Range expansion of the Hadeda Ibis (*Bostrychia hagedash*) in Pietermaritzburg, KwaZulu-Natal: an urban environment

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ABSTRACT

Many animal species are typically negatively affected by urbanization; however those species which are not negatively affected are those that can use resources available in urban areas to survive. Hadeda Ibis (*Bostrychia hagedash*) is an indigenous southern African bird that was previously threatened and associated with wetlands but has become an urban exploiter and increased its population size and expanded its range across South Africa with a pattern following urbanization. The aim of this thesis was to investigate the factors that promoted this range expansion in urban areas particularly in Pietermaritzburg, KwaZulu-Natal.

To determine the urban ecology of Hadeda Ibis, flying, foraging, calling and perching activities were compared between summer and winter and between areas differing in proportion of green and grey space. We expected there to be differences between seasons and we predicted that Hadeda Ibis, although an urban exploiter, would show a lower urban tolerance for areas with a larger proportion of grey space. Five suburbs of varying degrees of green to grey space were surveyed in summer and winter for Hadeda Ibis activity. Results indicated that calling behaviours differed between seasons with more calling observed in summer. This may be because of individuals communicating with conspecifics that were more dispersed in summer due to nesting habits while there were more individuals at colonial roosts in winter. There was no significant difference in foraging and flying between seasons or between the different areas. This was probably due to adequate foraging resources being available throughout the year with the maintenance of green spaces in terms of grass lawns kept well watered and short. Hadeda Ibis were observed using urban features to perch but not for nesting or roosting which indicated that although they have a high degree of urban tolerance, they still depend on trees in green spaces for nesting and roosting for their urban persistence and were more common in suburbia than the city centre in Pietermaritzburg.

To determine Hadeda Ibis nesting and roosting habits in Pietermaritzburg, we measured roost tree height and analyzed roost and nest location to establish possible roost and nest habitat preference. We expected their roosts and nests to be in close proximity to green spaces, for instance wetlands, and that they would use exotic trees more than indigenous trees. We mapped known nests and roosts onto aerial photographs with a habitat land use layer using ArcGIS and roost tree height was measured. The surrounding habitat types within a radius of 10 km from each roost and nest was analyzed and roost tree height compared. As expected Hadeda Ibis used more exotic trees for roosting and nesting because of availability and there were no differences with roost tree height. The 10 km area around nest and roost locations showed a variety of habitats suggesting that Hadeda Ibis need not nest or roost close to natural habitats like wetlands. This pattern can be explained by the fragmented nature of urban environments where green space is scattered between other urban features thereby providing Hadeda Ibis with nesting, roosting and foraging opportunities throughout the urban area of Pietermaritzburg.

To determine the home range and habitat use of urban Hadeda Ibis in Pietermaritzburg, we attached GPS/GSM transmitters to four individuals to track their movements. However all transmitters failed and data were recoverable from only one. Those data combined with general observations of colour ringed individuals, suggested that Hadeda Ibis have a relatively small home range for a bird of its size. We also confirmed that Hadeda Ibis show roost site fidelity.

In conclusion, urban areas provide Hadeda Ibis with foraging, nesting and roosting resources required for its urban persistence. Short grass lawns that are well watered are ideal for Hadeda Ibis foraging and exotic trees that are abundant in urban areas provide adequate nesting and roosting sites. The species has also been observed using alternative food sources like garbage and dog food and urban features like swimming pools as a substitute for wetland habitat. The combination of these factors has resulted in Hadeda Ibis having increased its population and expanded its range. Provision of resources factored within urban design and planning may help to conserve species threatened by increased urbanization just as Hadeda Ibis has gone from having low population numbers and being associated with wetlands to urban success.

PREFACE

The data described in this thesis were collected in the Republic of South Africa from February 2012 to February 2014. This study 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, Pietermaritzburg, 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.

………………………….

Preshnee Singh

November 2014

I certify that the above statement is correct

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Professor Colleen T. Downs

Supervisor

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I, Preshnee Singh, declare that

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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

P Singh and CT Downs. Hadedas in the hood: Hadeda Ibis (*Bostrychia hagedash*) activity in suburban neighbourhoods of Pietermaritzburg, KwaZulu-Natal, South Africa.

Author contributions:

PS conceived paper with CTD. PS collected and analyzed data, and wrote the paper. CTD contributed valuable comments to the manuscript.

Publication 2

P Singh and CT Downs. Hadeda Ibis (*Bostrychia hagedash*) urban nesting and roosting habits in Pietermaritzburg, KwaZulu-Natal, South Africa.

Author contributions:

PS conceived paper with CTD. PS collected and analyzed data, and wrote the paper. CTD contributed valuable comments to the manuscript.

Publication 3

P Singh and CT Downs. Hadeda Ibis (*Bostrychia hagedash*) home range and habitat use in an urban environment: Pietermaritzburg, KwaZulu-Natal, South Africa

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CHAPTER 1

Introduction

Urban ecology

Ecology basics and the effect of urban environments

Ecology is the study of the interactions between abiotic and biotic components in an ecosystem and urban refers to space transformed by humans to satisfy their living needs (Adams et al. 2006). Ecology can be simplified into four main ecological principles: diversity, interrelationships, cycles, and energy (Adams et al. 2006). Diversity is the variety in an ecosystem which may refer to variations in habitats, species, or communities (Adams et al. 2006). Urban environments transform space from complex natural diversity to artificial uniformity (Adams et al. 2006). Although urban environments are artificial, it can be argued that they are diverse (Wilby and Perry 2006). Humans have different uses for land on small and large scales creating a mosaic of different habitats (Adams et al. 2006; Alberti et al. 2003; Davis et al. 2011; Lososová et al. 2012; Wilby and Perry 2006). Small scale diversity can be seen within residential lands where the land is split into an area for a house, a garden, and/or a swimming pool or pond. Large scale diversity can be seen with urban planning where space is allocated for buildings, residential houses, cemeteries, landfills, recreational parks, airports, and golf courses. Therefore urban environments are diverse but certainly not in the same way as natural environments (Wilby and Perry 2006).

Interrelationships refer to the interaction between abiotic and biotic components in an ecosystem and urban environments affect these interactions, generally in a negative way (Adams et al. 2006; Alberti et al. 2003; Aronson et al. 2014). There are four combinations of interactions namely, abiotic on abiotic (example, temperature and rainfall), abiotic on biotic (example, soil nutrients and plant growth), biotic on abiotic (example, nitrogen fixing bacteria and soil nitrogen concentration), and biotic on biotic (example, herbivores and vegetation) (Adams et al. 2006). Examples of the way urban environments negatively impact these interactions can be seen with: greenhouse gases from human industry affecting temperature which changes rainfall patterns (abiotic on abiotic), urban development practices remove nutrient rich topsoil which impedes healthy plant growth (abiotic on biotic), human urban activities like industry and waste removal pollute the air, water and soil (biotic on abiotic), and humans removing native vegetation for urban development (biotic on biotic).

Cycles are processes that have different elements acting on each other and there is a sequence to these processes. For ecology, cycles refer to the way in which ecosystems reuse limited resources like purified water and limited nutrients like carbon (Adams et al. 2006). Urban environments and human activities negatively affect the elements in the cycle which disrupts the entire process (Adams et al. 2006; Alberti et al. 2003). For instance, in the water cycle artificial surfaces prevent water from penetrating, and being filtered through, the soil as well as replacing vegetation which prevent water filtration through transpiration (Adams et al. 2006). Carbon emissions from urban environments and deforestation for urban development negatively affect the carbon cycle by creating more carbon than the system can process (Adams et al. 2006; Alberti et al. 2003).

All organisms need energy to survive and this energy is ultimately supplied by the sun (Adams et al. 2006). Sunlight energy, captured by plants through photosynthesis, is transferred through the ecosystem via food webs. Humans do not use sunlight as the primary source of energy but instead use fossil fuels to power urban environments (Adams et al. 2006; McPherson et al. 1995). Fossil fuels are non-renewable, polluting and require alteration of the environment to access, all of which are damaging to ecosystem functioning.

Urban definitions clarified

As mentioned previously urban refers to space transformed by humans to satisfy their living needs (Adams et al. 2006). However, this definition is vague and can refer to a wide range of human transformed spaces. For instance, under this definition people camping out in a field is urban because they have altered that space (by clearing the area and setting up a tent) for their living needs. More specifically all urban areas have two common elements, a concentration of people and a dramatically altered natural landscape designed according to human need or preference (Benton-Short and Short 2008; Francis and Chadwick 2012). Even with these two distinctions, an accurate urban definition is difficult to identify because the concentration of people and the degree to which the natural landscape is transformed needs to be quantified (Francis and Chadwick 2012). The quantification of these distinctions varies among countries and also among studies on urban environments (Francis and Chadwick 2012). For instance, in the United Kingdom urban areas are defined as areas with more than 10 000 people, whereas in Albania areas with more than 400 people are considered urban (Francis and Chadwick 2012). Determining the proportion of the area covered by buildings can be used to quantify urban where a sparse urban area will have 0-33% building cover, a moderate urban area 34-66%, and a high urban area 67-100% (Francis and Chadwick 2012). Various studies have attempted to quantify urban areas by assessing both human population densities along with the percentage of building cover (Benton-Short and Short 2008; Francis and Chadwick 2012). Some studies include descriptions of urban infrastructure like electricity and water supply along with population density and building cover in their definitions of urban (Francis and Chadwick 2012).

Urban areas can be classified into different categories, determined by population densities and percentage building cover, which describe varying degrees of urban (Francis and Chadwick 2012). There are four main categories of urban areas namely, wild-land (comprising 0-2% buildings and non-building, such as roads, urban features, a building density of 0, and a population density of < 1 person per hectare), rural/exurban (comprising 5-20% urban features, < 2.5 buildings per hectare, and 1-10 people per hectare), suburban (comprising 30-50% urban features, 2.5-10 buildings per hectare, and > 10 people per hectare), and urban (comprising > 50% urban features, > 10 buildings per hectare, and > 10 people per hectare) (Benton-Short and Short 2008). Urban ecology studies usually compare the ecological feature under study in urban and wild-land or along a gradient from urban to wild-land to determine the effect urban areas have on abiotic and biotic components in an ecosystem (Alberti et al. 2003; Ramalho and Hobbs 2012). The trend is that the severity of the changes to the abiotic and biotic components increases as land becomes more altered along the urban gradient, i.e. from wild-land to urban (Adams et al. 2006).

Urbanization is the process of transforming natural or wild-land into urban space and these areas are expanding rapidly as the need for suitable human habitats increases with an ever increasing human population (Adams et al. 2006; Francis and Chadwick 2012; Ramalho and Hobbs 2012). The phrase urban sprawl has been frequently used to describe the patterns of urbanization (Alberti et al. 2003; Ramalho and Hobbs 2012). These patterns generally comprise of rapid development of low density urban areas in a fragmented and scattered manner (Alberti et al. 2003). The degree of change of wild-lands varies with the different patterns of urban sprawl thus affecting wild-land resilience to urbanization (Adams et al. 2006; Alberti et al. 2003; Ramalho and Hobbs 2012).

The term synanthropic refers to species which are associated with humans because they are commonly found in urban areas (De Laet and Summers-Smith 2007; Francis and Chadwick 2012; Rodewald and Shustack 2008). There are several examples of these synanthropic species including plants [example, Wall-rue (*Asplenium ruta-muraria*), Rustyback (*Ceterach officinarum*)], invertebrates [example, mosquitoes (*Aedes aegypti*, *A. albopictus*), dust mites (*Dermatophagoides pteronyssinus*, *D. farinae*), cockroaches (*Periplaneta americana*, *Blattella germanica*), flies (*Musca domestica*)] and vertebrates [example, House mice (*Mus musculus*), Brown rats (*Rattus norvegicus*), European foxes (*Vulpes vulpes*), Rock doves (*Columba livia*), House sparrows (*Passer domesticus*), Blackbirds (*Turdus merula*)] (Francis and Chadwick 2012; Kopij 2015; Murgui and Macias 2010; Rodewald and Shustack 2008). Many synanthropic species are synurbic species (Francis and Chadwick 2012). Synurbic species are classified as those species whose population density in an urban area exceeds the population density in the surrounding wild-lands (Francis and Chadwick 2012). Such species can be indigenous or exotic and they are able to succeed in an urban environment because of adaptation (Francis and Chadwick 2012; Møller 2008). Synurbanization is when a species is adapting (in the process of developing increased capacity to survive) to an urban environment, i.e. becoming synurbic (Francis and Chadwick 2012). Few species are truly synurbic as many are able to survive in an urban environment because of phenotypic plasticity and not as a result of adaptation (Francis and Chadwick 2012).

Species responses to urbanization

Urbanization modifies landscapes, creating new habitats which can allow some indigenous and exotic species to exist (Adams et al. 2006). These species are either indigenous species able to persist with the change or else species introduced into urban areas in uncontrolled (accidental) and controlled (purposeful) ways (Adams et al. 2006; Bourdages and Lavoie 2011; Harhay et al. 2011; Kohli et al. 2006; Kopij 2015; Lososová et al. 2012; Møller et al. 2012). Although native species can become problematic in urban environments, for example White-tailed deer (*Odocoileus virginianus*) (Adams et al. 2006), exotic species tend to more frequently cause severe problems (Kohli et al. 2006; Møller et al. 2012; Sol et al. 2012). Uncontrolled exotic introductions can occur with the transportation of products for human use or with the transportation of people (Bourdages and Lavoie 2011; Harhay et al. 2011). Controlled exotic introductions include introducing plants for gardens and landscaping, and introducing animals as domestic pets (Adams et al. 2006; Kohli et al. 2006; Lososová et al. 2012; Møller et al. 2012). Both controlled and uncontrolled exotic introductions can cause a variety of ecological problems like increasing predation pressure on native species or increasing competition with native species (Kohli et al. 2006; Sol et al. 2012).

A large and concentrated human population in urban environments, along with the products of these environments, like domestic pets, can cause the spread of diseases and increased health risks for humans from urban adapted species (Harhay et al. 2011; Raedeke and Raedeke 1995). Zoonotic diseases, which are diseases that can be transferred from animals to humans, can come from native or exotic wild species adapting to an urban environment (Adams et al. 2006; Harhay et al. 2011). For example, urban carnivores like racoons (*Procyon lotor*), kit foxes (*Vulpes macrotis*), striped skunks (*Mephitis* spp.), and domestic cats (*Felis catus*) and dogs (*Canis familiaris*) have the potential to and have spread zoonotic diseases in urban environments (Gehrt et al. 2010; Raedeke and Raedeke 1995).

Urbanization is thought to result in an overall decrease in species diversity and abundance because native species in particular respond unfavourably to changes in the environment (Blair 1996; Bland et al. 2004; Dures and Cumming 2010; Wilby and Perry 2006). Indeed native species diversity decreases with increasing urbanization, however overall species diversity and abundance does not (Blair 1996; Bland et al. 2004; Chace and Walsh 2006; Kopij 2015; Lososová et al. 2012; Raedeke and Raedeke 1995; van Rensburg et al. 2009; Sol et al. 2012; Wilby and Perry 2006). There is a shift in species composition, with an increase in abundance, from those species that cannot tolerate the urban environment, i.e. urban avoiders, to species which can use urban resources effectively and survive in an urban environment, i.e. urban exploiters (Blair 1996). Urban exploiters can survive and in some cases thrive in an urban environment, such as synanthropic and synurbic species, by altering their life histories as well as using habitats or elements that are unique to urban areas (Adams et al. 2006; Sol et al. 2012).

Urban exploitive plant species experience reduced competition and reduced predation in urban environments and although urban exploitive animal species also experience reduced competition and reduced predation, they find an abundance of food in urban environments as well (Adams et al. 2006; Chace and Walsh 2006; Lososová et al. 2012; Møller 2008; Rodewald and Shustack 2008; Sol et al. 2012). This consequently results in urban exploiters having overall greater reproductive success therefore resulting in large urban populations (Adams et al. 2006; Blair 1996; Kopij 2015; Møller 2008; Møller 2009; Murgui and Macias 2010; Rodewald and Shustack 2008). Large populations of urban adapted plant and animal species can result in these species being viewed as weeds or pests to human inhabitants in urban areas and with animals this sometimes creates human-animal conflicts (Adams et al. 2006; Gehrt et al. 2010; Lososová et al. 2012). Many animal urban adapted species become familiar with humans exhibiting low fear thresholds; for instance urban birds when compared with non-urban birds are more tolerant of approaches by humans as they do not fly as far to escape, and allow a shorter distance between the individual and the approaching human before an escape response is triggered (Adams et al. 2006; Bateman and Fleming 2011; Møller 2008; Møller 2009; Sol et al. 2012).

There are several ways a native species may react to increasing urbanization (Adams et al. 2006). First, the population may suffer local extinctions in a newly urbanized area and as a result become entirely absent from that environment (Adams et al. 2006). Second, the species distribution may shift to refuge areas which are areas within or around the urban environment that still maintain the natural ecosystem (Adams et al. 2006; Agee 1995; Raedeke and Raedeke 1995; Veech et al. 2011; White et al. 2005). Lastly, the species may be able to adapt to survive within the urban environment and sometimes possibly even thrive (Adams et al. 2006; Evans et al. 2010; Rodewald and Shustack 2008; Rutz 2008). A species response to urbanization depends on the flexibility of that species in terms of its behaviour and ecological niche (Bonier et al. 2007; Møller 2009; Sol et al. 2012). Generalist species tend to have a greater capacity to adapt to change than specialist species which require very specific and strict environmental conditions to survive (Barnagaud et al. 2011; Bonier et al. 2007; Evans et al. 2009; Kopij 2015; Lososová et al. 2012; Sol et al. 2012).

Species responses to urbanization and species in urban environments were previously seldom studied because natural scientists preferred to study species in natural, pristine environments (Alberti et al. 2003; Aronson et al. 2014; Benton-Short and Short 2008; Ramalho and Hobbs 2012). However, urban areas are rapidly expanding and this expansion results in natural habitat loss, reduced biodiversity and increased habitat disturbance (Benton-Short and Short 2008; Lososová et al. 2012; Ramalho and Hobbs 2012; Wilby and Perry 2006). Although urban areas are relatively small, compared with land area globally, the impact of these areas to the overall environment is large (Alberti et al. 2003). Focus has therefore shifted over the past few years from studies of natural ecology only to studies of urban ecology (Benton-Short and Short 2008; Ramalho and Hobbs 2012; Wilby and Perry 2006). Studies on urban ecology provide insight into how species have and will react to increasing urbanization which can help in conservation efforts (Garden et al. 2010; Ramalho and Hobbs 2012; White et al. 2005; Wilby and Perry 2006). Urban adapted animal species show changes in ranges, habitat use, movements, foraging and reproduction (Adams et al. 2006). The following sections will highlight and discuss these changes focusing particularly on urban adapted bird species.

Range expansion and Home Range

Invasion is when an exotic species is introduced to and colonises new areas outside its geographic range while range expansion is when a native species starts to occur in areas where it was previously absent within its geographic range (Evans et al. 2010). Both invasion and range expansion follow the same three stages, i.e. arrival, adjustment, and spread (Croci et al. 2007; Evans et al. 2010). Arrival of a species to an urban area is usually the result of urbanization due to changes in the environment creating opportunities for foraging and breeding, and decreased predation (Evans et al. 2010). As discussed earlier, species can react in one of three ways to urbanization of natural areas, i.e. die out, take refuge, or adapt to the urban environment (Adams et al. 2006). Species that adapt to the urban environment go through the adjustment stage where behavioural and ecological niche flexibility, life history traits, and phenotypic plasticity contribute to their success (Evans et al. 2010). In this stage species shift from using natural resources to using urban resources, mainly for foraging and breeding (Evans et al. 2010; Veech et al. 2011). Urban areas have unique habitats which offer large amounts of food and alternate nesting sites, in the case of birds, to those species which can use them effectively (Adams et al. 2006; Veech et al. 2011). The third stage, which is spread, occurs when a species has become established in the urban environment by achieving a large population size and being able to exploit urban resources effectively (Evans et al. 2010). Once a population is established it will spread further out into the urban area and/or spread to surrounding urban areas (Adams et al. 2006; Evans et al. 2009; Evans et al. 2010).

There are push and pull forces acting on species with regard to shifting ranges in response to urbanization (Adams et al. 2006). Many species are pushed out of their natural habitats to urban areas because urbanization results in natural habitat loss, land use changes and ecosystem changes (Adams et al. 2006). Species are pulled into urban areas because these areas provide alternate resources such as increased food availability, reduced predation, and breeding opportunities in terms of availability of nesting sites (Adams et al. 2006; Aronson et al. 2014; Veech et al. 2011). This push and pull dynamic can be seen in the case of the Australian White Ibis (*Threskiornis molucca*) which has shifted its range from wetlands to an urban environment (Smith and Munro 2010). Habitat destruction of the wetlands was the push force and increased food availability in landfills was the pull force which prompted *T. molucca* to move into an urban environment (Smith and Munro 2010). Although the case of the *T. molucca* shows both push and pull forces prompting a range shift, push or pull forces may act on a species exclusively to cause a range shift into urban areas. Any species that may be adequately adapted for exploiting urban resources may be pulled to urban areas. An example of this can be seen in the House Sparrow which became synonymous with urban areas because of its ability to exploit human inhabited habitats effectively by foraging for fallen grain and nesting in artificial structures (De Laet and Summers-Smith 2007; Murgui and Macias 2010). Any species that is threatened in its natural range by habitat loss or by a dramatic decline in natural resources may be pushed into urban areas. An example of this can be seen with Australian parrots where factors like increased fire and decreased rainfall in natural areas has resulted in parrots moving into urban areas (Davis et al. 2011).

A species home range refers to the area covered during its daily or seasonal movements with regards to foraging and breeding activities (Barrows 2011). The size of a species home range depends on several factors including the size of the animal, mode of locomotion and physical barriers, energy requirements and distribution of resources, and behaviour. A larger species will generally require more space (Raedeke and Raedeke 1995) and therefore have a larger home range than a smaller species (Moorcroft and Lewis 2006). Mode of locomotion is important in a species home range because that, and the presence of physical barriers in the environment, determines how far a species can travel. Therefore a species that can fly can potentially have larger home ranges than a species that cannot fly. Energy requirements determine a species home range because a species that has high daily energy requirements may need to travel further to forage on appropriate resources. Generally if resources are spaced far apart then one would expect a species using those resources to have a large home range, and if resources are spaced closer together then a smaller home range is expected. Urban adapted species generally have smaller home ranges because resources in an urban environment are spaced relatively closer together than in a natural environment (Adams et al. 2006; Gehrt et al. 2010). The behaviour of a species can affect the size of its home range because territorial species, or actively breeding species with nests or dens, will have small home ranges and may not move very far were as nomadic species may have large shifting home ranges (Moorcroft and Lewis 2006).

Habitat Use

Urban environments are fragmented with multiple habitats resulting from different land uses (Adams et al. 2006; Alberti et al. 2003; Lososová et al. 2012; Wilby and Perry 2006). Urban habitats can be classified into two main groups, green and grey spaces (Adams et al. 2006; Wilby and Perry 2006). Species use both green and grey spaces differently depending on their need and niche. Green spaces include sports fields, gardens, recreational parks, golf courses, and cemeteries whereas grey spaces include buildings, roads and bridges, airports, industrial areas, and landfills (Adams et al. 2006; Raedeke and Raedeke 1995; Wilby and Perry 2006). Urban green spaces have vegetation that is usually exotic and these spaces are maintained according to human preference to be aesthetically pleasing, i.e. grass is kept short, well watered and green, and dead vegetation is removed (Adams et al. 2006; Raedeke and Raedeke 1995; White et al. 2005). Vacant land is also under the grouping of green space but these areas are not maintained and are left natural (Adams et al. 2006; Agee 1995). Although vacant land has not been altered for a specific human use, it has usually been disturbed therefore invasive vegetation tends to dominate (Adams et al. 2006; Agee 1995; Bourdages and Lavoie 2011; Kohli et al. 2006; Lososová et al. 2012). Even areas near streams or rivers that are deliberately left untouched by urban planners, because of flood risks to buildings, are disturbed by urban development (Adams et al. 2006). Although plants struggle to survive in the regularly disturbed habitat of highly compacted and chemically saturated soil, landfills provide food for a multitude of animal species and are ideal environments for a select few (Adams et al. 2006). Residential gardens are common to suburban areas and are very well used green spaces particularly by birds (Adams et al. 2006; Blair 1996; Paker et al. 2014). These spaces usually consist of a variety of exotic plants and well watered, short grass lawns (Adams et al. 2006; Blair 1996; Chace and Walsh 2006; Paker et al. 2014). Birds are able to use garden trees for nesting or roosting and the garden as a foraging area (Blair 1996; Chace and Walsh 2006; Paker et al. 2014).

Grey spaces can be used by only a few species which depends on the resource the space offers (Adams et al. 2006). For example, many buildings offer birds nesting sites like the Chimney Swift (*Chaetura pelagica*) which uses chimneys to nest in or Barn Swallows (*Hirundo rustica*) which have been found to nest under bridges (Adams et al. 2006). Raptors seem to prefer to nest on tall buildings and are becoming common to urban areas (Adams et al. 2006; Chace and Walsh 2006; Rutz 2008; Stout and Rosenfield 2010). Artificial water sources like ponds and swimming pools as well as storm water basins can provide drinking water for many species and a breeding area for others (for example, frogs) (McCarthy and Lathrop 2011; Raedeke and Raedeke 1995). Grey spaces are made up of artificial materials like concrete and asphalt which are water proof and retain heat (Adams et al. 2006). These spaces can create microhabitats for species, for example Mosquitoes (*Aedes aegypti*) using water that has pooled on roofs for reproduction (Pilger et al. 2011).

Movement

Foraging and breeding decisions will ultimately determine movement during an animal's active period and this depends on which habitats are used for these activities (Morrison et al. 2006). Daily movements will differ with a species home range and if the species is diurnal, it will be active during the day moving through the urban landscape, and return to a safe area at night (Polak et al. 2011; Smith and Munro 2010). For instance the Australian White Ibis will leave their breeding colony to forage at a landfill during the day and will return to the colony before dark (Smith and Munro 2010). If the species is nocturnal, the opposite pattern will be observed, for example insectivorous bats will forage at night for insects around street lights and return to their roosts in urban structures for resting during the day (Adams et al. 2006; Polak et al. 2011). Species will forage to fulfil their daily energy intake and due to the fragmented nature of urban environments, they may not need to move very far to find available resources as there may be multiple areas of the same habitat type within the greater urban area (Adams et al. 2006; Morrison et al. 2006). For example, if bats feed on insects, and use urban lights to help catch them, they will not need to travel very far to find artificial lights especially in or close to a city (Polak et al. 2011).

Seasonal movements are dependent on resource availability and some bird species have forgone migrating altogether because of year round food availability within urban areas, as can be seen with Canadian Geese (*Branta canadensis*) (Adams et al. 2006). *Threskiornis molucca* also takes advantage of year round food availability in urban areas as it moves seasonally from wetlands outside the urban area to an urban breeding ground (Smith and Munro 2010). Urban environments change micro-clime temperatures with buildings and concrete structures retaining heat (Collier 2006; McPherson et al. 1995) so some species need not move to warmer areas for breeding with the advent of colder seasons (Adams et al. 2006; Wilby and Perry 2006). Many species make use of the vegetation between urban structures to move between the fragmented patches and urban planners have been taking, and should take, these corridors into account with urban designs (Adams et al. 2006; Raedeke and Raedeke 1995; White et al. 2005; Wilby and Perry 2006).

Foraging

Urban areas have an abundance of food resources for many species (Adams et al. 2006; Anderies et al. 2007; Fuller et al. 2008). Species that are generalists tend to be better at exploiting such resources in the urban environment (Adams et al. 2006; Barnagaud et al. 2011; Bonier et al. 2007; Chace and Walsh 2006; McCarthy and Lathrop 2011). Specialist species can also utilize food resources available in an urban environment and they tend to expand their niches and shift from being a specialist to becoming a generalist species (Barnagaud et al. 2011). Species diets change in an urban area as they adapt to human food products and human food waste (Adams et al. 2006; Gehrt et al. 2010).

Urban areas produce large amounts of waste food which are discarded in garbage cans and bags and then transported to landfills (Adams et al. 2006; Gehrt et al. 2010). Species such as the Australian White Ibis, Crows (*Corvus* spp.), Raccoons (*Procyon lotor*), Coyotes (*Canis latrans*), Feral Cats (*Felis catus*), and Rats (*Rattus* spp.) are examples of species that utilize garbage as a food source (Adams et al. 2006; Gehrt et al. 2010; Smith and Munro 2010). The waste food available in garbage is more easily accessible than spending energy hunting for food so much so that cats have been observed eating garbage with rats instead of hunting them (Adams et al. 2006).

Garbage is an unintentional provided source of food to urban species but people do sometimes intentionally feed animal species in their urban environment (Adams et al. 2006; Anderies et al. 2007; Chamberlain et al. 2009; Davies et al. 2009). The use of bird feeders, like nectar feeders, or seeds to attract birds to gardens is common (Chace and Walsh 2006; Davies et al. 2009) and exotic fruit trees in gardens may attract various frugivores (Møller et al. 2012).

Food given to pets can also be used by urban adapted animals as a source of food (Adams et al. 2006; Gehrt et al. 2010). Examples of this can be seen with Racoons, Striped Skunks (*Mephitis mephitis*), and Kit Foxes (*Vulpes macrotis*) eating dog pellets (Adams et al. 2006; Gehrt et al. 2010). Domestic pets themselves are also a source of food with cases of coyotes catching and eating small dogs from suburban gardens (Adams et al. 2006; Raedeke and Raedeke 1995). Garden ponds provide food by containing ornamental fish, algae, and insect larvae. There are many tall structures in urban environments like signboards, light poles, telephone poles, rooftops, aerials, towers and buildings (Adams et al. 2006). Birds of prey may use these perches as vantage points to survey the surrounding areas (Adams et al. 2006; Stout and Rosenfield 2010). Other bird species may use these vantage points for vigilance to avoid being preyed on.

Reproduction

In urban environments, ponds and pools in gardens or storm water basins can be used by frogs and fish for reproduction (McCarthy and Lathrop 2011). Mosquitoes can use standing water sources that collect on urban structures like roof gutters for reproduction (Pilger et al. 2011). Breeding behaviour, particularly in birds, changes as these species become urban tolerant (Chamberlain et al. 2009; Stout and Rosenfield 2010; Wang et al. 2009). Changes include shifts in the time of breeding, the type of structure used for nesting and the materials used to construct nests (Chamberlain et al. 2009; Stout and Rosenfield 2010; Wang et al. 2009). Other changes in breeding include higher breeding densities, earlier laying dates and increased offspring survival (Chamberlain et al. 2009). Urban areas affect bird vocalisations with birds calling earlier in the mornings to avoid interference particularly from early morning traffic on urban roads and some birds have even changed the frequencies they call at to be heard over urban noise (Cardoso and Atwell 2011; Luther and Derryberry 2012).

Natural and artificial structures are available for nesting in the urban environment with trees, both indigenous and exotic, amongst artificial structures like buildings, bridges and telephone poles (Blair 1996; Brubaker et al. 2003; Chace and Walsh 2006; Soldatini et al. 2008; White et al. 2005). Many urban birds nest in trees among urban structures and several species have shifted from using indigenous trees to using exotic trees which are generally more common in urban environments (Blair 1996; Lerman et al. 2014; Stout and Rosenfield 2010; White et al. 2005). Some urban birds have adapted to nesting in or on artificial structures like telephone poles or buildings which substitute for trees or rock cliffs (Adams et al. 2006; Brubaker et al. 2003; Soldatini et al. 2008; Stout and Rosenfield 2010). For example, Barn Owls (*Tyto alba*), Barn Swallows (*Hirundo rustica*), House Sparrows, Yellow-legged Gulls (*Larus michahellis*), and Cooper's Hawks (*Accipiter cooperii*), nest in or on urban structures and their common names, with the exception of Yellow-legged Gulls and Cooper's Hawks, are indicative of this behaviour (Adams et al. 2006; Soldatini et al. 2008; Stout and Rosenfield 2010). Several bird species have been found to use decommissioned telephone poles for nesting in the Chihuahuan desert such as the Chihuahuan Raven (*Corvus cryptoleucus*) and Swainson's Hawk (*Buteo swainsoni*) (Brubaker et al. 2003). Birds also adjust their nest composition from using natural materials exclusively to incorporating anthropogenic materials, like plastics and fibres, into their nests as these materials become more common in increasingly urbanized areas (Wang et al. 2009).

Hadeda Ibis (*Bostrychia hagedash*)

The Hadeda Ibis (*Bostrychia hagedash*) (Fig. 1) belongs to the order Pelecaniformes in the Threskiornithidae family and is indigenous to southern Africa (Vernon and Dean 2005). It is a large wading bird with a grey neck and head, metallic green rump and bright bronzy green upper wing which sometimes reflects purple (Vernon and Dean 2005). The sexes are alike with individuals approximately 76 cm tall and weighing about 1.25 kg (Vernon and Dean 2005). The Hadeda Ibis has a raucous call which was suggested to be used to locate conspecifics and this is usually exhibited when taking off before flight from a roost (Vernon and Dean 2005). The species is sedentary exhibiting nomadic responses to local rainfall events and is found naturally in open grasslands, clearings at forest edges, short-grass marshes and moist grassland habitats (Vernon and Dean 2005). Hadeda Ibis are usually observed in pairs or small family groups of about three individuals; they are seldom observed alone or in large flocks (Vernon and Dean 2005). More individuals have been observed at roosts during winter compared with summer which suggested seasonal movements but this has not been confirmed (Vernon and Dean 2005). They forage for invertebrates by probing the ground and need moist soil to forage effectively (Duckworth et al. 2010; Vernon and Dean 2005). Breeding occurs in the wet seasons which are from September to January for eastern South Africa and from May to September for western South Africa (Duckworth et al. 2012; Vernon and Dean 2005). They lay 1 to 5 eggs which they incubate for about 25 to 28 days and chicks fledge within 33 to 40 days (Vernon and Dean 2005). Fidelity to nesting area and breeding partner has been suggested but is yet to be confirmed (Duckworth et al. 2012; Vernon and Dean 2005).

Hadeda Ibis has been able to increase in population size and expand its range by 40% from 1910 to 1985 (Macdonald et al. 1986) and its range is still increasing particularly across urban environments (SABAP 2, 2014). Apart from its natural habitats, the species has also been observed in irrigated crop lands, pastures, playing fields, airfields and lawns (Vernon and Dean 2005). The success of the species in these different environments may be due to changes in their breeding habits as well as changes in their foraging behaviour (Duckworth and Altwegg 2014; Duckworth et al. 2012; Macdonald et al. 1986). In urban and suburban areas, well watered lawns may be providing optimal moist conditions for foraging (Duckworth and Altwegg 2014; Duckworth et al. 2010). This may be especially important for Hadeda Ibis during the drier seasons. Alternate food sources may also be a factor with the species shifting their diet to incorporate anthropogenic food sources. Hadeda Ibis may also be using exotic trees, which are common to urban environments, for nesting and roosting (Macdonald et al. 1986; Raedeke and Raedeke 1995).

The aim of this study was to investigate the range expansion of the Hadeda Ibis (*Bostrychia hagedash*) in Pietermaritzburg, KwaZulu-Natal, South Africa. This study examined which factors, including general distribution and habitat use, have contributed to the increased range of the Hadeda Ibis in an urban environment, particularly in Pietermaritzburg, KZN.

Motivation

This study was an urban ecology project investigating the conditions that have allowed the Hadeda Ibis to expand its range. From understanding why and how they have been able to adapt to an urban environment, by changing their nesting and foraging habits, we can create effective conservation programs regarding birds in urbanized areas. Provision of resources in urban environments has been previously proposed to help conservation and limit the impact that urbanisation has on birds (Davies et al. 2009; Fuller et al. 2008; Rutz 2008). This study may help in conserving biodiversity in urban and suburban areas and will help with urban planning and management programs.

Arrangement of thesis

This thesis is presented as chapters each prepared as a manuscript for an international peer reviewed journal. Consequently some repetition was unavoidable. The chapters are as follows:

Chapter 2: Hadedas in the hood: Hadeda Ibis (*Bostrychia hagedash*) activity in suburban neighbourhoods of Pietermaritzburg, KwaZulu-Natal, South Africa;

Chapter 3: Hadeda Ibis (*Bostrychia hagedash*) urban nesting and roosting habits in Pietermaritzburg, KwaZulu-Natal, South Africa;

Chapter 4: Hadeda Ibis (*Bostrychia hagedash*) home range and habitat use in an urban environment: Pietermaritzburg, KwaZulu-Natal, South Africa.

Also there is a concluding chapter highlighting and synthesising the main findings from previous chapters. This chapter gives an overview of Hadeda Ibis (*Bostrychia hagedash*) in an urban environment, specifically in Pietermaritzburg, KwaZulu-Natal, South Africa.

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Figures

Fig. 1. Hadeda Ibis (*Bostrychia hagedash*) on a branch in Pietermaritzburg, KwaZulu-Natal, South Africa.

CHAPTER 2

Hadedas in the hood: Hadeda Ibis (*Bostrychia hagedash*) activity in suburban neighbourhoods of Pietermaritzburg, KwaZulu-Natal, South Africa

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Formatted for Urban Ecosystems

Abstract Urban environments are a combination of green and grey spaces and although many species are unable to live in these transformed areas there are some that can use urban features to benefit their persistence here. The Hadeda Ibis (*Bostrychia hagedash*) is one such species and this study investigated the urban ecology of these birds. Five suburbs of Pietermaritzburg in KwaZulu-Natal, South Africa were surveyed for Hadeda Ibis engaged in flying, foraging, perching and calling behaviours. Each suburb differed in the degree of urbanisation and we expected that their morning activity would differ accordingly. A difference in Hadeda Ibis calling, foraging and flying activity between summer and winter was also expected because of seasonal rainfall patterns. Although Hadeda Ibis were more common in suburbia than the city centre in Pietermaritzburg, they occurred throughout. More were observed calling in summer than in winter probably because of changes in distribution during the breeding season with more family groups of two or three individuals. There was no significant difference in Hadeda Ibis flock size when comparing foraging during summer with winter despite greater summer rainfall. Also there was no significant difference in flock size with flying activity for both seasons nor suburb although it was expected that Hadeda Ibis would need to travel further during winter and

from suburbs with more grey space to access ideal foraging areas. Hadeda Ibis need moist soil to forage effectively and in an urban environment short grassed, well watered lawns provided an ideal foraging habitat regardless of season. Hadeda Ibis used urban structures like house roofs, poles, pylons, and fences for perching but continued to roost in trees so while they are able to use urban features, they still rely on a certain degree of green space for urban persistence.

Keywords *Bostrychia hagedash*, urban ecology, activity behaviour, seasonal behaviour, degree of urbanisation

Introduction

Urban environments are typically a mosaic of green and grey space where green spaces include gardens, recreational parks, cemeteries, and sports fields while grey spaces include buildings, roads, airports, and landfills (Adams et al. 2006; Davis et al. 2011; Reale and Blair 2005; Wilby and Perry 2006). The degree to which an area is urbanized results in different proportions of green to grey spaces with highly urbanized areas having more grey than green spaces and suburban areas a fair balance of both (Adams et al. 2006; Francis and Chadwick 2012). Although grey spaces are not ideal habitats for many species, some animal species are able to survive and sometimes be successful in urban environments (Adams et al. 2006; Blair 1996; Bland et al. 2004; Bonier et al. 2007; Chamberlain et al. 2009; Francis and Chadwick 2012; Rutz 2008). Species that are successful in urban environments are termed urban exploiters and species that are unable to tolerate urban environments are urban avoiders (Blair 1996). Urban exploiters are successful because they are able to use the features of urban environments to aid in their survival and reproduction. For example, House mice (*Mus musculus*), Rock doves

(*Columba livia*), House sparrows (*Passer domesticus*), and Brown rats (*Rattus norvegicus*), are all vertebrates that successfully forage, breed, and have significantly large populations in urban environments (Francis and Chadwick 2012; Murgui and Macias 2010; Rodewald and Shustack 2008).

There are many examples of bird species that are urban exploiters and many studies have examined their success in urban environments (including (Anderies et al. 2007; Barnagaud et al. 2011; Blair 1996; Bland et al. 2004; Bonier et al. 2007; Chamberlain et al. 2009; Croci et al. 2007; Evans et al. 2009; Evans et al. 2010; Fuller et al. 2008; Møller 2008; Møller 2009; Reale and Blair 2005; Rutz 2008; Stout and Rosenfield 2010; Veech et al. 2011; White et al. 2005). Urban birds readily use structures common to urban environments and in these environments there are usually more buildings and poles than there are trees and native vegetation, therefore species that rely on trees tend to use urban structures as a substitute (Adams et al. 2006; Brubaker et al. 2003; De Laet and Summers-Smith 2007; Soldatini et al. 2008; Stout and Rosenfield 2010; White et al. 2005). For instance some bird species, such as the House Sparrow, Barn Swallow (*Hirundo rustica*), Cooper's Hawk (*Accipiter cooperii*), Barn Owls (*Tyto alba*), Yellow-legged Gull (*Larus michahellis*) nest in or on buildings and the Chihuahuan Raven (*Corvus cryptoleucus*) and Swainson's Hawk (*Buteo swainsoni*) have been found to nest on telephone poles (Adams et al. 2006; Brubaker et al. 2003; Soldatini et al. 2008; Stout and Rosenfield 2010). Besides nesting, birds use trees for protection from predators, to survey for prey or potential foraging areas and tall trees may also give some advantage when communicating with conspecifics as it may be easier to be heard or seen while perched high in a tree (Krams 2001; Møller 2011; Sprau et al. 2012).

In urban environments noise pollution has caused a problem for many urban exploitive birds. Urban birds have had to change the timing and frequency of their calls in order to communicate with each other through urban noise (Cardoso and Atwell 2011; Luther and Derryberry 2012). Urban birds have been found to call earlier than birds in more rural areas and the frequency of calls has also changed with urban birds calling at higher pitched frequencies (Luther and Derryberry 2012). Diurnal birds typically start calling just before or at dawn prior to beginning the day's foraging (Burt and Vehrencamp 2005).

There are many foraging opportunities in urban environments especially for avian generalist feeders (Adams et al. 2006; Anderies et al. 2007; Fuller et al. 2008). Human domestic waste whether at residential houses or at landfills can be an easily accessed source of food for many species (Adams et al. 2006; Gehrt et al. 2010; Martinez-Morales et al. 2010; Smith and Munro 2010). Residential gardens can also be a source of food both intentionally and unintentionally (Adams et al. 2006; Anderies et al. 2007; Chamberlain et al. 2009; Davies et al. 2009). Many people feed birds that live or visit their garden and bird feeders supplement both seed eating and nectar feeding birds (Chace and Walsh 2006; Davies et al. 2009). Unintentional feeding of birds can occur with frugivorous birds and fruit trees in gardens or insectivorous birds and common garden insects (Møller et al. 2012).

Despite urban exploiters using features in an urban environment to benefit persistence here, seasonal use of urban environments has been seen in some species. For instance, the Australian White Ibis (*Threskiornis molucca*) uses the urban environment during their breeding season because of increased food availability at landfills (Martinez-Morales et al. 2010; Smith and Munro 2010). Seasonal movements can also be caused by changes in rainfall patterns as in the case of Rainbow Lorikeets (*Trichoglossus haematodus*) which move into urban areas to access artificial water sources when there is decreased rainfall (Davis et al. 2011). Also, the Northern Goshawk (*Accipiter gentilis*) showed occasional movement into urban areas to forage before ultimately establishing an urban breeding population (Rutz 2008).

The Hadeda Ibis (*Bostrychia hagedash*) is an indigenous southern African bird that belongs to the Threskiornithidae family (Vernon and Dean 2005). The Hadeda Ibis is relatively large (± 1.2 kg) and has a raucous call usually exhibited when taking off before flight from a roost (Vernon and Dean 2005). Hadeda Ibis are generally a wetland associated species and forage in moist soil for invertebrates as well as move in response to local rainfall patterns (Duckworth et al. 2010; Vernon and Dean 2005). In South Africa the Hadeda Ibis population and range has increased from 1910 to 1985 and is still increasing, particularly in urban environments and appears to be a successful urban exploiter (Macdonald et al. 1986; SABAP 2, 2014).

Consequently this study investigated the urban ecology of the Hadeda Ibis. Summer and winter observations of Hadeda Ibis were made in various suburbs of Pietermaritzburg, KwaZulu-Natal of different activities namely flying, perching, foraging and calling. We hypothesised that these activities would vary in the different suburbs depending on the proportion of green to grey space within each. We expected that there would be less individuals observed for all activities in the areas of the city with a greater proportion of grey space (i.e. areas with the most urban development). We also hypothesised that there would be differences in these activities depending on season. We expected less activity in winter compared with summer as Pietermaritzburg receives summer rainfall and the Hadeda Ibis, being a wetland associated species, forages most effectively in moist soil.

Methods

This study was conducted within the city of Pietermaritzburg (29°37’S, 30°23’E), KwaZulu-Natal, South Africa (Fig. 1). September to February represented spring and summer while March to August represented autumn and winter. The city of Pietermaritzburg (Fig. 1) is located along South Africa’s eastern coast where the winter has less rainfall compared with the summer (South African Weather Service 2014). Increased numbers of Hadeda Ibis at roosts in winter has been assumed to be a result of seasonal movements but is yet to be confirmed (Vernon and Dean 2005).

Five suburbs in the city (City Centre, Northdale, Scottsville, Wembley and Hayfields, Fig. 1) were chosen. A grid was created, using Hawth’s Analysis Tools for GIS in ArcGIS v.9.3, over aerial photographs of these suburbs to determine the proportion of green to grey space. Each grid block (100 x 100m) was visually analysed and the percentage of green and grey space was estimated at a scale of 1:1616. Grid squares were analysed from north to south and from west to east for each suburb. On the suburb boundaries, edges that filled less than 25% of the grid block were not included in the analyses. After analysis of each grid block an overall estimate of the total proportion of green to grey space was then calculated for each suburb.

The five suburbs in Pietermaritzburg were surveyed in winter (from the end of June to the middle of July 2012) and in summer (from the middle to the end of January 2013) for Hadeda Ibis activity. Areas were sampled along roads created using a road map layer (which included suburban roads and highways) of Pietermaritzburg with ArcGIS v.9.3. Four routes were created for each suburb and one route was driven per day except for Wembley which was sampled over two days with two routes per day. Wembley has a relatively smaller area with very few roads compared with the other suburbs therefore only two routes per day ensured that the area was surveyed adequately between dawn and sunrise. Routes were driven during the early hours of the morning between dawn and sunrise from about 05h45 to 07h45 during winter and from 04h15 to 06h15 during summer. Northern, southern, eastern and western road junctions were chosen as different starting points for each route which also served as common checkpoints for the four routes in each suburb. Different starting points for each day and routes linking with checkpoints ensured that each route covered the approximate area of the suburb and that each portion of the suburb was surveyed at different times of the morning.

For all Hadeda Ibis observations, the date, time, suburb, location (i.e. road name, road junction or address), and number of individuals observed were recorded. Activities of Hadeda Ibis were categorised into flying, perched, foraging and calling. Observations of their calling were sometimes simultaneous with flying or perching. The direction of flying, and when possible calling, were also determined. Observations of perched individuals included recording the object perched on, for example roofs of houses, light or telephone poles, and trees. If four or more Hadeda Ibis were observed in a tree, it was assumed to be a roost, if three or less were observed, it was recorded as perched in a tree. Hadeda Ibis breed in pairs and juveniles may remain with their parents for up to 110 days post fledging, forming small family groups (Vernon and Dean 2005). Therefore considering a roost to have at least four or more individuals in a tree prevented an overestimation of roosts.

Calling frequency of Hadeda Ibis was determined per time of day which was categorised into 5 min intervals. Differences in foraging and flying for summer and winter were determined by combining individuals observed across all suburbs for each seasons. Data for mean differences in flock sizes between seasons were analysed using non-parametric Mann-Whitney U tests because the assumption of normality was not satisfied even after transformations for both foraging and flying observations. Observations of flying and foraging per suburb were determined by combining individuals observed in each suburb and mean differences of flock size were analysed using Kruskal-Wallis H tests. Total numbers of Hadeda Ibis observed perching for the five suburbs was determined for each type of structure perched for both seasons and the percentage usage of the different types of structures perched on was calculated. Total numbers of Hadeda Ibis were calculated including individuals observed flying, foraging, calling and perching to compare relative abundance across all five suburbs and between seasons. Data were analysed and figures created using STATISTICA v. 7.1 and Microsoft Excel 2007.

Results

The order of suburbs from largest to smallest in terms of area was as follows: Northdale, City Centre, Scottsville, Hayfields, and then Wembley (Table 1). On average the City Centre and Northdale had greater proportions of grey than green space while Scottsville, Wembley and Hayfields had greater proportions of green than grey space (Table 1). The City Centre had the greatest mean percentage of grey space and the lowest mean percentage of green space among the five suburbs while Hayfields has the greatest mean percentage of green space and the lowest mean percentage of grey space (Table 1). Although Hadeda Ibis were more common in suburbia than the city centre in Pietermaritzburg, they occurred throughout irrespective of season (Table 2).

Overall there were more Hadeda Ibis observed calling in summer than in winter and calling was mostly between dawn and sunrise for both seasons (Fig. 2). There was no significant difference in foraging of Hadeda Ibis between the seasons ($p = 0.312$, $n = 99$, $U = 1074.00$, Fig. 3) or across suburbs ($p = 0.473$, $n = 99$, $df = 4$, $H = 3.528$, Fig. 3). Also there was no significant difference in Hadeda Ibis observed flying between the seasons ($p = 0.885$, $n = 172$, $U = 3619.00$, Fig. 4) or across suburbs ($p = 0.636$, $n = 172$, $df = 4$, $H = 2.550$, Fig. 4). The City Centre had more Hadeda Ibis perching on trees than on artificial structures during both seasons although there were more artificial perches available than trees (Table 2). Northdale had the only observations of Hadeda Ibis perched on pylons and there were more individuals observed perched on artificial structures than trees for both seasons in this suburb (Table 2). Scottsville had the greatest number of Hadeda Ibis perched overall for both seasons and there were fewer Hadeda Ibis observed on poles in winter compared with summer (Table 2). For total usage of structures, the structure perched on the most by Hadeda Ibis was house roofs during both seasons with 44% in summer and 43% in winter. There were significantly more Hadeda Ibis observed on trees in winter (34%) than in summer (18%) (Chi^2, $P < 0.05$) and more on poles in summer (34%) than in winter (21%) (Chi^2, $P < 0.05$) (Table 2).

A total of 1819 Hadeda Ibis individuals were observed across all five suburbs for both seasons (Table 3). Although more individuals were observed in summer (1077 individuals) compared with winter (742 individuals) (Table 3) in the various suburbs, there was no significant difference between seasons ($t = 2.06$, $P = 0.109$). The City Centre had the smallest number of individuals observed compared with all other suburbs (74 individuals in summer and 67 individuals in winter), while Scottsville had the highest number of individuals observed compared with all other suburbs (417 individuals in summer and 239 individuals in winter) (Table 3).

Discussion

We expected that there will be more calling behaviour in summer than in winter based on the assumption that Hadeda Ibis would move away from urban areas during winter due to less rainfall. Overall more Hadeda Ibis were observed calling in summer than in winter which may suggest that there were more Hadeda Ibis in the urban environment during summer than in winter. The total number of individuals observed for all activities and across all suburbs also suggests that there were more Hadeda Ibis in the urban environment in summer compared with winter. However, the Hadeda Ibis breeding season is from September to March coinciding with South Africa's spring-summer. Hadeda Ibis are very vocal birds that communicate with conspecifics especially when leaving and returning to roosts and during the breeding season they pair off to breed while during the non-breeding season they congregate in large communal roosts (Vernon and Dean 2005). Therefore more calling may have been observed in summer because of breeding pairs and small family groups communicating with others spread out across the urban environment. Many urban song birds have had to alter the frequency they sing at and some have changed the time they sing to be heard over urban noise (Cardoso and Atwell 2011; Luther and Derryberry 2012). Song birds generally sing while perched and these birds are typically smaller relative to a Hadeda Ibis. Most calling observations were between the dawn and sunrises as Hadeda Ibis were leaving roosts. Hadeda Ibis have a loud, distinctive call, call while in flight and it is suggested that individuals call frequently to locate conspecifics so they may be able to hear each other through urban noise much better than passerines (Vernon and Dean 2005).

There was no significant difference in Hadeda Ibis foraging or flying between the seasons although more were expected to be seen in summer than in winter because of rainfall patterns. Hadeda Ibis need moist soil to forage effectively because they probe the ground with their long bills for invertebrates (Vernon and Dean 2005). Although the five suburbs analysed differed in the mean percentage of green and grey space, all suburbs had a certain degree of green space that Hadeda Ibis may be able to use. In the urban environment, lawns are common patches of green space that are usually kept short and are frequently watered especially during the drier seasons for human aesthetic appeal (Adams et al. 2006). Hadeda Ibis use these spaces for foraging and the short grass which is artificially watered simulate their natural wetland habitat making lawns an ideal foraging habitat (Macdonald et al. 1986). Urban environments alter ecological cycles like the water cycle, and seasonal changes, like less rainfall, can be opposed by introducing and transporting water from other sources (Adams et al. 2006). Therefore Hadeda Ibis may not need to move seasonally out of urban environments because their ideal foraging habitats are present regardless of season. This may also explain why there was no significant difference in number of Hadeda Ibis observed flying across the various suburbs. If resources required for a species survival are readily available, then species need not travel very far to access them.

In the City Centre, Hadeda Ibis were observed perching more in trees than on buildings although there are more buildings and fewer trees in this area. The City Centre has a high proportion of grey space with pockets of green spaces particularly on the periphery which was where Hadeda Ibis were mostly observed. Within an urban environment there are different levels of urban from highly developed areas to suburban areas with various mixes of grey and green space (Adams et al. 2006; Francis and Chadwick 2012). Although urban exploiters can tolerate an urban environment, each species differs in the degree of tolerance they have which is based on the proportion of grey to green space. For example, Rock doves (*C. livia*) and Brown rats (*R. norvegicus*) can tolerate a higher proportion of grey space and can be successful in completely grey spaces whereas other species, like the Northern Goshawk (*Accipiter gentilis*) still depend on green spaces for some part of their survival which limits their distribution within urban spaces (Adams et al. 2006; Rutz 2008). Hadeda Ibis are still dependent on green spaces as they roost and nest in trees, forage on lawns and are more common in suburban areas, which have greater proportions of green space, rather than in the middle of completely grey spaces. Although still using trees for nesting and roosting, Hadeda Ibis used urban structures (poles, house roofs, pylons and fences) for perching. House roofs appear to be an ideal perching spot for Hadeda Ibis as suggested by the total perching observations. In the mornings because roofs are more exposed to the sun they will get warmer quicker than in a tree under the cover of leaves. This may benefit Hadeda Ibis thermoregulation as in other bird species that sun themselves particularly on cold mornings (Dean and Williams 1999). Also foraging areas are easier to access as lawns are close to houses, so by sitting on roofs Hadeda Ibis can survey for potential danger (such as dogs) or perceived danger (such as humans) before flying down to forage. Alternatively congregating on roofs may facilitate interspecific communication in Hadeda Ibis but no evidence has been published.

Hadeda Ibis have moved from being associated with wetlands and become common in urban environments. Seasonal rainfall changes seem to have very little effect on this species in urban areas probably because their ideal foraging habitat is available throughout the year where gardens are watered and swimming pools are available. Although some individuals have begun to use alternative food sources such as garbage and pet food, they still need to forage for invertebrates to meet their daily energy needs. Hadeda Ibis appear to communicate with conspecifics without much interference from urban noise pollution and although they are able to use the features of urban environments, they still depend on green spaces (like lawns, fields) and areas with trees scattered in between buildings and roads, for foraging, roosting and breeding.

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Tables

Table 1 Mean ± SD percentage green and grey space calculated from 100 x 100 m grid squares overlaid on aerial photographs of five Pietermaritzburg suburbs

Suburb	Area (km^2)	Mean % green	Mean % grey	Squares analysed
City	7.587	26.16 ± 30.88	73.88 ± 30.86	770
Northdale	9.897	47.50 ± 31.32	52.50 ± 31.32	1151
Scottsville	7.372	54.96 ± 30.35	45.06 ± 30.34	830
Wembley	2.894	62.61 ± 31.61	37.39 ± 31.61	352
Hayfields	6.203	66.13 ± 30.35	33.87 ± 30.35	735

Table 2 Total number of Hadeda Ibis (*Bostrychia hagedash*) observed perched on various structures for five Pietermaritzburg suburbs during summer and winter

Summer

Suburb	Tree	Roof	Fence	Pylon	Pole	**Total**
City Centre	8	2	0	0	1	**11**
Northdale	11	27	0	8	11	**57**
Scottsville	21	40	0	0	45	**106**
Wembley	1	0	0	0	8	**9**
Hayfields	5	27	1	0	9	**42**
Total	**46**	**96**	**1**	**8**	**74**	**225**

Winter

Suburb	Tree	Roof	Fence	Pylon	Pole	**Total**
City Centre	5	4	0	0	0	**9**
Northdale	9	35	0	4	14	**62**
Scottsville	34	36	2	0	17	**89**
Wembley	14	16	0	0	9	**39**
Hayfields	22	21	0	0	17	**60**
Total	**84**	**112**	**2**	**4**	**57**	**259**

Table 3 Total number of Hadeda Ibis (*Bostrychia hagedash*) individuals observed overall in five Pietermaritzburg suburbs during summer and winter

Suburb	**Summer**	**Winter**	**Total**
City Centre	74	67	**141**
Northdale	198	200	**398**
Scottsville	417	239	**656**
Wembley	155	66	**221**
Hayfields	233	170	**403**
Total	**1077**	**742**	**1819**

Figures

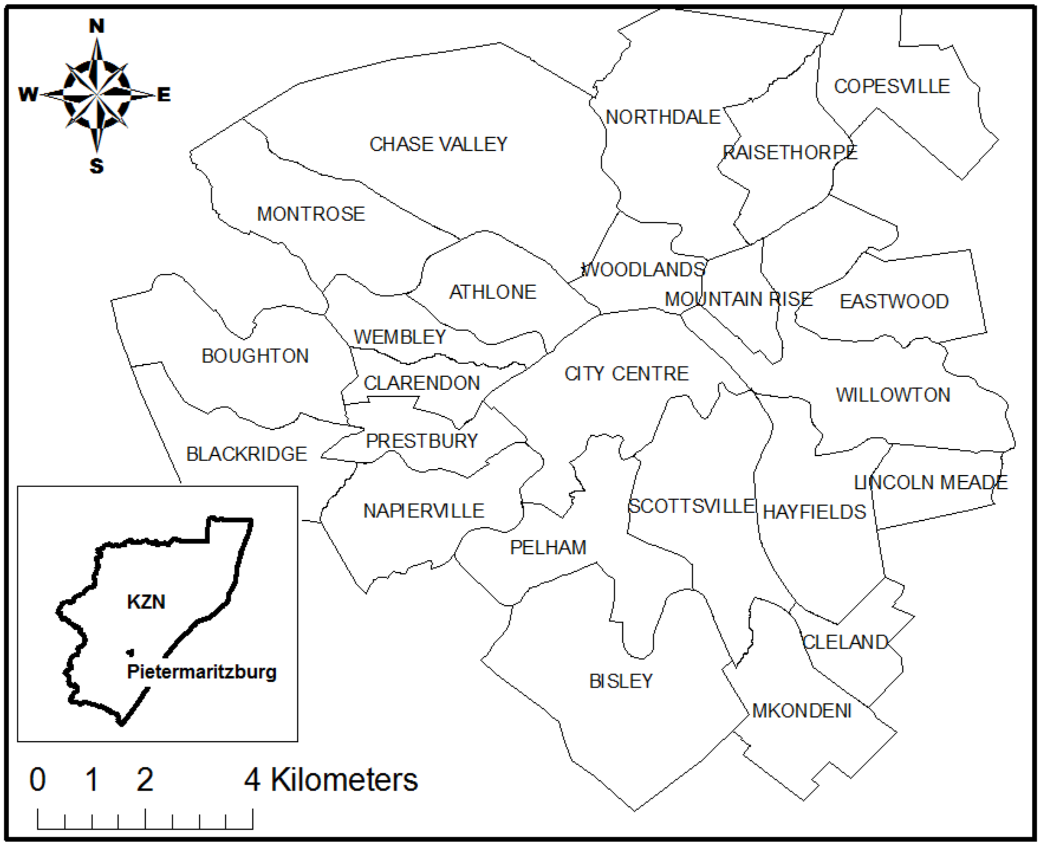

Fig. 1 The location of Pietermaritzburg in KwaZulu-Natal, South Africa and its various suburbs.

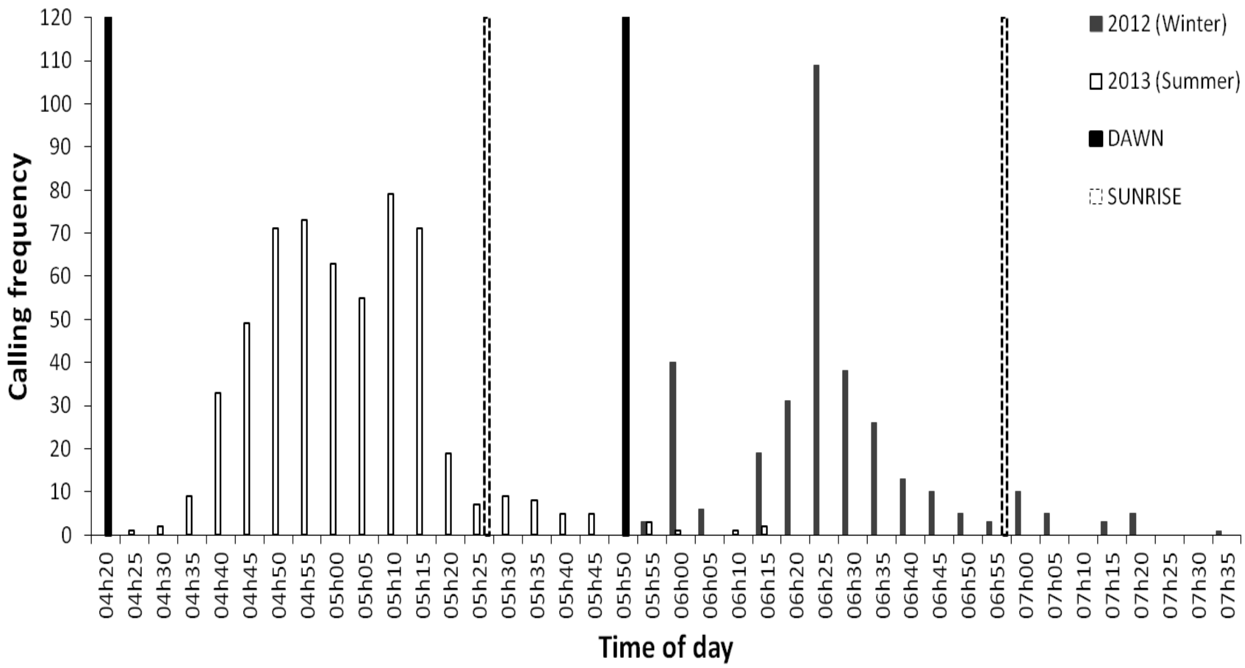

Fig. 2 Calling frequency of Hadeda Ibis (*Bostrychia hagedash*) at different times of day represented here in five minute intervals for summer 2013 (with dawn at 04h25 and sunrise at 05h55) and winter 2012 (with dawn at 05h25 and sunrise at 06h55).

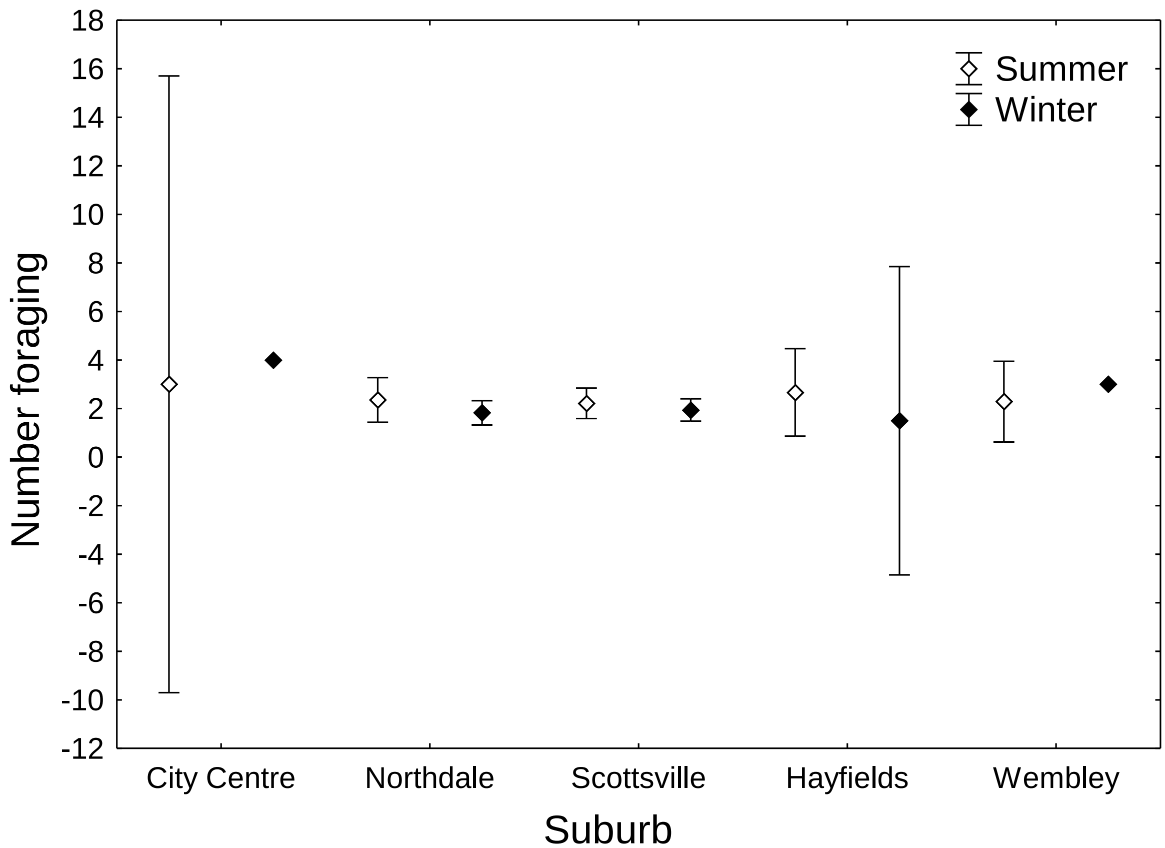

Fig. 3 Hadeda Ibis (*Bostrychia hagedash*) (Mean ± SE) flock size observed foraging in various suburbs of Pietermaritzburg for summer and winter.

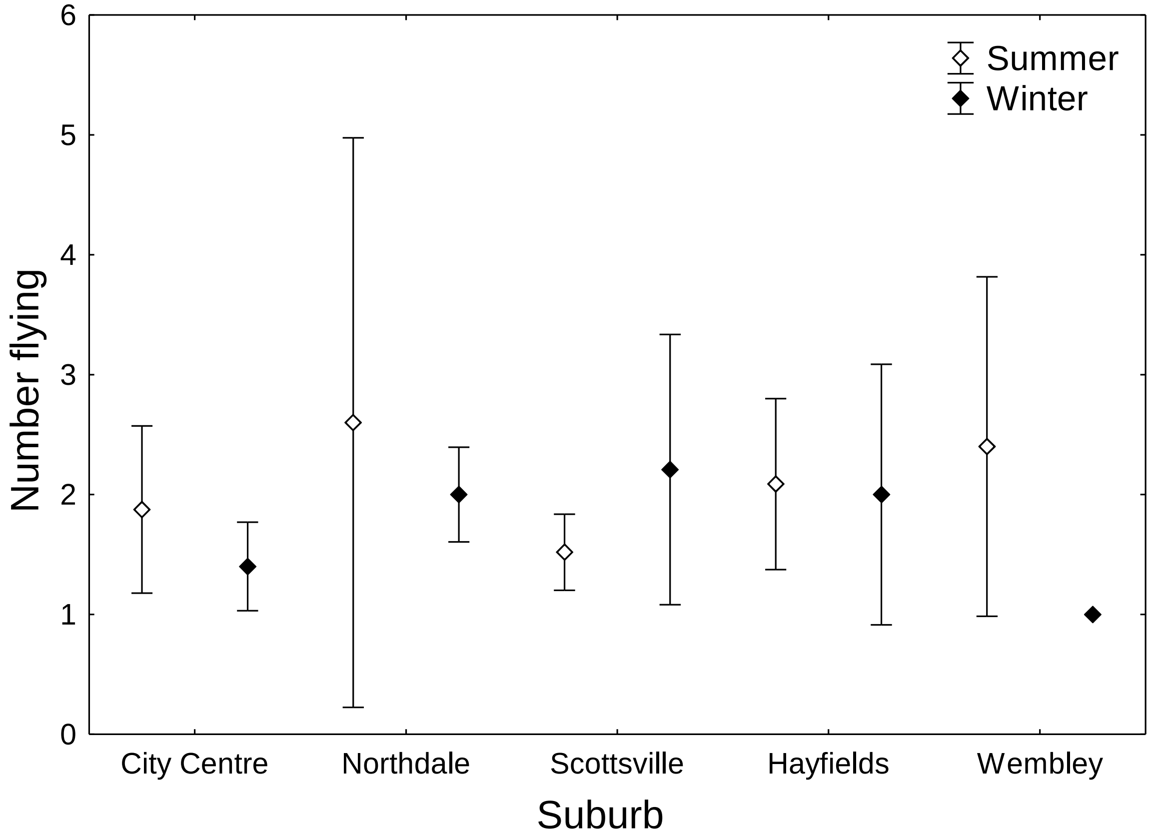

Fig. 4 Hadeda Ibis (*Bostrychia hagedash*) (Mean ± SE) flock size observed flying in various suburbs of Pietermaritzburg for summer and winter.

CHAPTER 3

Hadeda Ibis (*Bostrychia hagedash*) urban nesting and roosting habits in Pietermaritzburg, KwaZulu-Natal, South Africa

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Abstract Hadeda Ibis (*Bostrychia hagedash*) have increased in population size and expanded in range in South Africa possibly as a result of increased use of exotic trees for nesting and roosting in urban areas. We investigated the urban nesting and roosting habits of the Hadeda Ibis by measuring tree height and species used by Hadeda Ibis for nesting and roosting in Pietermaritzburg, KwaZulu-Natal, South Africa. We expected Hadeda Ibis nests and roosts to have habitats, like wetlands, to be within 10 km of the roost or nest tree. Hadeda Ibis nest and roost locations were mapped using ArcGIS v. 9.3.1 and available resources (grasslands, wetlands, plantations, other natural water sources) 10 km around each roost and nest tree were determined. Results showed that Hadeda Ibis use exotic trees for nesting and roosting in urban areas more than indigenous trees. This may be because exotic trees are more available in urban environments, particularly those trees that have ornamental value. Hadeda Ibis did not nest and roost closer to expected resources. Although previously associated with wetlands, Hadeda Ibis in urban environments were not close to natural water sources. This can be explained by swimming pools providing accessible drinking water and well watered lawns providing suitable foraging habitat so allowing them to roost and nest in this urban habitat.

Keywords *Bostrychia hagedash*, urban ecology, roosting behaviour, habitat selection, colonial roosting, urban forest

Introduction

Urban environments typically have more exotic than indigenous vegetation because of the introduction of non-native plant species into urban areas intentionally, for ornamental purposes, or through accidental introductions (Alberti et al. 2003; Alvey 2006; Blair 1996; Evans et al. 2010; Lososová et al. 2012; Møller et al. 2012; Paker et al. 2014; Raedeke and Raedeke 1995). The vegetation in urban areas is fragmented producing a mosaic of buildings and roads with urban forest (Chace and Walsh 2006; Chamberlain et al. 2009; Lososová et al. 2012; Raedeke and Raedeke 1995; Reale and Blair 2005; Wilby and Perry 2006). Urban forest is the term used for the collective tree vegetation present in an urban area and this includes trees in parks, vacant lots, unused sites, residential gardens and tree lined streets (Adams et al. 2006; Agee 1995; Alvey 2006).

Generally where there is a high degree of urbanization it is expected that there will be a reduction in tree species diversity because of biotic homogenization; which is the process of replacing local native tree species with exotic tree species (Alvey 2006; Paker et al. 2014; van Rensburg et al. 2009). Exotic plants have the potential to outcompete with indigenous vegetation for resources, would generally suffer less predation in a non-natural environment, and have a better reproductive output, when compared with indigenous plants (Alvey 2006; Paker et al. 2014). These factors make exotic plant species resilient to environmental disturbance which allows them to persist and proliferate and can sometimes result in these species becoming invasive in urban areas (Alvey 2006; Paker et al. 2014).

Although there is a reduction in native tree species diversity with increasing urbanization, urban areas are not completely void of biodiversity rather the degree of biodiversity depends on the management of the area (Alvey 2006). The same biodiversity concepts that are used for ecology can be applied to urban ecology however some of these concepts will differ in an urban context (Savard et al. 2000). For instance, because of the fragmented and complex nature of urban areas, scale is very important to consider when looking at the biodiversity in these areas with the local scale being a more accurate indicator of species diversity (Benton-Short and Short 2008; Garden et al. 2010; Savard et al. 2000). The urban gradient shows a correlation between biodiversity and the socioeconomic gradient (Ramalho and Hobbs 2012); which various studies on diversity in suburban gardens seem to support (including Bland et al. 2004; Chamberlain et al. 2009; Davies et al. 2009; Paker et al. 2014; White et al. 2005). Due to an increasing human population and the expansion of urban areas, suggestions have been made to manage urban forests for conservation purposes, and with particular reference to birds, these studies suggest providing a range of food and nest sites to increase bird diversity in gardens (Bland et al. 2004; Chamberlain et al. 2009; Davies et al. 2009; Garden et al. 2010; Paker et al. 2014; Savard et al. 2000; White et al. 2005; Wilby and Perry 2006).

Food and nest site availability are the two key factors that determine the population size and distribution of urban tolerant birds (Anderies et al. 2007; Blair 1996; Reale and Blair 2005; Rutz 2008). Urban forests can have just as many bird species as the surrounding natural environment, however species and abundance will differ with more and greater numbers of exotic and urban tolerant species found in urban areas (Bland et al. 2004). Native bird species in urban areas mostly rely on the remnants of indigenous vegetation for nesting while exotic and urban tolerant birds seem to prefer using exotic vegetation (Chace and Walsh 2006; Reale and

Blair 2005; White et al. 2005). This selection of exotic vegetation by urban birds has been suggested to be a result of greater protection from predators however exotic vegetation is not the only resource for urban tolerant birds as some of these species use buildings and poles for nesting and roosting (Chace and Walsh 2006). For instance, the Peregrine Falcon (*Falco peregrinus*) substitutes high rise buildings for cliffs, White Storks (*Ciconia ciconia*) build their nests on chimneys, the Yellow-legged Gull (*Larus michahellis*) nests on the roofs of buildings, and the Chihuahuan Raven (*Corvus cryptoleucus*) has been found to use decommissioned telephone poles for nesting (Brubaker et al. 2003; Savard et al. 2000; Soldatini et al. 2008).

The Hadeda Ibis (*Bostrychia hagedash*) (Pelecaniformes order, Threskiornithidae family) is a relatively large (± 1.2 kg) wetland associated bird, indigenous to southern African (Vernon and Dean 2005). They roost colonially in trees and show roost and nest site fidelity (Vernon and Dean 2005). An increase in exotic trees particularly in urban areas, resulting in greater availability of possible nesting and roosting sites, has been suggested to be a key factor in the range expansion of this species which has also increased its population across South Africa (Macdonald et al. 1986). Therefore we investigated the urban nesting and roosting habits of the Hadeda Ibis. Tree height was measured and tree type, in terms of indigenous or exotic to South Africa, and species were determined for known Hadeda Ibis roosts across the city of Pietermaritzburg, KwaZulu-Natal. Hadeda Ibis nest and roost locations were analysed using a land use layer in ArcGIS to examine resource availability by habitat type around each location. We expected Hadeda Ibis to be roosting mostly in taller exotic trees. We also expected Hadeda Ibis nests and roosts to be in close proximity with habitats favourable to their survival like wetlands, plantations and grasslands, and further from urban features like roads.

Methods

We conducted the study within the city of Pietermaritzburg (29°37'S, 30°23'E), KwaZulu-Natal (KZN), South Africa. Locations of Hadeda Ibis roosts and nests were reported by the public in response to a newspaper article in 2009 requesting public information on these. Nests and roosts, with the addition of roosts found during observations of Hadeda Ibis activity in June 2012 and January 2013 (Singh and Downs in prep), were visited and tree height and type were determined in February 2014. Where possible tree height was measured using a range finder (Vertex III v.1.5.) which is designed to determine tree height, and when access to the tree was restricted because of private property, tree height was estimated using accessible trees as a reference. Tree species were identified and tree type was determined in terms of indigenous or exotic species to South Africa. Tree heights between exotic and indigenous roost tree species could not be statistically compared because of a skewed sample size therefore a general comparison between tree heights was done.

We mapped the geographical coordinates of roost and nest trees onto aerial photographs using ArcGIS v. 9.3.1. and a 10 km buffer around each tree was analysed in terms of habitat type using a land use layer. The land use layer consisted of 47 different land use categories of which 14 were chosen as relevant to the Pietermaritzburg landscape and to Hadeda Ibis. These included: natural water, plantation, wetlands, built up dense settlement, golf courses, forest, dense bush (70-100cc), bushland (<70cc), grassland/bush clump mix, grassland, KZN national roads, KZN main district roads, water dams, and airfields.

Results

Twenty three Hadeda Ibis nests and 50 Hadeda Ibis roosts in Pietermaritzburg were analysed. Of the 50 roosts, 13 were in *Platanus acerifolia*, 10 in *Jacaranda mimosifolia*, and six in *Eucalyptus globulus* (Table 1). *Cinnamomum camphora*, *Bauhinia variegata*, *Tipuana tipu* each had three roosts while all other trees, *Acacia xanthophloea*, *Callistemon salignus*, *Persea americana*, *Pinus australis*, *Podocarpus macrophyllus*, and *Podocarpus latifolius* one each (Table 1). Of the 50 Hadeda Ibis roost trees 48 (96 %) were exotic species and two were indigenous to South Africa (Table 1). The shortest roost tree was 20 m while the tallest was 90 m and the mean height of all 50 roost trees was 39.8 ± 13.9 m (Table 1). The mean *P. acerifolia* tree height was 43 ± 13.3 m, 40 ± 13.1 m for *J. mimosifolia*, 75 ± 14.1 m for *E. globulus*, 25 m for *B. variegata*, 40 ± 17.3 m *C. camphora* and 48 ± 2.9 m for *T. tipu*.

Of the 23 nests, four were in *P. acerifolia*, *P. americana*, and *J. mimosifolia* each, two were in *C. camphora*, *Acacia sieberiana*, *Grevillea parallela*, and *P. australis* each while *Tipuana tipu*, *Cinchona spp.*, and *Carya illinoiensis* had one each (Table 2). Of the 23 Hadeda Ibis nest trees 21 (91 %) were exotic and two were indigenous to South Africa (Table 2). The shortest nest tree was 20 m while the tallest was 60 m and the mean height of all 23 nest trees was 37.8 ± 7.9 m (Table 2). The mean *P. acerifolia* height was 42.5 ± 6.5 m, 38.8 ±16.5 m for *P. americana* and 31.3 ± 7.5 m for *J. mimosifolia* (Table 2).

All 23 Hadeda Ibis nests and 50 roosts in Pietermaritzburg had built up dense settlement and dense bush within a 10 km radius. All nests had grassland within 10 km while there were two roosts with no grassland within a 10 km radius. These two roosts were located in the Pietermaritzburg City Centre (Fig. 1). The habitat type “natural water” was found within 10 km of 12 % of nests and 14 % of roosts and “water dam” within 16 % of nests and 10 % of roosts

(Table 3). There was a large wetland habitat in the Willowton suburb which is the Darville sewage works but of the 50 roosts and 23 nests, none were within 10 km of that habitat. However, there were seven roosts that were within 20 km of the sewage works. The habitat type “plantation” was found within 10 km of 28 % of nests and 32 % of roosts, “forest” had 20 % of nests and 8 % of roosts, “bushland<70cc” had 96 % of nests and 30 % of roosts, and “grassland/bush clump mix” had 92 % of nests and 60 % of roosts within 10 km (Table 3). The “golf course” habitat type had no nests and 10 % of roosts within a 10 km radius while the “airfield” had 8 % of nests and 2 % of roosts (Table 3). “KZN national roads” had 32 % of nests and 36 % of roosts and “KZN main district roads” had 84 % of nests and 72 % of roosts within 10 km (Table 3).

Discussion

The urban nesting and roosting habits of the Hadeda Ibis were investigated by determining tree height, tree species, and nest and roost location within various habitats in Pietermaritzburg, KwaZulu-Natal. As expected Hadeda Ibis roosts and nests were mostly in exotic trees. Of the 50 roosts and 23 nests, only four were in tree species indigenous to South Africa. Of these four, two nests were found in *Acacia sieberiana*, and one roost each in *A. xanthophloea*, and *Podocarpus latifolius*. *Acacia sieberiana* is a fairly common indigenous species in and around the Pietermaritzburg area while *A. xanthophloea*, and *P. latifolius* are commonly used for ornamental purposes in gardens (Coates Palgrave 2005).

South Africa has a long history of exotic vegetation with the first introductions dating back to the mid 1600’s during early colonial times (Bennett 2014). During these times introductions of exotic trees were for ornamental purposes, to limit flows of streams, or for timber (Bennett 2014). The view of exotic species as a threat, and the degree to which it influences indigenous habitats, started sometime before 1940 and has had much debate over the years (Bennett 2014). Most of the indigenous conservation efforts before 1995 were focused on the Cape floristic region and little to no attention was paid to exotic trees (Bennett 2014). However in 1995 an organisation called Working for Water (WFW) was established and it has attempted to tackle specifically invasive exotic trees, mostly by direct removal with some use of biological control, for the explicit purpose of preserving water (Bennett 2014). Working for Water has a category system for vegetation to prioritise invasive exotic threats dividing them into three main categories. Category 1 plants are seen as major threats and must be removed and controlled. Category 2 plants are those used for commercial purposes or have economic value. These are allowed to be planted only for commercial purposes and must be removed when found outside plantations. Category 3 plants are those that are used for ornamental purposes. These are plants that are allowed if already established but must not be propagated further.

Exotic tree species that were common for roosting and nesting were *P. acerifolia*, *J. mimosifolia*, *P. americana*, *C. camphora*, *Tipuana tipu*, and *P. australis*. *Carya illinoinensis* and *P. americana* are used for their edible products while *P. acerifolia*, *J. mimosifolia*, *C. camphora*, *Tipuana tipu*, *B. variegata*, *Callistemon citrinus*, *Melia azedarach*, *Cinchona spp.*, *G. parallela*, and *P. macrophyllus* are all used for ornamental purposes in gardens and/or along streets. *J. mimosifolia* is considered a category 3 species in the WFW priority system and *E. globulus*, *Eucalyptus grandis*, and *P. australis* are category 2 plants that are used mainly for timber (Coates Palgrave 2005).

Regarding tree height, Hadeda Ibis used a range of trees for roosting, 20 m to 90 m with a mean of 39.80 ± 13.86 m. Tree species varied in height with *E. globulus* and *Eucalyptus grandis* with the tallest roost trees while most other species averaged at about 40m. The use of tall trees may be for a vantage point perhaps for protection from predators or for effective communication with conspecifics as a higher vantage point may allow calls to be heard over a greater distance (Møller 2011; Sprau et al. 2012). In an urban setting, the mosaic of different land uses with the lack of very dense forests and tall trees scattered around may create sufficient vantage and communication points regardless of the availability of taller trees.

Hadeda Ibis use of exotic trees was suggested as one of the reasons for their success in urban habitats (Macdonald et al. 1986) and we have found that these birds use many more exotic trees than indigenous for urban roosting and nesting. Although currently there are programs like WFW, and the interest to preserve indigenous biodiversity globally and in South Africa, historically exotic vegetation has become well established in older towns and cities creating urban forests (Alvey 2006; Bennett 2014; White et al. 2005). Typically native species rely on remnant patches of indigenous vegetation in urban environments (White et al. 2005) but given enough time and the pull of available stable foraging resources in urban areas, native species can adjust their behaviour to fit into urban areas (Adams et al. 2006). It is difficult to identify whether this pattern of behaviour change is because of phenotypic plasticity or adaptation, however most urban tolerant species show phenotypic plasticity (Francis and Chadwick 2012). The pull force for Hadeda Ibis moving into urban areas was probably more a result of foraging stability with urban areas providing a buffer regardless of rainfall and weather patterns, which provides adequate foraging habitat, and capitalising on the availability of exotic trees (Duckworth and Altwegg 2014).

We expected Hadeda Ibis nests and roosts to be closer to habitats favourable to their survival like wetlands, plantations and grasslands, and further from urban features like roads as many animal species tend to avoid urban features depending on their urban tolerance. However, Hadeda Ibis showed a high urban tolerance by 84 % of nests and 72 % of roosts within 10 km of main roads and 32 % of nests and 36 % of roosts near the main highway through the city. These birds did not nest and roost closer to expected resources although previously being a wetland associated species. We expected that Hadeda Ibis would need to be in the proximity of natural water sources, natural water sources like rivers, dams, ponds, even in urban environments but found this to not be the case with only 12 % of nests and 14 % of roosts within 10 km natural water and 16 % of nests and 10 % of roosts within 10 km of water dams. However there were about seven roosts within 20 km of a natural wetland habitat. Swimming pools may provide accessible drinking water and well watered lawns provide suitable foraging habitat in urban areas so Hadeda Ibis need not be associated with wetland habitats.

All nests and roosts were within 10 km of the habitat “built up settlement” and although this implies solely houses and buildings with other purely urban features, gardens also fall into that habitat type. Gardens are human altered habitat with plant species and general design (many trees or greater lawn space, artificial water supply with sprinklers, etc.) are carefully created by people so within themselves gardens vary greatly. Gardens have supplied many urban tolerant species with nest, roost and foraging resources which has allowed many species to become successful in urban areas (Blair 1996; Bland et al. 2004; Chamberlain et al. 2009; Davis et al. 2011). Also, all nests and roosts were within 10 km of dense bush and all but two roosts were within 10 km of grassland habitat. Dense bush habitat referred to Pietermaritzburg’s many small pockets of green space mostly in vacant lots between buildings and grassland habitat consisted mostly of sports fields and school grounds, providing Hadeda Ibis with foraging habitat or trees for nesting and roosting. About 28 % of nests and 32 % of roosts had the plantation habitat within 10 km but none were within a plantation itself. Plantations refer to trees planted and harvested for commercial use. It is understandable why there were no Hadeda Ibis nests or roosts in this habitat because the trees are cut down every few years and these birds show roost fidelity (Vernon and Dean 2005).

The 10 km buffer around each nest and roost was based on the maximum movement of only one GPS tracked individual for about a month and therefore does not give an accurate representation of Hadeda Ibis habitat use. However, observations of Hadeda Ibis leaving roosts, as undertaken for data collection in Singh and Downs (in prep), found that many individuals do not typically venture far from their roosts and forage near their roosts for a time before setting off further, indicating that they do use the immediate space around their roosts.

In conclusion, it appears that Hadeda Ibis in urban environments do not need to nest or roost close to natural water sources as gardens and swimming pools provide similar resources that would be available in wetlands. Also with urban habitats being fragmented, having a variety of habitats in a small area in close proximity, and the availability of particularly exotic trees in urban areas, Hadeda Ibis are provided with adequate nesting and roosting trees and suitable foraging habitat to sustain an urban population in the urban area of Pietermaritzburg.

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Tables

Table 1 Summary of Hadeda Ibis (*Bostrychia hagedash*) roosts tree species in Pietermaritzburg with minimum, mean and maximum tree heights.

Species	Common name	Exotic/ Indigenous	Number of trees with roost	Min. height (m)	Mean ± SD height (m)	Max. height (m)
Acacia xanthophloea	Fever Tree	Indigenous	1	30	30	30
Bauhinia variegata	Orchid Tree	Exotic	3	25	25	25
Callistemon citrinus	Crimson Bottlebrush	Exotic	1	25	25	25
Carya illinoinensis	Pecan Nut Tree	Exotic	4	25	44 ± 18.9	60
Cinnamomum camphora	Camphor Tree	Exotic	3	30	40 ± 17.3	60
Eucalyptus globulus	Blue Gum	Exotic	2	55	75 ± 14.1	90
Eucalyptus grandis	Saligna Gum	Exotic	4	65	76.3 ± 11.1	90
Jacaranda mimosifolia	Jacaranda	Exotic	10	25	40 ± 13.1	55
Melia azedarach	White Cedar	Exotic	2	55	58 ± 3.5	60
Persea americana	Avocado	Exotic	1	20	20	20
Pinus australis	Longleaf Pine	Exotic	1	45	45	45
Platanus acerifolia	Plane Tree	Exotic	13	25	43 ± 13.3	65
Podocarpus macrophyllus	Japanese Yew	Exotic	1	25	25	25
Podocarpus latifolius	Real Yellowwood	Indigenous	1	35	35	35
Tipuana tipu	Rosewood	Exotic	3	45	48 ± 2.9	50
Total			**50**	**20**	**39.8 ± 13.9**	**90**

Table 2 Summary of Hadeda Ibis (*Bostrychia hagedash*) nest tree species in Pietermaritzburg with minimum, mean and maximum tree heights.

Species	Common name	Exotic/ Indigenous	Number of trees with nest	Min. height (m)	Mean ± SD height (m)	Max. height (m)
Acacia sieberiana	Paperbark Thorn	Indigenous	2	30	37.5 ± 10.6	45
Carya illinoiensis	Pecan Nut Tree	Exotic	1	50	50	50
Cinchona spp.	Quina	Exotic	1	50	50	50
Cinnamomum camphora	Camphor Tree	Exotic	2	20	27.5 ± 10.6	35
Grevillea parallela	Silver Oak	Exotic	2	30	37.5 ± 10.6	45
Jacaranda mimisofolia	Jacaranda	Exotic	4	20	31.3 ± 7.5	35
Persea americana	Avocado	Exotic	4	20	38.8 ± 16.5	60
Pinus australis	Longleaf Pine	Exotic	2	25	32.5 ± 10.6	40
Platanus acerifolia	Plane Tree	Exotic	4	35	42.5 ± 6.5	50
Tipuana tipu	Rosewood	Exotic	1	30	30	30
Total			**23**	**20**	**37.8 ± 7.9**	**60**

Table 3 Total and percentage Hadeda Ibis (*Bostrychia hagedash*) nests (23) and roosts (50) in Pietermaritzburg with various habitat types within a 10 km radius.

Habitat type	Total nests	Nest (%)	Total roost	Roost (%)
Natural water	3	13	7	14
Plantation	7	30	16	32
Wetlands	0	0	0	0
Built up dense settlement	23	100	50	100
Golf courses	0	0	5	10
Forest	5	22	4	8
Dense bush	23	100	50	100
Bushland	22	96	15	30
Grassland/Bush clump mix	21	91	30	60
Grassland	23	100	48	96
KZN National Roads	7	30	18	36
KZN Main District Roads	20	86	36	72
Water dams	4	17	5	10
Airfields	2	9	1	2

Figures

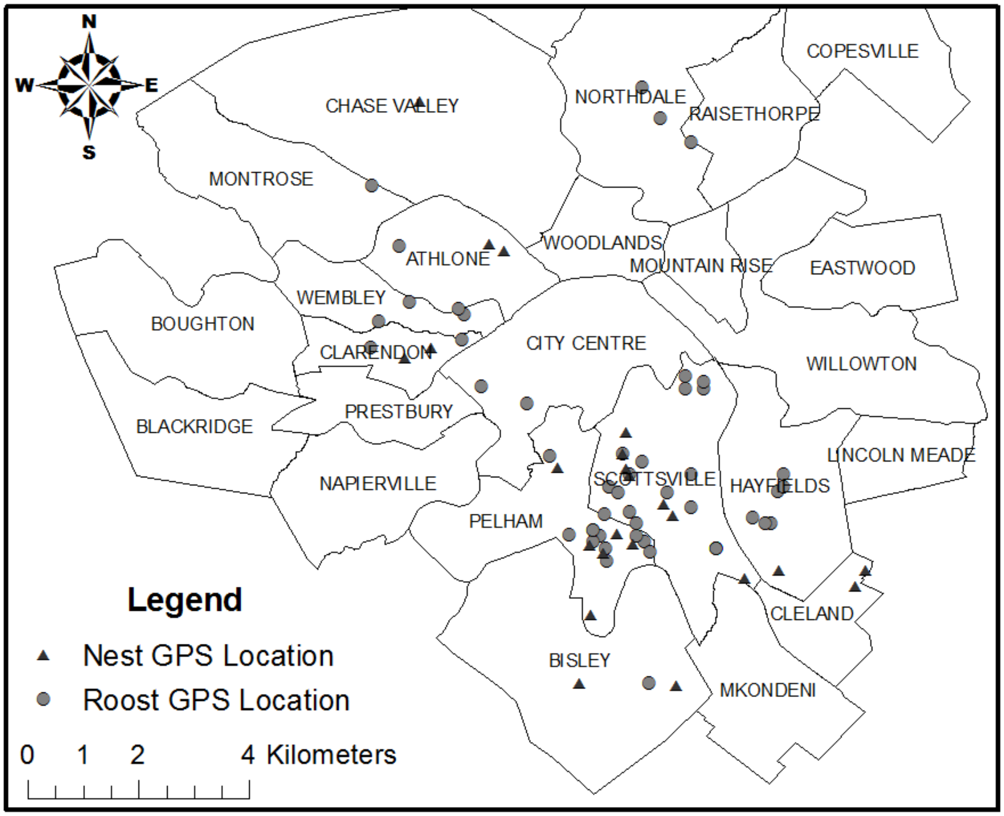

Fig. 1 Geographical locations of 23 Hadeda Ibis (*Bostrychia hagedash*) nests and 25 Hadeda Ibis roosts in Pietermaritzburg suburbs.

CHAPTER 4

Hadeda Ibis (*Bostrychia hagedash*) home range and habitat use in an urban environment: Pietermaritzburg, KwaZulu-Natal, South Africa

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Abstract The Hadeda Ibis (*Bostrychia hagedash*) is an urban tolerant bird species but there is little known about their home range, habitat use and movements in urban areas. We determined home range and habitat use of four Hadeda Ibis in Pietermaritzburg, KwaZulu-Natal using GPS/GSM transmitters and colour banded other individuals. Only one transmitter yielded 51 points of usable data which was analysed using ArcGIS Hawth's analysis tools to create a minimum convex polygon then overlaid on an aerial photograph. The minimum convex polygon was calculated at 0.01 km^2 which is relatively small for a bird of this size. The small home range was supported by colour ringed individuals observed within 2 km of where they were captured for more than a year. The tracked individual foraged in gardens and on roadsides and used swimming pools for drinking. In conclusion data supported roost site fidelity but more is needed to understand home range, daily and seasonal movements, and broader scale habitat use of Hadeda Ibis.

Introduction

Home range refers to the area covered during daily and seasonal movements of an animal over its lifetime while it is engaged in foraging and breeding activities (Barrows 2011). Urban areas have a mosaic of different land uses very close together which creates a concentration of resources (Adams, Lindsey, et al. 2006, Blair 1996, Morrison, Marcot, et al. 2006). This has led to smaller home ranges of some urban exploitive animals compared with their counterparts in natural environments (Adams, Lindsey, et al. 2006, Gehrt, Riley, et al. 2010, Vangestel, Braeckman, et al. 2010). However, urban species that depend on specific resources, for instance frugivores, or species that use two different types of resources, for example a bird that breeds on a golf course and forages in a landfill, may have very large home ranges. Urban adapted animals differ in habitat use depending on resource needs and their degree of urban tolerance (Blair 1996, Bonier, Martin, et al. 2007, Møller 2009, Sol, Bartomeus, et al. 2012). Gardens provide a diverse range of resources for many bird species such as trees for roosting and nesting, foraging opportunities with garden insects or fruit trees, and swimming pools or water features may provide drinking water (Adams, Lindsey, et al. 2006, Blair 1996, Chace and Walsh 2006).

The Hadeda Ibis (*Bostrychia hagedash*, Pelecaniformes order, Threskiornithidae family) is an indigenous southern African bird that has expanded in range and increased in population size with increased urbanization (Duckworth and Altwegg 2014, Duckworth, Altwegg, et al. 2012, Macdonald, Richardson, et al. 1986, Vernon and Dean 2005). The species forages by probing moist soil for invertebrates showing seasonal movements with rainfall patterns (Duckworth and Altwegg 2014, Duckworth, Altwegg, et al. 2010, Vernon and Dean 2005). The species is relatively large weighing about 1.25 kg and being about 76 cm tall (Vernon and Dean 2005). Hadeda Ibis roost and nest site fidelity has also been observed but is yet to be confirmed

(Duckworth, Altwegg, et al. 2012, Vernon and Dean 2005). There is little known or documented on Hadeda Ibis home range and habitat use in urban areas. Therefore the aim of this study was to determine urban Hadeda Ibis home range, movements and habitat use. We predicted that Hadeda Ibis would have a relativity small home range in the urban area of Pietermaritzburg, KwaZulu-Natal because of their use of mainly suburban gardens for foraging.

Methods

This study was conducted in Pietermaritzburg (29°37'S, 30°23'E), KwaZulu-Natal, South Africa. We caught seven Hadeda Ibis during 2013 using a bow net spring trap, originally designed for catching vultures, which were processed and released at the capture site. Trapping was done in suburban areas based on information from land owners and previous observations of foraging Hadeda Ibis. All seven birds captured were ringed with both a SAFRING and a colour ring. All birds were most likely resident adults except for one (colour ring ID BA) which appeared to have recently fledged. All birds were weighed and measurements of wing, tail, head and bill length, and wing moult, were possible, were taken (Table 1). Notes on location caught, general observations about bird condition were also taken. A DNA sample of all seven birds was taken with a drop of blood (<100µl) extracted from above the claw on the toe using a sterile disposable Healthease® syringe and the area was swabbed to prevent infection. Four of the adults caught were fitted with an Avi-Track (Pietermaritzburg, RSA) GPS/GSM transmitter. Transmitters weighed about 30 to 40 g and were attached with 6 mm Teflon® ribbon as a backpack. The transmitters were solar powered and programmed to determine geographical position, by using at least three satellites, once every two hours from 06h00 to 18h00, transmitting data once per day. Usable GPS point data were analysed using Hawth's analysis tools in ArcGIS v. 9.3.1. A minimum convex polygon was created with the data and overlaid on an aerial photograph.

Results and Discussion

Two of the individuals caught and ringed both had string wrapped around one of their feet which were removed. Hadeda Ibis have been observed foraging in rubbish bins and because they walk around while foraging they can get fibres attached to their feet. A few individuals have been observed with missing toes and this seems to be one of the problems the species faces living in urban areas. Their foraging in garbage creates a human-wildlife conflict which has been seen with other urban adapted animals, particularly mammals, like racoons and brown bears (Adams, Lindsey, et al. 2006).

One tracked Hadeda Ibis was found dead in August 2013. The individual had drowned in a stagnant swimming pool and data were irrecoverable. Two transmitters malfunctioned yielding no usable data. Only one transmitter managed to record some usable data before malfunctioning and was removed from the individual in November 2013 (colour ring ID BB, Table 1). About 51 data points were recorded during the week from 12 April 2013 to 19 April 2013. The calculated minimum convex polygon was about 0.01 km^2 which is small for a bird this size (Figure 1). Although all transmitters failed to provide consistent data, individuals were identifiable by colour rings. Captured Hadeda Ibis were occasionally observed within 2 km of the catch site as much as six months later which suggests and supports a relatively small home range.

The first and last data point of each day was about the same indicating fidelity to its roost tree (Figure 1), which has been previously suggested of the species (Vernon and Dean 2005). Seasonal movement of Hadeda Ibis has also been suggested because of the observed increase in numbers at colonial roosts during winter (Vernon and Dean 2005). This particular individual was observed roosting and nesting in the same tree throughout the year so it has not shown any seasonal movement.

There are a few GPS points near swimming pools and on house roofs (Figure 1). Swimming pools provide drinking water and Hadeda Ibis being a wetland associated species may use these as a substitute (Vernon and Dean 2005). During our catching attempts we have observed that these birds are cautious and when disturbed from foraging they will fly off and perch on fences or roofs and wait until the disturbance has passed before resuming foraging. House roofs therefore may serve as a possible vantage point. Hadeda Ibis need moist soil to forage effectively (Duckworth and Altwegg 2014, Duckworth, Altwegg, et al. 2010, Vernon and Dean 2005) and the GPS points place the bird in a few neighbourhood gardens probably at the time the individual was foraging (Figure 1). Some points also show the bird at the side of the road (Figure 1) which may probably be because of foraging on the grass between the curb and the sidewalk.

The individual that we have data from has had its diet supplemented as it has been fed dog food by one of the home owners in the neighbourhood for about 10 years (Mr Frost, pers. com.).This may contribute to the small home range because of accessibility to food throughout the year and may not be applicable to all urban Hadeda Ibis. However, with observations of the other captured Hadeda Ibis, identifiable by colour rings, has placed them relatively close to the area they were captured so the urban home range of the species may be larger than in Figure 1 but may be not span many kilometres.

More data are needed for us to understand Hadeda Ibis home range in urban areas as well as habitat use and daily and seasonal movements. From the patterns we can see so far, provided that Hadeda Ibis has access to roosting and nesting sites, water sources like swimming pools, and well watered lawns for foraging or alternative food sources, they will have a relatively small home range for a relatively large bird.

Acknowledgements

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Tables

Table 1: Measurements of seven Hadeda Ibis (*Bostrychia hagedash*) captured in Pietermaritzburg, KwaZulu-Natal, South Africa

No.	Date Captured	Colour Ring ID	Transmitter	Wing (mm)	Tail (mm)	Head (mm)	Bill (mm)	Wing Moult	Weight (g)
1	Jan 2013	BA	No	305	124	126	88	5^10	503
2	Jan 2013	BB	Yes	344	150	180	112.1	5^9 10	1089
3	Feb 2013	BX	No	360	120	160	148	Not recorded	1500
4	Feb 2013	BD	Yes	360	160	148	122	Not recorded	1250
5	Apr 2013	BH	No	350	164	160	122	0^9	1200
6	Apr 2013	BJ	Yes	340	173	160	125	5^4 5^4 0^5	1600
7	May 2013	BI	Yes	360	150	180	125	Not recorded	1648

Figures

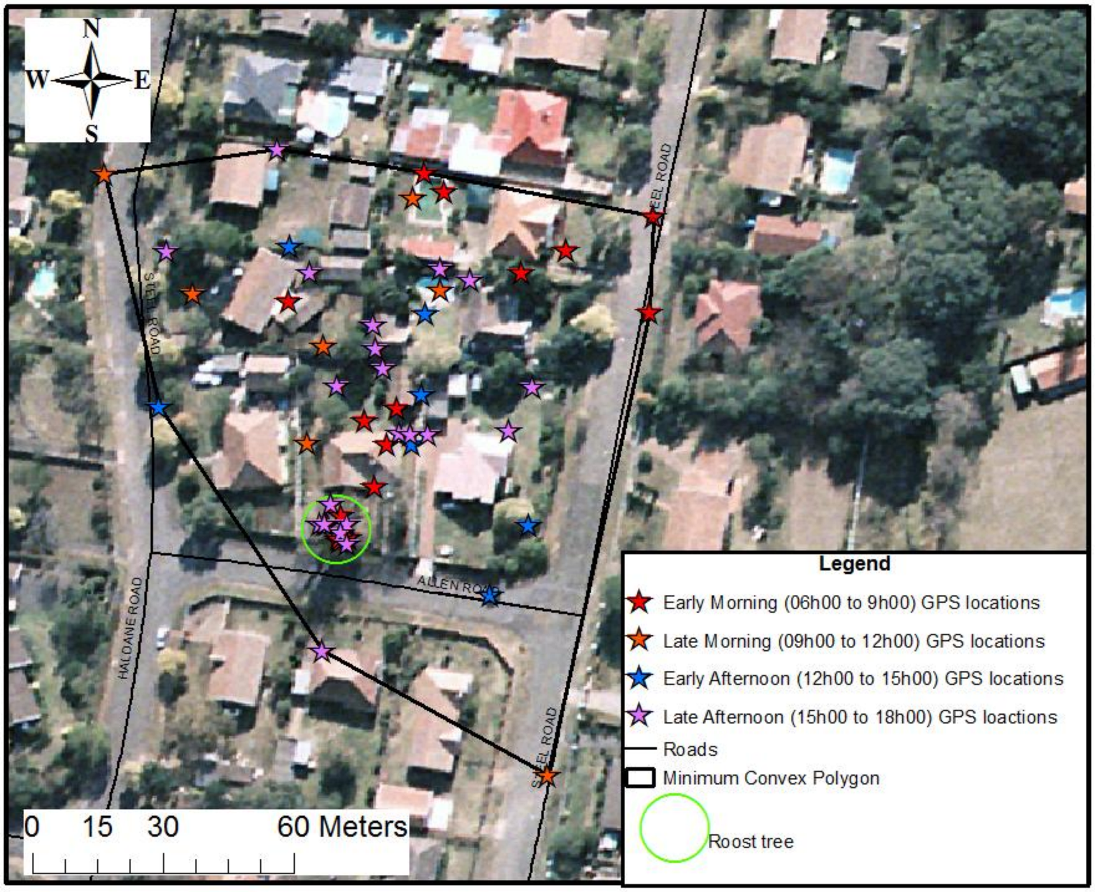

Figure 1: Geographical positions of a tracked Hadeda Ibis (*Bostrychia hagedash*), with a minimum convex polygon, in Pietermaritzburg, KwaZulu-Natal, South Africa.

CHAPTER 5

Conclusion

Urbanization has a large impact on local species which is typically negative (Adams et al. 2006). However, for those species that are able to not only tolerate urbanization but capitalise on available resources, there can be a large positive impact (Veech et al. 2011). These urban exploitive species can become more successful and have larger populations, greater foraging opportunities with less predation and greater breeding success (Adams et al. 2006; Blair 1996; Morrison et al. 2006). This is the case with the Hadeda Ibis (*Bostrychia hagedash*). The range expansion and population increase of Hadeda Ibis in urban areas was suggested as being a result of greater foraging opportunities and availability of roosting and nesting sites (Macdonald et al. 1986). The aim of this dissertation was to investigate the urban ecology of the Hadeda Ibis in the urban environment of Pietermaritzburg, KwaZulu-Natal, South Africa. We focused on behaviours, roosting and nesting habits, habitat use, foraging, and home range to gain an understanding of which factors may have contributed to the success of the species in urban areas.

The many different types of habitats within a concentrated area cause urban areas to be complex (Adams et al. 2006). Although Hadeda Ibis is a wading bird and has been associated with wetlands, previous to its range expansion, the species does not seem to require a wetland habitat in urban areas (Vernon and Dean 2005). The species forages by probing the ground for invertebrates and requires moist soil to do so effectively which is why they have previously shown seasonal movements depending on rainfall patterns (Duckworth et al. 2010; Vernon and Dean 2005). We have found that urban Hadeda Ibis do not necessarily depend on seasonal rainfall as urban green space, such as garden lawns and sports fields which may be kept green all year, can provide ideal foraging habitat (Chapter 2). These factors have also led to the species expansion to the west of the country which they were previously absent from (Duckworth and

Altwegg 2014; Duckworth et al. 2012). Alternative food sources, i.e. dog food and garbage, seem to have also provided the species with options possibly benefiting them most during the drier times of the year (Chapter 2, 4).

We have found that urban Hadeda Ibis use more exotic vegetation for nesting and roosting (Chapter 3) which is understandable as urban green spaces like gardens, parks and sports fields typically have more exotic than indigenous vegetation (Chace and Walsh 2006; Ikin et al. 2013; Raedeke and Raedeke 1995; White et al. 2005). Humans alter urban environments to preference and many exotic plant species have ornamental value and become features in gardens, parks and along streets (Adams et al. 2006; Chace and Walsh 2006; Raedeke and Raedeke 1995; Stout and Rosenfield 2010; White et al. 2005). This seems to create many possible roosting and nesting sites for Hadeda Ibis even though these sites may be scattered between other urban features like buildings and roads (Chapter 3).

Although more data are needed for us to gain a complete understanding of the home range of urban Hadeda Ibis, from the patterns we observed so far we can see that even within a small section of an urban area the species is provided adequate resources for survival and success (Chapter 4). Again this is because of the complexity of urban areas providing multiple habitat types within a concentrated area (Adams et al. 2006; Blair 1996; Morrison et al. 2006) which created a relatively small home range for a relatively large bird (Chapter 4). This pattern of smaller home ranges has been seen in many other urban adapted animals and it is understandable that a species need not have a large range if all required resources are available in a small area (Adams et al. 2006; Gehrt et al. 2010; Vangestel et al. 2010). For the Hadeda Ibis, suburban areas with many gardens, having trees and watered short grass lawns and even swimming pools, seem to satisfy the species main resource needs (Chapter 4).

Many urban birds have changed their behaviour with regards to communication because of interference from urban noise (Cardoso and Atwell 2011; Luther and Derryberry 2012). However, Hadeda Ibis is known by its distinctive call and seems to not be as affected as urban passerines have (Chapter 2). There is much more we need to understand about urban Hadeda Ibis such as urban population size, seasonal and daily movements with a better idea of home range and habitat use. Although there have been studies on the urban demographics of the species (Duckworth et al. 2012), there needs to be further investigation across a longer time scale.

The arrival, adjustment and spread stages of species invasion and range expansion together with push and pull dynamics (Adams et al. 2006; Croci et al. 2007; Evans et al. 2010), and comparison to the Australian White Ibis (*Threskiornis molucca*) (Martin et al. 2007; Martin et al. 2010; Smith and Munro 2010), can give use a clearer picture of Hadeda Ibis range expansion into urban areas. The arrival of Hadeda Ibis into urban areas was most probably because of increased foraging opportunities caused by irrigation in agriculture (Macdonald et al. 1986). They may have followed a similar pattern to the Australian White Ibis (*Threskiornis molucca*) which has also shifted its range from wetlands to an urban environment because of increased food availability provided by landfills (Martin et al. 2010; Smith and Munro 2010). The adjustment stage of Hadeda Ibis would have included changes that depended on the flexibility of the species (Evans et al. 2010). During this stage the species probably moved seasonally from wetlands to urban gardens until it began nesting and roosting in the exotic trees that were available in and around urban areas. The Australian White Ibis shows this pattern currently as it has begun to breed in urban areas whereas previously there was seasonal movement (Martin et al. 2007; Martin et al. 2010; Smith and Munro 2010). The spread stage is when the species has become established by effectively exploiting urban resources and attaining larger populations (Evans et al. 2010). Hadeda Ibis has shown flexibility in foraging, with the use of urban resources in dog food and garbage, and the use of swimming pools as a substitute for wetland habitat features resulting in a shift from a wetland associated species to more of an urban exploitive generalist (Barnagaud et al. 2011; Blair 1996).

Hadeda Ibis showed a different pattern compared with most other urban exploiters in that the species may have not at first adapted to an urban setting but rather the common features of urban environments provided essential resources, i.e. tall trees for roosting and nesting, and ideal foraging habitat with well watered short grass lawns. The species then showed flexibility with the use of alternative food sources and urban features. The provision of resources as part of urban design for species displaced by urbanization has been previously suggested as a means to maintain biodiversity and reduce the impact to local species in developing urban areas (Davies et al. 2009; Fuller et al. 2008; Rutz 2008). The urban environment of Pietermaritzburg was created by human design according to human preference but inadvertently provided essential resources for Hadeda Ibis survival and success. Hadeda Ibis was once considered a threatened species (Macdonald et al. 1986), is now a successful urban exploiter, increased its population size, and has expanded its range across South Africa even to areas it was previously not found because of resources needed for its survival provided by the urban environment. This case shows that considering the provision of resources for various species survival in urban planning and design could enable us to conserve the local species of an area while still creating features needed for human habitation. This strategy may not work for all species but considering the rapid human population increase and increased urbanisation, it may allow us to conserve and maintain some biodiversity.

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