al. 2020; Downs et al. 2021). There has been a recent trend in studying avian species because they have the greatest mobility to move in and out of these anthropogenically fragmented areas. Therefore, they provide valuable information on the response of wildlife, especially those with decreasing natural habitat. However, there is a paucity of research on specific species, thus information about their urban ecology is relatively limited. The few studies that have been carried out were typically undertaken in well-developed regions such as Europe, where there is already low biodiversity as compared with developing regions or countries still relatively abundant in wildlife (Adams et al. 2006; Bressler et al. 2020). Southern Africa is one such region where there are relatively large areas of natural landscape with wildlife present. Although, it has been suggested that rapid urban development will take place in this region, in countries such as South Africa (Cohen 2006). This provides an opportunity for preliminary studies and collection of baseline data for avian species that are experiencing a reduction in their natural habitat and greater urban infringement. In South Africa, one such avian species that lacks urban ecological information is the Spotted Thick-knee (*Burhinus capensis*). Therefore, this thesis aimed to evaluate aspects of the Spotted Thick-knee's urban ecology in Pietermaritzburg, KwaZulu-Natal, South Africa. The thesis main research findings were as follows:

5.2 Research findings and synthesis

5.2.1 Distribution trends across South Africa

The objective was to examine whether Spotted Thick-knees have experienced changes in range, distribution and abundance across South Africa (Chapter 2). The study findings suggest that the Spotted Thick-knee has experienced a change in range with the species present in more areas (indicating colonisation) than in areas where it is currently absent (indicating species removal) or range distribution changes across South Africa. The Spotted Thick-knee has experienced an overall decrease in distribution over the region but has shown a range expansion into areas previously considered unsuitable for the study species to inhabit. The study has substantiated the usability and importance of citizen science data and atlas survey methods, providing valuable spatial information and monitoring species at a large-scale geographically (Chapter 2).

5.2.2 Human-wildlife interaction across an urban landscape

The objective was to assess and collect novel information on human-wildlife interactions that result from the presence of Spotted Thick-knees across a fragmented and human-modified landscape, which consists of varying anthropogenic developments (Chapter 3). The study findings showed that the Spotted Thick-knee included in the study were part of a resident population and their presence at select areas was not random. Spotted Thick-knees showed frequent inhabitancy of human-modified habitats such as gardens. Select areas provided suitable habitat for nesting as well as access to resources both natural and unnatural (i.e., supplemental feeding). These areas may also provide safety from natural predators. However, the risk of urban-dwelling survival was apparent, especially regarding novel pressures such as domestic pets (Chapters 2 and 3).

5.2.3 Nesting ecology

The objective was to investigate facets of nesting ecology and breeding habits of a Spotted Thick-knee population within and around the city of Pietermaritzburg, South Africa. Focus was placed on assessing their nest clutch size; nest outcomes; nest-site selection and survival; and incubation activity, within areas of different land-use and human activity (Chapter 4). Study findings revealed preference in select habitat and nest-site characteristics; successful nesting outcomes were significantly greater than failed nesting outcomes; incubation activity was significantly longer during the day; and incubation activity had a significant adverse relationship with disturbance in human modified habitats (Chapter 4).

5.3 Conclusions and recommendations

The studies carried out within this thesis, provided novel information on aspects of the Spotted Thick-knee's urban ecology. By examining their distributions across South Africa, there has been a change in their distribution range that is mostly indicative of species colonisation, especially in areas previously considered unsuitable for them. The colonisation of new areas is suggested to result from anthropogenic development and urban expansion into or close to these areas, making these locations more habitable for Spotted Thick-knee. The species has experienced a decrease in abundance in areas where they were frequently sighted in the past 25 years, and this trend has been attributed to the intense reduction of suitable natural landscape across South Africa.

Their increased presence in some urban areas may result from infringement on their habitats instead of the previously assumed increase in their population numbers. Although there was no conclusive evidence of this trend, it was suggested through findings from other aspects of their ecology, such as the human-wildlife interactions they experienced, or the anthropogenic impacts on their breeding.

It was apparent that novel pressures existed in human-modified habitats. Known causes of Spotted Thick-knee injuries or deaths were substantially associated with domestic pets. Despite this trend, there was an observed preference in the use of residential gardens for their nesting. Further investigation of their nesting revealed the influence of anthropogenic activity, which resulted in disruptions to incubation activity more often than not. The remote monitoring of select nest sites further emphasised the dangers experienced at some locations where domestic pets were close.

Each of the studies in the present thesis provided insight into Spotted Thick-knee ecology in an urban context, but when the findings of the studies are combined, the reasons for their persistence in urban areas becomes clearer. They may be specialists regarding their nesting habit but their generalistic diet; breeding behaviours such as alternating incubation roles; and precocial traits allow them to be more plastic and adaptable in their response to anthropogenic development and human activity. Wherever the studies within this thesis fail to generate 'statistically significant' evidence, they managed to provide insights into aspects that require further study. This is generally the case for preliminary studies, especially when they are carried out in complex systems such as human transformed habitats.

For example, the investigation of nest outcomes showed that land-use was not a significant factor in the result of a successful nesting attempt, although residential gardens were preferred as nesting sites. The evaluation of variables predicted to influence nest survival showed little support for the increase in grass cover at nest-plots leading to an increase in daily nest survival, and yet, Spotted Thick-knee breeding pairs showed preference in the proportion of grass cover and grass height in nest-plots, when compared with random sites. This shows that there was an interrelation between factors which could not be identified in the separate studies. It was known by the study investigator that the shrub-like nest structures were mostly found on residential properties and these properties also had the grass height shorter because it was managed (i.e., cut or mowed) more often than at other land-use areas. Feedback from public participation indicated appreciation and satisfaction from many respondents who had Spotted Thick-knees that were resident in their gardens or had been frequent visitors over a number of years. Some homeowners even provided resources to the Spotted Thick-knee pairs or family groups that resided within their gardens. Their preference in the use of residential gardens becomes more apparent and comprehensible when one considers the findings of all the studies or rather, as many 'aspects' as possible. This is especially important for ecological studies which should, as the name suggests, investigate interactions and interrelationships where possible.

Spotted Thick-knee are categorised as 'Least Concern' on the IUCN Red List (BirdLife International 2016), although we suggest a re-evaluation of the reasons that were stated for them to be categorised as such, specifically claims that their population numbers are stable and there is no evidence of a decline in their distribution over South Africa. We provide few comments about their conservation or the conservation of similar species in an urban context, reason being that they are the first terrestrial dependent species in South Africa to be studied with this approach and the findings for most sections can be considered to be preliminary. However, we do recommend that future studies take a similar approach to that found in this thesis, especially for single-species studies that focus on species with similar behaviours and traits. This is because, depending on the species, the factors of influence may vary. The aims and objectives in this thesis may not necessarily apply to a raptor species which would require alternative methods of investigation because of the difference in aspects such as their ecological niche. Some aspects do relate, such as the examination of spatial distributions, which has been shown to be beneficial to the understanding of life-histories for some species, especially those of conservation importance (Austin 2007; Hofmeyr et al. 2014). For similar species that may be studied in an urban-ecological context, the inclusion of investigations relating to human-wildlife interactions will be beneficial in supporting the findings from the more conventional scientific methodologies. We recommend the inclusion of citizen science components as well as methods of remote monitoring such as the use of camera traps. This may not only lead to novel findings but also make the intended research more feasible. There is limited time in a day for a study investigator to carry out research and this can be very restrictive to studies which could otherwise reveal significant findings.

5.4 References

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